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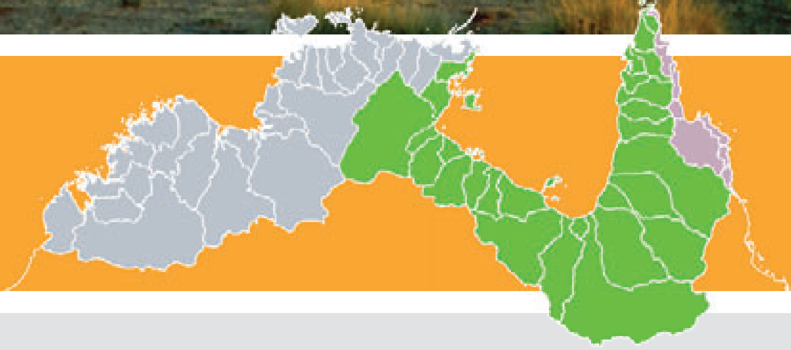

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# Water in the Gulf of Carpentaria Drainage Division

## A report to the Australian Government from the CSIRO Northern Australia Sustainable Yields Project

August 2009

Australian Government
National Water Commission
Raising National Water Standards Program

**Northern Australia Sustainable Yields Project acknowledgments**

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The Project was guided and reviewed by a Steering Committee (Kerry Olsson, NWC – co-chair; Chris Schweizer, Department of the Environment, Water, Heritage and the Arts (DEWHA) – co-chair; Tom Hatton, CSIRO; Louise Minty, Bureau of Meteorology (BoM); Lucy, Vincent, Bureau of Rural Sciences (BRS); Tom Crothers, QDERM; Lyall Hinrichsen, QDERM; Ian Lancaster, NRETAS; Mark Pearcey, DoW; Michael Douglas, Tropical Rivers and Coastal Knowledge (TRaCK); Dene Moliere, Environmental Research Institute of the Supervising Scientist (*eriss*); secretariat support by Angus MacGregor, DEWHA) and benefited from additional reviews by a Technical Reference Panel and other experts, both inside and outside CSIRO.



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Cover photograph: Sun setting on cattle amongst spinifex near Hughenden, QLD 1992.

Courtesy of CSIRO Division Land and Water

Photographer: John Coppi

# Director’s Foreword

Following the November 2006 Summit on the southern Murray-Darling Basin (MDB), the then Prime Minister and MDB state Premiers commissioned CSIRO to undertake an assessment of sustainable yields of surface and groundwater systems within the MDB. The project set an international benchmark for rigorous and detailed basin-scale assessment of the anticipated impacts of climate change, catchment development and increasing groundwater extraction on the availability and use of water resources.

On 26 March 2008, the Council of Australian Governments (COAG) agreed to expand the CSIRO assessments of sustainable yield so that, for the first time, Australia would have a comprehensive scientific assessment of water yield in all major water systems across the country. This would allow a consistent analytical framework for water policy decisions across the nation. The Northern Australia Sustainable Yields Project, together with allied projects for Tasmania and south-west Western Australia, will provide a nation-wide expansion of the assessments.

The CSIRO Northern Australia Sustainable Yields Project is providing critical information on current and likely future water availability. This information will help governments, industry and communities consider the environmental, social and economic aspects of the sustainable use and management of the precious water assets of northern Australia.

The projects are the first rigorous attempt for the regions to estimate the impacts of catchment development, changing groundwater extraction, climate variability and anticipated climate change on water resources at a whole-of-region scale, explicitly considering the connectivity of surface and groundwater systems. To do this, we are undertaking the most comprehensive hydrological modelling ever attempted for the region, using rainfall-runoff models, groundwater recharge models, river system models and groundwater models, and considering all upstream-downstream and surface-subsurface connections.

To deliver on the projects CSIRO is drawing on the scientific leadership and technical expertise of national and state government agencies in Queensland, Tasmania, the Northern Territory and Western Australia, as well as Australia’s leading industry consultants. The projects are dependent on the cooperative participation of over 50 government and private sector organisations. The projects have established a comprehensive but efficient process of internal and external quality assurance on all the work performed and all the results delivered, including advice from senior academic, industry and government experts.

The projects are led by the Water for a Healthy Country Flagship, a CSIRO-led research initiative established to deliver the science required for sustainable management of water resources in Australia. By building the capacity and capability required to deliver on this ambitious goal, the Flagship is ideally positioned to accept the challenge presented by this complex integrative project.

CSIRO has given the Sustainable Yields Projects its highest priority. It is in that context that I am very pleased and proud to commend this report to the Australian Government.

Dr Tom Hatton

Director, Water for a Healthy Country

National Research Flagships

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# Contributors* to the Northern Australia Sustainable Yields Project

| | |
|---|---|
| Project director | Tom Hatton |
| Sustainable Yields coordination | Mac Kirby |
| Project Leader | Richard Cresswell |
| Project Support | Andrea Davis, Malcolm Hodgen, Sue Jackson, Helen Beringen, Justin Story, Siobhan Duffy, Therese McGillion, Jeff Camkin |
| Data Management | Mick Hartcher |
| Climate | Tim McVicar, Randall Donohue, Janice Bathols, Francis Chiew, Dewi Kirono, Lingtao Li, Steve Marvanek, David Post, Nick Potter, Ian Smith, Tom Van Neil, Wenju Cai<br>*New South Wales Department of Water and Energy*: Jin Teng |
| Catchment Yield | Cuan Petheram, Paul Rustomji, Jamie Vleeshouwer, Donna Hughes, Jean-Michel Perraud, Ang Yang, Lu Zhang<br>*Sinclair Knight Merz*: Brad Neal, Amanda Bell, Werner Hennecke, Damon Grace, Derek Goodin, Rory Nathan, David Stephens, Nicola Logan, Sarah Gosling, Zuzanna Graszkiewicz<br>*Queensland Department of Environment and Resource Management*: Alex Loy, Greg Hausler, Sarah Giles, David Li, Amanda Casey |
| Groundwater | Glenn Harrington, Russell Crosbie, Phil Davies, James McCallum, Warrick Dawes, Matthew Lenahan, David Rassam<br>*Sinclair Knight Merz*: Rick Evans, Roger Cranswick, Eliza Wiltshire<br>*Jolly Consulting*: Peter Jolly<br>*Environmental Hydrology Associates*: Peter Evans, Jerome Arunakumaren, Wesley Burrows, Judith Raue<br>*Northern Territory Department of Natural Resources, Environment, The Arts and Sport*: Anthony Knapton, Lynton Fritz, Steven Tickell<br>*Queensland Department of Environment and Resource Management*: Linda Foster, Ralph DeVoil |
| Environment | Dave McJannet, Anne Henderson, Joe McMahon, Jim Wallace |
| Reporting | Susan Cuddy, Becky Schmidt, Heinz Buettikofer, Elissa Churchward, Alex Dyce, Simon Gallant, Chris Maguire, Frances Marston, Linda Merrin, Ben Wurcker<br>*dmwcreative*: Maureen Wicks, David Wicks |

* CSIRO unless otherwise indicated; Team Leaders underlined

# Executive Summary

A lot of rain falls on northern Australia, but its arrival is restricted in time and uneven in its distribution. Where and when it occurs is generally impractical for water resource development and there are large variations in how much comes year to year. There is little or no rain for three to six months every year and potential evapotranspiration rates are very high. Runoff follows a similar pattern to rainfall. The landscape is generally not amenable to storing water and the climate is not conducive to keeping it. Consequently, few rivers flow during the dry season and those that do are fed by groundwater, mostly at discrete points. Groundwater offers potential for increased extractions, but aquifers are seasonally dynamic and there is little opportunity to increase groundwater storage as the aquifers fill during the wet season and drain through the dry. Any change to surface or groundwater regimes will likely have consequences to the environment. Future rainfall is expected to be similar to that experienced historically, with future potential evapotranspiration being slightly higher throughout the year.

## The Northern Australia Sustainable Yields Project

The National Water Commission – on behalf of the Council of Australian Governments and in consultation with the Australian Government Department of the Environment, Water, Heritage and the Arts – commissioned CSIRO to assess the water resources of northern Australia, covering the Timor Sea and Gulf of Carpentaria drainage divisions and that part of the North-East Coast Drainage Division which lies north of Cairns. This area comprises 64 Australian Water Resources Council river basins, including the Torres Strait Islands, Gulf of Carpentaria islands and Tiwi Islands. Building on the success of the Murray-Darling Basin Sustainable Yields Project (completed in 2008), the Northern Australia Sustainable Yields Project has developed a methodology for a spatially contiguous and repeatable assessment of water resources and has applied those methods to assess water resources under four scenarios:

- historical climate (1930 to 2007) and current development
- recent climate (1996 to 2007) and current development
- future climate (~2030) and current development
- future climate (~2030) and likely future development.

Development relates the use of surface and groundwater supplies, and this project assumes full allocation of existing (current) and planned (future) water entitlements, as determined by the jurisdictions. Wherever possible, actual use, which is generally less than entitlements for northern Australia, is also assessed for modelling and discussion. The project presents the potential changes in the hydrological regime at sites of important environmental assets (which are often important social and cultural sites); considers the unique seasonal climate characteristics of northern Australia; and investigates surface–groundwater interactions. The project also assesses current water storages and storage options, including groundwater storage, under the different scenarios, but has not carried out a site specific assessment, nor carried out a storage-yield-reliability assessment.

This project is a desktop study. No new data have been collected. New data were generated through numerical modelling using existing data as a base, while new interpretations of existing data were undertaken. The project highlights areas (regions and information) that require further investigation, and includes a gap analysis.

Assessments, and subsequent reporting, have been made at the region scale, with regions ranging from 45,000 $km^2$ to 165,000 $km^2$, and comprising one or more river basins. Thirteen regions are defined for this purpose. Modelling, however, is performed at a resolution of about 29 $km^2$ (0.05 by 0.05 degree cells) for rainfall, evapotranspiration, recharge and runoff analysis, and at variable resolution for the groundwater analyses. These results are aggregated to the region scale; commentary at the local scale would require further, more detailed investigations. Generally, however, there are inadequate data to test models at the finer scale.

This project marks the first time a consistent, robust and transparent assessment has been carried out across the three jurisdictions of northern Australia, and the first time models have included an assessment of possible future climate implications. The findings from this project derive from the outcomes of modelling and the synthesis of existing data and information used to calibrate and substantiate that modelling. Some of these findings echo previous commentary, such as can be found in the National Land and Water Resources Audit.

This project constitutes the first activity under the Northern Australia Water Futures Assessment (NAWFA) and provides critical information for the Northern Australia Land and Water Taskforce (NALWT).

This project provides three division reports (one for each of three drainage divisions, and including the 13 region reports), as well as Science Reports. This report records the results of investigations across the Gulf of Carpentaria Drainage Division. The Gulf of Carpentaria Drainage Division comprises 29 Australian Water Resources Council river basins, which, for ease of reporting, have been amalgamated into six regions. This executive summary provides 19 key findings derived from the assessment of the Gulf of Carpentaria Drainage Division.

## Assessing water resources across the Gulf of Carpentaria Drainage Division

For each region this project assesses past, present and possible future water resources. Future climate estimates use internationally recognised global climate models. Where feasible, water availability is assessed through modelling surface water, groundwater and surface–groundwater interaction. This project does not assess sustainable yield. A complete **water sustainable yield assessment**, which incorporates consideration of the purposes of water use and its environmental, social, cultural, economic and political values, is outside the scope of biophysical modelling that CSIRO was commissioned to complete within this project.

A **water resource assessment** has been achieved for all regions of the Gulf of Carpentaria Drainage Division. This identifies how much water there is, in all its guises, at any given location, at any given time within the constraints of the current data. We have climate data (rainfall, solar radiation, minimum and maximum temperature, humidity), which is measured both spatially and temporally at an adequate resolution for a regional assessment; landscape information at a reliable resolution; and sufficient surface and groundwater monitoring to make an informed assessment of components of the hydrological cycle. The climate data provides input for the rainfall-runoff modelling, generation of streamflow data and diffuse groundwater recharge modelling.

The aim of a **water availability assessment** is to determine the amount of water that could be diverted or extracted from each source, at any given location, at any given time. This requires detailed numerical models for surface water systems or groundwater, and preferably for both. Numerical modelling requires adequate data to calibrate the models and to provide sufficient spatial and temporal information to represent past conditions. A sufficient period of monitoring is required to provide both baseline conditions and confidence in forward projections and detailed information on water storage capacity is essential. In the Gulf of Carpentaria Drainage Division, there are river systems models for large parts of the Mitchell, South-East Gulf and Flinders-Leichhardt regions, which are developed to partition estimated water resources using historical hydrological data (Figure I).

**Key finding 1**

Water availability assessments can be made for parts of key catchments

Limited parts of three regions – the Mitchell, South-East Gulf and Finders-Leichhardt – have sufficient information and models for comment on water availability. These models, however, are designed to support resource operating plans and not water assessment and must be combined with the additional factors of: hypothetical storage potential, climate variability, environmental flows, social acceptance and political for a full assessment of sustainable yield. While these models are capable of assessing storage potential (and to consider basin-wide hydrological implications) if there is a reason to do so, they were not modified for the purposes of this project.

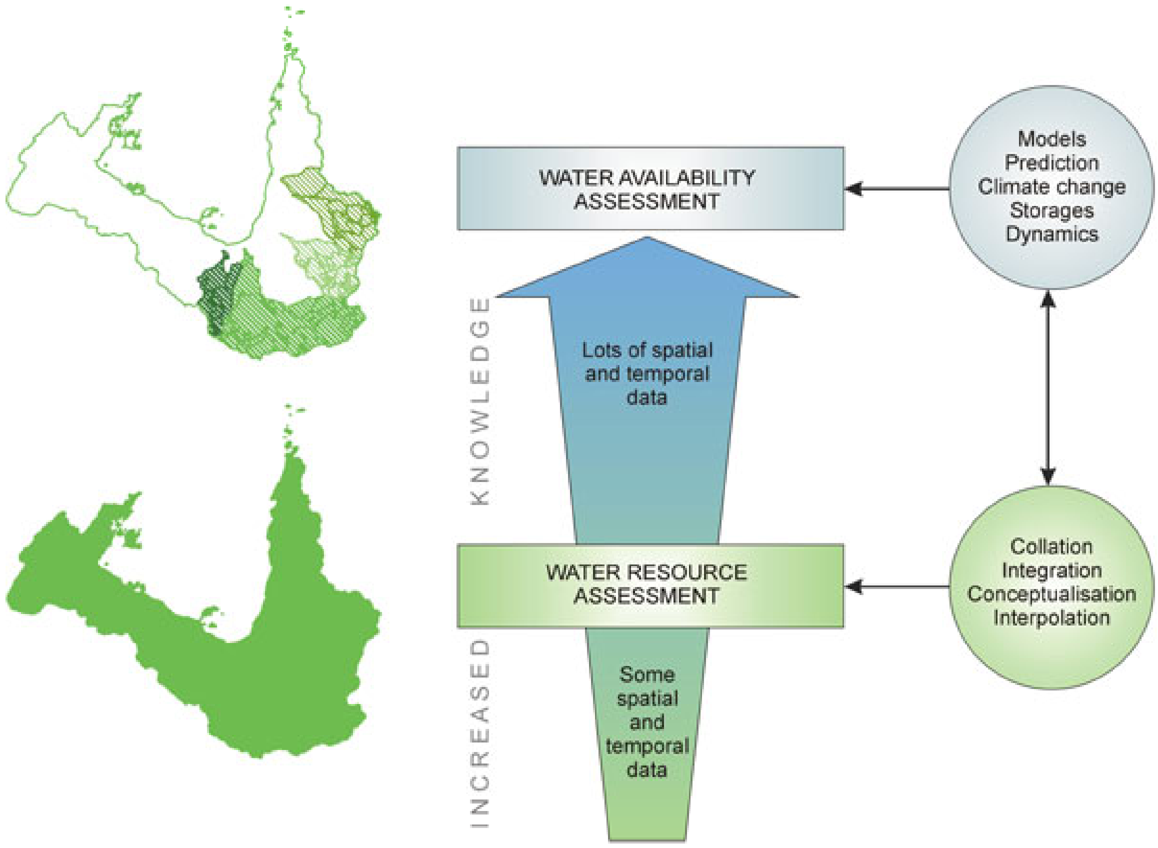


Figure I. Schematic illustrating the levels of water assessment capability for the Gulf of Carpentaria Drainage Division. Shaded areas have sufficient information **and** management models to carry out the labelled level of assessment

Integral to this project is the identification of gaps in three areas: data, information and knowledge. A key limitation of the project lies in the lack of water-related data for northern Australia. We restrict climate analyses to the 77 years from 1930 to 2007. Prior to this there are too many gaps across northern Australia to allow a contiguous analysis. Even today, there are still significant spatial gaps in rainfall data that restrict detailed analysis, particularly in the important headwater regions (Figure II), Stream gauging stations and reliable groundwater monitoring bores are sparsely located. The level of confidence in low flow records at many stream gauging stations is poor. The paucity of flow datasets greatly inhibits the potential to assess the linkages between ecological systems and hydrological regime. Data are especially sparse in floodplain regions where maintenance of recording equipment is difficult. For streamflow data, establishing rating curve relationships can be difficult and confidence in data can be compromised. Reliable groundwater monitoring bores are also sparse, but locally have adequate concentration for modelling.

**Key finding 2**

There is a paucity of quality data for water resource accounting

Surface water model calibration relies heavily on streamflow data 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. Groundwater information is locally available, but large areas remain devoid of any quantitative groundwater data.

Across the Gulf of Carpentaria Drainage Division, climate was modelled at a daily time step since 1930 (more than 28,000 days) at a spatial resolution of ~29 km$^2$ across 627,000 km$^2$ (generating more than 50,000 grid cells). Twenty-six variables were processed for each cell for each day. Future scenario modelling required this to be repeated for 15 global climate models (GCMs) to produce climate data for our best estimate of ~2030 conditions. These data were fed into rainfall-runoff models, run at the same spatial and temporal resolution, producing streamflow data at more than 130 streamflow reporting nodes, which included all gauging station locations, sites of environmental importance and key tributary junctions and surface water storage locations, and at more than 75 river system model nodes. At the

42 environmental asset sites, the streamflow conditions were assessed for low and high flow regimes and annual flow metrics were produced. The streamflow data were assessed against gauging station data, of which there are only 51 still in operation across the entire drainage division (Figure II).

The climate data also feed into a diffuse recharge model to provide potential shallow groundwater recharge estimates across the 12 major soil types of northern Australia; for 3 different vegetation habitats.

Nowhere across this region were there numerical groundwater models available for regional assessment, nor is data sufficient to warrant development of any models for this project. Local models exist and the Great Artesian Basin (GAB) groundwaters have been assessed as part of the GAB Strategic Management Plan (GABCC, 2000), but modelling at a regional scale is currently not possible.

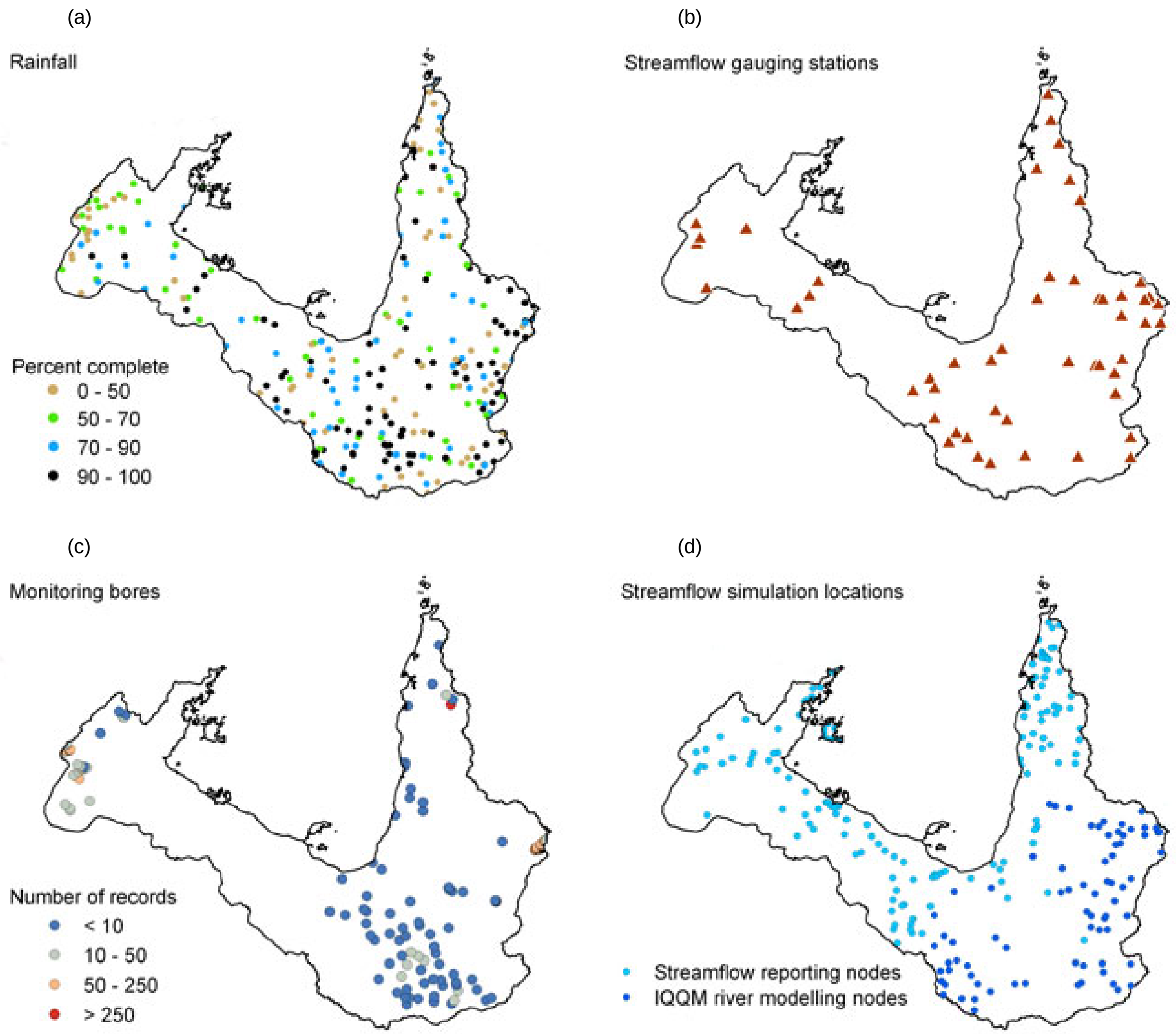


Figure II. Locations across the Gulf of Carpentaria Drainage Division of (a) Australian Bureau of Meteorology stations measuring daily rainfall used in the SILO database for the current decade; (b) currently active streamflow gauging stations, (c) current groundwater monitoring bores and (d) streamflow reporting nodes for this project

 

# An extreme climate

The Gulf of Carpentaria Drainage Division receives a substantial amount of rainfall each year. An average of more than 500,000 GL (equivalent to over 45 times the capacity of Lake Argyle, or 1000 Sydney Harbours) of rain fell across the drainage division each year between 1930 and 2007. From year to year, however, there is great variability in this amount (Figure III). The driest year, 1952, received half (251,000 GL) the mean amount; the wettest year, 1974, received twice (1,057,000 GL) as much. Averages belie this variability and a single extremely wet year can dramatically increase the long-term average. This variability increases away from the coast and towards the south. The Flinders-Leichhardt region has twice the coefficient of variability for rainfall compared to the Western Cape region (Table I).

**Key finding 3**

There is high inter-annual climate variability

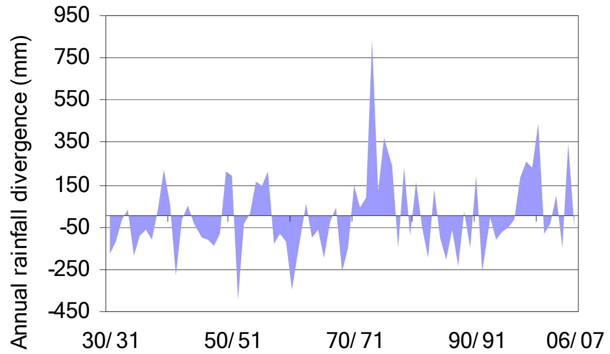


Figure III. Annual historical rainfall divergence (mm) from the historical mean, averaged over the Gulf of Carpentaria Drainage Division

Over 94 percent of annual rainfall falls between November and April, and between three and six months of the year receive little to no rain at all. The potential for evaporation, and for plant transpiration, is high throughout the year. On average, potential evapotranspiration is greater than the amount of rainfall received for 10 months of the year. During a few months in the wet season rainfall exceeds potential evapotranspiration and this drives seasonal stream flow. Climatically, on an annual basis, rainfall is insufficient to meet evaporative demand and the landscape may be described as water-limited (Figure IV).

**Key finding 4**

The climate is extremely seasonal and the landscape may be described as annually water-limited

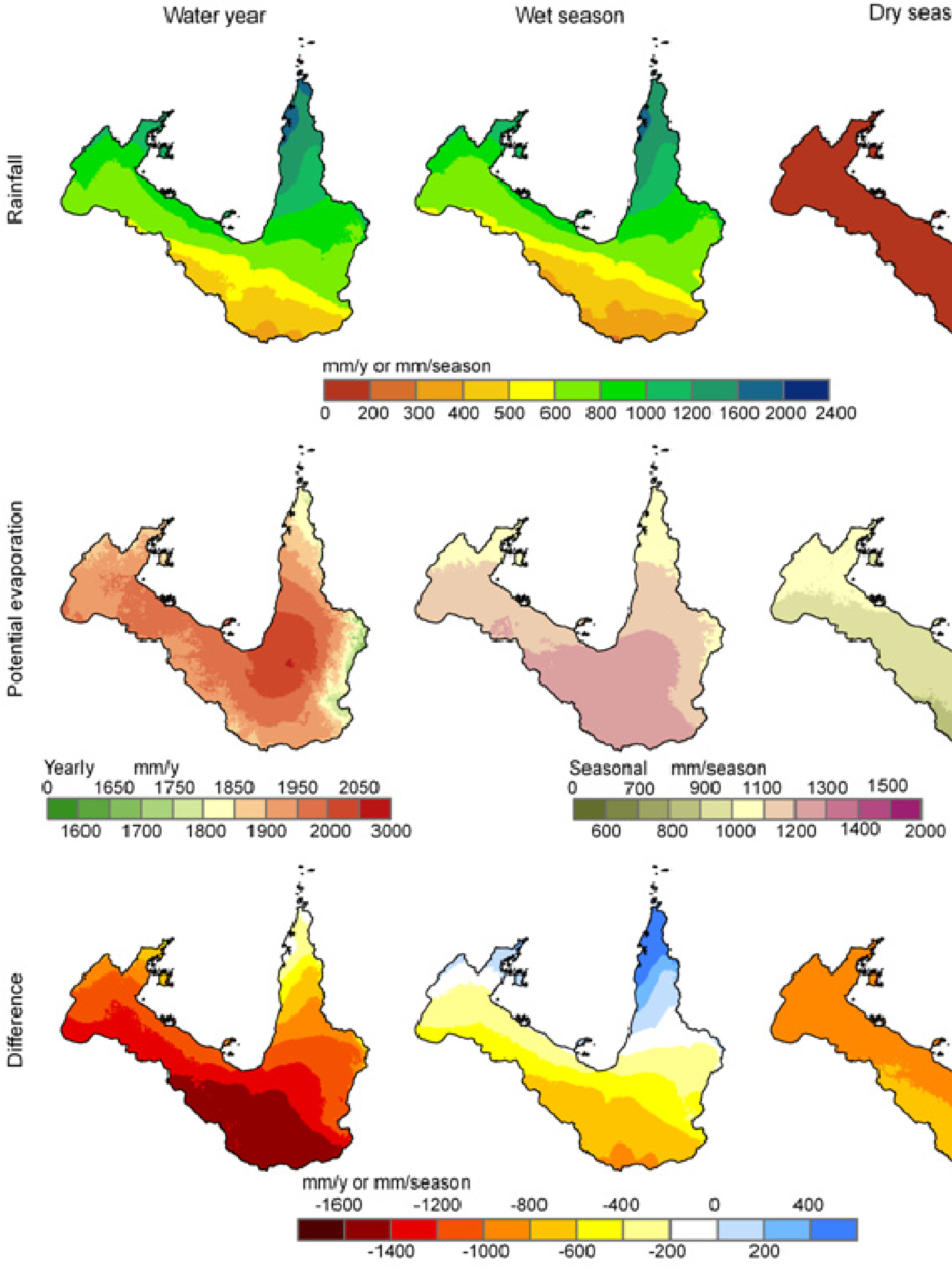


Figure IV. Spatial distribution of historical mean annual (water year = 1 September to 31 August), wet season (1 November to 30 April) and dry season (1 May to 31 October) rainfall and areal potential evapotranspiration (potential evaporation) and their difference (rainfall less areal potential evapotranspiration) across the Gulf of Carpentaria Drainage Division

# Historical and current water resources

**Key finding 5**

Most rain, and runoff, occurs near the coast, not the river headwaters

Most rain falls near the coast, on the estuaries, not in the rivers' headwaters (unlike the Murray-Darling Basin for example). Rainfall decreases away from the northern coast and runoff patterns mimic this rainfall distribution (Figure V). Consequently, most runoff occurs on the low-lying and flat coastal areas and produces large floods. Runoff varies from about 60 percent of rainfall in the high rainfall areas, to less than 3 percent in the far south of the drainage division, generating about 90,000 GL of streamflow across the drainage division. (This compares to 95,600 GL reported by the jurisdictions for the National Land and Water Resources Audit.) As this surface flow occurs mostly on the expansive floodplains, however, capture and storage of water are difficult. In the headwaters, where capture and storage are more feasible, rainfall and hence streamflow is low, whilst the high evaporation rates mean that storage volumes need to be substantially larger than in the southern parts of Australia for an equivalent yield and reliability of supply.

**Key finding 6**

There are significant constraints on the viability of surface water storages

Parts of the headwaters of the river basins in the north and east of the drainage division also receive sufficient rainfall to generate flows in the Mitchell and Western Cape regions (Figure V) yet these areas also have low relative relief.

(a) (b)

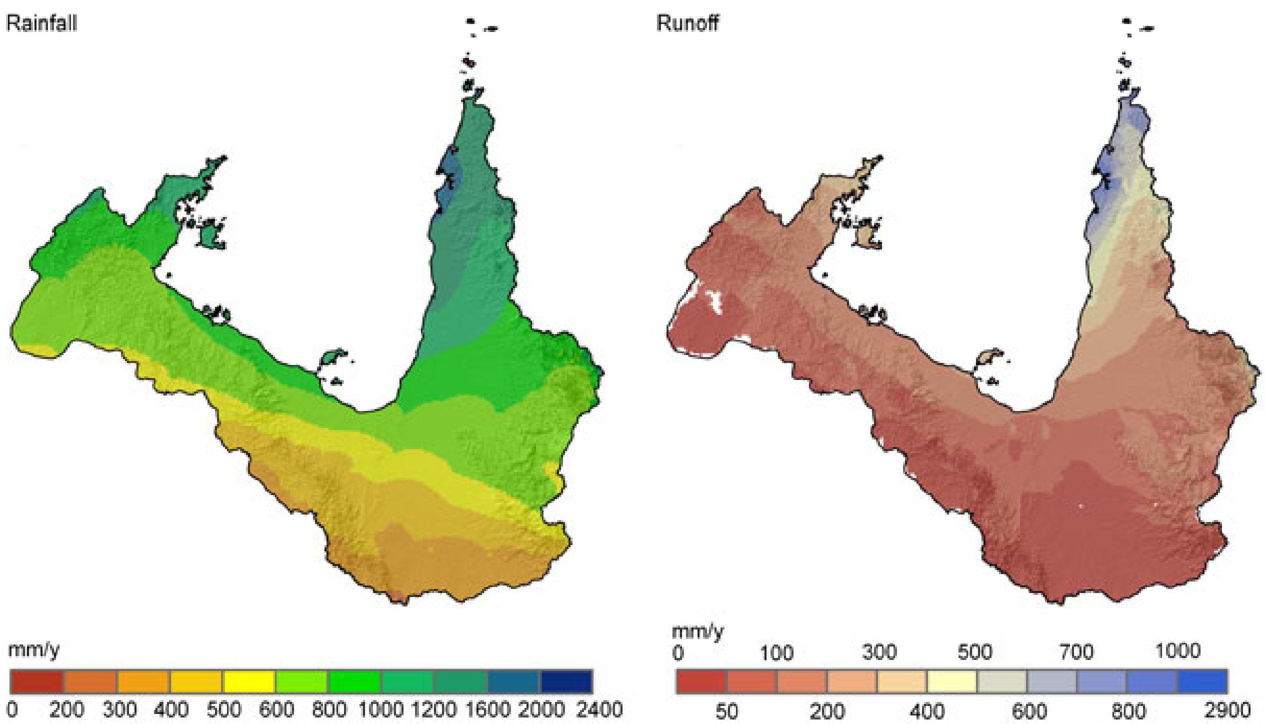


Figure V. Spatial distribution of historical mean annual (a) rainfall and (b) modelled runoff across the Gulf of Carpentaria Drainage Division overlaid on a relative relief surface. White pixels on the runoff map are areas that were not modelled

**Key finding 7**

Most catchments have largely unimpeded flow

The majority of rivers in the drainage division, and the catchments they support, flow largely unimpeded. This is reflected in the large number of wetlands registered in the Directory of Important Wetlands, the proposed Heritage listing of Cape York Peninsula and the Wild Rivers legislation adopted across many rivers of the drainage division. A wild river declaration preserves a wild river's natural values by regulating development within the wild river and its catchment area, and by regulating the taking of natural resources from the area. The few regulated rivers generally have a high degree of regulation and these have had local consequences to flow regimes downstream and around regulation structures.

**Key finding 8**

There are very few perennial river reaches and these have high cultural, social and ecological value

The high evaporation rates and the long dry season mean that there are very few rivers that flow year-round. Indeed, very few river reaches across the 627,000 km$^2$ of the Gulf of Carpentaria Drainage Division have sustained dry season flow and consequently these are highly valued. Values for these reaches are inter-twined and these perennial streams are of environmental, cultural, social and developmental value. They support endemic ecosystems, provide tourism and fishing opportunities and have high spiritual significance for indigenous and non-indigenous people alike.

**Key finding 9**

Inland perennial reaches are sustained by point discharge of groundwater

Critically, the inland rivers that flow through the dry season are sustained through localised groundwater discharge: Where streams cross outcrops of the shallow aquifers, or where deeper artesian waters puncture the landscape generating springs (Figure VI). These localised points of discharge are few and the risk of impact from development is high. In these environments, ecosystems are adapted to stream flow conditions that are rainfall-dependent in the wet season and groundwater dependent in the dry season.

**Key finding 10**

Shallow groundwater provides opportunities for development, but its dynamic behaviour poses risks of impacting local streamflow

Water tables in shallow aquifers respond dramatically to the seasonal rains, often rising several metres each year. Many shallow aquifers fill to capacity, and drain slowly during the dry season.

Shallow groundwaters generally have good quality water, reflecting the annual fill and spill cycle, and can be good supplies of potable water. Extractable yields are determined by the extent to which these dynamic systems can recover each year. The annual natural rise and fall of water levels, however, means these systems have lower extractable yields than deeper, regional systems or the confined aquifers of the Great Artesian Basin (GAB), and there is risk to reducing any streamflow of local rivers reliant on groundwater input.

**Key finding 11**

Groundwater recharge is complex and not directly proportional to rainfall amount

Groundwater recharge rates are variable across the landscape, and depend on soil type, vegetation and topography as well as rainfall amount. The complex interplay between these parameters means there is not a direct correlation with rainfall amount. Modelling indicates that rainfall regime (rain per rain day, number of rain days) is critical, and lower total rainfall might still result in higher recharge. There are also complex pathways for water infiltration to water tables, such as via fractures in rocky outcrops, or preferential flow through cracks and tree root holes, and these may change in importance through the year. Hence, rivers may recharge groundwaters during the wet months, whilst discharging groundwater maintain river flow during the dry months. The large area of carbonate aquifers across the west of the drainage division lend themselves to karst development and sinkholes and dissolution features can be important channels for water to penetrate the ground.

 

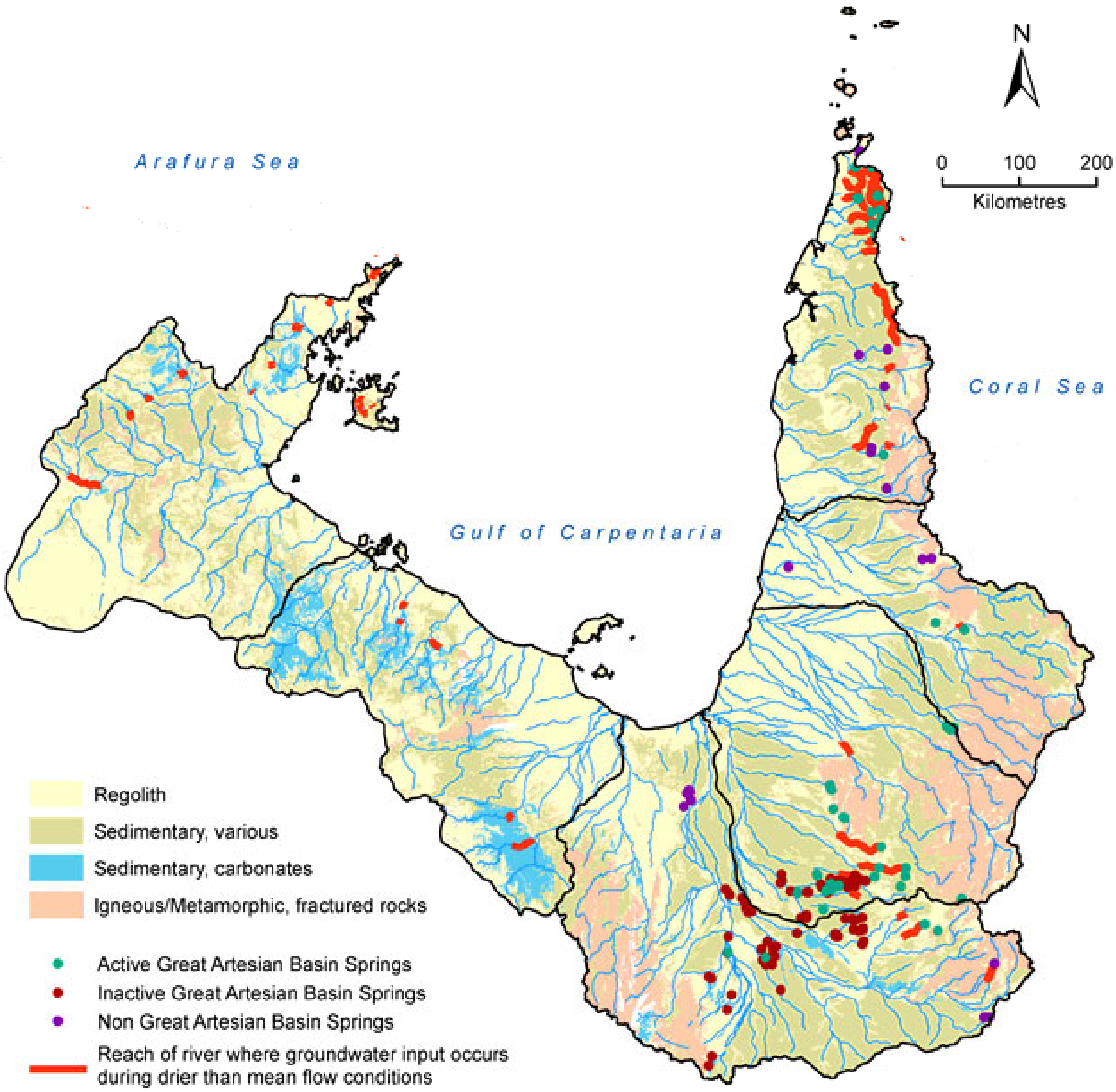


Figure VI. Surface–groundwater connectivity map for the Gulf of Carpentaria Drainage Division. The few rivers that flow through the dry season are related to discharge either from Great Artesian Basin aquifers in the east, or carbonate aquifers in the west

Groundwater data is very sparse for most aquifers and there are large uncertainties regarding the volumes of groundwater that might be safely extracted. This uncertainty is greater than the variability inherent in any possible changes expected due to climate change. Increased extraction will have consequences down-gradient that currently cannot be evaluated. There is also a risk of reducing up-gradient groundwater levels and hence spring discharge.

**Key finding 12**

There is little potential for managed aquifer recharge

There is little potential to increase the storage of shallow aquifers through artificial, or managed aquifer, recharge (MAR). These systems fill and spill with the seasons, and the time when the aquifers have drained sufficiently to accept more water coincides with the time when there is little surface water with which to recharge them. Further, much of the terrain is heavily weathered, with hard pans and laterites restricting the ability to use infiltration pits. Hence, more expensive injection wells would be required, reducing the economic viability.

Floods are vital ecosystem events, flushing nutrients into the near-shore marine environment and providing vast on-shore breeding grounds. Flooding across floodplains also fills hollows and pools that persist through the dry season, sustaining vital ecosystems until the next wet season.

**Key finding 13**

Floods are essential to sustain ecosystems

Across the 29 river basins in the Gulf of Carpentaria Drainage Division there are 35 sites on the Directory of Important Wetlands that were examined. None have ecosystem response indicators against which to judge whether a change in flow would be detrimental to the ecosystem. Approaches to address this lack of information are being investigated as part of the Northern Australia Water Futures Assessment Ecological Program.

**Key finding 14**

Consequences of flow changes on ecological systems is largely unknown

There are currently no adequate ecosystem function indicators to allow quantitative assessment of the consequences of changed flood regimes on the health of aquatic ecosystems. Whilst changes to flow at locations of important environmental assets can be characterised, the lack of quantitative relationships between flow and specific ecological entities (e.g. macrophyte populations, fish passage, faunal and floral habitats) means that the consequences of these flow changes on ecological systems is largely unknown.

# Historical and recent climate trends

Examination of historical (1930 to 2007) climate suggests a slight increase in rain per rain day and that the recent past (back to 1996) for the Gulf of Carpentaria Drainage Division has been 19 percent wetter overall than the previous 66 years (Figure VII). Across the Gulf of Carpentaria Drainage Division, the west has been 30 percent wetter in the recent past compared to the historical (1930 to 1996) record, while the east has been statistically similar through the entire record.

**Key finding 15**

The climate of the past decade is not indicative of historical variability or the possible range of future conditions

The last eleven years of data do not exhibit the full range of climatic variability seen in the historical record, nor the extremes of possible future conditions. There is considerable risk in using recent past conditions to guide future water planning. A single very wet year can significantly bias the historical mean.

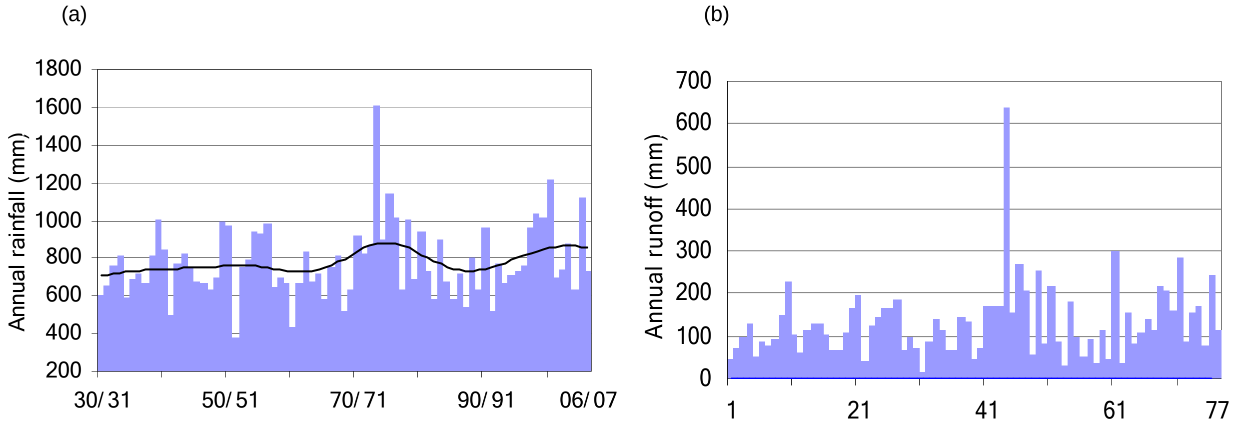


Figure VII. Historical annual (a) rainfall and (b) modelled runoff averaged over the Gulf of Carpentaria Drainage Division. The low-frequency smoothed line in (a) indicates longer term variability

 

# What the future holds

The consensus in modelling future (around 2030) conditions, using the global climate models (GCMs) suggested by the Intergovernmental Panel of Climate Change in their latest (4th) Assessment Report of 2007, is that rainfall across the Gulf of Carpentaria Drainage Division will be similar to conditions of the 1990s, with slightly higher evaporation rates.

**Key finding 16**

Global climate models suggest future rainfall will be similar to historical averages; potential evapotranspiration may be slightly higher

The GCMs used to model future conditions generate a range of possible future conditions based on a range of input assumptions. A consensus of models provides confidence in the predictions. Modelling provides confidence at large (regional) scales, becoming less predictive at small (local) scales. Results provide a good indication of possible trends, but should not be used to identify local changes. For the Gulf of Carpentaria Drainage Division, the consensus of models predict little change in rainfall relative to ~1990 conditions, within a range of plus or minus five percent, whilst most models predict an increase in potential evapotranspiration of between one and four percent (Figure VIII).

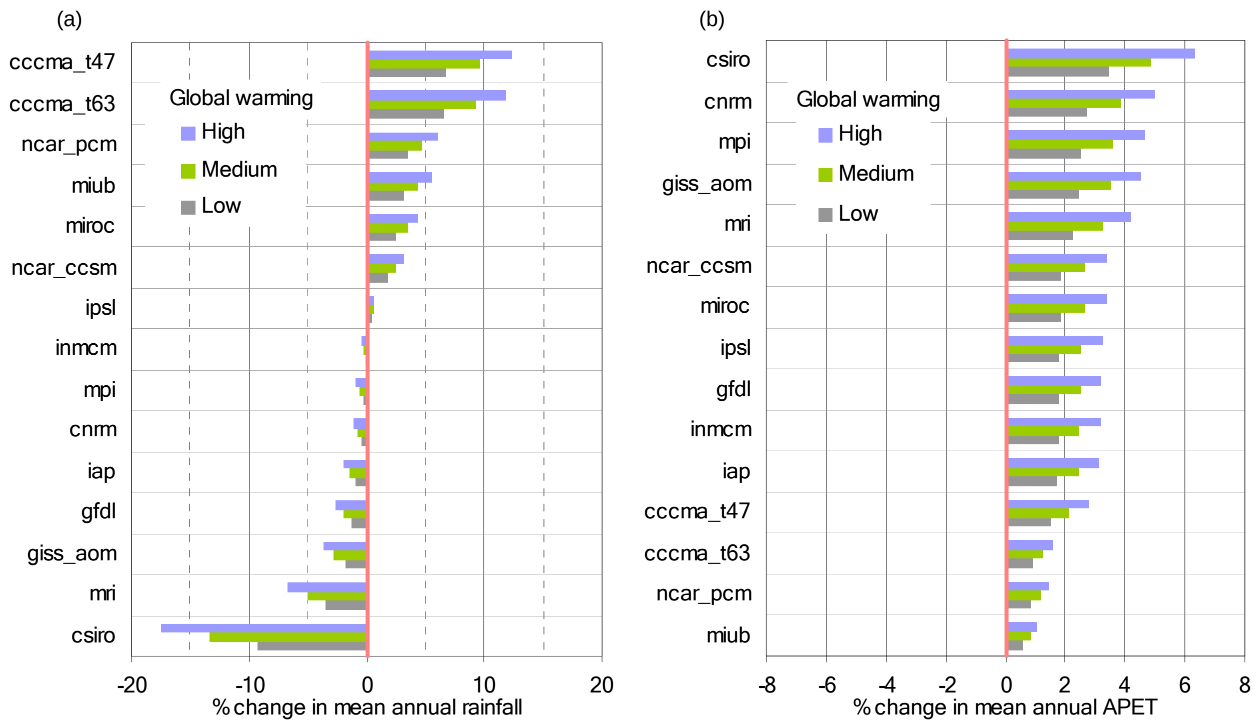


Figure VIII. Percentage change in mean annual (a) rainfall and (b) areal potential evapotranspiration under the 45 future climate simulations (15 global climate models and three global warming scenarios) relative to historical rainfall and areal potential evapotranspiration (~1990)

**Key finding 17**

Planned development will have minimal consequence to regional water resources, but may have local impacts

Consideration of planned development (where expressions of interest have been agreed) revealed little impact on the water budget at the regional scale in the short term (to about 2030), though longer-term impacts may have negative consequences, particularly where groundwater is being extracted. Local consequences may be significant, particularly where groundwater is being extracted and surface water-groundwater interaction is prevalent.

Groundwaters take 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 reducing groundwater levels may not be realised for many years. Modelling of groundwater systems helps reduce risk, but these models require sufficient time series data (generally >10 years) for calibration if they are to be predictive.

**Key finding 18**

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

**Key finding 19**

The Great Artesian Basin aquifers may support further development, but safe extraction yields have not been determined

Deep groundwater supplies of the GAB are a potential additional source of water within the drainage division. There is already significant use for stock and domestic purposes, and the resource may support further use, but more monitoring of groundwater dynamics is needed to determine safe extraction levels. The GAB aquifers likely discharge beneath the Gulf of Carpentaria; the consequences of this discharge to the marine environment have not been investigated. Further inland, groundwater from the GAB is the most important source of dry season flow in rivers, and supports numerous artesian spring groups (Figure VI).

Low flow conditions may be the most sensitive to modelled climate change. However, the paucity of calibration data provides low confidence in the quantitative assessments of flow regime change.

# Region results

This report is organised by regions (Figure IX). For each region, three chapters are provided: first, a synopsis of the water resources addresses the Terms of Reference; second, contextual information compiles relevant data collected by others prior to this project; and third, the results of the modelling for each region is presented in some detail. Further details of the modelling are reported in separate Water for a Healthy Country Flagship Science Reports. Facts and figures for each region are summarised in Table I, and are compared across all regions of the project, as well as summarised by drainage division and (where applicable) for the entire project area.

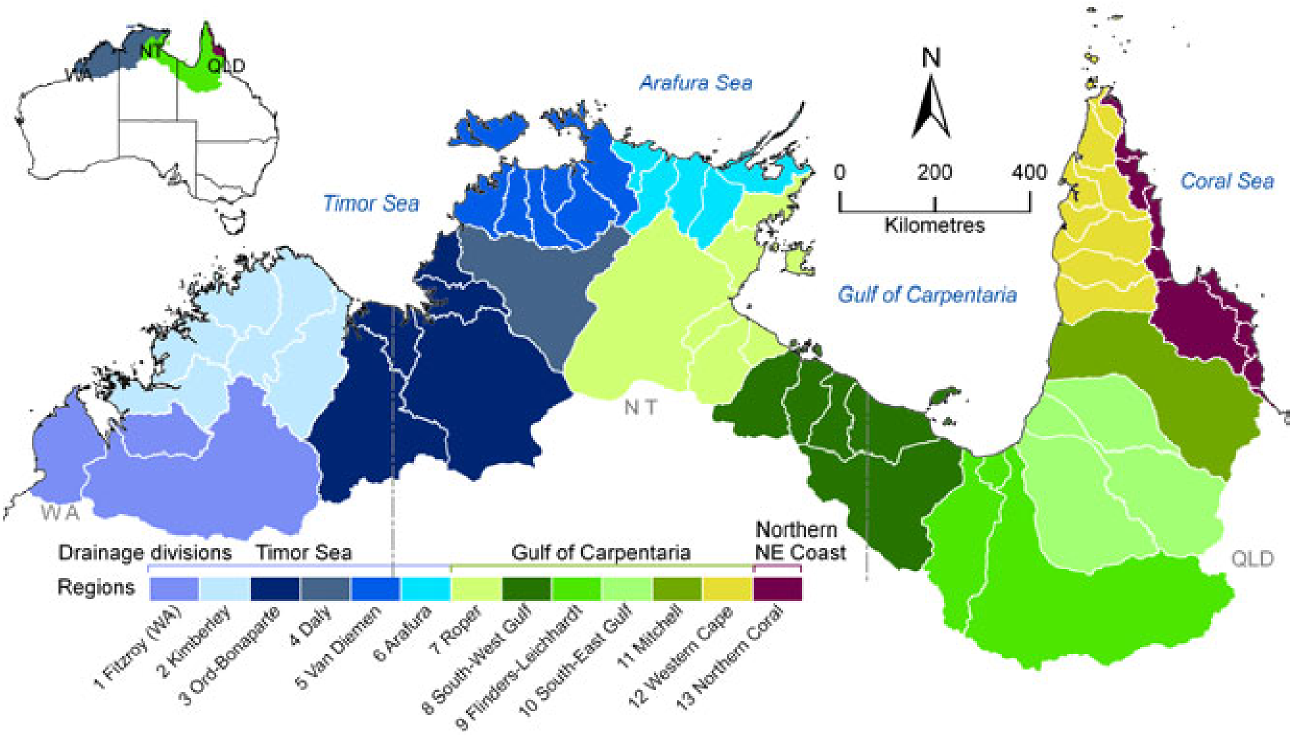


Figure IX. Reporting regions for the Northern Australia Sustainable Yields Project

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Table I. Summary facts and figures for each region, drainage division and all-of-project area

| | Regions of the Timor Sea Drainage Division | | | | | |
|---|---|---|---|---|---|---|
| | Fitzroy (WA) | Kimberley | Ord-Bonaparte | Daly | Van Diemen | Arafura |
| Area ($km^2$) | 131,606 | 109,761 | 164,529 | 54,423 | 67,586 | 45,499 |
| Relief (m) | 980 | 906 | 919 | 478 | 568 | 464 |
| Data availability | sparse | very sparse | sparse (locally reasonable) | sparse (locally reasonable) | locally dense | sparse |
| Climate | | | | | | |
| Rainfall inter-annual variability | high | high | high | moderate | moderate | moderate |
| Rainfall coefficient of variation | 0.39 | 0.30 | 0.32 | 0.25 | 0.21 | 0.23 |
| Mean annual rainfall (mm) | 577 | 950 | 730 | 1019 | 1390 | 1186 |
| Mean annual volume of rain (TL) | 76 | 104 | 120 | 55 | 94 | 54 |
| $10^{th}$ percentile rainfall (mm/y) | 963 | 1223 | 1486 | 1493 | 1695 | 1383 |
| $90^{th}$ percentile rainfall (mm/y) | 383 | 628 | 441 | 667 | 1155 | 920 |
| Annual APET | high | high | high | high | high | high |
| Mean annual APET (mm) | 2023 | 1994 | 1988 | 1942 | 1936 | 1898 |
| Mean annual rainfall deficit (mm) | -1446 | -1044 | -1258 | -923 | -546 | -712 |
| Seasonality of rainfall | strong | strong | strong | strong | strong | strong |
| Mean wet season rainfall (mm) | 534 | 898 | 689 | 975 | 1327 | 1140 |
| Median wet season rainfall (mm) | 515 | 876 | 682 | 954 | 1308 | 1136 |
| Percent wet season rainfall | 93% | 95% | 94% | 96% | 95% | 96% |
| Daily rainfall intensity | high | high | high | high | high | high |
| Daily rainfall intensity trend | increasing | increasing | increasing | increasing | increasing | increasing |
| Wettest year | 2000 | 2000 | 1974 | 1974 | 2000 | 2001 |
| Driest year | 1953 | 1936 | 1952 | 1952 | 1952 | 1952 |
| Rainfall gradient | moderate | moderate | moderate | moderate | moderate | moderate |
| Rainfall gradient (mm/km) | 1.8 | 1.4 | 1.8 | 1.9 | 3.0 | 1.6 |
| Recent rainfall relative to historical | wetter | wetter | wetter | wetter | wetter | wetter |
| Recent rainfall percent difference | 37% | 27% | 35% | 25% | 19% | 22% |
| Future rainfall relative to historical | same | same | same | same | same | same |
| Future rainfall percent difference | 0% | 1% | 2% | 1% | 0% | 1% |
| Future rainfall relative to recent | drier | drier | drier | drier | drier | drier |
| Surface water | | | | | | |
| Runoff inter-annual variability | high | high | moderate | moderate | low | low |
| Mean annual runoff (mm) | 76 | 153 | 112 | 159 | 375 | 240 |
| Mean percent of rainfall | 13% | 16% | 15% | 16% | 27% | 20% |
| Runoff coefficient range | 3-25% | 10-30% | 5-30% | 3-35% | 15-40% | 10-40% |
| Annual coefficient of variation | 0.93 | 0.78 | 0.67 | 0.69 | 0.49 | 0.48 |
| Wet season mean runoff (mm) | 73 | 148 | 110 | 149 | 361 | 217 |
| Wet season median runoff (mm) | 45 | 129 | 93 | 127 | 336 | 195 |
| Volume of streamflow (TL/y) | 10 | 17 | 18 | 9 | 25 | 11 |
| Percent runoff during wet season | 96% | 97% | 98% | 94% | 96% | 90% |
| Groundwater dependence for dry season flow? | yes | yes | yes | yes | yes | yes |
| Modelled availability (GL/y) | nm | nm | 4257 | 8184 | nm | nm |
| Estimated surface water use (GL/y) | NM | NM | 348* | minimal | NM | NM |
| Current level of use | NR | NR | 8% | <1% | NR | NR |
| Major perennial rivers | sub-flow | yes | artificial | yes | yes | yes |
| Monitoring of surface water use? | limited | no | yes | some | yes | no |
| Recent runoff percent difference | 51% | 71% | 56% | 66% | 44% | 38% |
| Future (Cmid) runoff difference | -3% | -1% | 0% | 1% | 1% | 1% |

* Does not include water release for hydropower generation (up to 2500 GL/year)
na is not applicable; NR is not reported; nm is not modelled; NM not measured.

 

| Regions of the Gulf of Carpentaria Drainage Division | | | | | | Drainage divisions | | | All-of-project area |
|---|---|---|---|---|---|---|---|---|---|
| Roper | South-West Gulf | Flinders-Leichhardt | South-East Gulf | Mitchell | Western Cape | Timor Sea | Gulf of Carpentaria | Northern North-East Coast* | |
| 128,518 | 111,890 | 145,223 | 122,094 | 72,229 | 66,766 | 573,400 | 627,000 | 46,551 | **1,246,951** |
| 441 | 431 | 1078 | 1068 | 1355 | 814 | 980 | 1355 | 1377 | **1377** |
| sparse | very sparse | locally reasonable | locally reasonable | locally reasonable | locally reasonable | sparse | sparse | sparse | **sparse** |
| Climate | | | | | | | | | |
| high | high | very high | high | moderate | moderate | high | high | moderate | **high** |
| 0.30 | 0.39 | 0.42 | 0.38 | 0.29 | 0.22 | 0.30 | 0.35 | 0.27 | **0.33** |
| 843 | 670 | 493 | 750 | 965 | 1417 | 868 | 779 | 1338 | **850** |
| 108 | 75 | 72 | 92 | 70 | 95 | 504 | 511 | 62 | **1077** |
| 1357 | 1168 | 812 | 1078 | 1615 | 1803 | 1688 | 1806 | 3640 | **3640** |
| 592 | 405 | 331 | 490 | 714 | 1054 | 383 | 334 | 917 | **331** |
| high | high | high | high | high | high | high | high | high | **high** |
| 1928 | 1961 | 1939 | 1980 | 1905 | 1874 | 1979 | 1939 | 1853 | **1954** |
| -1085 | -1291 | -1446 | -1230 | -940 | -457 | -1111 | -1160 | -515 | **-1104** |
| strong | strong | strong | strong | strong | strong | strong | strong | strong | **strong** |
| 805 | 631 | 437 | 710 | 917 | 1370 | 822 | 735 | 1233 | **802** |
| 812 | 549 | 396 | 675 | 913 | 1403 | 822 | 716 | 1252 | **785** |
| 95% | 94% | 89% | 95% | 95% | 97% | 95% | 94% | 92% | **94%** |
| high | high | high | high | high | high | high | high | high | **high** |
| increasing | increasing | increasing | increasing | increasing | increasing | increasing | increasing | increasing | **increasing** |
| 2001 | 2001 | 1974 | 1974 | 1974 | 1999 | 2000 | 1974 | 1974 | **1974** |
| 1952 | 1952 | 1952 | 1952 | 1952 | 1961 | 1952 | 1952 | 1961 | **1952** |
| moderate | moderate | weak | weak | weak | moderate | weak | weak | very steep | **weak** |
| 1.4 | 1.4 | 1.0 | 1.1 | 0.7 | 2.1 | 1.3 | 1.3 | 6.2 | **0.2** |
| wetter | wetter | similar | similar | similar | similar | wetter | similar | similar | **wetter** |
| 30% | 37% | 12% | 10% | 10% | 11% | 30% | 19% | 9% | **24%** |
| same | same | same | same | same | same | same | same | same | **same** |
| 0% | 0% | 0% | 0% | 1% | 1% | 1% | 0% | 1% | **0%** |
| drier | drier | same | same | same | drier | drier | same | drier | **drier** |
| Surface water | | | | | | | | | |
| moderate | high | very high | very high | moderate | low | moderate | high | low | **moderate** |
| 112 | 89 | 44 | 110 | 198 | 479 | 157 | 144 | 373 | **159** |
| 13% | 13% | 9% | 15% | 21% | 34% | 18% | 19% | 28% | **19%** |
| 4-35% | 4-20% | 3-25% | 4-16% | 15-60% | 15-50% | 3-40% | 3-60% | 10-50% | **3-60%** |
| 0.65 | 1.00 | 1.51 | 1.49 | 0.75 | 0.43 | nm | nm | 0.49 | **nm** |
| 103 | 87 | 43 | 109 | 194 | 458 | 149 | 140 | 333 | **nm** |
| 94 | 57 | 22 | 67 | 172 | 454 | nm | nm | 317 | **nm** |
| 14 | 10 | 6 | 13 | 14 | 32 | 90 | 90 | 17 | **197** |
| 92% | 98% | 98% | 99% | 98% | 96% | nm | nm | 89% | **nm** |
| yes | yes | yes | yes | yes | yes | yes | yes | yes | **yes** |
| nm | nm | 3391 | 3724 | 6786 | nm | na | na | nm | **na** |
| NM | NM | 218 | 29 | 81 | NM | >348 | >328 | NM | **>676** |
| NR | NR | 6% | 8% | 1% | NR | na | na | na | **na** |
| yes | yes | no | no | no | yes | yes | yes | yes | **yes** |
| no | no | yes | no | no | no | some | limited | no | **locally** |
| 54% | 78% | 9% | -13% | 16% | 27% | 56% | 30% | 19% | **41%** |
| -2% | -3% | 2% | -1% | -1% | 1% | -1% | -1% | 1% | **-1%** |

* Metrics for the Northern Coral region are the same as for the Northern North-East Coast Drainage Division.

Table I (cont'd). Summary facts and figures for each region, drainage division and all-of-project area

| | Regions of the Timor Sea Drainage Division | | | | | |
|---|---|---|---|---|---|---|
| | Fitzroy | Kimberley | Ord-Bonaparte | Daly | Van Diemen | Arafura |
| **Groundwater** | | | | | | |
| Surface–groundwater interaction | significant | none | strong | strong | strong | strong |
| Significant aquifers | alluvial/ Canning | fractured rock | carbonates | carbonates | carbonates/ sandstones | carbonates/ sandstones |
| Inter-regional groundwater system | yes | no | yes | yes | no | yes |
| Groundwater development | minor | none | minor | significant | part | none |
| Deep aquifers | Canning Basin | fractured rock | carbonates/ sandstones | carbonates | carbonates/ sandstones | carbonates |
| Quality | variable | good | variable | good | good | good |
| Shallow groundwater | alluvials | fractured rock | alluvials | carbonate | laterites | laterites |
| Monitoring of groundwater use? | some | no | some | some | some | most |
| Dominant groundwater use | irrigation/ public supply | none | minimal | irrigation/ public supply | public supply | mining |
| Impact of groundwater use on surface water | significant | significant | minimal | highly significant | significant | significant |
| Recharge mechanisms | diffuse | local | diffuse | local | local | complex |
| Modelled diffuse recharge (mm/y) | 50 | 120 | 70 | 150 | 295 | 190 |
| Groundwater extraction (GL/y) | 17 | NM | 40 | >30 | 37 | >15 |
| Future development | gas hub | not expected | not expected | irrigation | urban growth | not expected |
| **The environment** | | | | | | |
| Importance of groundwater to ecosystems | local | minimal | minimal | significant | minimal | minimal |
| Endemic wildlife | yes | yes | yes | yes | yes | yes |
| Tidal influence | significant | local | local | significant | local | local |
| Directory of Important Wetland sites | 10 | 3 | 7 | 3 | 9 | 2 |
| Sites selected for analysis | 4 | 3 | 4 | 3 | 6 | 2 |
| Number of stream reporting nodes | 8 | 4 | 8 | 5 | 14 | 4 |
| Nodes with reliable high flows | 4 | 3 | 5 | 5 | 13 | 4 |
| Nodes with reliable low flows | 2 | 2 | 3 | 5 | 10 | 2 |
| Sites with ecosystem response metrics | 1 | 0 | 1 | 1 | 0 | 0 |
| Flow conditions under future climate | similar | similar | similar | possible decrease | possible decrease | possible decrease |
| | | | | | | |

na is not applicable; NR is not reported; nm is not modelled; NM not measured

 

| Regions of the Gulf of Carpentaria Drainage Division | | | | | | Drainage divisions | | | All-of-project area |
|---|---|---|---|---|---|---|---|---|---|
| Roper | South-West Gulf | Flinders-Leichhardt | South-East Gulf | Mitchell | Western Cape | Timor Sea | Gulf of Carpentaria | Northern North-East Coast* | |
| Groundwater | | | | | | | | | |
| strong | limited | limited | limited | limited | strong | strong | limited | strong | **strong** |
| carbonates | carbonates | GAB | GAB | GAB | GAB | carbonates | carbonates/ GAB | GAB | **carbonates/ GAB** |
| yes | yes | yes | yes | yes | yes | yes | yes | yes | **yes** |
| none | none | undeveloped | undeveloped | undeveloped | capped | important | limited | none | **-** |
| carbonates | carbonates | GAB | GAB | sandstones | GAB | various | GAB | GAB | **various** |
| | | | | | | | | | |
| good | variable | variable | variable | variable | good | good | variable | variable | **variable** |
| laterites | sandstones | alluvials | alluvials | alluvials | sandstones | various | alluvials | alluvials | **various** |
| no | no | some | some | some | no | some | some | no | **some** |
| GDEs | mining | industry/ public supply | GDEs | stock and domestic | mining | various | various | various | **various** |
| significant | minimal | minimal | minimal | minimal | significant | significant | minimal | minimal | **significant** |
| complex | diffuse | diffuse | local | local | local | local | diffuse | local | **local** |
| 95 | 55 | 20 | 70 | 120 | 335 | 120 | 115 | 265 | **110** |
| NM | NM | 73 | 12 | 5 | 31 | >140 | >120 | 14 | **>275** |
| mining | mining | not expected | wild rivers | irrigation | wild rivers | various | various | negligible | **various** |
| The environment | | | | | | | | | |
| significant | significant | minimal | springs | local | significant | local | significant | minimal | **significant** |
| yes | yes | yes | yes | yes | yes | yes | yes | yes | **yes** |
| local | significant | significant | significant | significant | local | significant | significant | local | **significant** |
| 2 | 12 | 6 | 6 | 4 | 10 | 34 | 35 | 18 | **87** |
| 2 | 5 | 3 | 3 | 1 | 4 | 22 | 16 | 5 | **43** |
| 6 | 12 | 3 | 3 | 1 | 16 | 42 | 42 | 12 | **96** |
| 0 | 5 | 3 | 1 | 1 | 14 | 34 | 24 | 9 | **67** |
| 0 | 0 | 3 | 1 | 1 | 4 | 24 | 9 | 3 | **36** |
| 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | **3** |
| possible decrease | possible decrease | possible increase | possible increase | possible decrease | possible decrease | possible decrease | possible decrease | possible decrease | **similar** |
| | | | | | | | | | |

GAB – Great Artesian Basin aquifers; GDEs – groundwater-dependent ecosystems

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# Water in the Flinders-Leichhardt region



# Water in the South-East Gulf region

# Water in the Mitchell region



# Water in the Western Cape region



 

# Tables

# Figures



 

# Abbreviations and acronyms

| Abbreviation or acronym | Description |
|---|---|
| AHD | Australian Height Datum |
| AMTD | Adopted Middle Thread Distance (the distance along a river upstream from its outlet) |
| APET | Areal potential evapotranspiration |
| AR4 | The fourth assessment report of the Intergovernmental Panel on Climate Change |
| ARI | Average recurrence interval – the statistical length of time that might be expected to pass before a similar condition is repeated |
| AWRC | Australian Water Resources Council |
| BFI | Baseflow index – the ratio of baseflow volume to total flow volume over a specified period, commonly assumed to be the amount of groundwater input to stream flow |
| BRS | Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry |
| CLW | CSIRO Division of Land and Water |
| CMAR | CSIRO Division of Marine and Atmospheric Research |
| CMB | Chloride mass balance |
| $CO_2$ | Carbon dioxide |
| COAG | Council of Australian Governments |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DEM | Digital elevation model |
| DERM | (Queensland) Department of Environment and Resource Management |
| DEWHA | Department of the Environment, Water, Heritage and the Arts, Australian Government |
| DNRM | Previous incantation of DERM |
| DNRW | Previous incantation of DERM |
| DTW | Depth to watertable |
| E | Extraction |
| E/B | Extraction to baseflow ratio |
| E/R | Extraction to recharge ratio |
| $E_f$ | Future groundwater extraction |
| EC | Electrical conductivity, a measure of salinity. 1 EC (μS/cm) ≈ 0.6 mg/L TDS |
| ET | Evapotranspiration |
| FDC | Flow duration curve |
| GAB | Great Artesian Basin |
| GCM | Global climate model, also known as general circulation model |
| GDA | Geographic datum of Australia |
| GDE | Groundwater-dependent ecosystem |
| GRCI | Groundwater resource condition indicator |
| IQQM | Integrated Quantity and Quality Model – a river systems model |
| MAR | Managed aquifer recharge |
| MDB | Murray-Darling Basin |
| MGSH | Maximum gauged stage height |
| MSLP | Mean sea level pressure |
| NAILSMA | Northern Australia Indigenous Land and Sea Management Alliance |
| NAS | Network attached storage |
| NALWT | Northern Australia Land and Water Taskforce (http://www.nalwt.gov.au/) |
| NAWFA | Northern Australia Water Futures Assessment (http://www.environment.gov.au/nawfa/) |
| NRETA | Previous incantation of NRETAS |
| NRETAS | Northern Territory Department of Natural Resources, Environment, the Arts and Sport |
| NSE | Nash-Sutcliffe Efficiency coefficient used to assess the predictive power of hydrological models. Values range from -∞ to +1, where +1 is a perfect match to observations. Analogous to the $R^2$ coefficient of determination |
| PET | Potential evapotranspiration |
| R | Recharge |
| RAM | Random access memory |
| RSF | Recharge scaling factor |
| SAN | Storage area network |
| SILO | Enhanced meteorological datasets (http://www.bom.gov.au/silo/index.shtml) |

| Abbreviation or acronym | Description |
|---|---|
| SRN | Streamflow reporting node |
| TDS | Total Dissolved Solids (mg/L ≈ 1.7 EC) |
| TRaCK | Tropical Rivers and Coastal Knowledge Research Hub |
| WRON | Water Resources Observation Network |

# Units of measurement

| Measurement units | Description |
|---|---|
| ML | Megalitres, 1,000,000 litres |
| GL | Gigalitres, 1,000,000,000 litres |
| TL | Teralitres, 1,000,000,000,000 litres |
| Cumecs | Cubic metres per second; $m^3$/sec; equivalent to 1,000 litres per second |
| 1 Sydney Harbour | ~500 GL |
| 1 Lake Argyle | 10,380 GL |
| | |

# Glossary of terms

| Term | Description |
|---|---|
| Scenarios | Defined periods or conditions for comparative evaluation of water resource assessments. Each scenario has three variants: wet, mid and dry, representing the 90th, 50th and 10th percentile of ranked results for each modelled condition. These are referred to as the wet extreme, median and dry extreme variants for each scenario, A, B, C and D. Additional variants include: C range which represents the inter-quartile range of values (25-75% of values) and AN which represents the pre-development (i.e. near pristine) scenario based on Historical data. AN can be defined where river systems models are available |
| Historical | Scenario A: 1st September, 1930 to 31st August, 2007 – except for recurrence interval calculation, when Historical refers to the period 1st September, 1930 to 31st August, 1996 (i.e. prior to Recent) |
| Recent | Scenario B: 1st September, 1996 to 31st August, 2007 |
| Future | Scenario C: Climate conditions estimated for ~2030 compared to ~1990 conditions |
| Development | The use of surface and groundwater supplies. This assessment assumes that all current entitlements are being fully used and, where possible, actual use is also considered. Future development assumes all entitlements projected to be made available in 2030 are fully utilised. This is referred to as Scenario D |
| Without development | Scenarios AN, BN and CN. Represent conditions that would be expected under the climate scenarios without development, i.e. near-pristine conditions. These can be defined for systems with river systems models |
| Water Resource Assessment | An assessment that identifies the partitioning of rainfall through the water cycle, i.e. how much water there is in all its guises, at any given location, at any given time |
| Water Availability Assessment | An assessment that determines the amount of water that could be diverted or extracted from each water source, at any given location, at any given time |
| Water Sustainable Yield Assessment | An assessment that determines the amount of existing water resources that are available for consumptive use after the informed and equitable allocation of the resource between human uses and the environment |
| FCFC | Forest Cover Flow Change (*see* <http://www.toolkit.net.au/Tools/FCFC>) |
| AWBM, Sacramento, SIMHYD, SMARG | Rainfall-runoff models (*see* http://www.toolkit.net.au/Tools/RRL) |
| IHACRES Classic | IHACRES (Identification of unit Hydrographs And Component flows from Rainfall, Evaporation and Streamflow data) is a catchment-scale, rainfall-streamflow, modelling methodology that characterises the dynamic relationship between rainfall and streamflow, using rainfall and temperature (or potential evaporation) data, and predicts streamflow, developed by the Integrated Catchment Assessment and Management (iCAM) Centre, Faculty of Science, The Australian National University |
| MODFLOW | A groundwater flow model (http://water.usgs.gov/nrp/gwsoftware/modflow.html) |
| WAVES | An analytical recharge model developed by Zhang and Dawes (1998) used to estimate groundwater recharge under different soils, vegetation and climate scenarios |
| SRES 1B | A future (2100) greenhouse gas emissions scenario used to compare climate model forecasts |
| Unallocated water | Water that is identified as water potentially available for future allocation |
| General Reserve | Unallocated water which may be granted for any purpose |
| Strategic Reserve | Unallocated water which may only be granted for a state purpose |
| | |

 

# Preamble



## Northern Australia Sustainable Yields Project

This project assesses, and quantifies within the limits of available data, the change to water resources under a number of theoretical climate scenarios, and hence helps define the potential change to water availability under those climate regimes. This can aid in identifying regions that may come under increased, or decreased, stress following climate change, based on what has been observed in the historical past. The paucity of long-term information for the quantification of water resources of northern Australia limits this assessment to a comparison to 77 years of climate records across the entire region (from 1930 to 2007), though locally records may extend back beyond 100 years. In many regions, however, reasonable quality data extends back only to the 1960s, while a number of catchments still remain almost devoid of good water resource information.

This project is a desktop study. No new data have been collected. New data were generated through numerical modelling using existing data as a base, while new interpretations of existing data were undertaken. The project highlights areas  that require further investigation, and includes a gap analysis.

The assessments made under this project provide key information for further investigations into environmental impacts and socio-economic impacts as well as generating information to facilitate stakeholder and community consultation. Ultimately, this will inform water resource planning, management and investment (Figure 1).

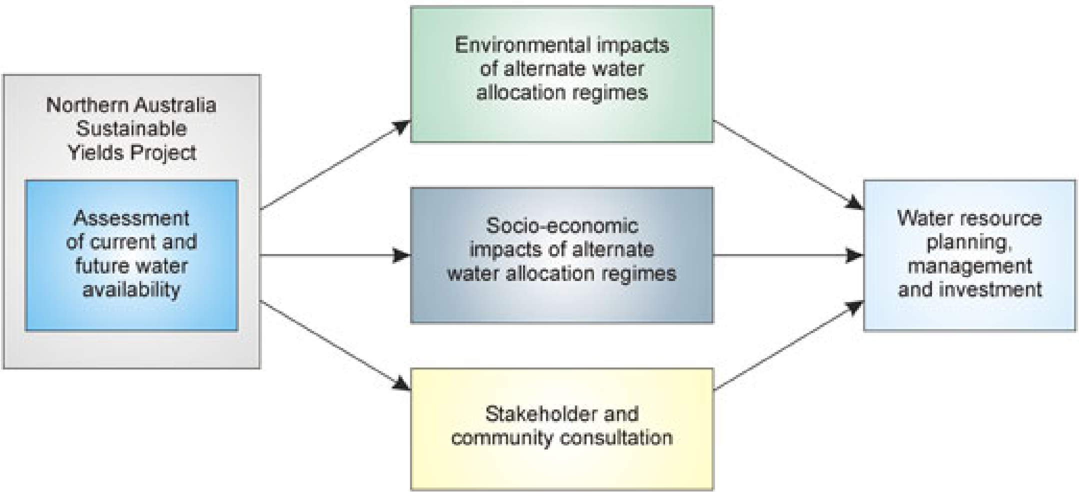


Figure 1. Project context

Determination of sustainable yield and/or over-allocation requires choices by communities and governments about the balances of outcomes (environmental, economic and social) sought from water resource management and use. These choices are best made in the light of sound technical information, and the fundamental underpinning information is a robust description of the extent and nature of the water resource.

While existing records of rainfall, streamflow and groundwater levels (and simulation models based on these data) provide a description of the resource from the past to the present, it is increasingly widely recognised that these data do not provide the best description of the likely extent and nature of the resource into the future, and thus no longer provide the best basis for planning. A careful examination of the likely implications of climate change on water resources is required as the basis for planning into the future. This includes a consideration of the direct effects (such as changes in rainfall and changes in evaporation) and indirect effects (such as changes in bushfire frequency and water demand).

The baseline information that is required for determining sustainable yields is thus an assessment of the current and likely future extent and variability of surface and groundwater resources. This project – commissioned by the National Water Commission (NWC) on behalf of the Council of Australian Governments (COAG) and in consultation with the Department of the Environment, Water, Heritage and the Arts (DEWHA) – has undertaken such an assessment of northern Australia. This one-year project (July 2008 to June 2009) covers key surface and groundwater systems and basins within the surface water drainage divisions (as defined by the Australian Water Resources Council (AWRC, 1987)) of the Timor Sea and Gulf of Carpentaria, and that part of the North-East Coast Drainage Division north of Cairns (herein referred to as the Northern North-East Coast Drainage Division) (Figure 2).

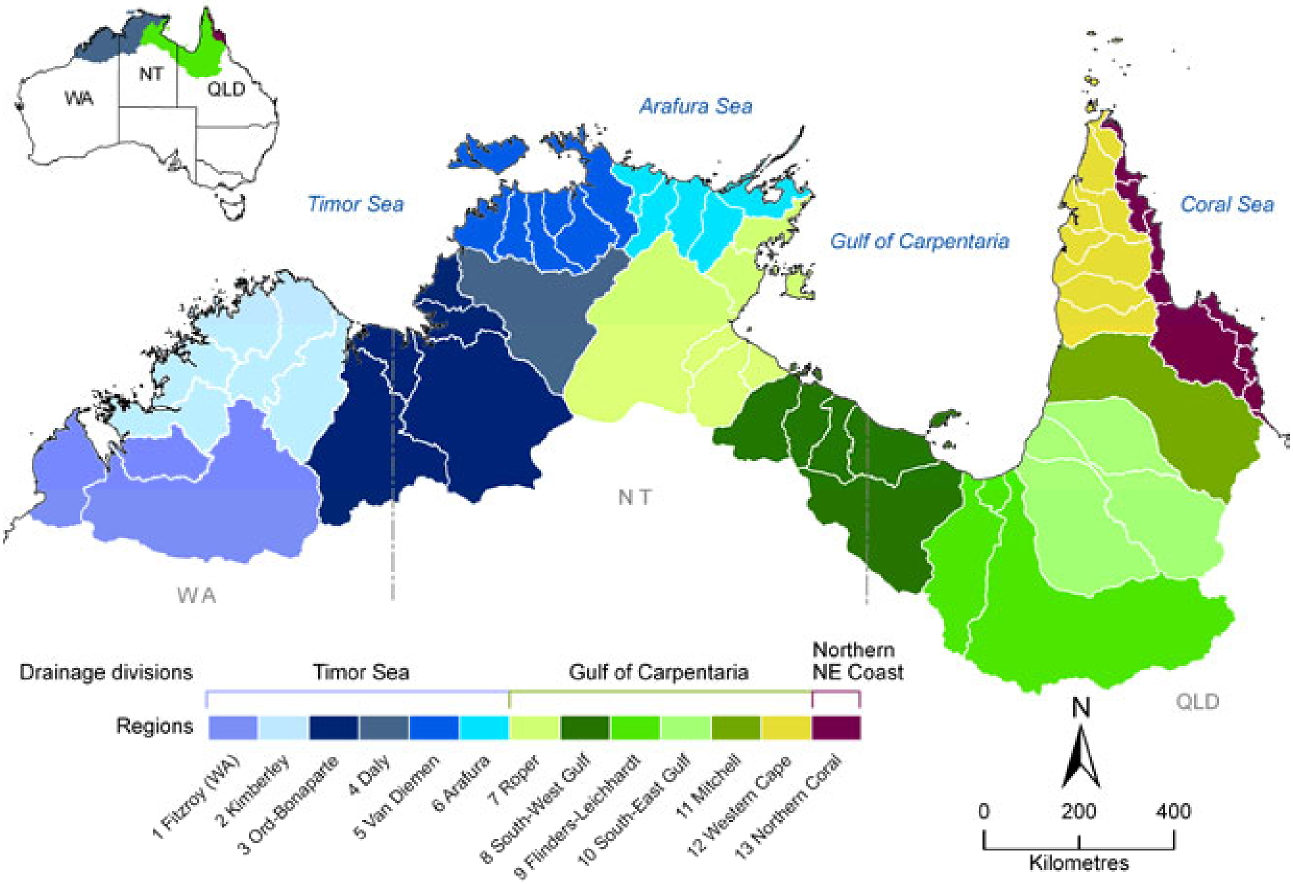


Figure 2. Extents of surface water river basins (white lines), regions and drainage divisions (inset) for the Northern Australia Sustainable Yields Project

Under the Terms of Reference, 'the CSIRO will:

1. Develop transparent, consistent and robust methodologies for determining the extent of available water resources in the catchments/aquifers of the study area, including guidance on:
    a. how to utilise the historical flow records used in surface water models and the recharge assumptions used in groundwater models, to factor in climate change and other risks;
    b. how to address the interaction between surface and groundwater systems;
    c. appropriate models/methodologies to use in regions which do not have existing surface water or groundwater models and/or which do not have comprehensive water resource data;
    d. ensuring that models/methodologies are capable of incorporating a range of 'development' scenarios or land use change activities;
    e. identifying significant knowledge and information gaps.

 

2. In the application of the methodologies, use existing legislation, water plans or other arrangements to guide the assessment. For catchments or aquifers either without current water resource arrangements or with plans for which environmental outcomes and/or levels of extractive use are not clear, these parameters may be inferred and any assumptions clearly stated.
3. Apply the above methodology to estimate water availability and demand in 2030 in the light of climate change and other risks to provide:
    a. Estimates of water resources on an individual catchment and aquifer basis using four different scenarios:
        i. historical climate and current development (Scenario A);
        ii. climate for the last 10 years and current development (Scenario B);
        iii. 2030 climate change and current development (Scenario C);
        iv. 2030 climate change and 2030 development of farm dams, plantations, groundwater systems and proposed irrigation development (Scenario D).
    b. For each of the scenarios (i) to (iv) above, provide an assessment of the impact of current and future predicted water resource development on key environmental assets.
4. Take into account the unique seasonal characteristics and the interconnectivity of surface and groundwater systems in northern Australia and advise on how these impact on water availability.
5. Assess water storage options in agreed catchments, including the storage of water in aquifers.
6. Work will be guided by a steering committee, chaired by the Commonwealth, with membership from the governments of Queensland, Western Australia, the Northern Territory, and the CSIRO.
7. The project will take account of current water resource assessment projects and activities underway in northern Australia where applicable, in particular those associated with the TRaCK (Tropical Rivers and Coastal Knowledge research hub) program, the Indigenous Water Policy group within NAILSMA (North Australian Indigenous Land and Sea Management Alliance) and any consultancy projects as identified by project contact group members.'



## Limitations and confidence levels

This project does not define the sustainable yields of water resources of northern Australia. The term 'sustainable yield' refers to the amount of a water resource that is available for use for human development after the informed and equitable allocation of the resource between human uses and the environment. A precise definition is elusive as sustainable yield is essentially a subjective measure that varies according to the nature of the resource and stakeholder priorities (Kalf and Woolley, 2005). Whilst sustainable yield is a term that applies to all water resources, greatest discussion occurs over its use relative to groundwater resources, where slow, and often indeterminate, response times of systems mean that real-time evaluations are problematic. For surface water systems, and particularly in the north, each year represents a re-setting of that water resource availability. The vagaries of the inter-annual variability of the Australian climate may thus produce several consecutive years of below-average rainfall. In this case, drought recurrence interval becomes important. Indeed, the north may be considered as experiencing drought conditions for several months every year. This, combined with the extremely high evaporation rates experienced in the north, means that most development will require water storages that are sufficient to supply water for many years (Petheram et al., 2008). The high evaporation rates and flat landscape across much of the north limits the use of surface water storages; hence groundwater may provide an important water storage resource potential.

## Report structure

This report is one of three prepared for the COAG Water Sub Group by the Northern Australia Sustainable Yields Project. A separate report is provided for each of the three drainage divisions of the north: Timor Sea, Gulf of Carpentaria and Northern North-East Coast (north of Cairns). All follow a similar structure that reflects the requirements of the Terms of Reference listed above.

The **Executive Summary** summarises the key messages from the project.

This **Preamble** covers the background and context of the project.

**Chapter 1** provides an overview of the drainage division, covering general physiography, climate, land use, vegetation, environmental assets, a summary of the drainage division's water resources, and an indication of water resource knowledge gaps.

**Chapter 2** outlines the assessment approaches for different components of the water cycle. Climate, surface water and groundwater methodologies are summarised and the techniques used to assess surface–groundwater interaction are outlined. Metrics are also developed which are derived from these assessments and which illustrate changes to the hydrological regime at sites of environmental, social and cultural importance. These assessment methods are illustrated using results at a division scale; they also apply to assessments made at the regional scale. Detailed aspects are provided in an accompanying technical report on methods (CSIRO, 2009).

**Subsequent regional chapters** report on the water resources of individual regions as defined in Figure 2. These chapters are distinguished with a two-letter prefix designating the region under evaluation: FI (Fitzroy (WA), KI (Kimberley), OB (Ord-Bonaparte), DA (Daly), VD (Van Diemen), AR (Arafura), RO (Roper), SW (South-West Gulf), FL (Flinders-Leichhardt), SE (South-East Gulf), MI (Mitchell), WC (Western Cape), and NC (Northern Coral). For each region, there are three chapters (replace 'ID' with the two-letter prefix for the region to obtain the actual chapter number):

***Chapter ID-1*** summarises the water resources of the region, using information from Chapter ID-2 and Chapter ID-3, and directly addresses the Terms of Reference, specifically terms 3, 4 and 5. Essentially, this chapter provides a synoptic view of the region and covers water resource assessment; changes to flow regime at environmental assets; seasonality of the resources; surface–groundwater interaction; and water storage options. This chapter also summarises data and knowledge gaps relevant to water resource management in the region.

***Chapter ID-2*** summarises the background information for the region, outlining existing knowledge of water resources and prior and current investigations relevant to the water resources of the region. This chapter also outlines the current and potential future legislation, water plans and other water resource management arrangements.

***Chapter ID-3*** describes the modelling results and the assessment of water resources undertaken by this project. Detailed, quantified assessments are made where possible and relevant, and confidence is estimated. This chapter focuses on climate, recharge, conceptual groundwater models, groundwater and rainfall-runoff modelling, and river system water balance. Changes to flow regimes at environmental assets are also assessed.

A series of CSIRO Water for a Healthy Country Flagship Science Reports accompanies these reports. These provide further detailed analysis of the modelling methods and results, as well as additional analyses relevant to water resources of northern Australia. Some are relevant for water resources across Australia, in particular those that relate to all Sustainable Yields Projects currently being carried out.

A significant component of this project is the exposure of information and knowledge gaps that require further investigation if the water resources of northern Australia are to be adequately managed. Whilst many of these gaps are presented within these reports, an accompanying Gaps Analysis report focuses on areas of research that would further our understanding of water resources of northern Australia and outlines regions that require additional data for adequate modelling and forecasting to take place.



 

## Northern Australia Water Futures Assessment and Northern Australia Land and Water Taskforce

The Northern Australia Sustainable Yields Project comprises the first phase of the Northern Australia Water Futures Assessment (NAWFA, <http://www.environment.gov.au/nawfa>), an Australian Government initiative. The objective of the NAWFA is to develop an enduring knowledge base of northern Australia's water resources, so that development proceeds in an ecologically, culturally and economically sustainable manner.

Subsequent phases of the NAWFA will comprise an ecological program, a social and cultural program, and the development of an enduring knowledge platform. These form the intermediate components of Figure 1, required before water planning should be undertaken. The role of this project, therefore, is not to report on consequences of changes to the water regime of the north as this will be undertaken under the subsequent programs of the NAWFA. The combined information from the completed NAWFA will take us closer to an assessment of sustainable yield for northern Australia.

The Northern Australia Sustainable Yields Project is also of interest to the Northern Australia Land and Water Taskforce <http://www.nalwt.gov.au>. The Northern Australia Land and Water Taskforce is a high-level independent group of Australian experts drawn from broad areas, including Indigenous groups, business, academia, conservation, tourism, agriculture, and the minerals and energy resource industries. The Taskforce is examining the potential for new developments in northern Australia that rely on significant local or regional water resources and are consulting with stakeholders in the north to identify opportunities for further development. The Taskforce will be informed of the outcomes of the Northern Australia Sustainable Yields Project through the Northern Australia Water Futures Assessment.



## Companion science reports

A series of CSIRO Water for a Healthy Country Flagship Science Reports accompanies this division report and contains the technical support material from which the observations and results presented in this report are drawn. These companion reports will be released in October 2009. Table 1 lists the indicative titles that will be available via the project website <www.csiro.au/partnerships/NASY>.

Table 1. List of indicative titles and authors for companion science reports

| Indicative title | Authors (provisional) |
|---|---|
| Data and knowledge gaps related to water resource assessment of northern Australia | Cresswell RG, Petheram C, Harrington GA, McVicar TR, McJannet DL, Hartcher M et al. |
| Diffuse groundwater recharge modelling across Northern Australia | Crosbie RS, McCallum JL and Harrington GA |
| Developing and implementing a report delivery framework for the Northern Australia Sustainable Yields Project | Cuddy SM, Schmidt B and McGillion T |
| Groundwater modelling of Fitzroy River Alluvium, Western Australia. Internal work document. | Dawes WR |
| Groundwater modelling in the Darwin Rural area, Northern Territory | Evans P, Arunakumaren J, Burrows W. and Raue J |
| Preliminary groundwater balances for northern Australia | Harrington GA, Dawes WR, Wiltshire E, Cranswick R, Evans R, Jolly P, Knapton A and Foster L |
| Groundwater model for the Tindall Limestone | Knapton A et al. |
| Climate data and their characterisation for hydrological scenario modelling across northern Australia | Li LT, Donohue RJ, McVicar TR, Van Niel TG, Teng J, Potter NJ, Smith IN, Kirono DGC, Bathols JM, Cai W, Marvanek SP, Chiew FHS and Frost AJ |
| High and low flow regime changes at environmental assets across northern Australia under future climate and development scenarios | McJannet DL, Wallace JW, Henderson A, McMahon J |
| Information supporting river modelling undertaken for the Northern Australia Sustainable Yields project | Petheram C, Hughes D, Rustomji P, Smith K, Van Neil TG and Yang A |
| Rainfall-runoff modelling across northern Australia | Petheram C, Rustomji P and Vleeshouwer J |
| Regionalisation of hydrologic indices. Northern Australia sustainable yields. | Sinclair Knight Merz |

## References


AWRC (1987) 1985 Review of Australia's Water Resources and Water Use, Volume 1: Water Resources Data Set, Department of Primary Industries and Energy, AGPS, Canberra.

CSIRO (2009) Description of project methods. Report to the Australian Government from the CSIRO Northern Australia Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, Australia. *In prep.*

Kalf F and Woolley D (2005) Applicability and methodology of determining sustainable yield in groundwater systems. Journal of Hydrogeology**,** 295-312.

Petheram C, McMahon T and Peel M (2008) Flow characteristics of rivers in northern Australia: Implications for development. Journal of Hydrogeology 357**,** 93-111.




 

# 1 Overview of the drainage division

This chapter summarises attributes relevant to understanding the water resources of the Gulf of Carpentaria Drainage Division. This chapter covers general physiography, climate, land use, vegetation and environmental assets. This chapter also summarises the drainage division's water resources as determined through this project and indicates water resource knowledge and information gaps. Detailed analyses of water resources are covered in the regional chapters. This chapter is divided into the following sections:

- physiography
- climate, land use and vegetation
- environmental assets
- current water resources of the division
- knowledge and information gaps.



## 1.1 Physiography

The Gulf of Carpentaria (Figure 3) is the large, shallow sea enclosed on three sides by northern Australia, and bounded on the north by the Arafura Sea.

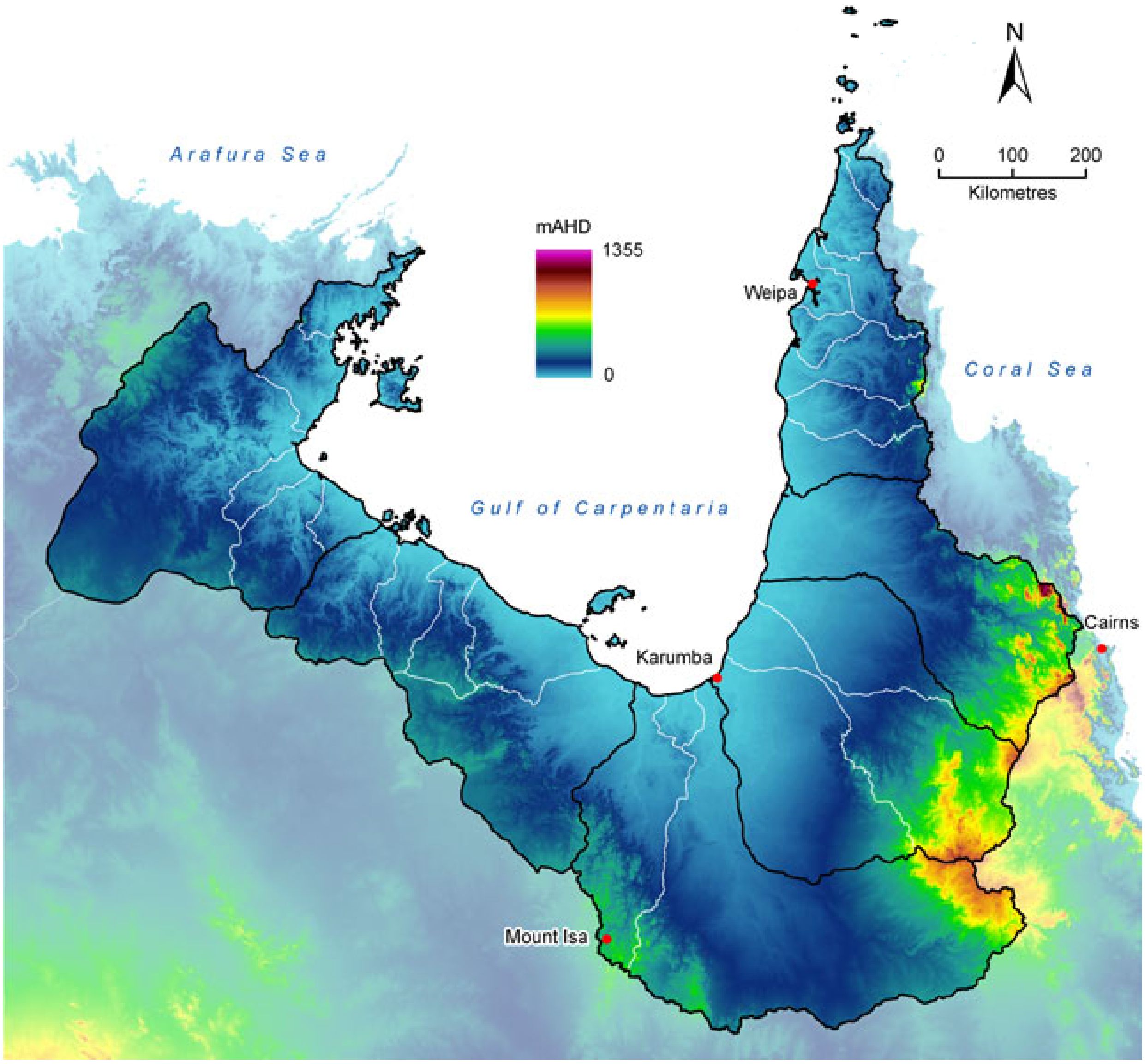


Figure 3. Topography of the Gulf of Carpentaria Drainage Division

In geological terms, the Gulf is young: it was dry land as recently as the last ice age. The land bordering the Gulf is generally flat and low-lying (Figure 4). To the west is Arnhem Land and the Top End, to the east Cape York Peninsula. The area to the south is known as the Gulf Country or simply the Gulf. In the Gulf Country, there are no mountains to restrict rainfall to the coastal band and the transition from the profuse tropical growth of the seaside areas to the arid scrubs of central Australia is gradual.

The Gulf of Carpentaria Drainage Division covers approximately 647,000 km$^2$ and comprises 29 Australian Water Resources Council (AWRC, 1987) surface water catchments (Figure 2). These have been grouped into six regions for this project. From west to east, these are: Roper, South-West Gulf, Flinders-Leichhardt, South-East Gulf, Mitchell and Western Cape.

A large portion of the region comprises floodplains, with very low relief (Figure 4), resulting in widespread inundation from catchment runoff during monsoonal periods or cyclonic events during the wet season.

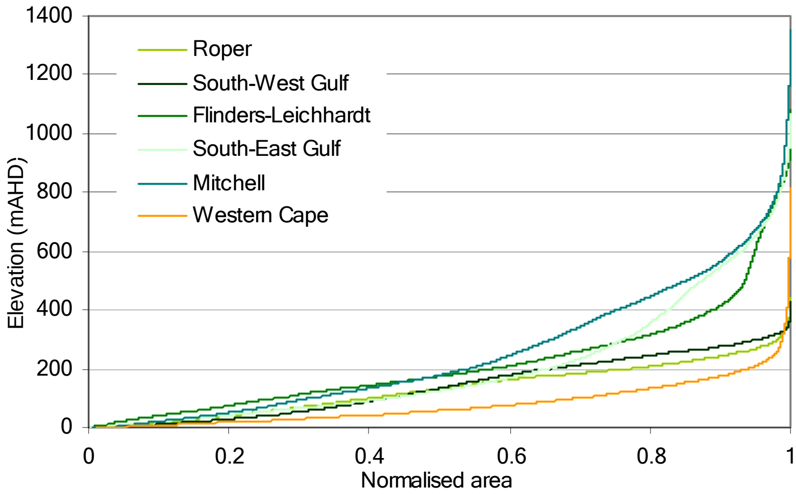


Figure 4. Hypsometric (relative relief) curves for the Gulf of Carpentaria Drainage Division regions

 

## 1.2 Climate, vegetation and land use

The Gulf of Carpentaria Drainage Division has climate gradients that are aligned with the coast, but with a strong north–south component (Figure 5). Mean wet season rainfall ranges between 300 mm in the south up to 1800 mm in the north with moderate to high variability year-to-year. Temperatures are hot with maximums around 36 °C. More frequent pleasant weather, however, is recorded in the far north coastal sections and the far eastern areas in Queensland. Dry season temperatures can drop after warm, sunny days, to an average overnight low of about 14 °C.

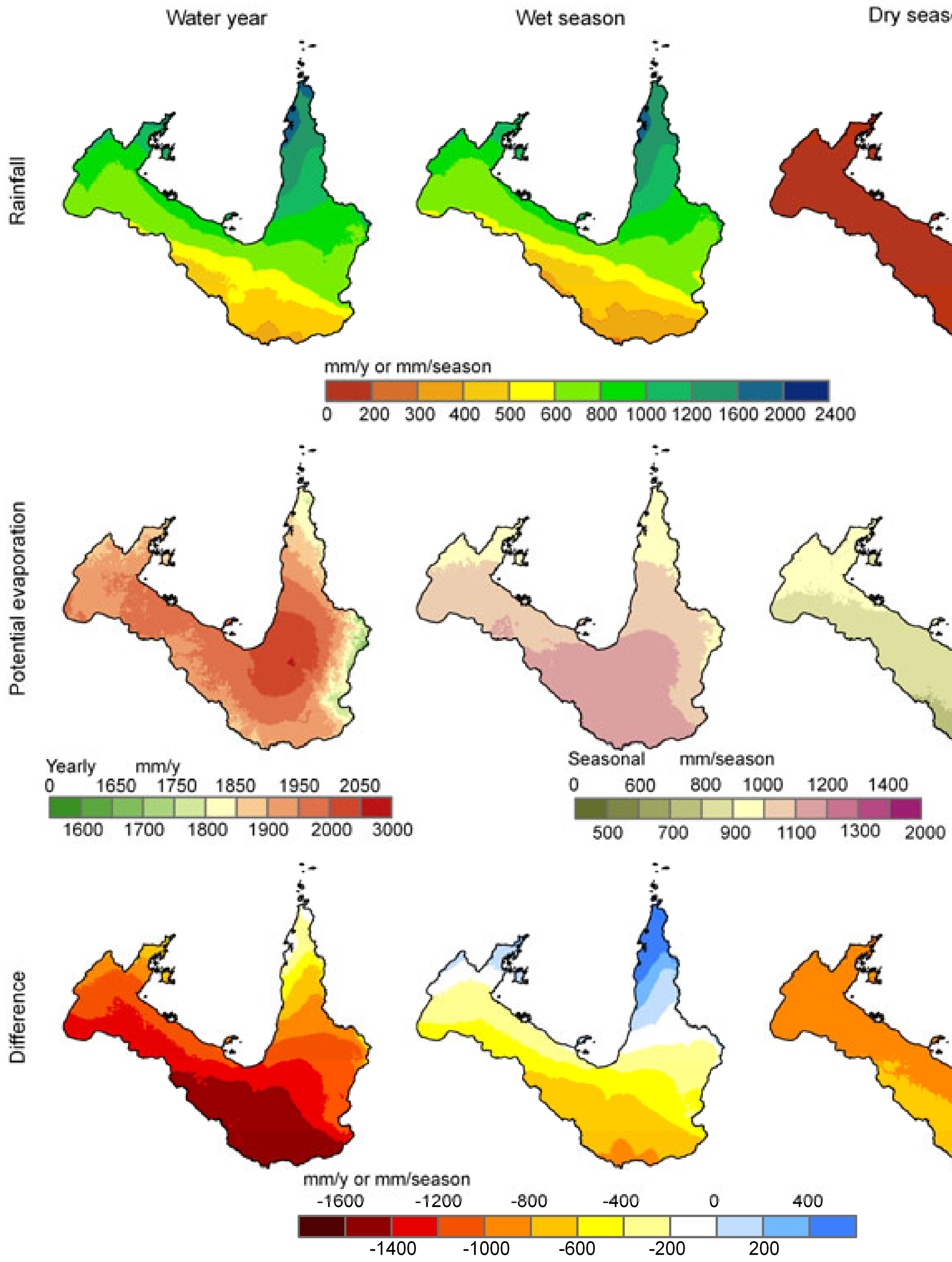


Figure 5. Spatial distribution of historical mean annual (water year = 1 September to 31 August), wet season (1 November to 30 April) and dry season (1 May to 31 October) rainfall and areal potential evapotranspiration (potential evaporation) and their difference (rainfall less areal potential evapotranspiration) across the Gulf of Carpentaria Drainage Division

The climate is hot and humid with two seasons per year. The dry season runs from about May until October; the wet season from November to April. Almost all rainfall is compressed into two or three months (Figure 6b), and during this period many low-lying areas are flooded. Wet seasons are hot and humid with maximum temperatures around 33 to 36 °C in January. During the wet season, this region is one of the cloudiest of the north, even though there is an average of seven to eight hours of sunshine each day. Dry season rainfall can be associated with the moist trade winds being uplifted over the coast. Temperatures are moderate in the dry with July average minimums dropping to approximately 21 °C in the north and 14 °C in the southern inland areas.

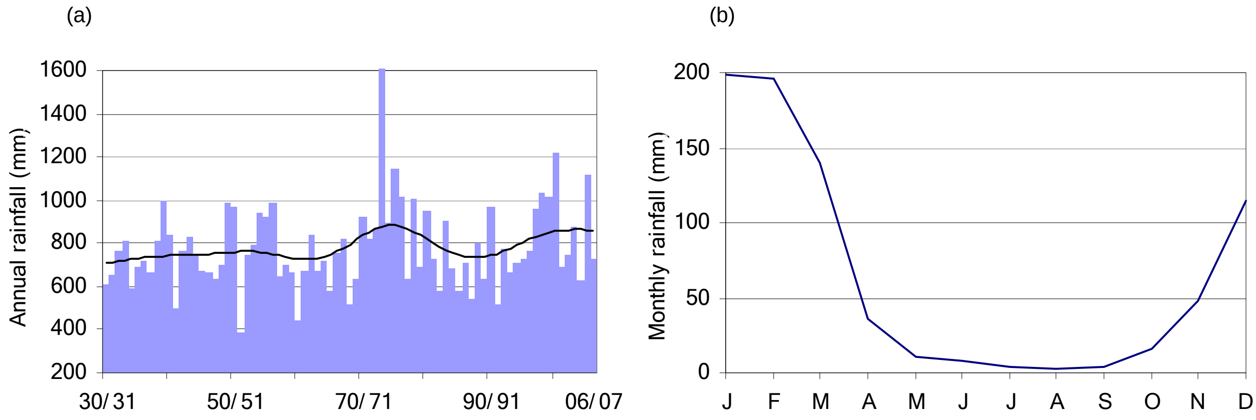


Figure 6. Historical (a) annual and (b) mean monthly rainfall, averaged over the Gulf of Carpentaria Drainage Division. The low frequency smoothed line in (a) indicates longer term variability

The region's climate grades from an equatorial savannah climate in the far north, southwards into tropical savannah, then grasslands, with small areas of rainforest and subtropical climate along the Great Dividing Range in the east (Figure 7). The far south grades into desert across a poorly-defined divide with the Lake Eyre Drainage Division.

Gulf Country rivers, though mostly fairly short, tend to be very large by Australian standards and carry a quarter (about 90 TL/year - where 1 teralitre (TL) is 1000 GL) of the continent's total yearly streamflow. Most rivers, however, flow only during the short tropical wet season.

Pastoralism is the dominant land use throughout the division. There are significant areas of nature conservation, Indigenous land use and forestry. Whilst the major land use in the region is grazing (81 percent of the area (ANRA, 2002), most income is generated by mining with several large mines in the region including the Mount Isa Copper Mine, the McArthur River and Century lead-zinc mines and Weipa aluminium mines. The fishing industry is also a major employer in the region, with important prawn and finfish industries supported by the extensive coastal wetlands and shallow coastal waters.

Only limited areas of the drainage division have been cleared (<1 percent) or used for intensive land uses. Grazing pressure and fire regime strongly affect native vegetation cover and weeds significantly influence native vegetation condition. Buffel grass, a pasture species, is changing the composition of native grasslands and increasing fire intensity.

The population of the region is reasonably sparse with most people living in the mining town of Mount Isa. The Indigenous population is a significant component (>25 percent) of the population.

The population figures in Table 2 are based on the Australian Bureau of Statistics Census of 2006 which is conducted in early August. Figures relate to urban centres and localities.

With no large towns and few smaller settlements, the key environmental issues for the division are the sustainable management of grazing and fishing and the management of mining water (including disposal of dewatering supplies).

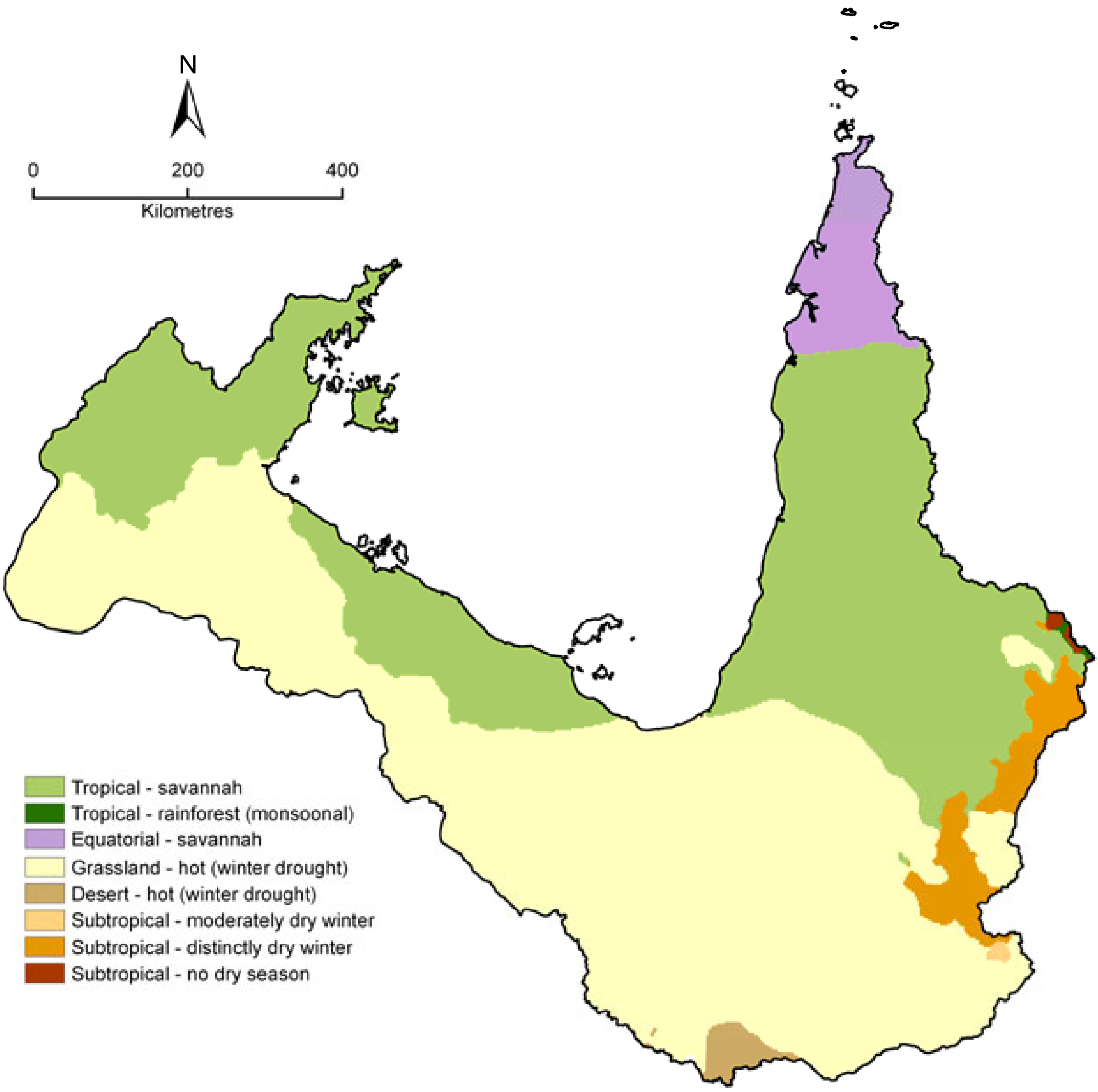


Figure 7. Climate zones of the Gulf of Carpentaria Drainage Division (Stern et al., 2000)

Table 2. Major towns of the Gulf of Carpentaria Drainage Division and their populations*

| Town | Region | Total population | Indigenous population |
|---|---|---|---|
| Mount Isa | Flinders-Leichhardt | 18,857 | 3089 |
| Weipa | Western Cape | 2,830 | 483 |
| Thursday Island | Western Cape | 2,546 | 1842 |
| Cloncurry | Flinders-Leichhardt | 2,384 | 521 |
| Hughenden | Flinders-Leichhardt | 1,154 | 137 |
| Normanton | South-East Gulf | 1,100 | 661 |
| Doomadgee | South-West Gulf | 1,052 | 979 |
| Kowanyama | Mitchell | 1,017 | 945 |
| Aurukun | Western Cape | 999 | 881 |
| Borroloola | South-West Gulf | 769 | 494 |
| Richmond | Flinders-Leichhardt | 554 | 45 |
| Karumba | South-East Gulf | 518 | 44 |

* Populations are for urban centres from 2006 Australian Bureau of Statistics data (<http://www.censusdata.abs.gov.au>).

## 1.3 Environmental and cultural assets

While the Gulf of Carpentaria Drainage Division supports a diverse array of vertebrate species it does not have the high levels of vertebrate biodiversity seen in the two higher rainfall divisions it borders (the Timor Sea and the Northern North-East Coast drainage divisions), with only three endemic freshwater fish species and no endemic birds.

Environmental assets were chosen from wetlands which are listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001). From this directory, environmental assets were shortlisted for assessing changes to the hydrological regime under the climate and development scenarios. The selection of this shortlist was undertaken in consultation with state governments and the Australian Government through direct discussions and through internal reviews. The shortlist was selected by identifying only those assets where stream gauging data was available at, or in close proximity to, the asset, thereby increasing confidence in the results reported at that asset. This shortlist was then reduced, where possible, to cover only the range of wetland and geographic types identified for the project area.

The shortlist is far from comprehensive and there are many more highly significant water-dependent assets, both environmental and cultural, which are not included in this report. The assessment approach utilised is based around changes to flow regime at distinct locations within the catchments considered. For a more comprehensive analysis of ecological impacts of changes in flow regime, the river system should be considered as a whole.

All nationally, or internationally, important wetlands listed for the Gulf of Carpentaria Drainage Division in the Directory of Important Wetlands in Australia (Environment Australia, 2001) are detailed in Table 3, with asterisks identifying the 16 assets shortlisted for assessment for this division. In deciding whether it is feasible to report hydrological metrics for these shortlisted assets, it is important to consider the confidence levels in modelled streamflow (as described in Section 2.2.6 of the division-level Chapter 2). Regional chapters (Section ID-1.3 in Chapter ID-1 and the final section in Chapter ID-3) present the assessment of these shortlisted assets and reports metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis.

The types of wetland assets present in the Gulf of Carpentaria Drainage Division include lakes, mangroves, area subject to inundation, saline coastal flats, watercourses and swamps. There are no wetlands classified as a Ramsar sites in this drainage division. Wetlands may be nationally or regionally significant depending on more locally specific criteria. All wetlands are important for a variety of ecological reasons or because they have historical significance or high cultural value, particularly to Indigenous people, or a combination of these reasons.

In Indigenous belief systems, water is a sacred and elemental source and symbol of life (Langton, 2006) and aquatic resources constitute a vital part of the Indigenous customary economy. Water plays a central role in Indigenous cultures and societies: ‘their lives and various religious, legal, social and economic beliefs and practices’ (Barber and Rumley, 2003). Indigenous groups conceptualise water sources and rivers, as with the land, as having derived from the Dreaming, the time when the world attained its present shape (Barber and Rumley, 2003; Langton, 2002; Toussaint et al., 2005; Yu, 2000). Further, these studies emphasise the importance of mythic beings as significant to the origin and maintenance of all water sources.

Cultural affiliations to water are expressed in many different ways: through social etiquette, place-based knowledge, narratives, beliefs and daily practices (Toussaint et al., 2005). Water’s vitality is underscored in the cultural studies from north Australia; it is often described as a living element that creates the defining shape and character of country (see (Toussaint et al., 2005; Yu, 2000). In contexts where resources or places are under pressure or threat there is a tendency to focus on key places or sacred sites as people strive to retain their traditions (Kolig, 1996). However, the affiliations to water are much broader than those encompassed by the conventional cultural heritage paradigm: these humanitarian values relate to notions of sociality, sacredness, identity and life-giving.

Given that rivers have little rain water to ensure a continuous flow during the dry season, all perennial rivers and ephemeral springs are important sources of water, and most are also sacred sites (Altman and Branchut, 2008). Water values pervade all aspects of Indigenous life, as is evidenced from the recurring themes of water myths, spirits and species that pervade Indigenous art (CNR, 2003).

 

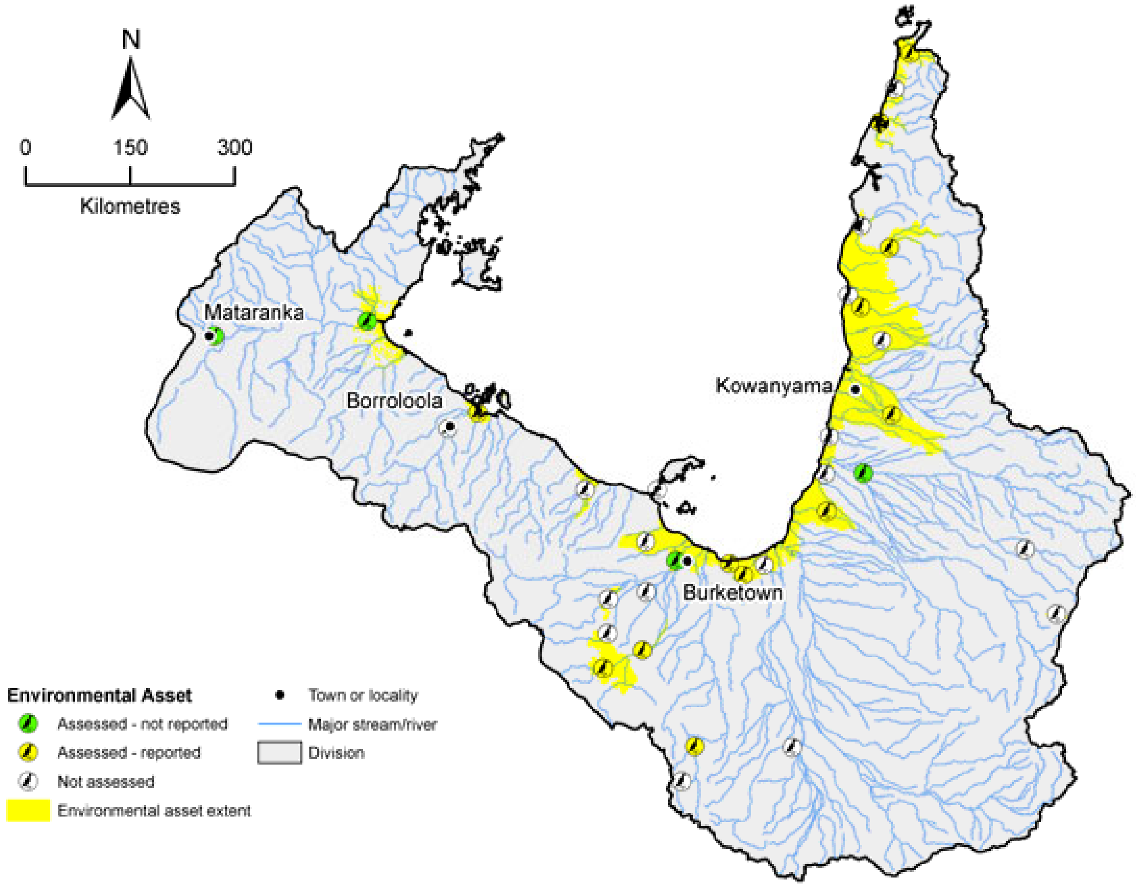


Figure 8. Location of environmental assets selected for assessment for the Gulf of Carpentaria Drainage Division

Table 3. List of Wetlands of National Significance located within the Gulf of Carpentaria Drainage Division

| Site code | Name | Area | Region |
|---|---|---|---|
| | | ha | |
| NT007 * | Limmen Bight (Port Roper) Tidal Wetlands System | 185,000 | Roper |
| NT003 * | Mataranka Thermal Pools | <10 | Roper |
| QLD102 | Bluebush Swamp | 879 | South-West Gulf |
| NT006 | Borroloola Bluebush | 70 | South-West Gulf |
| QLD105 | Forsyth Island Wetlands | 6,390 | South-West Gulf |
| QLD119 * | Gregory River | 26,600 | South-West Gulf |
| QLD101 | Lawn Hill Gorge | 1,130 | South-West Gulf |
| QLD108 | Marless Lagoon Aggregation | 167,000 | South-West Gulf |
| QLD110 | Musselbrook Creek Aggregation | 45,100 | South-West Gulf |
| QLD111 * | Nicholson Delta Aggregation | 63,600 | South-West Gulf |
| NT008 * | Port McArthur Tidal Wetlands System | 119,000 | South-West Gulf |
| QLD114 * | Southern Gulf Aggregation | 546,000 | South-West Gulf/Flinders-Leichhardt/South-East Gulf |
| QLD122 * | Thorntonia Aggregation | 299,000 | South-West Gulf |
| QLD116 | Wentworth Aggregation | 82,300 | South-West Gulf |
| QLD103 * | Buffalo Lake Aggregation | 1,910 | Flinders-Leichhardt |
| QLD120 * | Lake Julius | 1,940 | Flinders-Leichhardt |
| QLD121 | Lake Moondarra | 1,740 | Flinders-Leichhardt |
| QLD106 | Lignum Swamp | 283 | Flinders-Leichhardt |
| QLD115 | Stranded Fish Lake | 68 | Flinders-Leichhardt |
| QLD104 * | Dorunda Lakes Area | 6,810 | South-East Gulf |
| QLD107 | Macaroni Swamp | 258 | South-East Gulf |
| QLD109 * | Mitchell River Fan Aggregation | 715,000 | South-East Gulf/Mitchell |
| QLD112 * | Smithburne–Gilbert Fan Aggregation | 251,000 | South-East Gulf |
| QLD113 | Southeast Karumba Plain Aggregation | 336,000 | South-East Gulf/Mitchell/Western Cape |
| QLD094 | Undara Lava Tubes | 1,250 | South-East Gulf |
| QLD067 | Northeast Karumba Plain Aggregation | 183,000 | Mitchell |
| QLD093 | Spring Tower Complex | 75 | Mitchell |
| QLD056 | Archer Bay Aggregation | 29,900 | Western Cape |
| QLD057 * | Archer River Aggregation | 150,000 | Western Cape |
| QLD058 | Bull Lake | 27 | Western Cape |
| QLD063 * | Jardine River Wetlands Aggregation | 81,800 | Western Cape |
| QLD068 * | Northern Holroyd Plain Aggregation | 1,110,000 | Western Cape |
| QLD071 * | Port Musgrave Aggregation | 52,700 | Western Cape |
| QLD074 | Skardon River – Cotterell River Aggregation | 63,200 | Western Cape |
| QLD075 | Somerset Dunefield Aggregation | 7,940 | Western Cape |

* Asterisk against the site code identifies those assets shortlisted for assessment of changes to hydrological regime.

 

## 1.4 Water resources

### An extreme climate

The rainfall of the Gulf of Carpentaria Drainage Division is very strongly seasonal, has high inter-annual variability, a strong north–south gradient, and with high potential evapotranspiration rates year-round.

Historical (1930 to 2007) mean annual rainfall is 779 mm, with an annual variance (1σ) of ±289 mm, and ranges between 334 and 1806 mm. Annually, rainfall provides about 510 TL (510,000 GL) of water to the drainage division. Approximately 94 percent of this rain falls during the wet half of the year, most between December and March. Rainfall amount varies across the region from a mean annual value of about 300 mm/year in the south, up to about 2400 mm/year in the far north. Distribution is not uniform with steeper gradients near the coast. Assessing cumulative rainfall (highest pixel value to lowest) against distance from the coast reveals that roughly 50 percent of all rain falls over only 40 percent of the total land area (Figure 9).

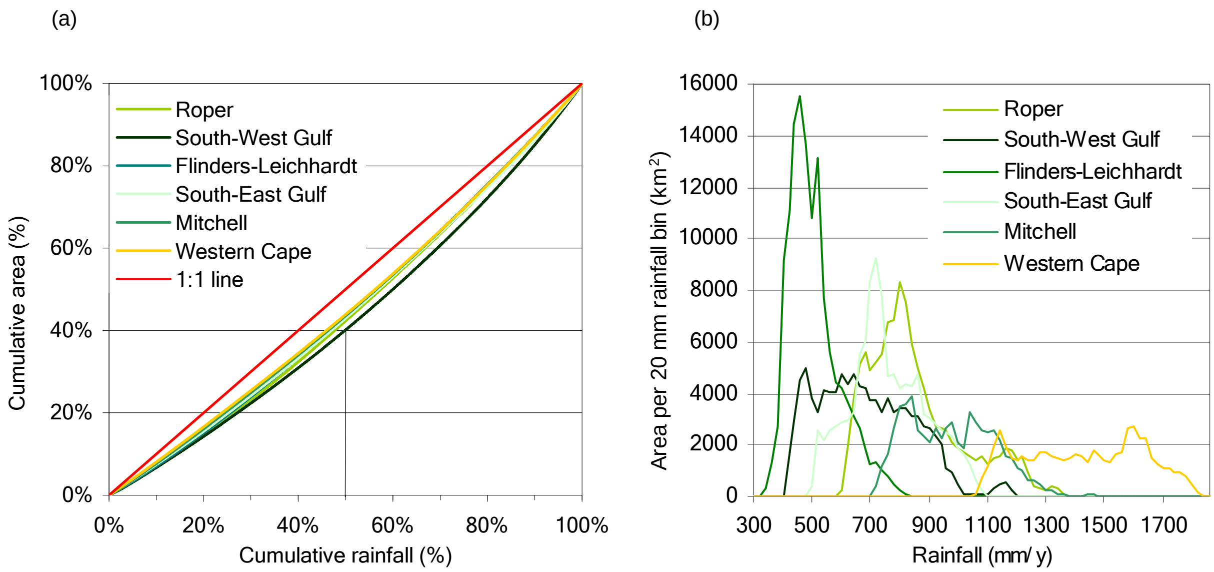


Figure 9. Rainfall plotted as a function of area for each of the six regions of the Gulf of Carpentaria Drainage Division. Ranked percentage values (a) indicate that more rain falls near the coast than inland. The areal distribution of rainfall amounts (b) shows that the Western Cape region receives high, but variable rainfall amounts; the Mitchell region receives moderate rainfall and the other regions receive generally low amounts, particularly the Flinders-Leichhardt region

Runoff follows this pattern with largest flows between January and April. A historical mean of 90 TL/year (144 mm/year) flows across the landscape, though one-third of this occurs in the Western Cape catchments (32 TL/year or 479 mm/year). The Flinders-Leichhardt region has less than one-tenth this amount.

High levels of net radiation (more in the wet season than the dry season) and vapour pressure deficit (more in dry season than the wet season) combine to result in high areal potential evapotranspiration (APET) rates year-round. Historical mean annual APET is 1939 mm/year and ranges between 1592 and 2054 mm/year. Wet season APET is only 10 percent higher than the dry season APET, indicating that the seasonal changes in the net radiation outweigh the seasonal changes in vapour pressure deficit. Annually rainfall is usually less than APET and climatologically the landscape may be described as water-limited.

There is a strong rainfall gradient away from the northern coasts, and this combines with the generally low relief of most of the coastal region to provide little opportunity to increase surface storages. Surface storage opportunities occur mainly in the upper reaches of catchments, where rainfall is lower and more sporadic yet where APET is highest.

The coastal regions are flood-dominated, which can locally result in poorer quality surface water, both through increased sediment load and increased tidal influence. Rainfall intensity also decreases rapidly away from the northern coast. Extreme rainfall events (>100 mm/day) occur along the northern coast during the wet season.

Groundwater recharge is also strongly seasonal and dependent on the recharge capability of the surface soils and outcrops.

## Historical and recent climate

The recent (1996 to 2007) climate has not been statistically significantly different to the historical climate for most of the region. The far west and north, however, have been significantly wetter over the past 11 years when compared to the historical climate (Figure 10), and the division-average rainfall for the last 11 years has been wetter than the previous 66 years. The wettest year for the Roper and South-West Gulf regions occurred in 2001; for the Western Cape it was 1999. The south of the drainage division, however, experienced the wettest year in 1974, with the last 11 years being no wetter, nor drier, than historical conditions. The driest year throughout the drainage division was 1952. Highest APET occurred in 1992 and the lowest in 1974, though the mid-1930s were hot for the south and south-east of the drainage division.

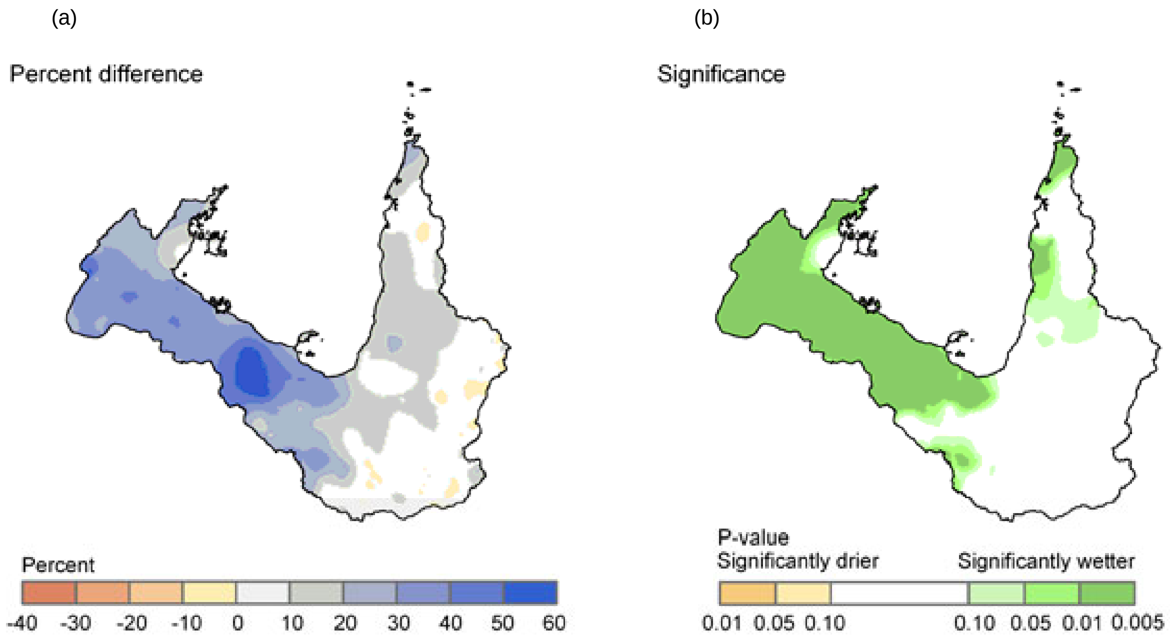


Figure 10. Spatial distribution of (a) the relative percent difference between the mean historical and recent rainfall and (b) the statistical significance of that difference across the Gulf of Carpentaria Drainage Division. (Note that historical in this case is the 66-year period 1930 to 1996)

An average recurrence interval was calculated for the drainage division (Figure 11). This is the average waiting time until an independent 11-year wet (or dry) sequence would occur that is equal to or wetter (or drier) than the 11 years from 1996 to 2007 (i.e. the recent past). This is calculated assuming that the climate is stationary. Results show that average recurrence intervals are less than 50 years for most of the Gulf of Carpentaria Drainage Division, reflecting the similarity between the recent and historical climate conditions.

Rainfall intensity (mm rain per rain day) has very slightly increased through the last 77 years, with a slight increase both in rain days and rainfall per day, but this is not statistically significant, except for the northern catchments.



 

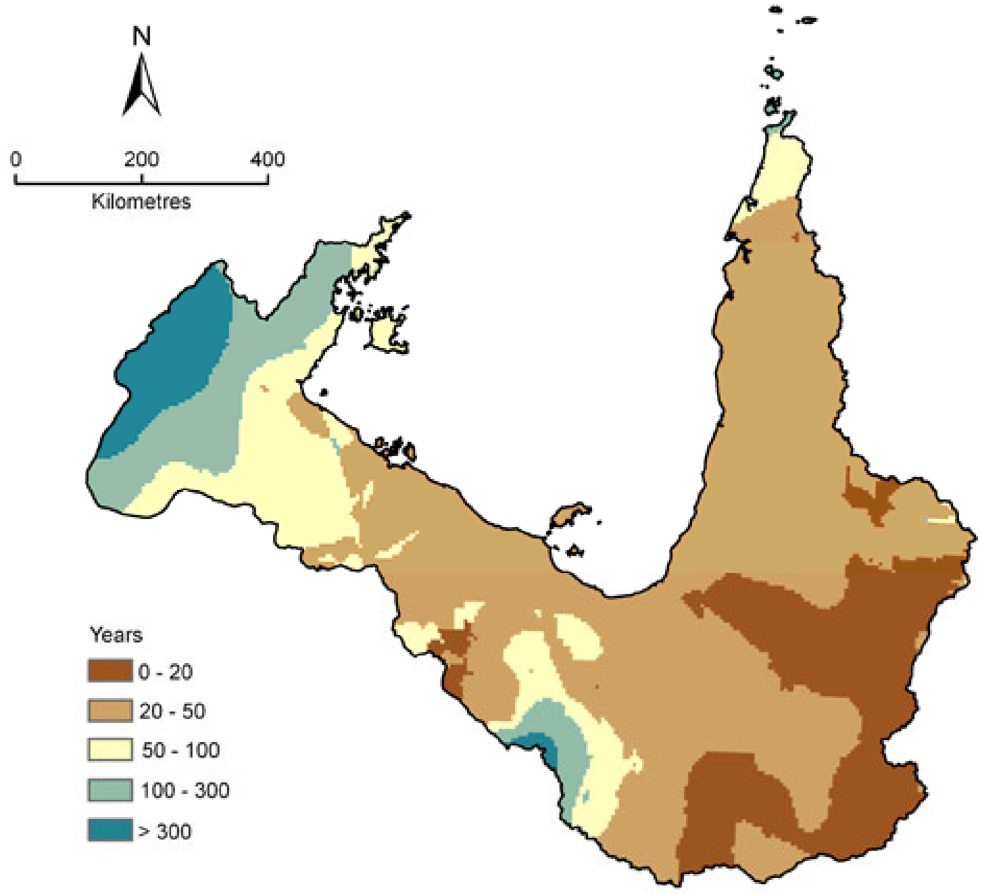


Figure 11. Spatial distribution of average recurrence intervals of recent rainfall relative to historical rainfall across the Gulf of Carpentaria Drainage Division



## Future climate

Future climate (~2030) is expected to be similar to the historical climate, with a mean annual rainfall of 777 mm/year (median modelled result). Under future climate, 93 percent of this rain falls in the wet season. Modelling gives a future range of between 7 percent lower and 7 percent higher rainfall. APET increases under all future scenarios, possibly up to 4 percent relative to the historical climate.

Extreme rainfall events are expected to increase along the northern coast, particularly in the north of the Western Cape region. However, the implications with respect to the El Niño-Southern Oscillation (ENSO) index have not been considered (but see below).

Change in runoff is more strongly controlled by rainfall than APET (Chiew, 2006). Hence, despite higher future APET, it is unlikely to result in a significantly different runoff regime, and future runoff is expected to be similar to historical runoff.

There are three parts to estimating future streamflow. The first is estimating what the future climate will look like, in particular rainfall which is the main driver of streamflow. This generally comes from global warming projections from the International Panel on Climate Change (IPCC) and simulations of local/regional climate from global climate models (GCMs) (IPCC, 2007). The second is obtaining catchment-scale climate time series, informed by GCM simulations for the future and current climates, to drive the hydrological models. The methods range from (i) empirically scaling the historical climate series, (ii) statistically downscaling synoptic large-scale atmospheric predictors to catchment-scale climate and (iii) dynamic downscaling to provide climate at a higher spatial resolution. The third is driving the hydrological models with the future climate series to estimate future streamflow.

The tools for the second and third parts are generally available. There are methods available to convert large-scale GCM projections to catchment-scale climate (see above), and continuing research on development and testing will further improve these methods. There are hydrological modelling initiatives in Australia to improve runoff prediction in ungauged catchments, river system modelling in managed systems and adapting/extrapolating models for climate change impact assessment (e.g., relative runoff sensitivity to rainfall and temperature, model calibration over wet/dry periods, altered hydrological processes, etc.). For climate change impact assessment, the hydrological models need to be driven with multiple replicates of synthetic future climate series that take into account climate variability and climate change.

The largest uncertainty in estimating future streamflow characteristics and water availability is the future rainfall projections. For the short to medium term projection, the largest uncertainty comes from the large range of GCM projections of future local and regional rainfall. The GCM projections should become more accurate and consistent with progress in climate change and climate modelling science, which is a key area of research in Australia and elsewhere.

Future recharge is expected to be similar to historical levels based on potential recharge modelling. Recharge is generally low across the drainage division.

## Cyclones and El Niño

Cyclones are important events in producing heavy rainfall events in the Gulf of Carpentaria Drainage Division, contributing about 30 percent of all rainfall. Cyclone here includes the low pressure system prior to it reaching cyclone strength and the low pressure system after it has declined below cyclone strength. Cyclones which have brought heavy to very heavy rain to the Gulf include Charlotte in January 2009, Craig in March 2003, Steve in February 2000, Les in January 1998, May in February 1998, Sadie in January 1994 and Sandy in March 1985.

Whilst cyclones are important and dramatic rainfall events, there are also often localised and intense, resulting in high local runoff. Larger, regional-scale, lows often produce larger amounts of rainfall over much greater areas and may be more important from a water resources perspective.

One of the key findings of the IPCC and its advisory committees is that it is *likely* that future tropical cyclones will become more intense, with larger peak wind speeds and heavier precipitation. This conclusion, however, relates to continental, regional and ocean basin scales, where numerous long-term changes in climate have been observed. These include changes in the intensity of tropical cyclones.

A link between the intensity of hurricanes (tropical cyclones) in the Atlantic Ocean with sea surface temperature (Emanuel, 2005) triggered a flurry of research into the relationship between tropical cyclones and climate change. While the relationship between intensity of tropical cyclones and sea surface temperature is now more widely accepted, at least for the Atlantic, the continuation of the causal link into the future has been questioned. The critical issue is whether the observed increase in hurricane intensity in the Atlantic is due to the relatively higher increase in sea surface temperature in the Atlantic relative to other ocean basins or whether it is related directly to the absolute increase in sea surface temperature, regardless of what is happening in other ocean basins (Vecchi et al., 2008). If tropical cyclone intensity is linked to relative sea surface temperatures, then the intensity might relax to earlier levels as inter-ocean basin sea surface temperatures equilibrate. On the other hand, if intensity is related to absolute sea surface temperatures, then the link between climate change and cyclone intensity is strong, with even more intense cyclones expected later this century. The observational record is not yet long enough, and the basic process-level understanding is not yet good enough, to distinguish between the two possible futures (Will Steffen, pers. comm.).

El Nino events appear to become more prevalent after 1977 (Power and Smith, 2007) and this has coincided with a decrease in the total number of tropical cyclones in the Queensland region. At the same time, there is some evidence that the number of severe tropical cyclones has increased (CSIRO and BoM, 2007).

The current, state-of-the-art coupled climate models used in the IPCC Fourth Assessment (AR4) (IPCC, 2007) have a typical resolution of 1.5 to 3 degrees in the atmosphere and 1 degree in the ocean. In neither component are some key aspects of the climate systems (such as the influence of ocean eddies, orographic forcing of the atmosphere, tropical cyclones) adequately represented. Predicting cyclone activity is currently a topic of much scientific research, and therefore not available in current GCM output used in the three Sustainable Yields Projects, and hence was not available for future climate scenarios in this project.

The AR4 (IPCC, 2007) documented that a robust result in high resolution model simulations of tropical cyclones in a warmer climate has been that there will be an increase in precipitation associated with cyclones. They have stated that the mechanism is simply that as the water vapour content of the tropical atmosphere increases, the moisture convergence for a given amount of dynamical convergence is enhanced.

 

The IPCC has also noted that the resolution of current global circulation models limits the proper representation of tropical cyclones and heavy rainfall.

For the modelling carried out for this project, we assessed rainfall amounts, intensity and rain days, with no reference to rainfall source, be it a cyclonic event, low pressure system or small convective cell. Hence, only rainfall processes were explicitly incorporated.

## Surface water potential

There are few rivers in the Gulf of Carpentaria Drainage Division that flow all year. Most rivers cease to flow during the dry months. The few that maintain flow are mostly driven by shallow groundwater systems, or discharging artesian springs. Shallow groundwater systems, however, are generally variable both in storage capacity and water quality, both spatially and temporally.

Rivers across the drainage division are dominated by flood conditions during the wet season and much of the drainage division is inundated near the coast and for many kilometres inland.

The low gradients and generally flat landscape do not provide for good surface water storage, except in the headwater regions where rainfall is lower, so storages have to be large enough to withstand long periods of below average rainfall.

Eleven rivers basins in the region are either declared or potential wild river areas. In-stream dams and weirs cannot be constructed in wild rivers, or their major tributaries.

## Groundwater potential

Rapid runoff of rainfall results in low actual groundwater recharge rates so there are limited storage opportunities of groundwater in the landscape. The Great Dividing Range along the eastern margin provides recharge to the Great Artesian Basin and rejected recharge and artesian conditions result in spring discharge within the drainage division. The greatest stores of groundwater are in the deep aquifers. There is currently insufficient data, however, to adequately quantify the amount stored, recharge rates and sustainable extractable yields. These storages are largely undeveloped.

There is an intricate balance between surface and groundwater flows and the environmental regimes they support, resulting in a high level of endemic species across northern Australia.

## Surface–groundwater interaction

The few perennial river reaches are supplied through the dry season by discharging groundwaters, mostly from active Great Artesian Basin springs, particularly in the east of the drainage division. Rejected recharge along the Great Artesian Basin intake beds can supply streamflow throughout the year, especially in the north (Figure 12). Groundwater extraction in the vicinity of these springs can, therefore, have a significant impact on surface water supplies and flow.

The western catchments are typified by discharge from carbonate aquifers, particularly in the Roper, and Gregory river catchments.

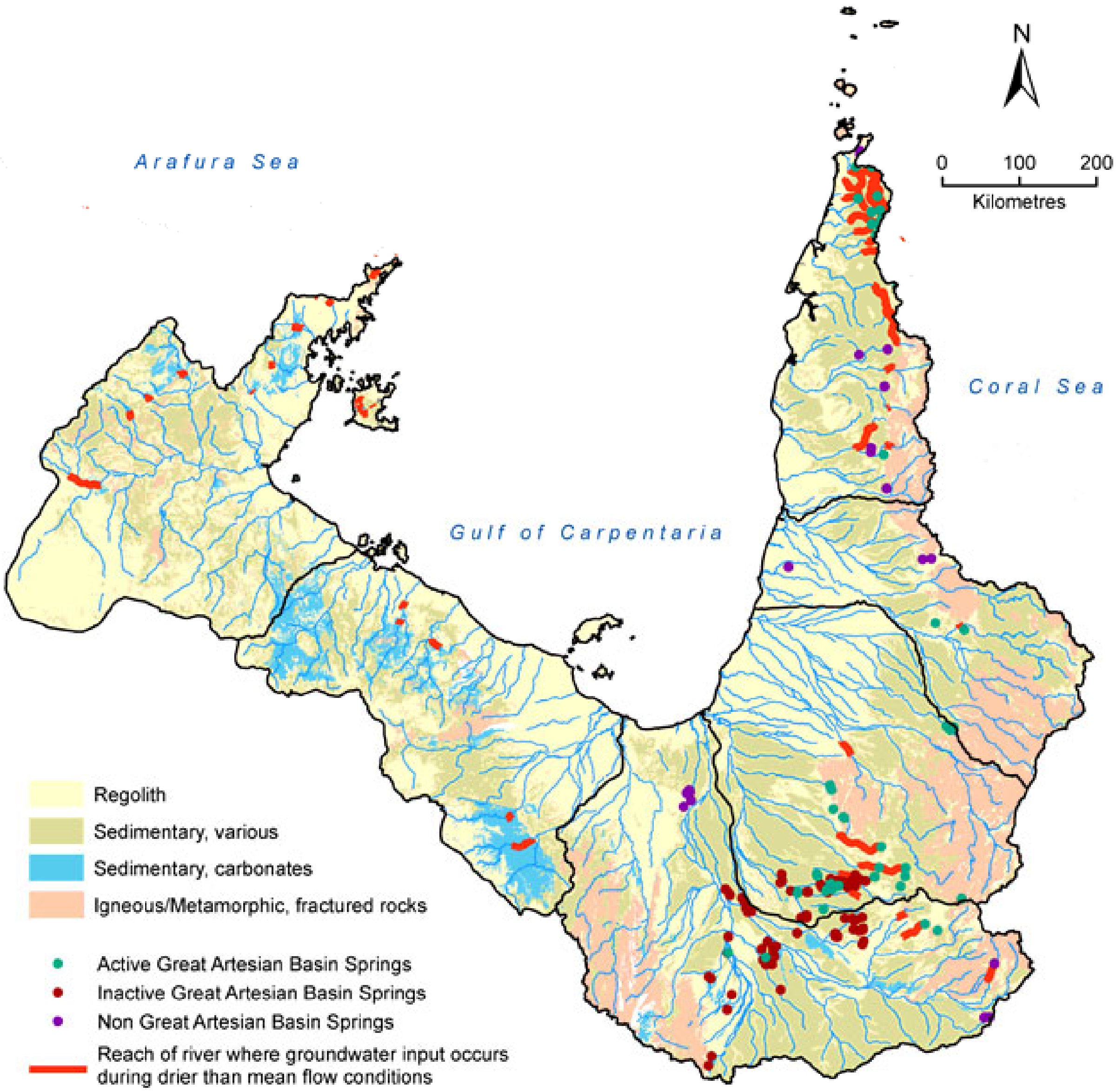


Figure 12. Surface–groundwater connectivity map for the Gulf of Carpentaria Drainage Division

 

# 1.5 Knowledge and information gaps

To assess the quantity of water that could be made available for consumptive use in a given catchment requires detailed assessment of the environmental, economic, hydrological and social factors that drive water use. A key hydrological factor is assessment of the storage potential of each catchment. Once the storage potential of a catchment has been established, this could be coupled with the hydrological characteristics of the rivers in the region to make a preliminary assessment of the yield that could feasibly be achieved for various degrees of reliability. This information will be essential to informing the debate about Australia's potentially exploitable water resources.

Paucity of data is a major limitation both for water resources assessment and development evaluation. Even for relatively good datasets, such as the rainfall records, there are both spatial and temporal gaps in the data, particularly in the important headwater regions. Data are especially sparse in floodplain regions where maintenance of recording equipment is difficult, locating a suitable control section often problematic and multiple channels that vary in size and direction with each season. To allow better estimates of confidence in both surface water and groundwater modelling, daily estimates of error in the input climate datasets are needed, as these can then be propagated through these models, allowing levels of confidence to be better conveyed to managers and policy-makers.

Many of the streamflow gauging stations in the Gulf of Carpentaria Drainage Division are remote and are inaccessible by land during the wet season. These factors make it challenging to establish mid- to high-flow rating curves, and thus many of the gauging stations have a low maximum gauged stage height compared to their maximum stage height. Consequently, most of the streamflow gauging stations in the Gulf of Carpentaria have a significant proportion of their total flow volume above their maximum gauged stage height (Figure 13). About 20 percent of the gauging stations in the Gulf of Carpentaria Drainage Division have more than 90 percent of their flow volume occur at a stage higher than the maximum gauged stage height.

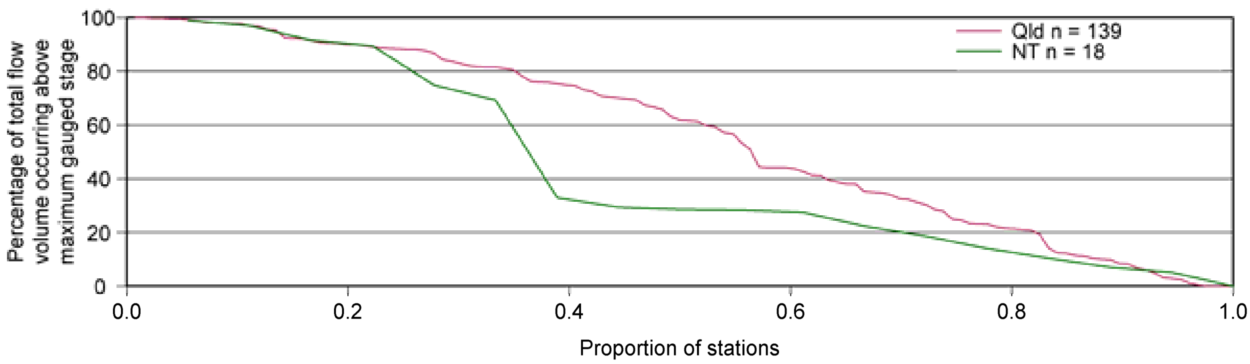


Figure 13. Proportion of streamflow gauging stations in the Gulf of Carpentaria Drainage Division which have the percentage of their total flow volume occurring above their maximum gauged stage height. This analysis only includes stations with a minimum of ten years of record

For many environmental assets it is not possible to calculate the potential impacts of the various scenarios because both the high and low ends of the flow regime are not well defined. The collection of further reliable flow data, especially for high and low flows, is required to remedy this situation.

In some streams dry season low flows are largely sustained by groundwater flows. To predict the potential impacts of the various climate scenarios, these streams require hydrological models that combine surface and groundwater regimes, and these are rarely available for the northern Australian rivers. Further combined surface and groundwater modelling is therefore required to produce more accurate dry season low flows.

Flooding is an important factor that sustains many environmental assets and this occurs when the stream breaks out of its banks (a level known as bankfull stage or discharge). However bankfull discharge is generally not known for many environmental assets, so it is difficult to predict when they become inundated. Further information about bankfull stage and discharge are needed for most environmental assets.

The conversion of river high and low flows into environmental impacts requires quantitative relationships between flow and specific ecological entities (for example, macrophyte populations, fish passage, faunal and floral habitats, etc.). These are not available for rivers in the Gulf of Carpentaria, so further survey of key ecological assets is required under a range of flow conditions. Many environmental assets depend not simply on duration above or below certain flow levels, but on triggers (e.g. for reproduction or migration) set by the rate of change of flow. Further analysis is therefore required to quantify how the timing and rate of rise and fall in flow rates at critical times of the season varies under the range of climate and development scenarios.

Some environmental assets depend on the frequency and duration of events that occur less than annually (i.e. once every 5, 10 or 20 years or more). Further analysis is therefore required to quantify how the frequency and duration of these events varies under the various scenarios.

Limited groundwater information results in poor knowledge of surface–groundwater interaction, with insufficient data for modelling. There is little to no information on actual groundwater use, with only best estimates used for water planning.

There is only sufficient information across the drainage division to carry out water resource assessments (Figure 14). Where river system models have been developed, surface water availability assessments can be made. These are available for large parts of the Mitchell, Gilbert, Flinders and Leichhardt river systems.

There is currently insufficient information to make availability assessments for any groundwater supplies. This excludes the deeper Great Artesian Basin aquifers, which are considered under the *Great Artesian Basin Strategic Management Plan*. Most groundwater assessments for other aquifers in the region are based on conceptualised models only.

For many regions, where development is, or is expected to be, minimal, models are unnecessary to make informed management plans. Where development requires the consumptive use of water, however, modelling gprovides a means to assess the equitable allocation of available water. The area with modelling capability or data to carry out the different levels of assessment is shown in Figure 14. Thus, whilst the entire drainage division can be assessed for total water resources (that is, the amount of water moving around the hydrological cycle), only parts of the Mitchell, Gilbert, Flinders and Leichhardt catchments can be assessed for water availability, and then only for their surface water supplies under a historically-constrained scenario. This assessment is achieved through the use of river system modelling (in this case IQQM).

There are currently no areas that can be assessed for water sustainability across the Gulf of Carpentaria Drainage Division. For this to occur additional information on the uses of water must be available and the environmental, social, cultural, economic and political values placed on water use must be incorporated into models. Allocations to environmental and cultural flows need to be considered, as well as community acceptance of changes to the water regime. There is a requirement that sufficient data are available, in time and space, to provide calibration of models and provide confidence in prediction of future consequences of changes to water allocations. For the Gulf of Carpentaria Drainage Division, information and data are currently inadequate to provide this level of assessment.

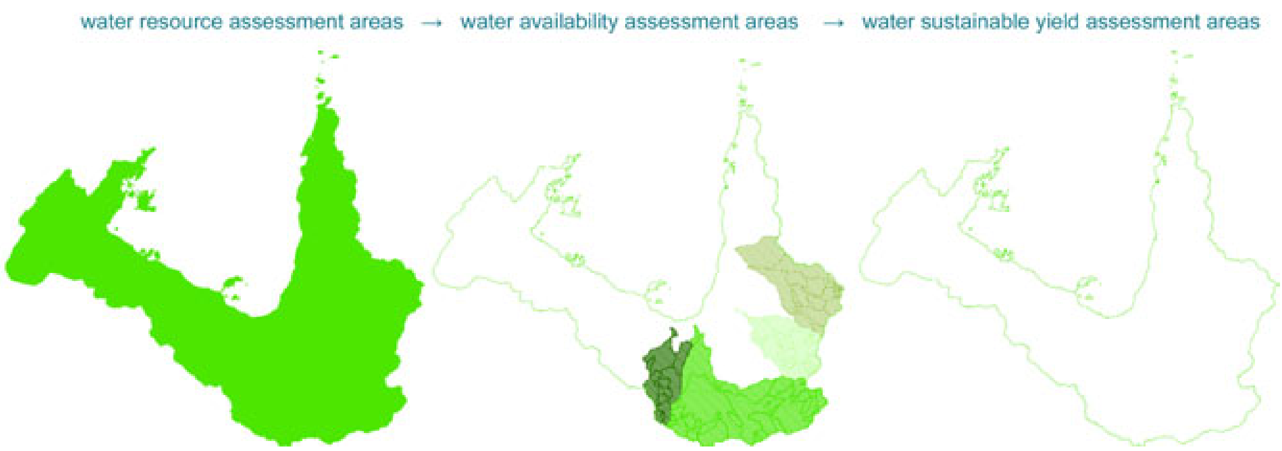


Figure 14. Water assessment capability within the Gulf of Carpentaria Drainage Division. Shaded areas have sufficient information and models to carry out the labelled level of assessment

 

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# 2 Assessment approaches

Term of Reference 1

This chapter outlines the assessment approaches for different components of the water cycle. Climate, surface water and groundwater methodologies are summarised and the techniques used to assess surface–groundwater interaction are outlined. Metrics are also developed which are derived from these assessments and which illustrate changes to the hydrological regime at sites of environmental, social and cultural importance. These assessment methods are illustrated using results at a division scale; they also apply to assessments made at the regional scale. Detailed aspects are provided in an accompanying technical report on methods (CSIRO, 2009).

As in real-world hydrological systems, the assessment approach relies on integration of different components of the water cycle and requires a process requiring interaction between the different teams assessing different components of the water cycle to provide an internally consistent, defensible, measured assessment of water resources. Where applicable, this also includes the provision of water availability assessment through the use of groundwater and river systems models. Assessments of flow regimes also incorporate information from ecological environmental assessments, while water models require knowledge and information on water use and governing principles.

The process adopted by this project is illustrated in Figure 15. Interactions and flow of activities are illustrated with arrows. Additional information required to make the assessments are presented in red boxes and some contextual information on these elements is presented in the region contextual chapter. Additional work on these elements is being carried out through the other programs of the Northern Australia Water Futures Assessment (NAWFA). The information provided through the modelling described in this chapter will also be integrated into the other NAWFA programs.

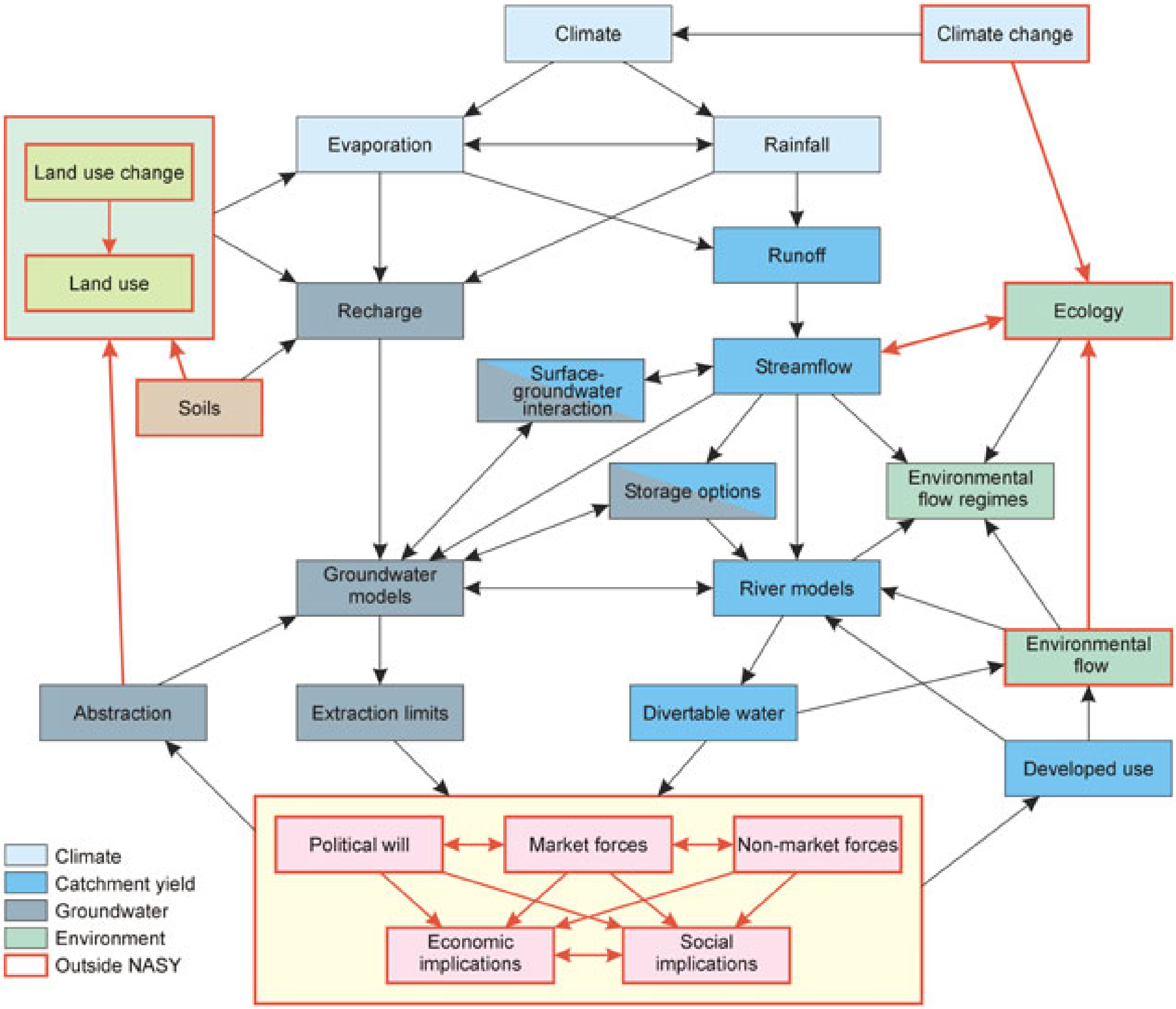


Figure 15. Concept diagram for assessment activities carried out under the Northern Australia Sustainable Yields Project. Red boxes and arrows indicate activities outside the scope of this project

The drainage division is the most appropriate scale to describe the climate data, so additional information is provided in this chapter for rainfall and evapotranspiration results. Surface water is best considered at the catchment scale, thus most data relating to surface water assessments may be found in the region chapters. Similarly, whilst groundwater systems may underlay significant portions of the drainage division, impacts and studies are generally carried out at the regional scale, hence groundwater results may also be found in the region chapters.

Further, whilst climate provides the primary drivers for water resources, water planning is carried out for surface and groundwaters only, hence a regional assessment of these components of the hydrological cycle is warranted.

Assessing the hydrological regime at environmental assets is carried out at the local (streamflow reporting node) scale. Again this is reported within the region chapters.

This chapter is divided into the components of the hydrological cycle and covers:

- climate scenario estimation
- surface water assessment
- groundwater assessment
- surface–groundwater interaction assessment
- changes to hydrological regime.

## 2.1 Climate scenario estimation

Water resources are assessed under four scenarios:

- historical (1930 to 2007) climate and current development (Scenario A)
- recent (1996 to 2007) climate and current development (Scenario B)
- future (~2030) climate and current development (Scenario C)
- future (~2030) climate and future (~2030) development of farm dams, plantations, groundwater systems and proposed irrigation development (Scenario D).

The following three sub-sections describe the methods used to generate the required climate data for scenarios A, B and C (note that Scenario D uses the same climate data as Scenario C). Following this, confidence levels are discussed.



### 2.1.1 Historical climate (Scenario A)

Historical daily climate data from 1 September 1930 to 31 August 2007 at 0.05 x 0.05 degree (~ 5 x 5 km) grid cells across the project area were used. The source of the data was the SILO database developed and maintained in real time by the Queensland Climate Change Centre of Excellence <http://www.longpaddock.qld.gov.au/silo/> and (Jeffrey, 2006; Jeffrey et al., 2001). SILO provides surfaces of daily climate data interpolated from point measurements made by the observation network developed and maintained by the Australian Bureau of Meteorology (BoM).

As rainfall data are highly discontinuous in space and time, due to the processes governing tropical cyclone activity and local thunderstorms, their interpolation is particularly challenging. To overcome as many difficulties as possible, thereby maximising the quality of the resultant data, Jeffrey (2006) implemented an interpolation strategy where a rainfall normalisation parameter was interpolated with ordinary kriging and after removal of stations with large residuals the revised dataset is interpolated and the normalisation reversed. To capture air temperature lapse rates, and other near-surface elevation-dependent processes (McVicar et al., 2007), surfaces for the other climate variables were interpolated using a trivariate thin plate spline as a function of longitude, latitude and elevation (Jeffrey et al., 2001).

In addition to daily rainfall data, rainfall-runoff models also required areal potential evapotranspiration (APET) to limit the actual evapotranspiration. Morton's wet environment APET (Chiew & Leahy, 2003; Morton, 1983) was calculated for a daily time step at 0.05 x 0.05 degree resolution using SILO temperature; relative humidity (calculated as actual vapour pressure divided by saturation vapour pressure); and incoming solar radiation data. APET was defined as the evapotranspiration that would take place, assuming unlimited water supply, from an area large enough that the effects of any upwind boundary transitions were negligible, and local variations were integrated to an areal average.

The rainfall-runoff modelling results are much less sensitive to errors in the APET data than they are to errors in the rainfall data. It is also easier to provide reliable APET data for the rainfall-runoff modelling as APET is relatively conservative in space with smaller day-to-day variation than rainfall.

### 2.1.2 Recent climate (Scenario B)

The recent climate scenario (Scenario B) covers the period from 1 September 1996 to 31 August 2007 and was used to assess future water availability should the climate in the future prove to be similar to that of the recent past (i.e. 1 September 1996 to 31 August 2007). The recent climate scenario was compared to the historical record.

To compare two non-overlapping periods from the total rainfall in the two periods, the relative differences were calculated as $(P_{recent} – P_{historical}) / P_{historical}$ (then expressed as a percentage), where $P_{historical}$ is here taken as the previous 66 years (1930-1996). To assist with interpretation of this difference and percentage difference, a statistical test was performed using a two-sided, non-overlapping two-sample t-test with equal (pooled) variances across the two time periods (Li et al., 2009). The recurrence interval for the conditions of the recent past was also calculated within the data of the historical period.

The average recurrence intervals (ARIs) were calculated through a simulation approach. For each rainfall station, Scenario A rainfall was modelled with the lag-one autoregressive model of Frost et al. (2007). This model allows for non-Gaussian distributions using Box-Cox transformation and considers parameter uncertainty using Bayesian methods with

 

Markov Chain Monte Carlo parameter estimation. The prior distribution of the Box-Cox lambda parameter was bounded between –2 and 2. Frost et al.'s (2007) model was used to generate 100 replicates of 100,000 years of 'water year' (1 September to 31 August) rainfall. The ARI for Scenario B rainfall was then calculated directly from the 100,000-year water year replicates as the mean time between successive upcrossings (i.e. crossings from below) of a threshold equal to the mean of the recent rainfall. As the distribution of the ARI estimates can be highly skewed, particularly for the higher ARIs, the median ARI from the 100 estimates was reported as the ARI for Scenario B rainfall; full details of method used to calculate and interpret the ARIs are found in Potter et al. (2008).

The ARI is the average waiting time until an independent 11-year wet (or dry) sequence would occur that is equal to or wetter (or drier) than the recent past (i.e. Scenario B). Note that estimates of the ARIs are calculated under an assumption of climate stationarity. As rainfall in some of the project area can not be considered stationary over the Scenario A time period (i.e. increasing trends in rainfall since 1930 are present for most the Timor Sea Division and the western and northern portions of the Gulf of Carpentaria Division) it is expected that the method will result in extremely large ARIs. In this case, the large ARIs are indicative of non-stationary (trending) rainfall, and subsequent bias in the model parameters. In other words, it is likely that the wet conditions observed in recent years will occur sooner than is estimated by the ARI for those rainfall stations showing significant upward trends in rainfall.

To determine the number of rainfall stations on which to run the ARI algorithm, the number of BoM stations recording rainfall in each of the 13 regions comprising the project area, and the combined area, were identified. Then to ensure that interpolation was performed (as opposed to extrapolation) when a surface was generated for the project area from the ARI results calculated at the isolated BoM stations, the number of stations in a 2 degree (~200 km) buffer around the project area was calculated (denoted Buffered area in Table 4). Results presented in Table 4, show that at strict levels of completeness (e.g. > 90 percent) there are several regions that did not have a single rainfall station that passed the threshold. Consequently the threshold was relaxed to be 70 percent complete, as at this level at least one rainfall station was present in each region; there are 146 stations in the project area increasing to 279 when including all those within the buffer. At each station missing rainfall data were infilled from the SILO surfaces so that continuous daily rainfall records were presented to the algorithm used to calculate the ARI.

Table 4. Number of rainfall stations passing completeness thresholds in each region, the project area and an associated buffered area

| Region | 60% | 65% | 70% | 75% | 80% | 85% | 90% | 95% |
|---|---|---|---|---|---|---|---|---|
| Fitzroy | 25 | 23 | 21 | 20 | 15 | 13 | 6 | 2 |
| Kimberley | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 |
| Ord-Bonaparte | 22 | 20 | 20 | 17 | 12 | 9 | 7 | 2 |
| Daly | 4 | 4 | 3 | 2 | 2 | 2 | 0 | 0 |
| Van Diemen | 5 | 4 | 4 | 4 | 2 | 2 | 1 | 1 |
| Arafura | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 1 |
| Roper | 7 | 7 | 3 | 2 | 1 | 1 | 0 | 0 |
| South-West Gulf | 5 | 5 | 5 | 5 | 5 | 4 | 3 | 2 |
| Flinders-Leichhardt | 49 | 44 | 38 | 34 | 29 | 26 | 20 | 12 |
| South-East Gulf | 24 | 21 | 21 | 21 | 19 | 14 | 11 | 7 |
| Mitchell | 12 | 12 | 12 | 10 | 10 | 7 | 6 | 5 |
| Western Cape | 6 | 5 | 5 | 3 | 3 | 3 | 3 | 1 |
| Northern Coral | 15 | 12 | 10 | 7 | 6 | 6 | 5 | 2 |
| **Total project area** | **178** | **161** | **146** | **128** | **105** | **88** | **63** | **35** |
| Buffered area | 342 | 309 | 279 | 247 | 211 | 177 | 129 | 77 |

The ARI shown in Figure 16 quantify the probability of occurrence of Scenario B rainfall in the context of the variability of Scenario A rainfall. Results show that ARIs are less than 50 years along the eastern coast of the Northern North-East Coast Drainage Division and the south-eastern portion of the Gulf of Carpentaria Drainage Division; and in the western part of the Gulf of Carpentaria Drainage Division and for most of the Timor Sea Drainage Division rainfall ARIs are generally large (i.e. > 100 years and in some cases exceeding 300 years). A spatial surface of the ARIs was generated using Kriging interpolation and the input data available from the isolated BoM stations (Figure 16), noting that the ARI analysis was conducted at stations outside the area so the resultant surface was generated using interpolation not extrapolation. Results of this interpolation are shown in Figure 16 where the output surface clearly shows the east-west divide in rainfall ARIs experienced across the project area. This spatial pattern has general accordance with the long-term trends in rainfall.

Rainfall intensity was calculated by dividing the total rainfall, calculated annually and for the wet (1 November to 30 April) and dry (1 May to 31 October) seasons, by the number of rainy days, or days with recorded rainfall. Low and high rainfall events were not distinguished, though this analysis needs to be carried out if patterns of rainfall intensity are to be described.

Long-term rainfall trends suggest an increase in rainfall over the past 77 years, particularly along the northern coast. However whether this is due to: (1) an increase in the number of rain days; (2) an increase in the rainfall intensity; or (3) a combination of these is not known. Trend analysis was performed by fitting a linear regression (ordinary least squares) to each grid cell and determining the slope of the relationship for both the number of rain days and rainfall intensity analysis in the 77-year period. This was performed for the water year, wet season and dry season.

Results suggest that the increasing trend in rainfall intensity is the primary factor driving increasing rainfall trends over much of northern Australia over this period (Li et al., 2009). It should be noted, however, that there are stations with rainfall data extending back before 1900. A further analysis of trends using this complete dataset should be carried out where practicable. For consistency, and to allow comparison across northern Australia, the analysis is here limited to the last 77 years.

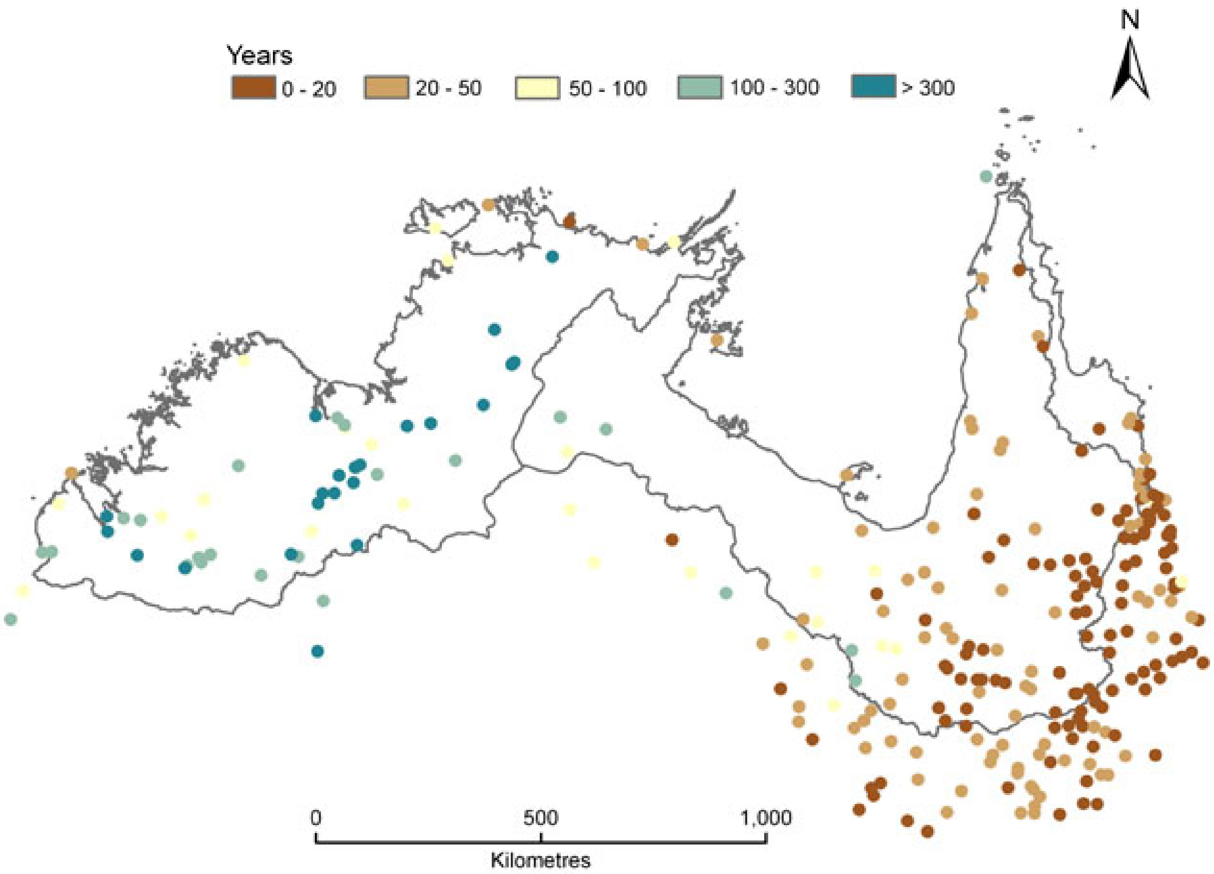


Figure 16. Average recurrence intervals for rainfall at Bureau of Meteorology stations in northern Australia under recent climate (Scenario B) relative to historical climate

### 2.1.3 Future climate (Scenario C)

The future climate scenario (Scenario C) was used to describe a range of possible climate conditions ~ 2030. This was achieved by scaling the climate data from 1 September 1930 to 31 August 2007 to represent the climate ~2030, based on analyses of 15 global climate models (GCMs) under three global warming scenarios. Thus, 45 future climate variants, each with 77 years of daily climate sequences for 0.05 x 0.05 degree grid cells across the project area, could be used for the rainfall-runoff modelling. The 15 GCMs are listed in Table 5. These represent the subset of GCMs that can generate daily sequences of data.

Table 5. List of 15 global climate models used

| Model | Modelling group, country | Horizontal resolution |
|---|---|---|
| | | km |
| CCCMA T47 | Canadian Climate Centre, Canada | ~250 |
| CCCMA T63 | Canadian Climate Centre, Canada | ~175 |
| CNRM | Meteo-France, France | ~175 |
| CSIRO-MK3.0 | CSIRO, Australia | ~175 |
| GFDL 2.0 | Geophysical Fluid, Dynamics Lab, USA | ~200 |
| GISS-AOM | NASA/Goddard Institute for Space Studies, USA | ~300 |
| IAP | LASG/Institute of Atmospheric Physics, China | ~300 |
| INMCM | Institute of Numerical Mathematics, Russia | ~400 |
| IPSL | Institut Pierre Simon Laplace, France | ~275 |
| MIROC-M | Centre for Climate Research, Japan | ~250 |
| MIUB | Meteorological Institute of the University of Bonn, Germany<br>Meteorological Research Institute of KMA, Korea | ~400 |
| MPI-ECHAM5 | Max Planck Institute for Meteorology DKRZ, Germany | ~175 |
| MRI | Meteorological Research Institute, Japan | ~250 |
| NCAR-CCSM | National Center for Atmospheric Research, USA | ~125 |
| NCAR-PCM1 | National Center for Atmospheric Research, USA | ~250 |

The method implemented to generate the Scenario C climate data was based upon that used in the Murray-Darling Basin Sustainable Yields Project, and the material herein draws heavily from Chiew et al. (2008). There are a variety of possible methods to obtain future catchment-scale climate data to drive hydrological models (see Chiew (2006) for an overview of methods). Statistical and dynamic downscaling methods that relate large synoptic-scale atmospheric variables to catchment-scale rainfall can potentially provide more reliable future rainfall inputs to drive hydrological models. However, the use of downscaling methods was not possible given the time constraints of this project. Additionally, downscaling methods may not necessarily provide more reliable future rainfall than the method used in this project because: (i) downscaling research is still developing and has not been used for hydrological investigations of this scale; (ii) it is difficult to calibrate the downscaling method for a large region like northern Australia; and (iii) there are limited archived daily GCM simulations from which to downscale to provide the range of uncertainties in the future climate.

The future climate scenario (Scenario C) provides estimates of possible conditions around the year 2030 under three potential global warming scenarios. This was achieved by using 'scaling factors', derived from GCM outputs, that rescaled the 1930 to 2007 historical climate data for each warming scenario.

Three global warming scenarios for ~2030 relative to ~1990 were used based on projected high, median and low greenhouse gas emissions. These three scenarios were inferred from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment (AR4) (IPCC, 2007) and the latest climate change projections for Australia (CSIRO and BoM, 2007). For this project, the increases in global mean near-surface air temperatures resulting from these low, median and high emissions scenarios are 0.7, 1.0 and 1.3 °C, respectively. (The corresponding values for the Murray-Darling Basin Sustainable Yields Project were 0.45, 1.03 and 1.60 °C, respectively. The slight difference in values used here is due to increased understanding of global temperature rises associated with projected low, medium and high emissions.)

The method used to derive Scenario C climate estimates is broadly outlined below. For more methodological detail, see Chiew et al. (2008).

1. Scaling factors for rainfall, net radiation, air temperatures and relative humidity were derived. Archived monthly simulations from 15 AR4 GCMs were analysed to produce scaling factors that denote the percent change in rainfall, solar radiation, maximum and minimum air temperature, and relative humidity per °C warming (i.e. globally averaged air temperature). For each of these climate variables, seasonal scaling factors

were produced for each grid cell in the project area. Daily scaling factors for rainfall were also obtained. In total 15 sets of seasonal scaling factors were produced: one set from each GCM.

2. An interim ~2030 APET was calculated and scaling factors for APET were derived. The GCMs do not produce estimates of future APET, hence APET scaling factors could not be derived directly from the GCM outputs. Instead, interim estimates of future solar radiation, maximum and minimum air temperature, and vapour pressure were calculated using respective rescaling factors and assuming a 1 °C rise in global air temperature. The four scaling factors (i.e. solar radiation, maximum and minimum air temperature, and vapour pressure) were then used to create an interim ~2030 APET. Scaling factors for APET were derived from the simulated future APET.

3. Estimates of ~2030 climate were produced by rescaling the historical climate data. Each set of scaling factors was multiplied by the amount of projected temperature increase (0.7, 1.0 and 1.3 °C) and then used to rescale historical climate variables to simulate possible 2030 climates. Rescaling of rainfall used both the seasonal and daily scaling factors. In total, 45 estimates of future climate were produced.



Monthly scaling factors were calculated for rainfall (and other climate variables) for the period 1870 to 2100 by plotting the simulated rainfall (or other climate variable) against the simulated global average air temperature. An ordinary linear regression is fitted through the data points and the slope of the linear regression is the scaling factor which gives the change in rainfall (or other climate variable) per degree of global warming. The scaling factors were then multiplied by the change in temperature for each of the global warming scenarios for ~2030 relative to ~1990 to obtain changes for rainfall (and other climate variables) for the different global warming scenarios. This was performed for each of the 15 GCMs, for each quarter (season) for each GCM grid cell. The 77-year historical daily climate data with 0.05 x 0.05 degree (~ 5 x 5 km) resolution grids were then scaled by the monthly scaling factors for each climate variable.

To account for changes in the future daily rainfall distribution, an additional percentile scaling factor was applied to daily rainfall. The scaling factors for the different rainfall percentiles/amounts were determined by comparing daily rainfall simulations from the 15 GCMs for a single SRES A1B run (IPCC, 2000) for two 20-year time slices, 2046 to 2065 and 1981 to 2000. The method used compared the 2046 to 2065 and 1981 to 2000 daily rainfall distributions, and developed a smooth transition in the 'daily scaling' factors. The percent changes were estimated by averaging the rainfall amounts over percentile ranges: 1$^{st}$ percentile (all points less than 2$^{nd}$ percentile), 5$^{th}$ percentile (all points between 2.5$^{th}$ and 7.5$^{th}$ percentiles), 10$^{th}$ percentile (all points between 7.5$^{th}$ to 12.5$^{th}$ percentiles), and every five percentile range downwards to the 'lowest category', where all the small rainfall amounts were considered together. This lowest category bound was defined by the percentile at which the observed rainfall was less than 1 mm, or the 30$^{th}$ percentile if the percentile at which the observed rainfall was less than 1 mm was less than the 30$^{th}$ percentile. This was performed as rainfall events less than 1 mm, or those below the 30$^{th}$ percentile, are not important for runoff generation. All rainfall events below the lowest category bound were lumped together and used to determine the single value of percent change. The percent changes at the discrete percentile values were then interpolated to obtain the percent changes for all the rainfall percentiles.

For each of the 15 GCMs and each of the three global warming scenarios, the above daily scaling factors were used to scale the different daily rainfall amounts in the 77-year daily rainfall series to obtain a daily rainfall series for a ~2030 climate relative to a ~1990 climate. The entire series was then scaled, using a different constant factor for each of the quarters (seasons), to ensure that the mean rainfalls in the quarters were the same as those determined using the seasonal scaling factors. This is because the seasonal scaling factors were determined using a large number of data points from several ensemble runs from the archived GCM continuous monthly simulations over more than 200 years, while the archived GCM daily simulations used to estimate the daily scaling factors were available only for two time slices from limited modelling runs. In addition, because of the large spatial resolution of GCMs, the monthly simulations were more realistic than the daily simulations. This daily scaling was only implemented for rainfall, as this is the most important variable for runoff generation; and, while some locations may experience lower annual total rainfall, the frequency of high intensity rainfall may increase resulting in increases in runoff for these conditions.

The project method took into account two types of uncertainties. The first uncertainty is in the global warming projection, due to the uncertainties associated with projecting greenhouse gas emissions and predicting how sensitive the global climate is to greenhouse gas concentrations. The second uncertainty is in GCM modelling of local climate in the project area. The method also took into account different changes in each of the quarters (seasons) as well as changes in the daily rainfall distribution. The consideration of changes in the daily rainfall distribution was important because many

GCMs indicate that future extreme rainfall in an enhanced greenhouse climate is likely to be more intense, even in some regions where a decrease in mean seasonal or annual rainfall is projected. As high rainfall events generate large runoff, the use of simpler methods that assume the entire rainfall distribution to change in the same way would lead to an underestimation of total runoff.

The project method is similar to, but not the same as, the approach used by CSIRO and the BoM (2007) to provide the climate change projections for Australia. The key differences are: (i) this project used 15 of the 23 AR4 GCMs, while the CSIRO/BoM projections use all 23 GCMs; (ii) this project assessed the extreme range of global warming by ~2030; and (iii) this project also considered changes in the daily rainfall distribution.

As the future climate series (Scenario C) was obtained by scaling the historical daily climate series for the 1931 to 2007 northern Australia water years (Scenario A), the daily climate series for scenarios A and C have the same length of data (77 years) and the same sequence of daily climate (potential changes in the frequency and timing of daily rainfall were not considered). Scenario C is therefore not a forecast climate at 2030, but a 77-year daily climate series based on 1931 to 2007 water year data for projected global temperatures at ~2030 relative to ~1990.



The range of rainfall and APET for the ~2030 climates relative to ~1990 levels for the three warming scenarios for the 15 GCMs (i.e. 45 climate estimates in total) are shown for rainfall (Figure 17a and Table 6) and APET (see Figure 17b and Table 7) across the project area. Some notable features emerge:

- for rainfall all global warming scenarios have GCMs that predict both increases and decreases in rainfall
- in contrast, for APET all GCMs in all three global warming scenarios predict increased APET
- the absolute relative changes of rainfall are predicted to be greater than APET for all warming scenarios
- for rainfall the high global warming scenario predicts greater absolute extreme values than the medium global warming scenario, which in turn predicts greater extreme values than the low global warming scenario
- for APET the high global warming scenario consistently predicts larger change than the medium global warming scenario, which in turn predicts consistently larger change than the low global warming scenario.

As the three global warming scenarios each produced 15 estimates of ~2030 rainfall and APET, three climate estimates were identified from the 45 which were considered to represent the breadth of range in the simulated ~2030 climates. The three representations are: a relatively wet ~2030 climate (‘Cwet’), a mid-range ~2030 climate (‘Cmid’), and a relatively dry ~2030 climate (‘Cdry’). As the high global warming scenario generally produced the wettest and driest climate simulations, the Cwet and Cdry climates were selected from the 15 climate simulations produced using the high global warming (+1.3 °C) scenario.

Cwet was identified at the second wettest climate (i.e. second highest mean annual rainfall) from within the 15 high global warming scenario climate estimates (see Table 6).

Cmid was identified as the median climate (i.e. eighth highest mean annual rainfall) from within the 15 medium global warming scenario climate estimates (see Table 6).

Cdry was the second driest climate (i.e. second lowest mean annual rainfall) from within the 15 high global warming scenario climate estimates (the high global warming scenario is used, not the low global warming scenario, as the high global warming scenario produced the largest changes in rainfall – refer to Table 6 and Figure 17).

This selection procedure was applied separately to each region, to each division and to the whole Northern Australia Sustainable Yields Project area. This means that adjacent regions can have ~2030 climates generated from different GCMs, and that the representative ~2030 climate for a division may not be the same as the aggregate of the representative climates of all its constituent regions.

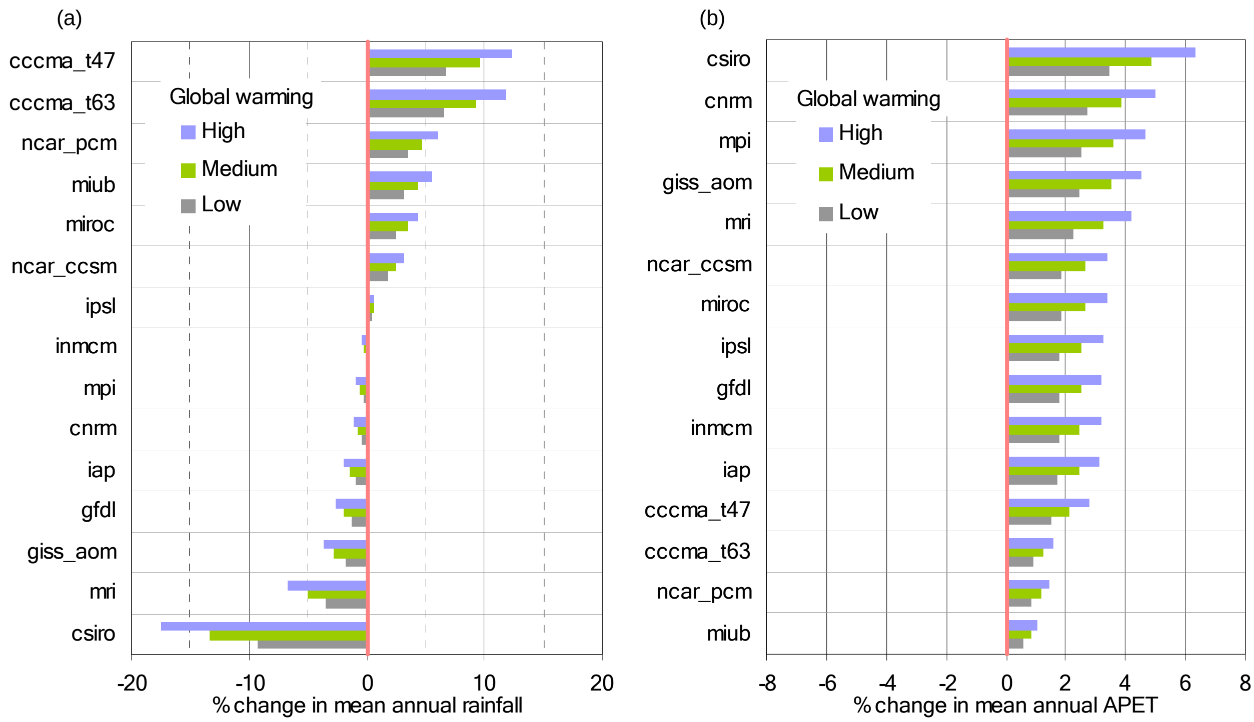


Figure 17. Percentage change in mean annual (a) rainfall and (b) areal potential evapotranspiration under the 45 future climate simulations (15 global climate models and three global warming scenarios) relative to historical rainfall and areal potential evapotranspiration (~1990) for the Gulf of Carpentaria Drainage Division

Table 6. Mean annual rainfall and its percentage change relative to historical climate under the 45 future climate (Scenario C) simulations for the Gulf of Carpentaria Drainage Division

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| Model | Rainfall | | Model | Rainfall | | Model | Rainfall | |
| | mm/y | percent change | | mm/y | percent change | | mm/y | percent change |
| csiro | 648 | -17.42% | csiro | 680 | -13.42% | csiro | 712 | -9.30% |
| **mri** | **732** | **-6.70%** | mri | 745 | -5.09% | mri | 758 | -3.47% |
| giss_aom | 756 | -3.66% | giss_aom | 764 | -2.74% | giss_aom | 771 | -1.83% |
| gfdl | 764 | -2.69% | gfdl | 769 | -2.00% | gfdl | 775 | -1.31% |
| iap | 769 | -2.00% | iap | 774 | -1.47% | iap | 778 | -0.94% |
| cnrm | 776 | -1.15% | cnrm | 779 | -0.82% | cnrm | 781 | -0.48% |
| mpi | 778 | -0.89% | mpi | 780 | -0.62% | mpi | 782 | -0.34% |
| inmcm | 782 | -0.43% | **inmcm** | **783** | **-0.26%** | inmcm | 784 | -0.09% |
| ipsl | 790 | 0.62% | ipsl | 789 | 0.55% | ipsl | 789 | 0.47% |
| ncar_ccsm | 809 | 3.10% | ncar_ccsm | 804 | 2.45% | ncar_ccsm | 799 | 1.81% |
| miroc | 819 | 4.37% | miroc | 812 | 3.43% | miroc | 805 | 2.49% |
| miub | 828 | 5.45% | miub | 818 | 4.26% | miub | 809 | 3.07% |
| ncar_pcm | 833 | 6.08% | ncar_pcm | 822 | 4.75% | ncar_pcm | 812 | 3.41% |
| **cccma_t63** | **878** | **11.88%** | cccma_t63 | 857 | 9.21% | cccma_t63 | 836 | 6.53% |
| cccma_t47 | 882 | 12.32% | cccma_t47 | 860 | 9.54% | cccma_t47 | 838 | 6.77% |

 

Table 7. Mean annual areal potential evapotranspiration and its percentage change relative to historical areal potential evapotranspiration under the 45 future climate (Scenario C) simulations for the Gulf of Carpentaria Drainage Division

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| Model | APET | | Model | APET | | Model | APET | |
| | mm/y | percent change | | mm/y | percent change | | mm/y | percent change |
| miub | 1958 | 1.04% | miub | 1954 | 0.81% | miub | 1949 | 0.59% |
| **ncar_pcm** | **1966** | **1.46%** | ncar_pcm | 1960 | 1.14% | ncar_pcm | 1954 | 0.82% |
| cccma_t63 | 1969 | 1.60% | cccma_t63 | 1962 | 1.25% | cccma_t63 | 1955 | 0.89% |
| cccma_t47 | 1991 | 2.75% | cccma_t47 | 1979 | 2.13% | cccma_t47 | 1967 | 1.51% |
| iap | 1999 | 3.13% | iap | 1985 | 2.42% | iap | 1971 | 1.72% |
| inmcm | 1999 | 3.18% | inmcm | 1986 | 2.46% | inmcm | 1972 | 1.75% |
| gfdl | 2000 | 3.20% | gfdl | 1986 | 2.48% | gfdl | 1972 | 1.76% |
| ipsl | 2001 | 3.24% | **ipsl** | **1986** | **2.51%** | ipsl | 1972 | 1.77% |
| miroc | 2004 | 3.39% | miroc | 1989 | 2.63% | miroc | 1974 | 1.86% |
| ncar_ccsm | 2004 | 3.41% | ncar_ccsm | 1989 | 2.64% | ncar_ccsm | 1974 | 1.87% |
| mri | 2018 | 4.16% | mri | 2000 | 3.22% | mri | 1982 | 2.27% |
| giss_aom | 2025 | 4.52% | giss_aom | 2006 | 3.49% | giss_aom | 1986 | 2.47% |
| mpi | 2028 | 4.66% | mpi | 2008 | 3.60% | mpi | 1987 | 2.54% |
| **cnrm** | **2034** | **4.97%** | cnrm | 2012 | 3.84% | cnrm | 1990 | 2.71% |
| csiro | 2060 | 6.32% | csiro | 2032 | 4.88% | csiro | 2004 | 3.44% |

### 2.1.4 Confidence levels for climate assessment

The gridded climate data were derived from observations that have been quality checked by the BoM and subjected to additional error checking by the Queensland Climate Change Centre of Excellence (Jeffrey et al., 2001). Nevertheless, it is inevitable that there will still be errors in the data; interpolation routines also introduce errors. In general, the data accuracy is expected to be lower in areas where the observation density is low relative to the climate gradients. In this context, it should be noted that rainfall has lower spatial and temporal auto-correlation than other climate variables. This has been compensated for by the BoM purposefully establishing the rainfall observation network with a higher density than for other climate variables, noting that the observing densities of both rainfall and maximum air temperature have increased over time.

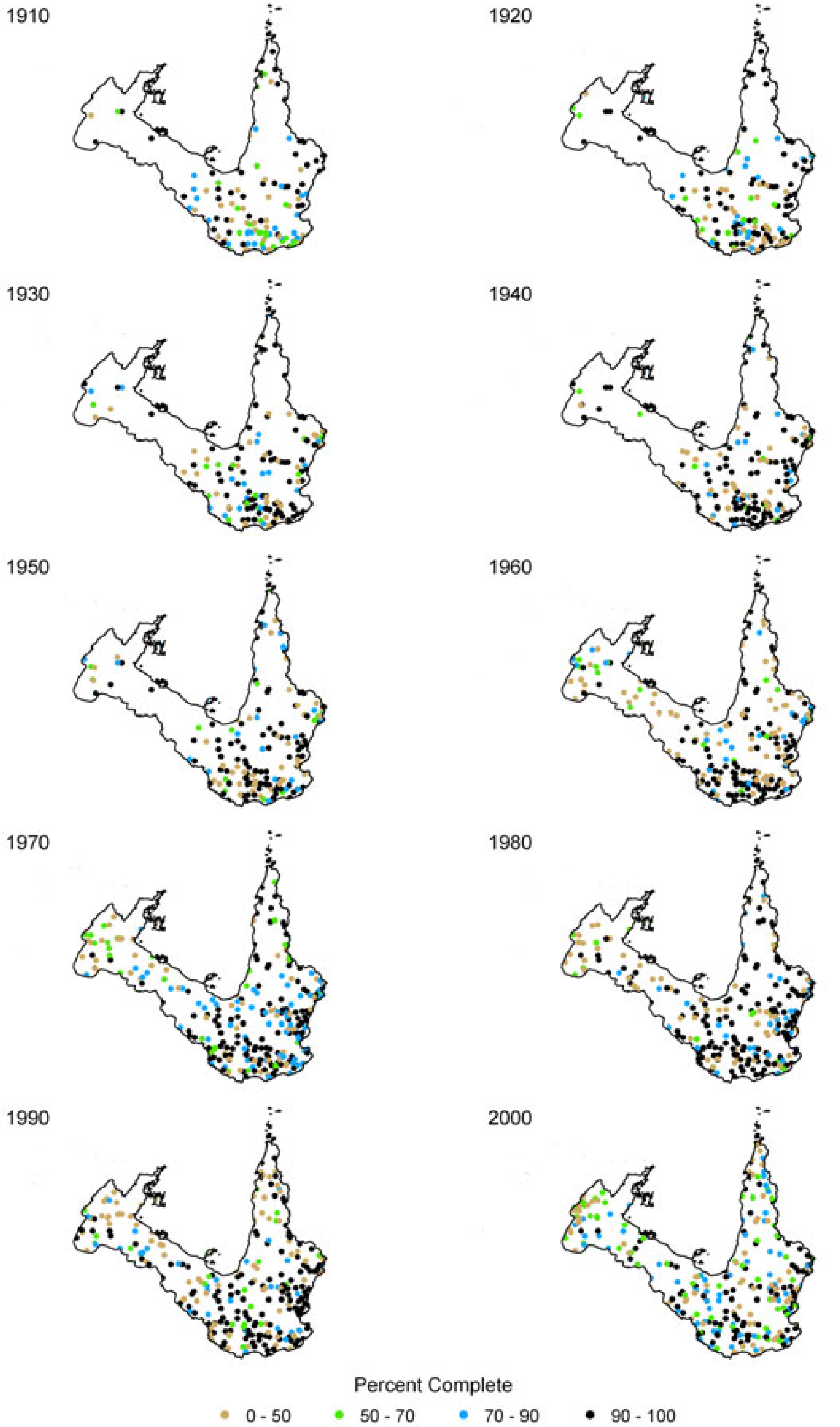


Figure 18. Locations of Australian Bureau of Meteorology stations in the Gulf of Carpentaria Drainage Division measuring daily rainfall used in the SILO database for each decade from 1 January 1910 to 31 December 2009

 

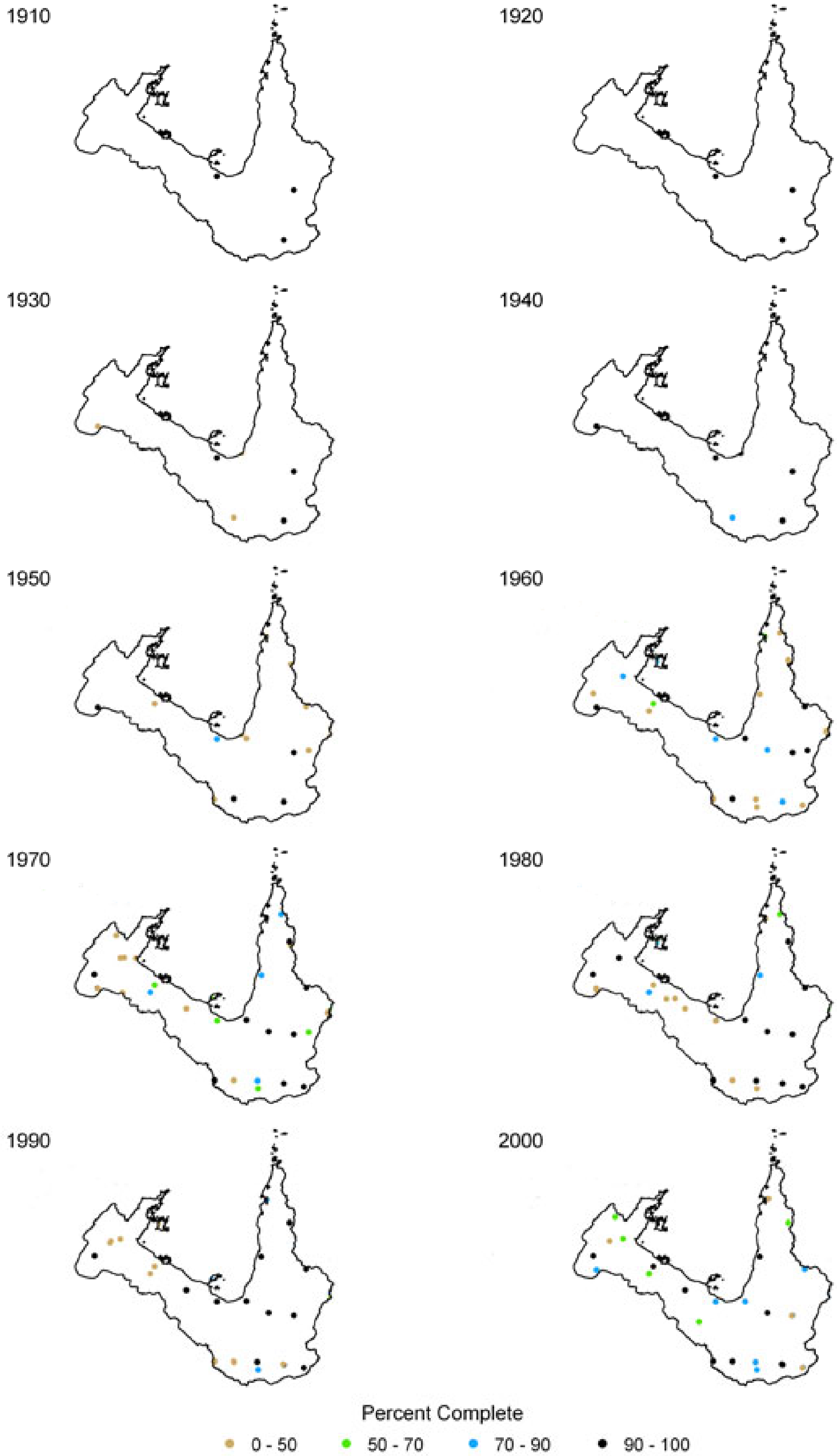


Figure 19. Locations of Australian Bureau of Meteorology stations in the Gulf of Carpentaria Drainage Division measuring daily maximum air temperature used in the SILO database for each decade from 1 January 1910 to 31 December 2009

A variety of metrics were calculated to characterise the level of confidence associated with the forcing data for the scenarios. Note that the term 'confidence level' analysis is used to mean a characterisation of the confidence, or uncertainty, involved in each scenario.

As rainfall is the variable with the greatest uncertainty when interpolating, and is the primary variable controlling runoff (Chiew, 2006), it is important to understand the confidence associated with this when interpreting rainfall-runoff modelling results. Both temporally-varying all-Australian averaged error statistics and temporally-static long-term mean maps of error have been reported (Jeffrey et al., 2001) which indicate levels of confidence of the data used in the construction of scenarios A, B and C. In this project an analysis to reflect the combined spatio-temporal dynamics was undertaken by analysing, on a decadal time step, both the distance of each grid cell to the nearest input station and the completeness of the record of that station per decade. This is termed the 'distance-completeness index', and the spatial distribution of this metric for rainfall and maximum air temperature for the decade 2000 to 2009 is shown in Figure 20. In this figure, a value of 1.0 indicates that the location is a station with a complete rainfall record, and the index decreases with distance away from stations and/or with decreasing completeness of rainfall record.

Given the greater spatial auto-correlation in air temperature when compared to rainfall, the spatial density of stations measuring temperature is, as expected, lower. The decadal evolution of the distance-completeness index from the 1930s to 2000s is shown in Li et al. (2009).

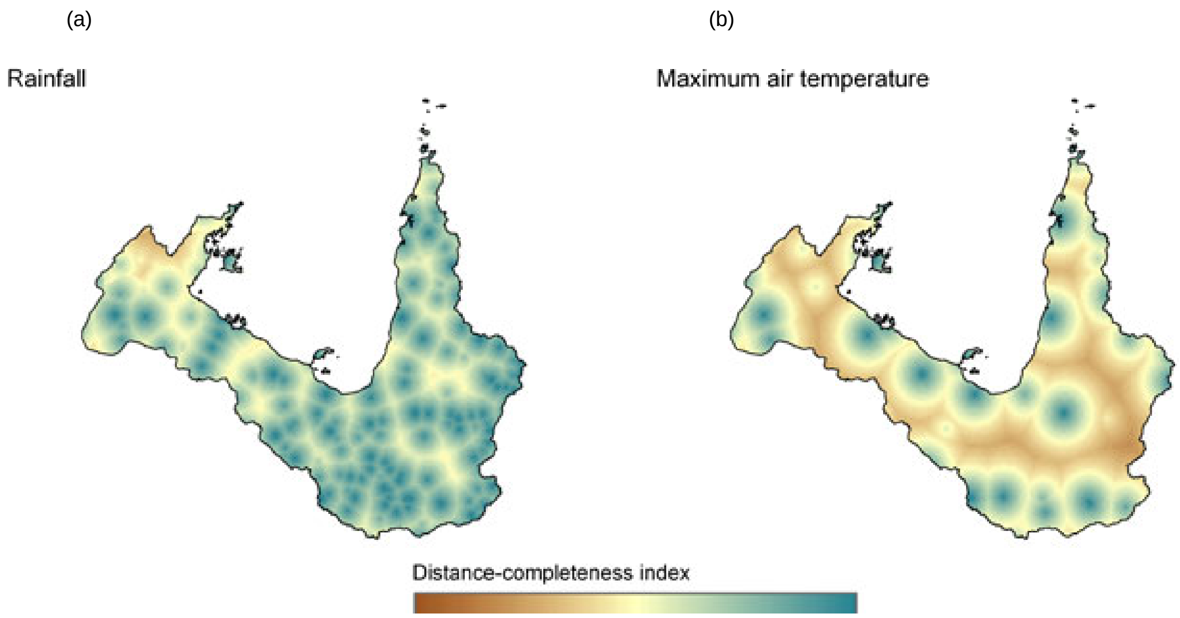


Figure 20. Spatial distribution of the distance-completeness index for the current decade for (a) rainfall and (b) maximum air temperature across the Gulf of Carpentaria Drainage Division

The distance-completeness index is a unitless metric, scaled consistently over the time series, which provides a quantitative illustration of the dynamics of the underpinning observation network. However, it should be noted that this metric cannot be used to propagate error in the rainfall-runoff modelling. To do this requires that daily surfaces of error, with the same units as the meteorological variable, are made available by providers of daily meteorological variables. Currently the Queensland Climate Change Centre of Excellence do not provide such daily error surfaces, and while the BoM do provide them at a similar resolution to this project (i.e. 0.05 x 0.05 degree or ~ 5 x 5 km) and for daily data, the BoM record only starts at 1 January 2005. This is not long enough for the modelling performed in this project (starting 1 September 1930).

 

## 2.2 Surface water assessment

### 2.2.1 General approach

The surface water assessment involved six separate tasks:

- gauging station selection and data preparation
- rainfall-runoff modelling at the regional scale for scenarios A, B and C
- river system modelling
- assessment of regions without river models
- evaluation of levels of confidence
- an alternative approach using multiple linear regression to compute key hydrological metrics.

Data assessment and rainfall-runoff modelling were undertaken on a region-by-region basis and are reported in the region chapters. Multiple linear regression was undertaken at the whole of northern Australia scale and a summary of the results from that analysis are presented in this chapter. A more detailed description of the rainfall-runoff modelling methods and the multiple regression analysis is provided by Petheram et al. (2009) and SKM (2009) respectively.

### 2.2.2 Gauging station selection and data preparation

The difficulty of operating and maintaining streamflow gauging stations in the harsh northern Australian environment meant that relative to the total project timelines, considerable time and resources were invested in assessing streamflow data quality. Establishing the streamflow station database for use in this project involved a trade off between maintaining high quality data and having a good spatial distribution of gauging stations.

Daily discharge and stage height data were obtained from government agencies for the 24 hour period from 9am(which coincides with the standard reporting period for rainfall). Each of the three jurisdictions use different codes to assign measures of data quality to stage height and discharge data. For this project these quality codes were standardised so that data coded the equivalent of satisfactory or good were accepted, and data coded the equivalent of poor or missing were rejected.

The initial criterion for the selection of gauging stations for this analysis was that they had a minimum of eight years of 'acceptable' monthly discharge data, although this criterion was relaxed where data were sparse. Because of the paucity of streamflow data in northern Australia, no minimum or maximum criteria for catchment area were specified nor was a calibration period between specified dates imposed. Nevertheless because most stations commenced operation after 1960, the majority of stations were calibrated over a period during the last 45 years. However, gauging stations were rejected if: their contributing area was deemed to be an 'open' system (as not being able to explicitly determine the catchment area draining to the gauging station violates the assumptions for the rainfall-runoff models used in this analysis); there was distributary flow into or out of the catchment upstream of the gauge, or if high or low flows were impeded at the 10 percent level (i.e. due to diversions or storages).

For the Queensland gauging stations, the non-descriptive nature of the data quality codes meant it was necessary to impose an additional requirement on those stations, such that a station could not have more than 60 percent of its total volume of flow occur at a height greater than its maximum gauged stage height. The selection of 60 percent was intuitive and based on a compromise between ensuring a reasonable spatial representation of gauging station and data quality. Recent maximum gauged stage height information was provided by Queensland state hydrographers. For stations in the Northern Territory, rating curves for most stations were inspected and those stations with a poor spread of gauged stage heights were rejected. Department policy in Western Australia meant supply rating curve information could not be provided, but qualitative assessments of the quality of low and mid- to high flow ratings were provided. Petheram et al. (2009) provide further details on station selection.

Every gauging station and streamflow reporting node was manually snapped to a streamline coverage, generated from the third version of the 9-second digital elevation model (DEM). The area upstream of each gauging station was computed and compared to areas stated in the Australian Water Resources Council (AWRC) gauging station catalogue. Where the computed area differed by more than 15 percent from the AWRC value, the relevant stage agency was approached. In the majority of instances it was agreed the gauging station had been appropriately sited on the DEM streamline network and the DEM-derived area was correct. Establishing the correct catchment area was important because catchment area is strongly correlated to streamflow. Streamflow reporting nodes (SRNs) were also sited on the DEM streamline network. These nodes were located at catchment outlets, gauging stations, environmental assets and other ‘dummy’ locations to provide an even spread of SRNs across the project area. In those AWRC river basins where river system models were available (i.e. Ord-Bonaparte, Daly and Van Diemen), SRNs were located so that they corresponded to the nodes within the river system model.

To produce spatially coherent maps of runoff, a subcatchment boundary (and subcatchment ID) were assigned to the relatively extensive coastal regions downstream of the SRNs. This resulted in each region being assigned between one and three ‘coastal subcatchments’, depending upon the length of its coastline, the diversity of climate along its length and the locations of suitable gauging stations.



### 2.2.3 Rainfall-runoff modelling

The rainfall-runoff modelling was used to estimate 77 years of daily catchment flows for three scenarios:

- Scenario A (historical climate sequence (from 1 September 1930 to 31 August 2007) and current development) – one simulation based on the historical climate series
- Scenario B (recent climate sequence (from 1 September 1996 to 31 August 2007) and current development) – one simulation of the climate from the past 11 years run seven consecutive times
- Scenario C (future (~2030) climate and current development).

For future development (Scenario D), projections of the growth in commercial forestry were obtained from jurisdictions. The projections of growth in Queensland were small and were deemed most likely to occur along the north-east coast, the majority being south of Cairns, outside of the project area. In the Northern Territory the majority of expansion in commercial forestry was expected to occur within the Daly River catchment, also outside the Gulf of Carpentaria Drainage Division. Projections for the growth in farm dams in northern Australia to 2030 indicate these will be negligible.

Therefore no Scenario D analyses were undertaken for the rainfall-runoff modelling because nowhere in the drainage division would future development differ significantly (i.e. within the error bounds of analyses) from current development (Scenario C).

Five lumped conceptual daily rainfall-runoff models (SIMHYD, Sacramento, IHACRES Classic, SMARG and AWBM) were trialled. Preliminary testing indicated that the ensemble of Sacramento and IHACRES Classic was the optimal combination of models for this project. This combination balanced model performance with the practicalities of running multiple rainfall-runoff models at a 5 x 5 km grid cell scale across an area of 1.25 million $km^2$ in a short space of time.

The Sacramento and IHACRES Classic models were used to extend streamflow records at existing gauging station locations and to simulate runoff at each 0.05 degree grid cell over the entire project region under each scenario. See Petheram et al. (2009) for further details on model selection.

The rainfall-runoff modelling steps were:

1. The rainfall-runoff modelling ensemble was set up to run at 0.05 x 0.05 degree (~ 5 x 5 km) grids across northern Australia. The use of a 0.05 degree grid allowed the best representation of the spatial patterns and gradients in rainfall, allowing improved accounting for the non-linear relationship between rainfall and runoff.

2. The 0.05 degree gridded daily rainfall and APET data across northern Australia for 1930 to 2007 was compiled (obtained, analysed and prepared). The SILO gridded data (Jeffrey et al., 2001; and <www.nrm.qld.gov.au/silo>) were used. APET was used, calculated from the SILO daily climate surfaces using Morton’s wet environment evapotranspiration algorithms (see <www.bom.gov.au/climate/averages> and Chiew and Leahy, 2003). The 0.05 degree grid cells were then mapped into each gauged catchment and SRN.

3. The rainfall-runoff models were calibrated against observed streamflow data from unregulated catchments (the same parameter values were used for all grids within a catchment). Calibration was carried out using an objective function that incorporated the Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970) of daily and monthly streamflow, dry season monthly streamflow, and the goodness-of-fit of daily flow duration curves, together with constraints to ensure that the total flow volumes were well modelled. Because objective functions that

 

incorporate the Nash-Sutcliffe efficiency are biased towards the high flows, lower flow are typically less well modelled, and this was reflected in the Nash-Sutcliffe efficiency for dry season monthly metrics and consequent representation in the lower half of the flow duration curve (FDC).

As the seasonality of flows in northern Australia needed to be addressed, it was necessary to improve the low flow calibrations. To do this several alternate objective functions which favoured good simulations at the low flows were trialled. This was primarily done by raising the observed and simulated terms in the objective function to the power of λ (see Chiew et al., 1993). Calibrations were undertaken for values of λ of 1, 0.5, 0.35, 0.2, 0.1 and 0.05, resulting in six optimised parameter sets for each model and for each calibration catchment. Using values of λ less than 1 during the calibration reduced the bias towards high flows. However, improving low flow calibrations usually comes at a cost to high flow calibrations. As flow volumes are strongly biased by high flow events, care needed to be taken to ensure that high flow calibrations did not markedly decrease. In most cases when selecting a parameter set from the six optimised sets, it was possible to considerably improve the Nash-Sutcliffe efficiency of low flow metrics through small sacrifices in the Nash-Sutcliffe efficiency of high flow metrics (typically resulting in a sacrifice of less than 0.05 Nash-Sutcliffe efficiency for daily flows). Streamflow routing was not explicitly incorporated by these implementations of IHACRES Classic and Sacramento; however, in small to medium sized catchments the use of 0.05 degree grids meant that routing was implicit in the calibration.

4. The calibration results were then ‘averaged’ to produce Nash-Sutcliffe efficiency for the two model ensemble (where each model had an equal weighting).
5. The ability of the model ensemble to estimate streamflow in ungauged catchments was assessed using the nearest neighbour approach, but also taking into account climatic gradients. Where multiple catchments were equally close, preference was given to the catchment with similar climatic characteristics (i.e. largely based upon distance from coast). The ability of the model ensemble to estimate streamflow in ungauged catchments is briefly discussed in each region chapter and a more detailed discussion is provided by Petheram et al. (2009).
6. Parameter values for all 0.05 degree grids across northern Australia were then estimated. Parameter values for the ungauged grids were based on a combination of values from the closest, or most hydrologically similar, grid and/or catchment where calibration was possible (e.g., Merz and Bloschl, 2004; Chiew and Siriwardena, 2005; Reichl et al., 2006). All grids within the contributing area of a SRN were allocated the same parameter set values.
7. The rainfall-runoff modelling ensemble was run in simulation mode using historical climate data (1930 to 2007) to estimate daily runoff for 0.05 degree grids across northern Australia. An ensemble runoff time series was generated taking the mean of the run time series generated by the Sacramento and IHACRES Classic models and spatially reporting the mean runoff for each grid cell.
8. The mean and 10th, 50th and 90th percentiles of annual and monthly runoff and daily FDC were then reported at the regional scale.

Once simulations for Scenario A were completed, simulations for Scenario B were run. For this scenario the rainfall-runoff modelling ensemble was run over the recent 11-year sequence, seven consecutive times, to give a time series of equal length (77 years) to Scenario A.

For each region, the Sacramento and IHACRES Classic models were run using the daily climate series for Scenario C and the two model runs were averaged. This provided 45 series of 77 years of modelled daily runoff (i.e. one climate series from each of the 15 GCMs for each of the low, medium and high global warming scenarios). For each region a Cdry, Cmid and Cwet scenario was reported. Scenarios Cdry and Cwet corresponded to the 10th and 90th percentiles of mean annual runoff in the high emissions scenario (i.e. obtained from the 14th and 2nd wettest GCM from the high global warming scenario). Scenario Cmid corresponded to the 50th percentile of mean annual runoff and was obtained from the 8th ranked GCM from the medium warming series. This represents the median result from the future climate models, and, for northern Australia, is indicative of the majority of GCM results.

The net effect of global warming and increased $CO_2$ concentrations on forest water use is difficult to estimate due to a lack of research data on the complex interactions between climate and the biosphere in northern Australia. Higher $CO_2$ concentrations, for example, may increase forest growth and leaf area index, resulting in higher interception loss, but this may be compensated by lower stomatal conductance and transpiration rates. No attempt was made, therefore, to quantify the effects of $CO_2$ fertilisation on plant water use and catchment yield.

### 2.2.4 River system modelling

Where possible river system models were used. These models encapsulate descriptions of current infrastructure, water demands and water management and sharing rules and can be used to assess the implications of the changes in inflows described in the rainfall-runoff section on the reliability of water supply to users. They may also be used to support water management planning by assessing the trade-offs between supplies to various competing categories of users. Given the time constraints of the project and the need to link the assessments to jurisdiction water planning processes, it was necessary to use the river system models currently used by these agencies. Where data information on infrastructure, water demand, water management and sharing rules or future development were not provided, a river modelling section was not warranted. Regions without river models are referred to as Tier B regions and are discussed further in Section 2.2.5.

Regions where river system models exist are referred to as Tier A regions. In the Gulf of Carpentaria Drainage Division, river system models exist for the Mitchell, South-East Gulf and Flinders-Leichhardt regions. In these regions a variety of metrics are reported, including water availability, level of consumptive use and storage behaviour of spills.

The main river system model in use in the Gulf of Carpentaria is the Integrated Quantity and Quality Model (IQQM). IQQM models have been developed by the Queensland Department of Environment and Resource Management (DERM) for the Flinders, Leichhardt, Gilbert and Mitchell catchments. These models were developed as planning tools and consequently have been set up assuming full use of existing entitlements. For the river system modelling section, Scenario A refers to the 77-year historical climate sequence, assuming full use of existing entitlements. Scenarios B and C refer to the recent and future climate respectively, assuming a full use of existing entitlements. For all scenarios the IQQM models were run once using the 77-year historical climate and modelled runoff sequence to get the initial storages for the model runs as of the 1 August 2007. The models were then run for 1 month to ‘prime’ the models (e.g. the modelled demand in month ‘n’ is dependent upon the simulation results for month ‘n-1’) before they were run for the 77-year scenario A, B and C sequences. Results are then reported over the period 1 September, Year 1 and 31 August, Year 77. The models were also run for a without-development scenario N, which used the climate and runoff sequences for scenarios A and C, but had storages and diversions removed from the model.

The modelled ensemble runoff series from Sacramento and IHACRES Classic were not used directly as subcatchment inflows in these river system models as this would compromise the calibrations of the river system models previously undertaken by the Queensland government which used a different runoff series. Instead, the relative difference between the average monthly runoff values (interpolated between months) of the historical climate (Scenario A) and the remaining scenarios (scenarios B and C), normalised to the average annual values of these scenarios, were used to modify the existing inflows series in the river system models. Scenario B and C inflow series for the river system modelling therefore have the same daily sequences, but different amounts, as the Scenario A river system modelling series. The same method was applied to rainfall and evaporation data.

### 2.2.5 Regions without river system models

In the non-IQQM regions of the Gulf of Carpentaria there were generally few suitable gauging stations in series. In these regions modelled ensemble runoff were used directly to model streamflow at each SRN within the region. Where suitable gauging stations existed, streamflow was modelled at that station using the ensemble results from the Sacramento and IHACRES Classic models. Where a SRN did not coincide with a suitable gauging station, a streamflow time series was generated by aggregating the grid-based runoff values (from Section 2.2.3) between the SRN and any upstream gauging stations. The aggregated runoff time series was then multiplied by its subcatchment area and added to the streamflow time series modelled at the upstream gauges to give a streamflow time series at the downstream node. Daily flow volumes less than 0.1 ML/day were set to zero. This approach, while being simple, was commensurate with available data and the time constraints imposed on the project, and minimised the extent to which errors were propagated downstream. There was little information to support the use of routing parameters outside of the IQQM regions. With the exception of the Roper, Nicholson and Norman catchments, the remaining catchments had relatively short flow paths. The streamflow time series at SRNs were used for the metric analysis in the environment Section (Chapter 2.5). In Tier B regions, changes in mean annual and dry season flow under the different climate scenarios are identical to those reported in the rainfall-runoff section. Consequently streamflow values at the SRN are not presented here, but are presented in Petheram et al. (2009). In the Gulf of Carpentaria, these Tier B regions are the Roper, South-West Gulf and the Western Cape.

### 2.2.6 Confidence levels for surface water assessment

The Gulf of Carpentaria Drainage Division experienced a slow growth in the number of streamflow gauging stations up until the 1960s when the Commonwealth government provided an injection of funding to the state-based surface water data collection programs. During the late 1980s the Commonwealth government redirected funding for the collection of hydrological data elsewhere. In the Gulf of Carpentaria Drainage Division this resulted in a sudden reduction in the number of operating streamflow gauging stations (Figure 21). Currently in the drainage division there are about 60 operational streamflow gauging stations. The spatial distribution of the operational and closed stations is shown in Figure 22. Closure of stations resulted in stations having relatively short record lengths and in some cases insufficient length of record for inclusion in this study. It also made it difficult to choose a common time period over which to calibrate the rainfall-runoff models.

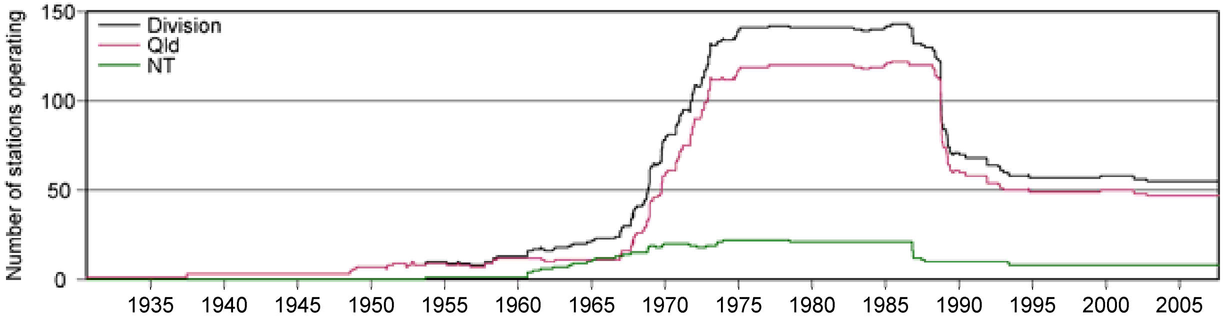


Figure 21. Number of operating streamflow gauging stations in the Gulf of Carpentaria Drainage Division for each state (Queensland and Northern Territory) and the entire drainage division between 1930 and 2007

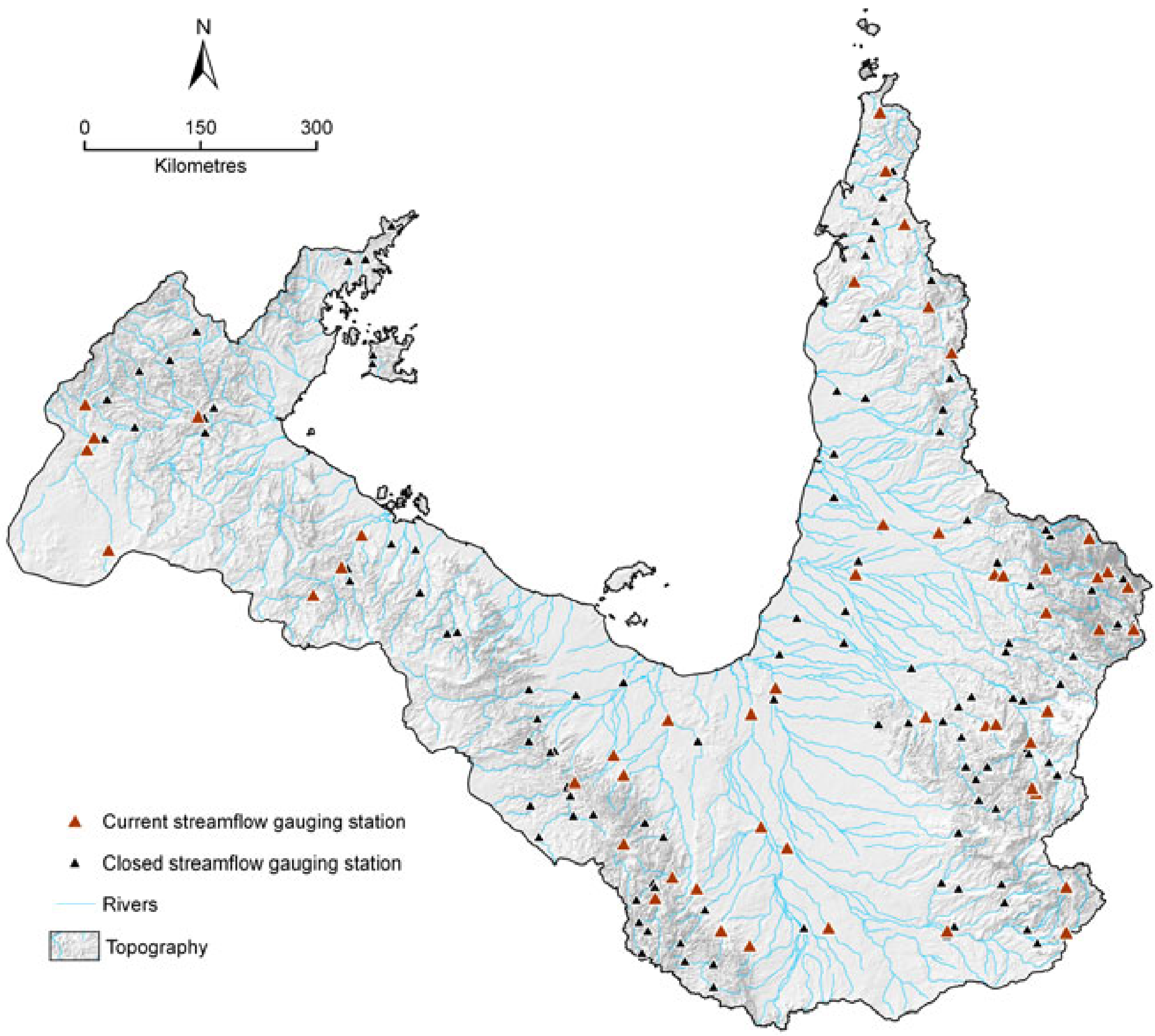


Figure 22. Location of operating (current) and closed streamflow gauging stations in the Gulf of Carpentaria Drainage Division overlaid on a relative relief surface

There is, thus, a spatial and temporal restriction on the confidence in the data. This makes regionalisation difficult. An assessment can be made, however, on the confidence in individual gauge information, as well as some informed judgement on the process of extrapolation across each region.

For rainfall-runoff modelling, the Nash-Sutcliffe efficiency (NSE) metrics provide a direct measure of level of confidence. These metrics were computed for every calibration catchment. However, in northern Australia there are vast ungauged areas. To assess the skill to which model parameters can be transposed from a gauged catchment to an ungauged subcatchment, cross-verification simulations were undertaken. In this analysis every calibration catchment was simulated using the parameters from every other calibration catchment, generating a cross-verification matrix of NSE values. For every calibration catchment a distribution of NSE values was then generated by randomly selecting with replacement 1000 donor catchments from the cross-verification matrix. Each NSE value was weighted by the inverse of the distance between the donor and target catchment and this weighting was applied to the frequency axis (i.e. distance-weighted frequency). A smoothed curve was then fitted through the frequency distribution of NSE values and the NSE value at the modal point was selected (i.e. 0.62 for the example in Figure 23).

 

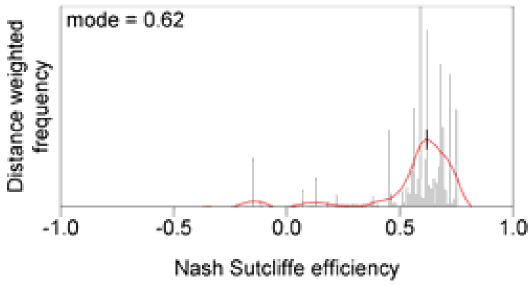


Figure 23. Example of a distance-weighted frequency and Nash-Sutcliffe efficiency values for a streamflow gauging station..The red line is a smoothed curve fitted to the distribution. In this example the modal point on the curve corresponds to a Nash-Sutcliffe efficiency of 0.62



A continuous surface of transposed NSE values was then generated by interpolating (using nearest neighbour spatial interpolation method) between the selected transposed NSE values as described above. The surface of transposed NSE metrics was combined with a map of calibration NSE metrics at gauged catchments to produce maps indicating the level of confidence in the rainfall-runoff and streamflow predictions.

Because rainfall runoff models are biased in their calibration to a particular range of flows, usually the mid-to high flows (i.e. peak flow events), the level of confidence for the high and low flow predictions may be different within the same subcatchment. Hence separate levels of confidence were provided for the mid- to high flows and for the dry season flows. The NSE values for daily flow were used to provide a measure of the level of confidence associated with the mid- to high flows and the NSE value of the monthly dry season flow was used to provide a relative measure of the level of confidence associated with dry season flows.

However, the use of the NSE metrics alone cannot properly convey the level of confidence in the rainfall-runoff and streamflow predictions for a region because in some cases qualitative information was also incorporated into the assessment. Consequently for each subcatchment the areal-mean NSE metrics were transformed into a generalised ranking, 1 through 5 as shown in Table 8. Subcatchments assigned a 1 were deemed to have the highest level of confidence and 5 was assigned to subcatchments with the lowest level of confidence. To account for the additional uncertainty associated with transposing parameters, ungauged subcatchments attracted a penalty of 0.1 to the mean NSE value as shown in Table 8.

Table 8. Levels of confidence ranking using Nash-Sutcliffe efficiency values from calibration and cross-verification results

| Level of confidence ranking | Calibration catchment | Ungauged catchment |
|---|---|---|
| 1 | mean NSE* > 0.8 | mean NSE > 0.9 |
| 2 | 0.8 > mean NSE > 0.6 | 0.9 > mean NSE > 0.7 |
| 3 | 0.6 > mean NSE > 0.4 | 0.7 > mean NSE > 0.5 |
| 4 | 0.4 > mean NSE > 0 | 0.5 > mean NSE > 0 |
| 5 | mean NSE < 0 | mean NSE < 0 |

* NSE – Nash-Sutcliffe efficiency value

Once a confidence level ranking had been assigned to each subcatchment on the basis of their NSE, the qualitative information was then incorporated into the assessment .Subcatchments attracted a penalty of 1 or more confidence rankings if they exhibited any of the following traits (details provided in Petheram et al., 2009):

- large catchment area
- potentially violated rainfall-runoff model assumptions (i.e. not a closed system)
- gauging station quality questionable
- markedly different hydrogeology between donor and target catchments (low flow penalty only)
- mean annual runoff values anomalous to the broader region (but no justification to remove the gauging station from the analysis)

- long distance between donor calibration catchment and ungauged target subcatchment
- uncertainty associated with input climate data (e.g. under-prediction in regions with strong orographic rainfall gradients like the North-East Coast)
- distributary flow channel above the gauging station.

It should be noted that the maps of level of confidence are not statistical confidence levels and are intended to only convey a broad reliability of prediction. The level of confidence map for dry season flow in particular requires careful interpretation. For example across most of northern Australia there is a high degree of confidence that dry season runoff is low because it is known that rainfall and baseflow are low during the dry season. Instead the level of confidence for the dry season flow map should be interpreted as providing a relative indication of how well dry season metrics, such as mean annual dry season flow and cease-to-flow criteria, are simulated. Metrics controlled by dry season flows may be important when assessing environmental flow requirements or potential dry season diversions.

It should also be noted that the level of confidence in streamflow predictions may vary slightly from the predictions for runoff. For example, for the simulation of runoff in a large calibration catchment (e.g. greater than 40,000km$^2$) there may be a high level of confidence in the simulated streamflow volume at the gauging station. However, there may be a much lower level of confidence in the spatial distribution of runoff within the large catchment. Furthermore, there may be a low level of confidence associated with ungauged runoff grid cell values immediately downstream of the large calibration catchment. However, the level of confidence in the streamflow volume immediately downstream of the large calibration catchment may still be high because that additional area of the ungauged runoff grid cells would be small in comparison to the area of the calibration catchment, and hence it would be expected that the streamflow volume would be similar.

### 2.2.7 Multiple linear regression approach

A multiple linear regression approach to predicting streamflow metrics in northern Australia was undertaken in parallel to the rainfall-runoff modelling described in Section 2.2.3. This alternative approach was undertaken because of the large area of ungauged land in northern Australia and the uncertainty associated with predicting streamflow in ungauged catchments. Comparing the results from the rainfall-runoff modelling with an alternative and independent method provided an additional assessment of the level of confidence of the predictions. At those SRN where there was good agreement between approaches, there is a higher level of confidence than at those SRN where there was poor agreement. Having two complementary approaches also enabled the better of the two approaches to be selected for a particular task, where one approach was superior to the other.

The multiple linear regression approach used a subset of the initial calibration catchment gauges. Two primary factors were taken into account when initially selecting a set of candidate gauged catchments. These were the period of record; and data quality. The selection of gauges involved a trade-off between these two factors and the number of candidate catchments that are made available for use in the subsequent regression analyses. For example, longer periods of record provide more reliable temporal estimates of the hydrological indices being calculated, but this lowers the sample size of candidate catchments and hence results in less reliable regression equations used to estimate the ungauged hydrological indices. When considering data quality, it is important to ensure that the data being used represents actual catchment behaviour as far as possible, and therefore has minimal infilling. Infilling the data can introduce hydrological characteristics which are an artefact of the infilling technique rather than the stream itself. SKM (2007) adopted a selection threshold allowing no more than 10 percent of the streamflow record to be infilled. CSIRO considered thresholds of both 5 and 10 percent.

A further criterion for a multiple regression approach was that gauging stations had a minimum of 90 percent of their record complete between 1972 and 1987. Stations were also excluded from the analysis if the station was known to have an unstable low flow rating curve, or considerable uncertainty associated with the high flow estimates, or if streamflow was considered to be impeded at the 10 percent level.

For the multiple linear regression the hydrological metric of interest was related to independent catchment (e.g. slope, mean elevation, percentage tree cover, drainage density, etc.) and climate attributes (e.g. mean annual rainfall, mean length of dry season) using multiple regression analysis, whereby the model was derived one step, one independent variable, at a time. Independent variables were selected based upon a physical understanding of the key factors controlling each flow parameter. The streamflow metrics investigated were:

 

- mean annual, wet season and dry season flow
- coefficient of variation of annual flow (i.e. standard deviation of annual flow divided by the mean annual flow)
- 10$^{th}$ percentile annual flow
- 50th percentile daily runoff
- 80$^{th}$ percentile annual flow
- percentage cease-to-flow
- baseflow index (BFI).

Once the multiple linear regression equations were established they were then used to predict the hydrological metrics at each SRN. A full description of the multiple linear regression method is provided in SKM (2009).

### Comparison of results from multiple regression approach and rainfall-runoff modelling

A comparison of the two approaches was undertaken using a set of gauging stations that were common to both approaches. For each gauging station a time series was generated using the calibration parameters for the gauge and calibrated parameters from the nearest neighbouring gauging station. The hydrological metrics listed above were then computed for each time series and compared to the observed streamflow data (between 1972 and 1987) and the values computed using multiple linear regression.

The results of the comparison of the two approaches indicate that over the 1972 to 1987 time period, the two approaches demonstrated similar skill at predicting mean annual flow in ungauged catchments in the Gulf of Carpentaria Drainage Division and at the all-of-project-area scale (Figure 24). Figure 24a plots cross-verified (XV) rainfall-runoff (RR) modelling results against observed flow (mm/day) and Figure 24b plots regression modelled results against observed flow (mm/day). In Figure 24, Figure 25 and Figure 26, Division is the Gulf of Carpentaria Drainage Division, NASY is the all-of-project area, NSE Division is the NSE value for the Division, and NSE NASY is the NSE value for the all-of-project area.

The multiple regression and transposition of rainfall runoff parameter methods had a similar predictive capability in the Gulf of Carpentaria Drainage Division and at the all-of-project-area scale for the high flow dominated metrics, namely the 10$^{th}$ percentile of daily flow (NSE value in the Gulf of Carpentaria Drainage Division of 0.93 versus 0.92) and the 20$^{th}$ percentile of daily flow (NSE value in the Gulf of Carpentaria Drainage Division of 0.9 versus 0.8).

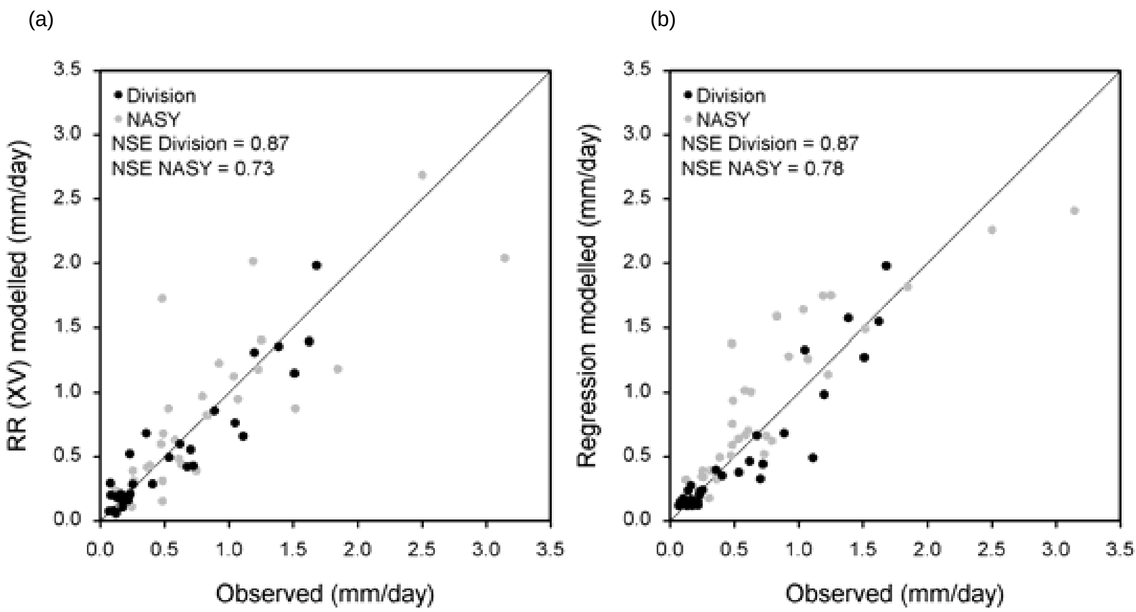


Figure 24 Comparison of (a) cross-verified rainfall-runoff modelling and (b) multiple linear regression methods for predicting mean annual flow in ungauged catchments for the Gulf of Carpentaria Drainage Division (black dots) and the all-of-project-area (grey dots). See text for discussion

Both methods were able to predict total dry season flow in ungauged catchments over the 1972 to 1987 period across all of NASY with a reasonable degree of confidence (Figure 25), although the transposition of rainfall-runoff model parameters approach appeared to be slightly superior at predicting dry season flow in the Gulf of Carpentaria Drainage Division than the multiple regression approach.

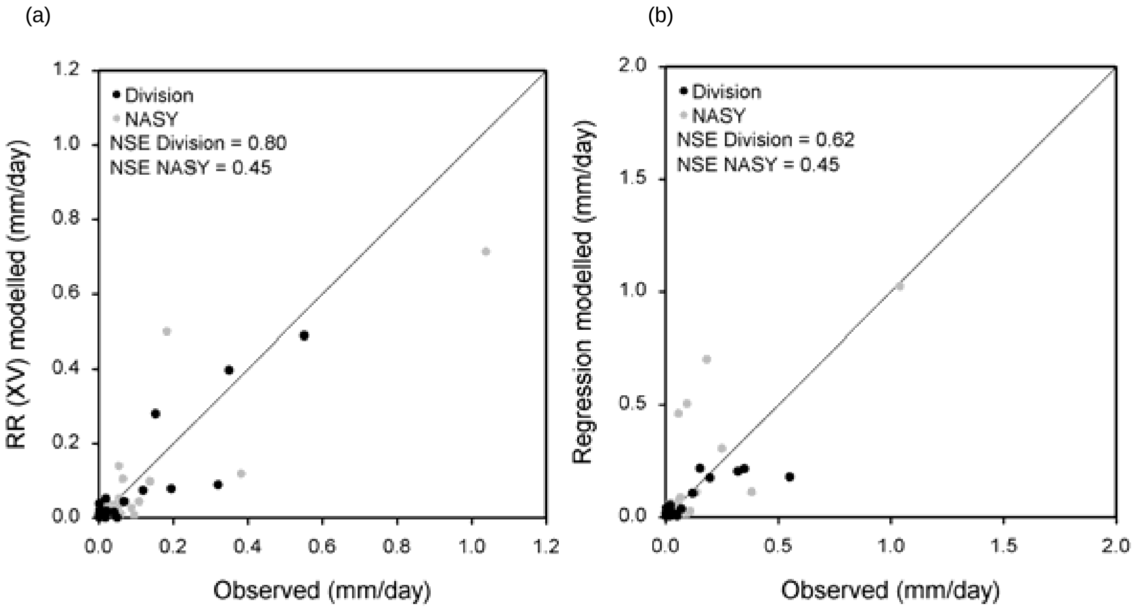


Figure 25. Comparison of (a) rainfall-runoff modelling and (b) multiple linear regression methods for predicting total dry season flow in ungauged catchments for the Gulf of Carpentaria Drainage Division (Division) and the all-of-project area

The multiple regression approach was, however, the superior of the two methods at predicting low flow metrics (i.e. cease to flow and 50$^{th}$ percentile and 80$^{th}$ percentile daily flow values). Figure 26 compares the two approaches at predicting the cease-to-flow condition (where zero flow was assumed to be less than 0.1 ML/day) for the Gulf of Carpentaria Drainage Division and all-of-project area. Transposing rainfall-runoff parameters was similar to the multiple regression approach at predicting the coefficient of variation of annual flow and the BFI in ungauged basins in the Gulf of Carpentaria Drainage Division and all-of-project-area scale.



 

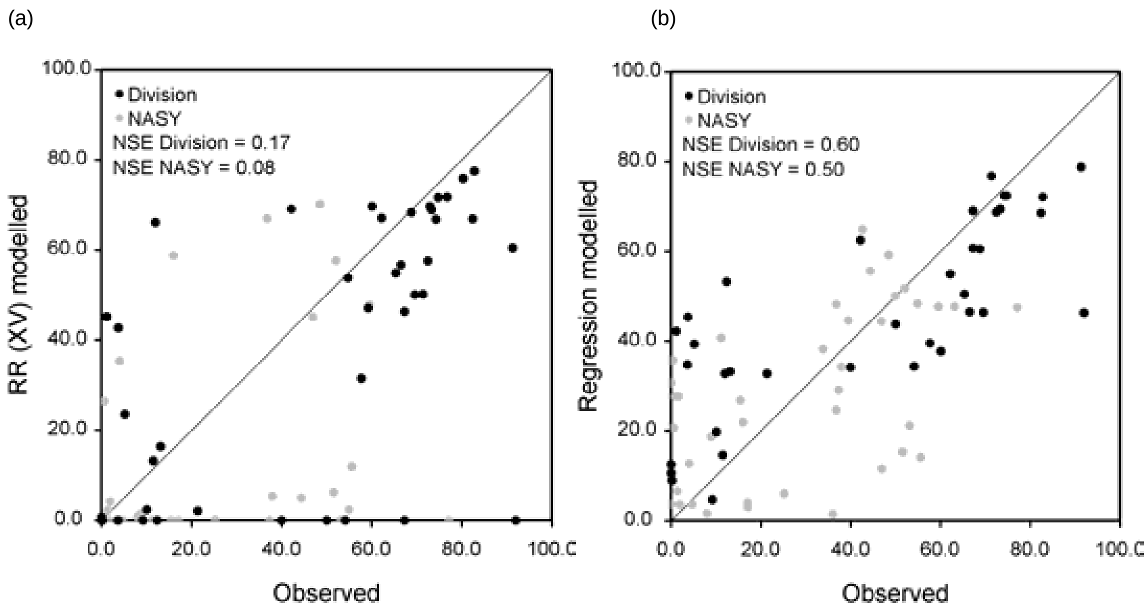


Figure 26. Comparison of (a) cross-verified rainfall-runoff modelling and (b) multiple linear regression methods for predicting cease-to-flow condition in ungauged catchments for the Gulf of Carpentaria Drainage Division (black dots) and all-of-project area (grey dots)

While the approaches used different gauging information and time periods (i.e. there was no specified start or end date for calibrating the rainfall-runoff models), it could be inferred that the skill of the two approaches at predicting mean annual flow, mid- to high flow metrics, total dry season flow, coefficient of variation of annual flows and baseflow index in ungauged catchments was broadly comparable.

Applying these two approaches concurrently provides an additional measure of the level of confidence in each prediction. For example, where the predictions of the two approaches are similar the level of confidence in the predicted value is greater than where the predictions made by the two approaches disagree.

The multiple regression approach appears to be the more suitable for predicting the low flow metrics; cease-to-flow and the 50$^{th}$ percentile and 80$^{th}$ percentile of daily flow, although when many of the observed values are small the NSE values can be biased by outlying values. Nevertheless this result is not surprising given the rainfall-runoff models were calibrated primarily to the mid- to high flows and parameters sets were transposed to ungauged catchments using the nearest neighbour approach. This approach of transposing parameter sets does not appear to be a suitable method for regionalising rainfall-runoff storage parameters. In the future there may be opportunity to integrate the two approaches to improve the low flow metric predictions from the rainfall-runoff models. This was beyond the scope of this project.

## 2.3 Groundwater assessment and modelling

### 2.3.1 General approach

The groundwater assessment and modelling component of the project collated existing data and knowledge to report on the occurrence, status and possible future condition of groundwater resources across the six regions within the Gulf of Carpentaria Drainage Division. Reporting is at the region scale. However contextual information and detailed assessments are focussed on the important aquifers and how they interact with one another and surface water systems, rather than on the surface water catchments that define each region (Figure 27).

All regions have an assessment of current and future levels of groundwater allocations and use, a conceptual groundwater recharge-flow-discharge model, and a detailed analysis of diffuse groundwater recharge rates under historical, recent and future climates.

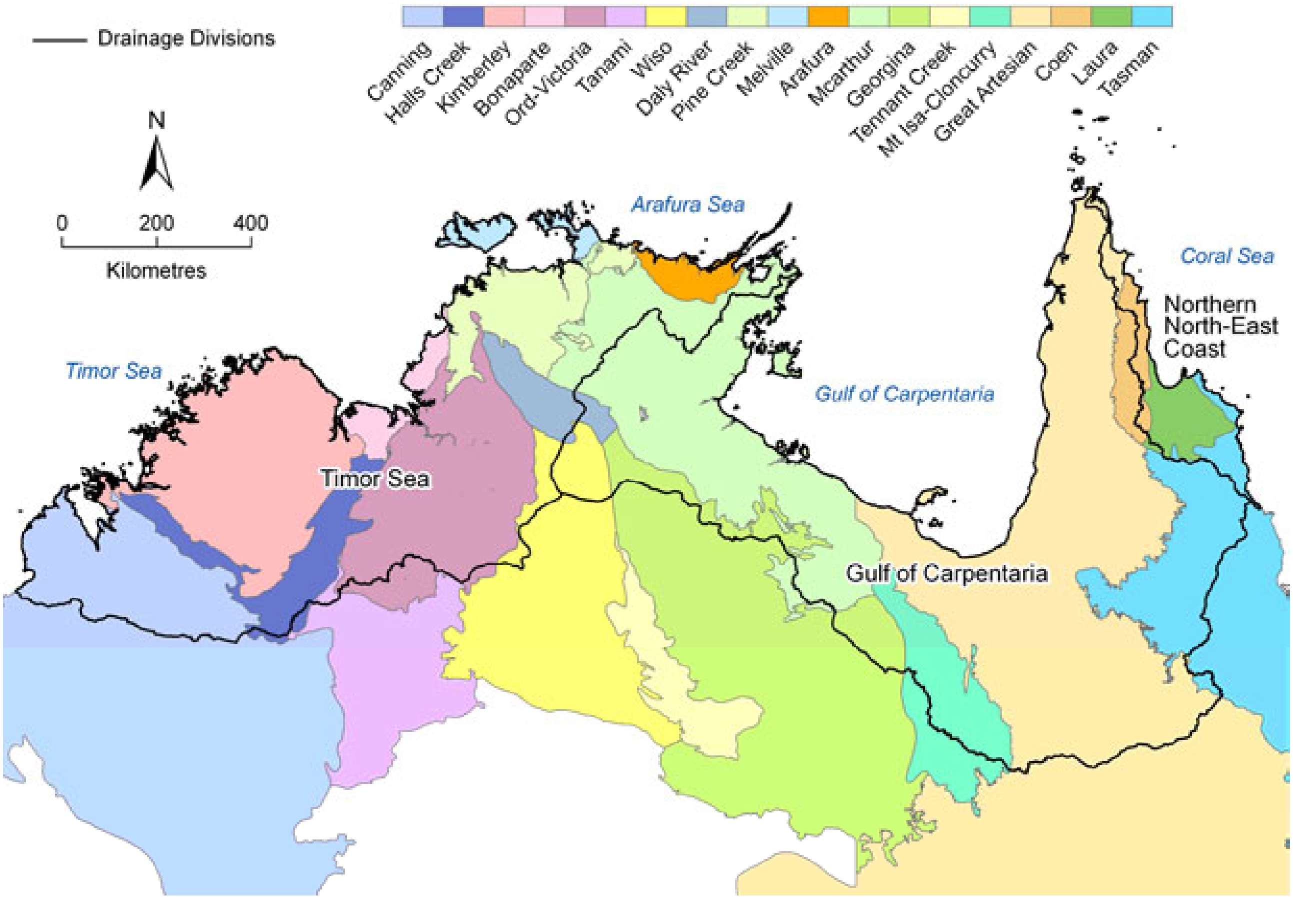


Figure 27. Extents of groundwater basins that (at least in part) underlie the drainage divisions of northern Australia. Note: Only the north-flowing region of the Great Artesian Basin is considered in this project

### 2.3.2 Prioritisation of aquifers

Regions within the project area were ranked by prioritising the main aquifers within each of them using two simple criteria: (i) a preliminary estimate of the ratio of current groundwater extraction relative to recharge (the latter has been used as a proxy for sustainable yield, which is not determined in this project); and (ii) a preliminary estimate of the mean annual recharge volume. The assumption in this approach is that highly-developed aquifers with large seasonal recharge warrant a higher priority for assessment at the national level than do undeveloped aquifers that receive minimal recharge. Obviously this approach does not consider potential future groundwater extraction, for example to support future mining activity in the Western Cape region. The prioritisation score for each region was determined through a matrix, with potential scores ranging from 1 (low priority) to 5 (high priority). Within the Gulf of Carpentaria Drainage Division, the South-West Gulf, South-East Gulf, Mitchell and Western Cape regions each received a score of 1; the Flinders-Leichhardt region received a score of 2; and the Roper region received a score of 3.

Six criteria were then used to determine the minimum type of assessment for each priority level in order to provide adequate technical support for future groundwater management in the region. The assessment levels were termed minimal (priority 1), simple (priority 2), moderate (priority 3), thorough (priority 4) and very thorough (priority 5), following the methodology used in the Murray-Darling Basin Sustainable Yields Project (Richardson et al., 2008). Some of the important aquifers within the Roper region failed to meet the criteria specified for the moderate level of assessment due to insufficient monitoring data, limited or no metered extraction data, and a basic conceptual understanding of surface–groundwater interactions. The Flinders-Leichhardt region was deemed to meet the criteria necessary for the simple level of assessment. The Western Cape, South-East Gulf and South-West Gulf regions met the criteria necessary for the minimal level of assessment. The Mitchell region ended up receiving a simple level of assessment, despite only requiring the minimal level of assessment.

Because some regions have a level of data and/or models different to that required for the minimum level of assessment, a simple five tier approach was adopted for this project, with Tier 1 reflecting a high priority system needing a very thorough assessment. Across the entire project area, the highest tiered region was the Daly region (Timor Sea Drainage Division), classified as Tier 3; the Fitzroy (WA), Flinders-Leichhardt, Mitchell and Roper regions as Tier 4; and the remaining eight regions (including the Western Cape, South-East Gulf and South-West Gulf regions in the Gulf of Carpentaria Drainage Division) as Tier 5 (low priority, minimal assessment required).

### 2.3.3 Potential diffuse recharge estimation

The method used for the estimation of the changes in dryland diffuse recharge for this project is based upon the method used for the Murray-Darling Basin Sustainable Yields Project (Crosbie et al., 2008). This involves modelling potential diffuse recharge at a series of control points throughout the area and upscaling to a 0.05 x 0.05 degree grid using mean annual rainfall, soils and vegetation as co-variates.

WAVES (Zhang and Dawes, 1998) is a one-dimensional soil-vegetation-atmosphere-transfer model that was used to model recharge for this project. This model was chosen because of its balance in complexity between modelling plant physiology, soil physics and the water balance. One of its advantages is the ability to simulate plant growth. WAVES can model the impact that changes in climate might have upon recharge via changes in different elements of the water balance. These include transpiration and the interception of rainfall on the plant canopy. WAVES requires three data sets to run: climate, soils and vegetation. The 77-year historical climate sequence was extracted from SILO for 23 control points selected to cover the rainfall gradient. The soils data was extracted from the ASRIS database for major soil types found in northern Australia and these were grouped according to the Australian Soils Classification (Isbell, 2002). This generated 12 soil classes for modelling. The vegetation was simplified from the Integrated Vegetation Coverage dataset (BRS, 2003) into three classes: savannah (including woodland and forests), perennial grasslands, and cleared areas which were modelled as annual vegetation. The WAVES model was used to model every combination of soil and vegetation type at every (rainfall) control point. The output from WAVES represents the drainage from a 4 m soil column assuming a free-draining lower boundary condition. This drainage is assumed to reach a shallow watertable and has therefore been termed recharge for this project.

The results of the WAVES modelling are used to create regression equations between mean annual rainfall and mean annual recharge for each combination of soil and vegetation type. This allows the recharge to be upscaled to a raster coverage of soils, vegetation and mean annual rainfall using a grid spacing of 0.05 x 0.05 degrees. Consecutive 23-year sequences from the 77-year historical sequence used for WAVES modelling were analysed and ranked to generate three 23-year variants of the historical climate (Awet, Amid and Adry variants) for forward groundwater modelling to 2030. In contrast to surface water assessments, groundwater systems do not re-set each year, but respond to longer period changes in rainfall. For this reason, representative sequences from the historical record were chosen to estimate groundwater responses in 23 years (2030) for a wetter than average, average and drier than average rainfall regime.

For the recent climate (Scenario B), relationships were established between mean annual rainfall and mean annual recharge from the recent (1996 to 2007) years of modelling, enabling a raster to be constructed. Dividing this new raster by the Scenario A raster produces a raster of recharge scaling factors (RSFs) used in further analysis.

For the future climate (Scenario C), the climate sequences extracted from SILO were scaled to account for a changed climate as projected by 15 different GCMs for three global warming scenarios. The 45 climate variants were modelled using WAVES at the 23 control points for every combination of soil and vegetation types. Regression equations were developed between mean annual rainfall and mean annual recharge for the 45 future climate variants and the 77-year historical base case. These regression equations allow upscaling of the results to produce 45 rasters of RSFs in the same manner as Scenario B. The mean RSF was aggregated to a region level and the different GCMs were ranked. Scenario Cwet is taken from the 14th ranked raster from the high global warming scenario, Scenario Cmid from the 8th ranked raster from the medium global warming scenario, and Scenario Cdry from the 2nd ranked raster from the high global warming scenario. For the groundwater models, the 23-year time period used for scenarios Cwet, Cmid and Cdry is the same as that used for the Amid variant.

In some locations, increasing recharge is modelled during periods of decreased mean annual rainfall. This counter-intuitive result can be explained if we consider the effects of the non-rainfall amount drivers of the model (Crosbie et al., 2009). Figure 28 presents a sensitivity analysis showing the effect of changes to three different climate variables on the estimation of recharge using WAVES (independent of changes in total rainfall).

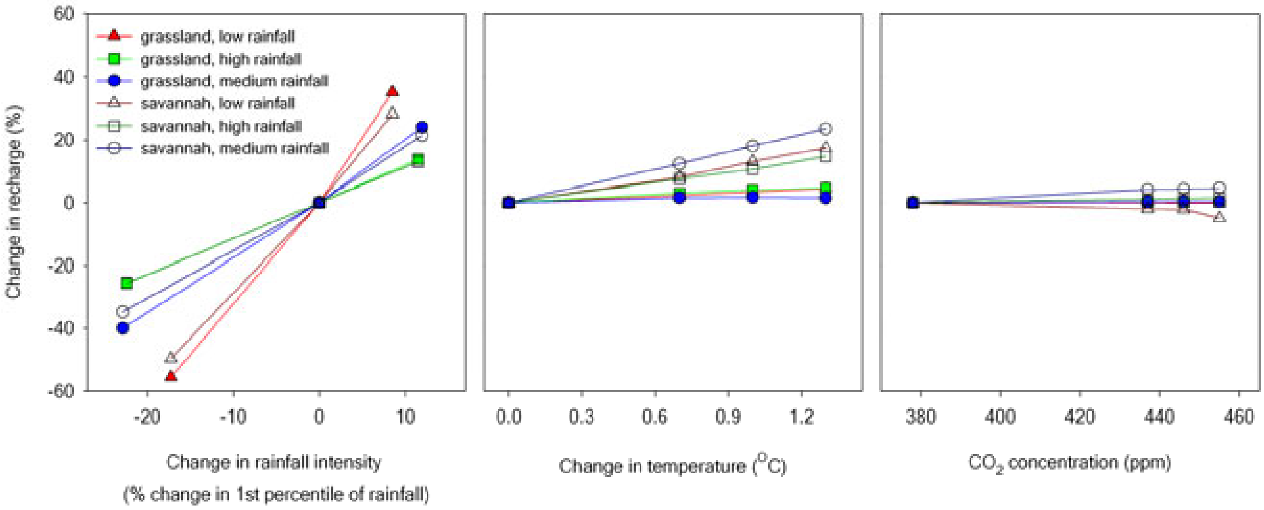


Figure 28. Results of a sensitivity analysis of WAVES estimates of recharge to changes in climate variables independent of changes in total rainfall. Three climate variables were investigated for two vegetation types and three rainfall zones

Changes in daily rainfall intensity have a large impact on the estimation of recharge, with increases in intensity resulting in increased recharge (Figure 28). This means that in some instances, total rainfall decreases, but WAVES may simulate an increase in recharge as a result of increased rainfall intensity. In this case, less rainfall is intercepted by the vegetation canopy, resulting in more rainfall infiltrating the soil and subsequently becoming recharge. Further, increased intensity of rainfall is accompanied by reduced evaporation, thereby making more rainfall available for recharge (and runoff). The amount of water reaching the ground surface exceeds the amount being removed by evaporation, hence infiltration will take place. During periods of lower intensity rainfall, however, recharge may significantly decrease, due to drying of the profile inhibiting infiltration. As runoff occurs as a result of an excess of water at the surface, this will only occur once the infiltration rate is exceeded, and is favoured at moderate to high rainfall intensities. Increased rainfall intensity with lower average annual rainfall, therefore, implies a greater proportion of lower rainfall days, where runoff will be negligible, but recharge may still operate. Hence, on a longer time frame such as annually, it is possible for recharge to increase even if rainfall decreases.

Increases in temperature also lead to increased recharge even though potential evapotranspiration will rise (Figure 28). This is a function of plant physiology. Above an optimum temperature, plants assimilate carbon less efficiently resulting in less leaf area. A decrease in leaf area results in less interception, more infiltration and subsequently increases in recharge (and runoff).

 

Increases in $CO_2$ concentration can lead to an increase or decrease in recharge, although the magnitude of changes is comparatively small (Figure 28). Increased $CO_2$ concentration in the atmosphere allows plants to assimilate carbon more efficiently and thus use less water. The direction of the change in recharge depends upon whether the reduction in transpiration is offset by an increase in interception due to increased leaf area.

This sensitivity analysis shows the directions of changes in recharge under a future climate scenario are not necessarily in the same direction as changes in rainfall. It must be noted, however, that these are all relative changes. In general, recharge is still roughly an order of magnitude lower in absolute volumes, than runoff, which in turn is up to an order of magnitude less than rainfall.

### 2.3.4 Groundwater assessments

None of the six regions within the Gulf of Carpentaria Drainage Division are represented with an existing, calibrated, regional-scale numerical groundwater flow model. Accordingly, quantitative assessments were restricted to groundwater balances for the three Tier 4 regions (Flinders-Leichhardt, Mitchell and Roper) based on historical conditions and limited data. Tier 5 regions (South-West Gulf, South-East Gulf and Western Cape) underwent descriptive assessment and conceptualisations where possible.

### 2.3.5 Groundwater assessment in sparsely monitored aquifers

Groundwater monitoring is in general very limited across the Gulf of Carpentaria Drainage Division, with the aquifers of the Great Artesian Basin by far the most comprehensively monitored in the drainage division. Across the remaining aquifers, including those in the Tier 4 Mitchell, Flinders-Leichhardt and Roper regions, monitoring records are very sparse. For these aquifers groundwater assessment was limited to simple water balance considerations that relied upon literature and single-point-in-time measurements from bores, mostly corresponding to the time of drilling.

### 2.3.6 Managed aquifer recharge feasibility assessment

Managed aquifer recharge (MAR) involves the artificial storage of excess surface water in aquifers for subsequent beneficial use. Recharge is generally achieved through either infiltration pits or injection bores. In the case of northern Australia, artificial recharge would occur in the wet season for groundwater extraction in the following dry season.

There are a number of criteria available for assessing the feasibility of a MAR scheme; these ultimately relate to end-user demand, aquifer properties, the availability and characteristics of source water, requirements for detention and level of expertise (Dillon et al., 2009). In general terms, the aquifers best suited to MAR in northern Australia will likely have the following physical and chemical attributes (after Dillon and Jimenez, 2008):

- storage capacity at the end of the wet season. In the case of unconfined aquifers this requires peak groundwater levels below the top of the aquifer. In the case of confined aquifers this requires a high storage coefficient
- carbonate matrix, which is generally least susceptible to physical clogging through injection of dissolved organic carbon
- ambient groundwater salinity <10,000 mg/L as total dissolved solids.

The lateritic soils that cover much of northern Australia will preclude the use of infiltration pits for MAR. In areas where infiltration can occur, recharge rates are comparatively high and the aquifer will be full at the end of each wet season. Therefore MAR will only have potential where groundwater development is already depleting the resource to the extent that recovered water levels at the end of the wet season do not fill the aquifer.

In this project, the opportunities for future MAR schemes are explored for each region but only in terms of the aquifer properties. Feasibility assessments beyond this level would require detailed field site investigations.

## 2.4 Surface–groundwater interaction

### 2.4.1 Baseflow analysis for groundwater assessments

Dry season groundwater-fed river flows have been estimated using a digital recursive filter (Lyne and Hollick, 1979) with a filter parameter value of 0.925. This analysis provides an estimate of baseflow index (BFI): the ratio of the baseflow volume to total flow volume over the time period of analysis. The filtered baseflow value represents the components of river flow that are predominantly groundwater discharge, but also includes delayed surface water flow; delayed groundwater flow (from perched aquifers); bank storage and unsaturated-zone flow. It is important to note that the technique used in this project to estimate dry season flow is derived from standard signal processing methods and does not explicitly represent the physical processes of surface–groundwater interaction.

The analysis was only performed on historical gauged data (i.e. no simulated or extrapolated flows) for the project area. A total of 159 gauges were selected based on the following criteria:

- more than 20 years of record in which less than 20 percent of daily flows are missing; or
- more than 40 years of record, regardless of the amount of daily data missing.

### 2.4.2 Surface–groundwater connectivity mapping

The Northern Territory Government has recently completed a map of the whole of Northern Territory showing locations of recorded springs and streams that flow throughout the dry season (Tickell, 2008). This map is the culmination of over a decade of work by many people, combining results from both regular and occasional streamflow gauging and groundwater monitoring with anecdotal evidence from field staff and Indigenous communities. Reporting regions that fall within the Northern Territory have this map as the basis for describing surface–groundwater connectivity.

For the five regions of the Gulf of Carpentaria Drainage Division that fall within Queensland, the project attempted to develop a hydrogeology map similar to that created for the Northern Territory. Very poor spatial and temporal groundwater level data meant this was not possible in all but the Flinders-Leichhardt region.

### 2.4.3 Modelling surface–groundwater interaction

Due to the absence of existing, regional-scale, numerical groundwater flow models for all of the surficial aquifer systems throughout the Gulf of Carpentaria Drainage Division, the assessment of surface–groundwater exchange fluxes was restricted to calculations of stream depletion (caused by groundwater pumping) using well-known analytical solutions (see next section). The regional numerical model for the Tindall Limestone (Knapton, 2006) does incorporate Mataranka Springs in the Roper region. This part of the model is currently only run in steady state and thus would not be useful for transient (i.e. temporal) flux analysis.

### 2.4.4 River flow impact assessment

Groundwater pumping initially depletes the aquifer but can eventually deplete flow in nearby rivers. The extent of river depletion depends on the magnitude of pumping and the connectivity between the river and the aquifer, while the associated time lag varies with aquifer properties (namely, transmissivity and specific yield) and the orthogonal distance between the river and the pumping activity (herein referred to as groundwater development).

River flow impact was calculated for all three Tier 4 regions in the Gulf of Carpentaria Drainage Division. However, given the low level of groundwater development in the Roper and Mitchell regions, these calculations were restricted to hypothetical situations. For the Flinders-Leichhardt region the analysis assumed that groundwater extraction is equal to the full allocation. The existing groundwater licences were grouped into two categories depending on whether they source water from an unconfined alluvial aquifer or a deeper, confined or semi-confined aquifer.



 

For unconfined alluvial aquifers, the most commonly used river depletion model (Glover and Balmer, 1954) was utilised. This model assumes a semi-infinite, homogeneous, unconfined aquifer in full hydraulic connection with a fully penetrating river. This analysis provides the magnitude of river depletion and its timing.

For confined aquifers, the solution of Hunt (2003) was used. However, since little is known about the deeper aquifers and their hydraulic connection to rivers, only a comparative analysis was conducted. In this type of analysis, all model parameters were assumed to be equal, except the distance between the river and the groundwater development. This provides a hierarchy of impacts, which highlights priority areas where further investigations need to be focussed in the future.

## 2.5 Changes to hydrological regime

Flow requirements for environmental assets and the ecosystems that they support are largely unknown across Northern Australia. In the Gulf of Carpentaria Drainage Division there are no known assets that have quantitative environmental flow information. To include these assets in our analysis and provide a consistent means for cross-region comparison, a common set of standard metrics of hydrological regime change to report against were derived. These standard metrics are described in Section 2.5.1.

The main uncertainties involving analysis and reporting of changes to hydrological regime at selected assets include:

- Aquatic and wetland ecosystems are highly complex and many factors in addition to water regime can affect ecological features and processes, such as water quality and land use practices.
- The indicators are based on limited hydrology parameters with no direct quantitative relationships for environmental responses. This project only makes general observations on the potential implications of changed water regimes and some related ecological responses.
- Considering only a few of the important environmental assets and using a limited number of indicators to represent overall aquatic ecosystem outcomes is a major simplification. Actual effects on these and other assets or localities are likely to vary.
- Uncertainties surround the hydrological information used in the environmental assessments.

### 2.5.1 Standard regime metrics

One of the key characteristics of the rivers of northern Australia is their highly seasonal flow regimes which can be partitioned into flood events and low flow (or no flow) periods (Hamilton & Gehrke, 2005). Each of these regimes, which are at opposite ends of the flow spectrum, will have different implications for aquatic biota and ecosystem processes. For example, flood events can be important for such things as wetland connectivity and floodplain rejuvenation (Douglas et al., 2005) while low flows can be crucial for survival of riparian vegetation (Lamontagne et al., 2005), maintenance of ecosystem production and food webs (Townsend & Padovan, 2005; Webster et al., 2005), and provision of refuge for sustaining populations of aquatic species (Hamilton et al., 2005).

Many metrics have been used in the literature to report changes to the low flow regime of a river (Olden and Poff, 2003; Nathan and McMahon, 1992; Kennard et al., In press). One of the most commonly used metrics is the flow that is exceeded for 90 percent of the time (Gordon et al., 1992). To determine changes to the low flow regime of northern Australian rivers, this metric was calculated for each of the 77 years in Scenario A, then the number of days that flow fell below this threshold in any hydrological year (September to August) was calculated for all other scenarios. The mean number of days below this threshold across all years was calculated and reported for all scenarios. It has been noted by Petheram (2008) that for many of the streams of northern Australia the value of this metric is zero, therefore it is best suited to rivers where flow is perennial. In streams that cease to flow, a more suitable metric is the mean number of days per year with zero flow. Finally, changes to the low flow regime were also assessed through changes to the mean dry season (May to October) flow.

Many of the wetlands of northern Australia require flood or high level flows to facilitate connectivity with other water bodies, therefore it was essential that metrics for assessing the change to the high flow regime at selected assets were defined. The flow above which floodplains commence inundation was not known for most of the asset locations. Therefore, a surrogate metric of high flow was required. Other studies have used high flow metrics based on flows exceeded between 10 and 1 percent of the time (Olden and Poff, 2003; Kennard *et al.*, In Press). In this project the flow exceeded 5 percent of the time for all 77 years was calculated for Scenario A. The number of days above this threshold was then calculated for each hydrological year and for all scenarios. This project reports, under all scenarios, the mean number of days per year that flow is above this threshold. Changes to high flows were also assessed through changes to the mean wet season (November to April) flow.

The final and most general metric reported is changes to the mean annual flow. Such a metric – when combined with wet season and dry season metrics described above – gives a good indication of the direction of changes to the hydrological regime under the climate and development scenarios.

 

The above low and high flow metrics are summarised as:

- annual flow (mean)
- wet season flow (mean)
- dry season flow (mean)
- low flow threshold (discharge exceeded 90 percent of the time under Scenario A)
- number of days per water year below low flow threshold (mean)
- number of days per water year of zero flow (mean)
- high flow threshold (discharge exceeded 5 percent of the time under Scenario A)
- number of days per year above high flow threshold (mean).

In reporting changes to the hydrological regime at an environmental asset it is important to consider the confidence levels in modelled streamflow. Confidence in results for low and high flows is reported separately on a scale of 1 to 5, with 1 indicating results with the highest confidence (see Section 2.2.6 in this chapter). Hydrological regime metrics for both high and low flows are only reported where confidence levels are 1, 2 or 3. If either the high or low flow metrics were ranked 4 or 5, results are not reported.

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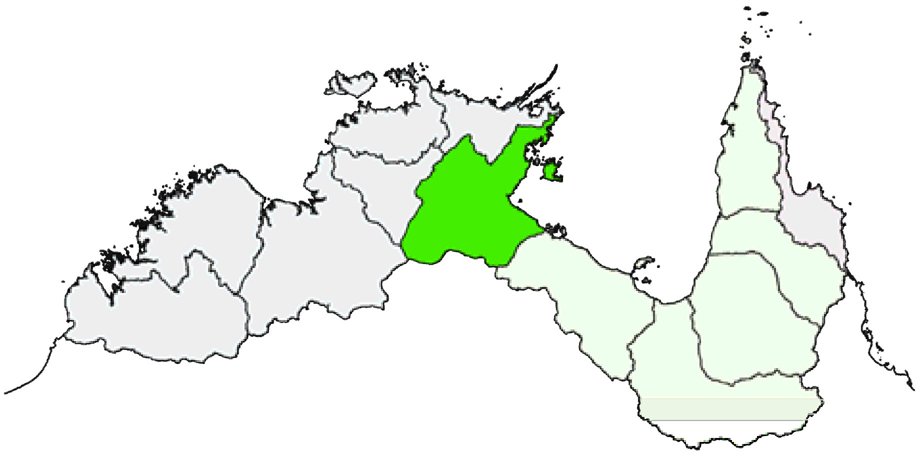
# Water in the Roper region



# RO-1 Water availability and demand in the Roper region

The first part of this report (the Preamble, Chapter 1 and Chapter 2) reports at the division level, including division-wide descriptions of climate and geology and methods which apply to all regions. Subsequent chapters report at the region level. In particular, Chapters RO-1, RO-2 and RO-3 focus on the Roper region (Figure RO-1).

This chapter summarises the water resources of the Roper region, using information from Chapter RO-2 and Chapter RO-3, and directly addresses the Terms of Reference, specifically terms 3, 4 and 5 as listed in the Preamble. Essentially, this chapter provides a synoptic view of the region and covers:

- regional observations
- water resource assessment
- seasonality of water resources
- surface–groundwater interaction
- changes to flow regime at environmental assets
- water storage options
- data and knowledge gaps.

For further details on the context of the region (physical and climate descriptions, hydrogeology and legislation) see Chapter RO-2. Region-specific methods and results are provided in Chapter RO-3. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2.

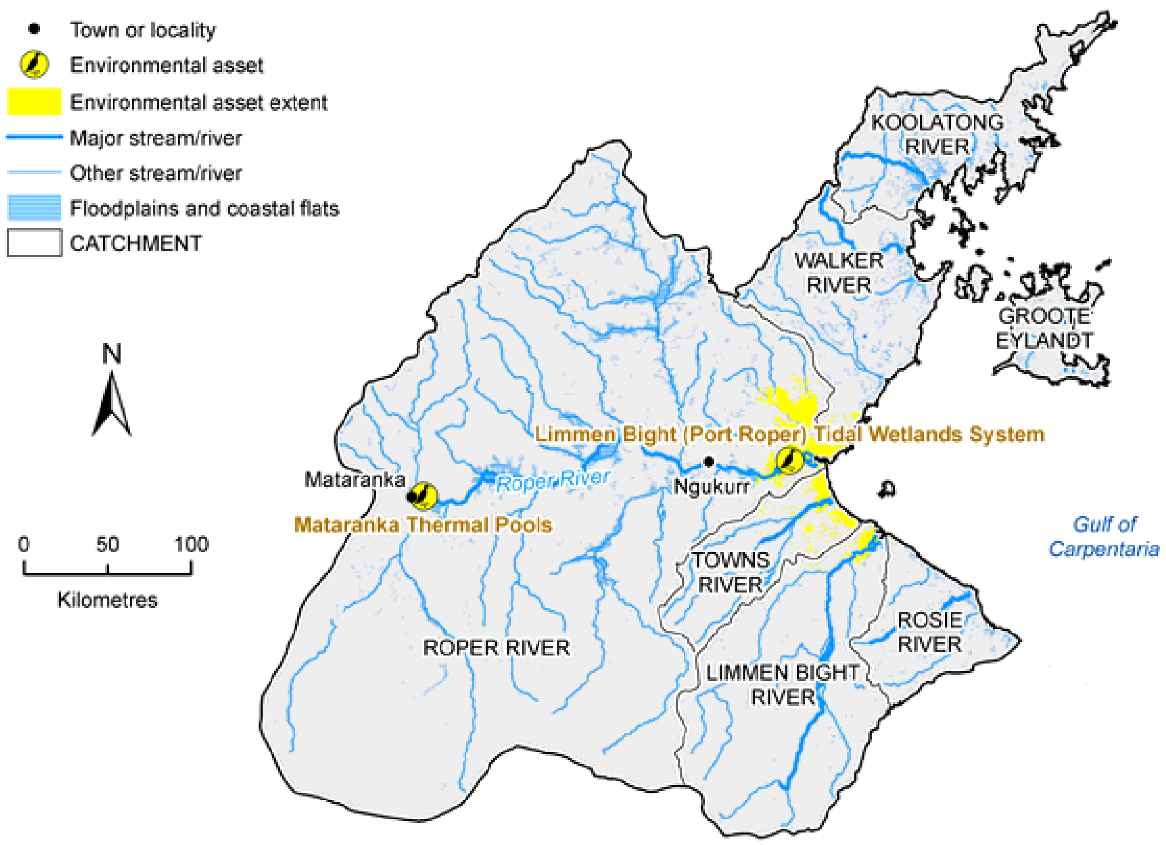



Figure RO-1. Major rivers, towns and location of environmental assets selected for assessment of changes to hydrological regime in the Roper region

## RO-1.1 Regional summary

These regional observations summarise key modelling results and other relevant water resource information about the Roper region.

The Roper region has a high inter-annual variability of rainfall and hence also runoff and groundwater recharge, with coefficients of variation of 0.25 and 0.67 for rainfall and runoff, respectively. These values reflect multiple years of significantly below average or above average rainfall.

Mean annual rainfall for the region is 843 mm. Mean annual areal potential evapotranspiration (APET) is 1477 mm. The mean annual runoff averaged over the modelled area of the Roper region is 112 mm, 8 percent of rainfall. Under the historical climate the mean annual streamflow over the Roper region is estimated to be 14,394 GL.

There is a strong seasonality with 96 percent of rainfall falling between November and May. The region has a relatively high rainfall intensity and hence rapid runoff and short lag between rainfall and runoff, with a slighting increasing amount and intensity of rainfall over the historical (1930 to 2007) period. Rainfall and runoff generation both decline with distance from the coast, with rainfall also showing a strong north-south gradient. Runoff has a stronger east–west gradient and varies from 20 to 4 percent of rainfall across the region. Lower reaches are flood determined and dominated.

The Roper region has a recent (1996 to 2007) climate that is wetter than the historical mean by 10 to 40 percent, and was wetter to the south and west. This resulted in a regionally averaged 54 percent increase in runoff compared to the historical mean. Modelling suggests that the future (~2030) climate conditions will be similar to the historical record, though drier than the recent past. Slightly wetter and drier conditions are expected under the wet extreme and dry extreme future climates, respectively.

The major aquifers in the region are in the Tindall Limestone, Dook Creek Formation and Cretaceous sediments, and these are the primary source of dry season (May to October) flow in the perennial rivers of the Roper region.

While groundwater use is not metered throughout the region, groundwater is sourced for both irrigation and mining development. Groundwater in the Tindall Limestone aquifer is sourced for large-scale irrigated agricultural developments in the Mataranka area, posing a significant risk to the ecology of the nearby Elsey National Park and the flow from the iconic Mataranka Hot Springs. Groundwater extracted on Groote Eylandt for the GEMCO manganese mine may impact on the perennial Angurugu and Emerald rivers.

The presence or absence of the Cretaceous sediments has a large impact on groundwater recharge rates to aquifers in the Tindall Limestone and Dook Creek Formation and more work is required to understand this impact. Recharge to aquifers in the Tindall Limestone and Dook Creek Formation via sinkholes and other preferential pathways such as remnant tree root channels is important but has not yet been quantified. Perennial rivers are fed by groundwater recharged from outside the Roper region. Similarly, groundwater recharged within the Roper region feeds perennial rivers outside of the region.

Confidence in streamflow and groundwater flow estimates in this region is not of sufficient level to assess changes to flow regime at environmental assets.

## RO-1.2 Water resource assessment

Term of Reference 3a

### RO-1.2.1 Under historical climate and current development

Term of Reference 3a (i)

Mean annual rainfall for the Roper region is 843 mm, with a standard deviation of 163 mm. Maximum recorded rainfall was 1477 mm in 2001; the lowest was 347 mm in 1952. Mean annual areal potential evapotranspiration (APET) is 1928 mm, with a relatively small variation (standard deviation of 29 mm). Highest APET occurred in 2005 (2040 mm); lowest in 1945 (1783 mm). The mean annual runoff averaged over the Roper region is 112 mm, 13 percent of rainfall.

Rainfall is very seasonal, with 96 percent falling during the wet season (November to April), and runoff is highest in February and March.

Licensed groundwater extraction in the Roper region currently amounts to 0.58 GL/year located around Mataranka. However, there is also a number of existing horticulture developments operating without a groundwater extraction licence. The actual rate of groundwater extraction is currently unknown.

Under a continued historical climate, mean annual groundwater recharge to watertable aquifers in the Roper region is similar to the historical (1930 to 2007) mean rate. Therefore these mean groundwater levels and fluxes would be maintained under historical climate and current development. Natural groundwater discharge plays a vital role in providing water to maintain dry season flow to the iconic Mataranka Hot Springs and surface flows in the Roper River and tributaries throughout the dry season (Table RO-1).

Table RO-1. Estimated groundwater contribution (baseflow) to streamflow, modelled diffuse recharge and groundwater extraction for the Roper region under historical climate

| Station | River | Station name | Annual BFI * | Dry season BFI * | Dry season baseflow * |
|---|---|---|---|---|---|
| | | | | | GL |
| G9030001 | Elsey Ck | Warloch Ponds | 0.18 | 0.27 | 0.0 |
| G9030013 | Roper | Elsey Homestead | 0.25 | 0.69 | 41.2 |
| G9030089 | Waterhouse | Rd Br | 0.19 | 0.68 | 6.2 |
| G9030090 | Chambers Ck | Wattle Hill | 0.09 | 0.39 | 0.0 |
| G9030176 | Roper | D/S Mataranka Homes | 0.25 | 0.86 | 30.8 |
| G9290006 | Angurugu | U/S Groote Eylandt Mission | 0.53 | 0.81 | 10.8 |
| | | Historical recharge ** | Estimated groundwater extraction | | |
| | | GL/y | | | |
| Entire Roper region | | 11,970 | unknown | | |

* BFI (baseflow index) and baseflow volume derived from gauged data.
** Aggregated recharge from Zhang and Dawes (1998).

### RO-1.2.2 Under recent climate and current development

Term of Reference 3a (ii)

The mean annual rainfall and runoff from 1996 to 2007 were 21 percent and 54 percent higher, respectively, than the historical (1930 to 2007) mean values. Rainfall increases occurred across the entire region relative to the historical pattern.

Under a continued recent climate, mean annual groundwater recharge to the watertable aquifers in the Roper region would be significantly higher than the historical mean rate. When combined with current levels of groundwater development, this means groundwater resource condition and dry season flows in the rivers could be better than what has occurred historically.

### RO-1.2.3 Under future climate and current development

Term of Reference 3a (iii)

Future (~2030) climate is expected to be similar to historical climate. Under the wet extreme, median and dry extreme future climates, annual rainfall is 932, 843 and 765 mm, respectively. Corresponding APET values under these scenarios are 1959, 2001 and 1996 mm, respectively.

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Roper region is slightly more likely to decrease than increase. Rainfall-runoff modelling with climate change projections from nine of the 15 GCMs suggests a decrease in mean annual runoff, while the other six of the GCMs suggest an increase in mean annual runoff.

The median estimate is a -2 percent change to the mean annual runoff by 2030. The extreme estimates range from an increase of 33 percent to a decrease of 18 percent in mean annual runoff.

Under future climate, mean annual groundwater recharge to the watertable aquifers in the Roper region is significantly higher than the historical mean rate. The fact that recharge rates are higher when rainfall is similar to the historical value reflects the importance of climate variables other than total rainfall in determining recharge. When combined with current levels of groundwater development, the higher recharge rate means groundwater resource condition and dry season flows in the rivers could be better than what has occurred historically.

### RO-1.2.4 Under future climate and future development

Term of Reference 3b

Without detailed river and groundwater models for the region, it is difficult to predict the changes in water resource condition that may occur under future climate and future development. However, any groundwater development that occurs within several kilometres of the Roper River and its spring-fed tributaries will have a detrimental (though possibly delayed) impact on dry season surface water flows in these watercourses.

## RO-1.3 Changes to flow regime at environmental assets

Term of Reference 3a (iv)

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Two environmental assets were shortlisted for the Roper region: the Limmen Bight (Port Roper) Tidal Wetlands System and the Mataranka Thermal Pools. These assets are characterised in Chapter RO-2.

In deciding whether it is feasible to report hydrological regime metrics for these shortlisted assets, it is important to consider the confidence levels in modelled streamflow (as described in Section 2.2.6 of the division-level Chapter 2). Confidence in results for low flows and high flows was calculated separately. Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are sufficiently high. If confidence in the low flow or high flow is too low, metrics are not reported, and hence an important gap in our knowledge is identified.

The confidence levels for both high flows and low flows for the Limmen Bight (Port Roper) Tidal Wetlands System are ranked unreliable. These confidence levels are insufficient to allow hydrological regime metrics to be calculated or changes to flow regime estimated.

The Mataranka Thermal Pools are fed by perennial groundwater springs in the upper reaches of the Roper River. However, there is currently not enough confidence in existing groundwater models to report results under different scenarios. In addition, the confidence levels for both high flows and low flows for the asset within the Roper region are ranked unreliable (4 or 5) and therefore are insufficient to allow environmental flow metrics to be calculated.

## RO-1.4 Seasonality of water resources

Term of Reference 4

The rivers have a marked seasonal flow regime of high water levels during the wet season (November to April) and decreased water flow and river stage towards the end of the dry season. Approximately 96 percent of rainfall and

92 percent of runoff occurred during the wet season months under the historical and recent climates. Very similar seasonal percentages (±2 percent) of rainfall and runoff are projected to occur at 2030.

The Roper region experiences a relatively large amount of dry season flow (equivalent to 8 percent of total runoff on average) under historical, recent and future climates.

## RO-1.5 Surface–groundwater interaction

Term of Reference 4

The following perennial rivers receive significant quantities of groundwater either flowing into or out of the Roper region:

- The Roper River, Durabudboi River and Wonga Creek receive groundwater sourced (at least in part) from recharge that occurs outside of the Roper region.
- The Flora River (in the adjacent Daly region) and Goyder River receive groundwater sourced (at least in part) from recharge that occurs within the Roper region.

Reaches of rivers where significant groundwater discharge is know to occur in the Roper region towards the end of the dry season are show in Figure RO-2. The data used to compile this map represent flows (expressed as cumecs, i.e. cubic metres per second) after a series of below average and above average wet seasons. These flows are sustained by significant regional groundwater discharges from aquifers developed in karstic rocks and Cretaceous sediments. The streams where dry season flow is sourced from karstic rocks are the Roper, Mainoru, Wilton, Koolatong, Walker and Rosie rivers and Flying Fox Creek. The perennial streams where dry season flow is sourced from Cretaceous sediments are the Durabudboi River and Wonga Creek on the mainland and the Angurugu, Emerald and Amagula rivers on Groote Eylandt.

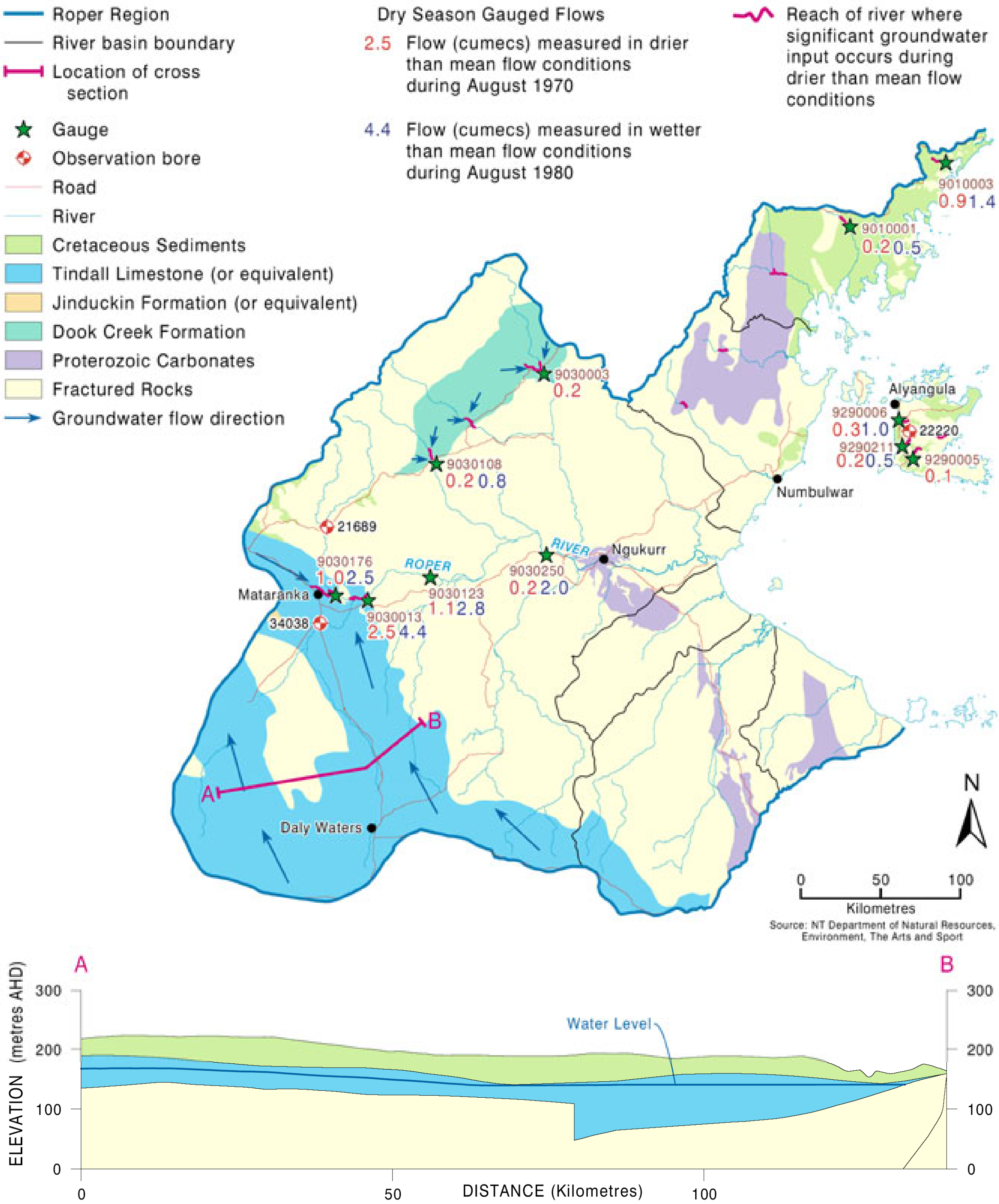



Figure RO-2. Hydrogeology of the Roper region (map provided by the Northern Territory Department of Natural Resources, Environment, the Arts and Sport)

A detailed analysis of dry season flow near Mataranka established the sympathetic relationship between flow and groundwater discharge from the Tindall Limestone (Jolly et al., 2004). The groundwater discharge component of flow at gauges G9030176 and G9030013 was modelled using empirical relationships between rainfall and dry season flow. This simple model simulated groundwater-fed flows for the period 1961 to 2004 (Figure RO-3) and illustrated the seasonal variability of recharge and discharge of the system.

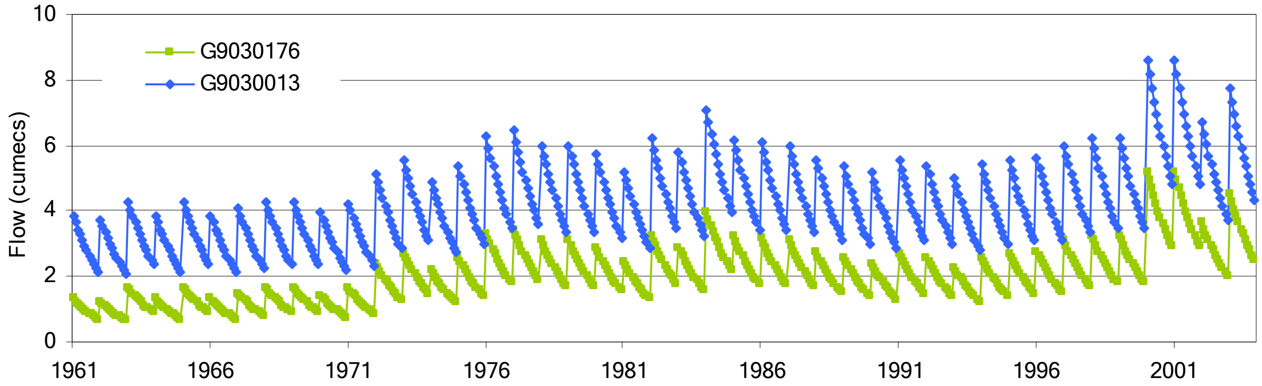



Figure RO-3. Modelled mean monthly groundwater discharge in the Roper River at gauges G9030176 and G9030013

Most of the spring-fed flow generated from the limestone is lost through evapotranspiration before the river reaches the estuary (Jolly et al., 2004). The relationship between the flow at gauges G9030013 and G9030250 situated just above the head of the estuary is shown on Figure RO-4 for the few times they have been gauged in the same week. The data indicate that approximately 2 to 2.5 cumecs is lost between the two gauges due to evaporation and transpiration. This loss equates to approximately 12 to 15 litres per second per kilometre, or is about two to three times the loss of other rivers for which this process has been quantified further north. When flows at Mataranka drop below 2.5 cumecs – as regularly occurred during the 1960s (Jolly et al., 2004) – no flow will reach the estuary.

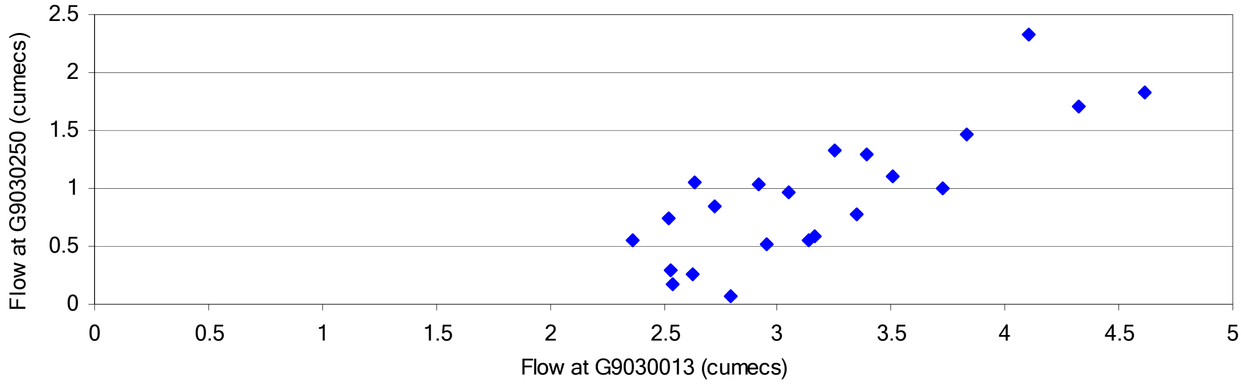



Figure RO-4. Relationship between flow at gauging stations G9030013 and G9030250 on the Roper River

## RO-1.6 Water storage options

Term of Reference 5

### RO-1.6.1 Surface water storages

There are currently no large surface water storages on the Roper River or its tributaries.

### RO-1.6.2 Groundwater storages

Groundwater development in the Roper region is low and groundwater recharge rates (for the northern half of the region) are high. Under current development managed aquifer recharge (MAR) would have limited applicability as storages in the local carbonate aquifers (i.e., Tindall Limestone and Dook Creek Formation) are likely to be at full capacity towards the end of the wet season when surface water is available for injection. Potential evaporation exceeds rainfall for most of the year resulting in near year-round water-limited conditions. When water is not limited aquifers are expected to be at full capacity. Therefore the only opportunity for MAR in the Roper region is if future development leads to groundwater levels not fully recovering each wet season.

## RO-1.7 Data gaps

Term of Reference 1e

There are only two weather stations in the region that have better than 80 percent record completeness, and none that pass 90 percent. Interpolation of climate data, therefore, relies on the assumption that these are representative of the region as a whole and that infilling of the temporal sequences used in SILO and other analyses is also representative.

In the Roper catchment, most of the stream gauges with reasonable quality data are located in the upper reaches and there are few gauges of reasonable quality against which to calibrate the rainfall-runoff models. We therefore do not have sufficient confidence in the streamflow estimations to report change in flow regime at environmental assets.

The aquifer in the karstic Dook Creek Formation is the source of dry season flow in perennial reaches of a number of tributaries of the Roper River. Insufficient data exists for both the aquifer and the rivers to enable any models to be developed. Given the mineral potential of this region, it is important to establish a representative network of gauging stations and groundwater monitoring sites so that the impact of future mining developments will be able to be adequately assessed.

## RO-1.8 Knowledge gaps

Streamflow in the Roper region is complicated by the nature of the karstic terrain over which the streams flow. Defining subcatchment boundaries is problematic as sinkholes and distributary channels in the upper reaches are difficult to accurately delineate with the digital elevation model (DEM) used in this project (~125 m resolution). Higher resolution DEMs and field mapping are required to verify surface features and establish if and how these features affect different flow regimes.

The aquifer in the Tindall Limestone is the target for sourcing water for large-scale irrigated agricultural developments in the Mataranka area. The development poses a significant risk to the ecology of the nearby Elsey National Park and the flow from the iconic Mataranka Hot Springs. Given the complex nature of karst hydrogeology and the proximity of the large-scale irrigated agricultural developments, detailed flow studies are required in order to develop an aquifer simulator model to quantify the impacts of these developments.

Groundwater being extracted to dewater pits at the manganese mine operated by GEMCO on Groote Eylandt may be having a significant impact on the perennial Angurugu and Emerald rivers. An aquifer simulator model needs to be developed to quantify the current and future impacts mining operations will have on flow and hence the aquatic ecology of these rivers.

The presence or absence of the Cretaceous sediments has a large impact on recharge to aquifers in the Tindall Limestone and Dook Creek Formation. Recharge via sinkholes to aquifers in the Tindall Limestone and Dook Creek Formation is important but has not yet been quantified. More work is required to evaluate recharge processes for both the Tindall Limestone and Dook Creek Formation.

Flooding is an important factor that sustains many environmental assets and this occurs when the stream breaks out of its banks (a level known as bankfull stage or discharge). However, bankfull discharge is not known for many streams, nor is the dependence of area flooded on increasing stream depth, so it is difficult to predict when assets are inundated. Further information about bankfull stage and discharge are needed for most environmental assets.

None of the environmental assets in this region have any site specific metrics by which to gauge the potential impact s of future climate change and development scenarios. In the absence of site specific metrics a set of standard metrics related to high and low flows have been utilised, however, the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and specific ecological entities (for example, macrophyte populations, fish passage, faunal and floral habitats, etc.).

Many environmental assets depend not simply on duration above or below certain flow levels, but on triggers (e.g. for reproduction or migration) set by the rate of change of flow. In addition, some environmental assets depend on the frequency and duration of events that occur less than annually (i.e. once every 5, 10 or 20 years or more). Further analysis is therefore required to look at how the timing, duration and rate of rise and fall in flow rates at critical times of the season will vary under the various scenarios.

Dry season flows are poorly understood in this region therefore the ability to predict the potential impacts of the various scenarios on low or zero flows at environmental assets is very limited. Improved monitoring of low streamflow conditions is needed along with the development of hydrological models that combine surface and groundwater regimes. Further monitoring of groundwater levels is also required so that the potential impacts of climate change and development scenarios on groundwater dependant ecosystems can be better understood.

## RO-1.9 References


Jolly P, Knapton A and Tickell S (2004) Water Availability from the Aquifer in the Tindall Limestone South of the Roper River Report. Department of Infrastructure, Planning and Environment, Darwin, Australia.

McJannet DL, Wallace JW, Henderson A and McMahon J (2009) High and low flow regime changes at environmental assets across northern Australia under future climate and development scenarios. A report to the Australian Government from the CSIRO Northern Australian Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, CSIRO, Australia. *In prep.*

Zhang L and Dawes W (1998) WAVES - An integrated energy and water balance model. Technical Report No. 31/98, CSIRO Land and Water.

# RO-2 Contextual information for the Roper region

This chapter summarises the background information for the region, outlining existing knowledge of water resources and prior and current investigations relevant to the water resources of the region. This chapter also outlines the current and potential future legislation, water plans and other water resource management arrangements. This chapter is arranged into four sections:

- physical and climate descriptions
- data availability
- hydrogeology
- legislation, water plans and other arrangements.

## RO-2.1 Overview of the region

### RO-2.1.1 Geography and geology

The Roper River starts as Roper Creek (also called Little Roper River) and becomes the Roper River downstream of Waterhouse River junction near Mataranka. The Elsey Creek system drains the large Sturt Plateau region, which is located in the south-west of the region. The Arnhem Land Plateau, rising up to 440 m, and the Wilton River Plateau are located in the north of the region, and consist predominantly of Kombolgie sandstone. The middle section of Roper River consists of a highly braided river channel. The Roper River flows generally in an easterly direction, although the geology of the catchment influences the direction of the drainage systems. The normal tidal limit of the Roper River is at Roper Bar Crossing (20 km upstream from Ngukurr, Figure RO-5). From this crossing, the Roper River traverses the alluvial coastal plain eastward for 145 km before entering the Gulf of Carpentaria.

Surveys providing detailed land systems, land unit or soils mapping have been carried out for areas throughout the Roper River catchment. Within the Roper region six major landforms are identified including plateau surfaces; plateau escarpments; gorges and ridges associated with the dissected plateau and hills; plains; drainage lines, associated floodplains and billabongs; salt pans and tidal flats.

The geological history of the area is complex. The McArthur Basin underlies the centre and east of the region. The McArthur Basin succession comprises sandstone, shale, carbonate, and interbedded volcanic and intrusive igneous rocks.

The connected Daly, Wiso and Georgina Groundwater Basins underlie the west of the region. The basins have strong similarities in terms of their stratigraphy and architecture. The Wiso Basin underlies the south-west of the region. The Palaeozoic platform succession generally is less than 300 m thick. The Daly Basin underlies the north-west of the region and is a north-west-trending intracratonic sedimentary basin up to 700 m thick. It contains the lower Palaeozoic Daly River Group, comprising, in ascending order, the marine Tindall Limestone, mixed peritidal Jinduckin Formation and carbonate peritidal Oolloo Dolostone. The Tindall Limestone usually rests disconformably on the Lower Cambrian Antrim Plateau Volcanics. The Georgina Basin contains a relatively thin stratigraphic succession, up to 450 m thick, deposited on a tectonically quiescent platform. Deposition in the central region commenced with a marine transgression in the early Middle Cambrian and may have extended into the Late Cambrian. The northern Georgina Basin is largely concealed beneath Cretaceous sediments.

The Carpentaria Basin underlies most of the eastern coastal area of the region. It is a broad north–south trending intracratonic basin. The Carpentaria Basin is the most northerly tectonic unit within the Great Artesian Basin (GAB). During the Early Cretaceous, fluvial sandstone deposition was widespread in the GAB. In the Middle Cretaceous, a widespread transgression brought coastal swamp conditions and then shallow marine conditions across the basin, with the deposition of a thick mudstone succession. A major regression in the late Middle Cretaceous resulted in a return to coastal swamp conditions.

The current drainage system probably came into existence in the Cretaceous when uplift in the north of the Northern Territory resulted in a drainage divide between inland-draining streams to the south and streams draining to the sea in the north.

The alluvial plains that cover an extensive area along the coastal eastern edge of the region are underlain by primarily marine sediments that have been deposited in the last 10,000 years since the end of the ice age.

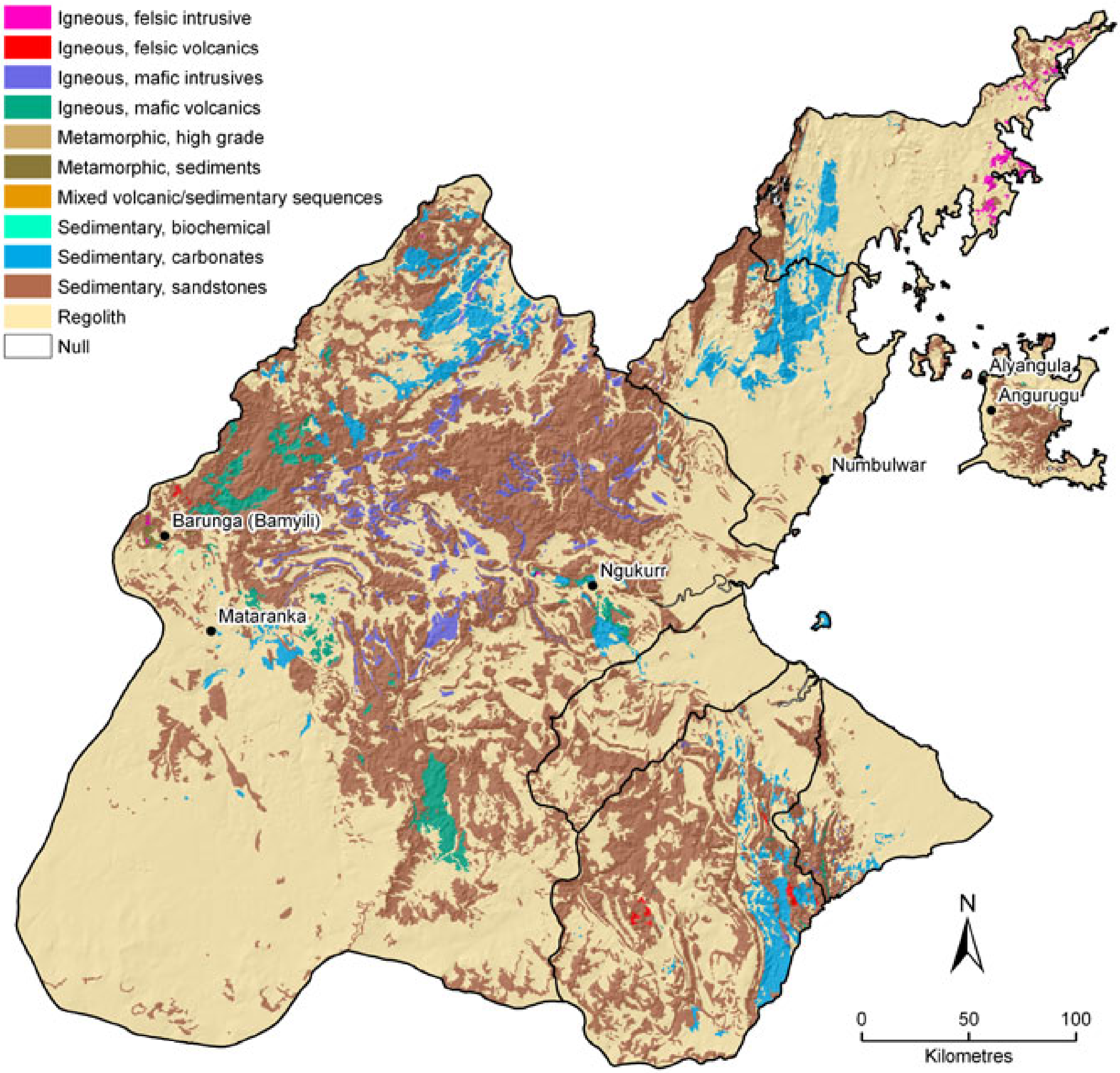



Figure RO-5. Surface geology of the Roper region overlaid on a relative relief surface

## RO-2.1.2 Climate, vegetation and land use

The Roper region receives an average of 843 mm of rainfall over a water year (September to August), most of which (805 mm) falls in the November to April wet season (Figure RO-6). Across the region there is a strong north–south gradient in annual rainfall, ranging from 1357 mm in the north to 592 mm in the south. Over the first half of the historical (1930 to 2007) period, annual rainfall has been relatively constant at around 750 mm. Conversely, the second half of the period has seen an increase in mean rainfall to approximately 950 mm. The highest yearly rainfall received was 1477 mm in 2001, and the lowest was 347 mm in 1952.

Areal potential evapotranspiration (APET) is very high across the region, averaging 1928 mm over a water year, and varies moderately across the seasons. APET generally remains higher than rainfall throughout the year resulting in year-round water-limited conditions, to which the vegetation has adapted.

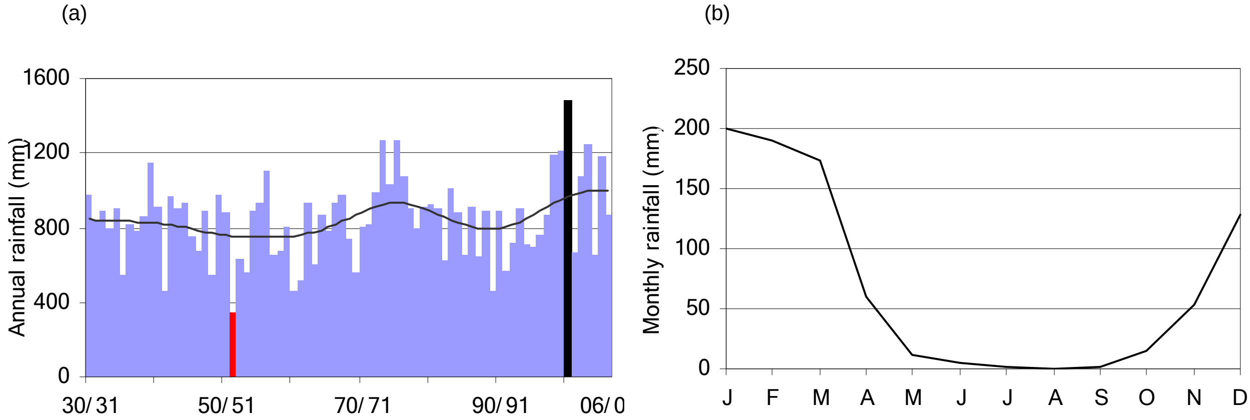



Figure RO-6. Historical (a) annual and (b) mean monthly rainfall averaged over the Roper region. The low-frequency smoothed line in (a) indicates longer term variability

The dominant vegetation communities (Figure RO-7) are eucalypt woodlands with hummock grass or tussock grass understorey (Connors et. al., 1996). However, the varied topography, particularly in the northwest is reflected in the diversity of plant communities. The most widespread communities include:

In the southeast a low open woodland of Snappy Gum (*Eucalyptus leucophloia*) with Bloodwood (*Corymbia terminalis*), Ironwood (*Erythrophleum chlorostachys*) over Curley Spinifex (*Plectachne pungens*) hummock grassland. Other associations include Northern Box (*E. tectifica*) with White Grass (*Sehima nervosum*) and Golden Beard Grass (*Chrysopogon fallax*).

Variable barked Bloodwood (*Corymbia dichromophloia*) and Stringybark (*E. tetrodonta*) also form low open woodland with Darwin Woolly Butt (*E. miniata*). In some areas woodlands include Rusty Bloodwood (*Corymbia ferruginea*), Lancewood (*Acacia shirleyi*). Coolibah (*E. microtheca*) occurs along some creeks and there are extensive paperbark swamps (*Melaleuca citrolens*) (Kerle, 1996).

In the north west of the region woodland communities include stringy bark, Cypress Pine (*Callitris intratropica*) and Silver Box (*E. pruinosa*) (Connors et. al., 1996). Northern cypress-pine has suffered where traditional Aboriginal fire regimes have been changed (Woinarski et. al., *In prep*).

Vine thickets are scattered along the rivers through the sandstone country and contain relict species including, rushes and reeds and the Fern (*Lygodium microphyllum*) as well as undescribed species of ferns (Morton et. al., 1995).

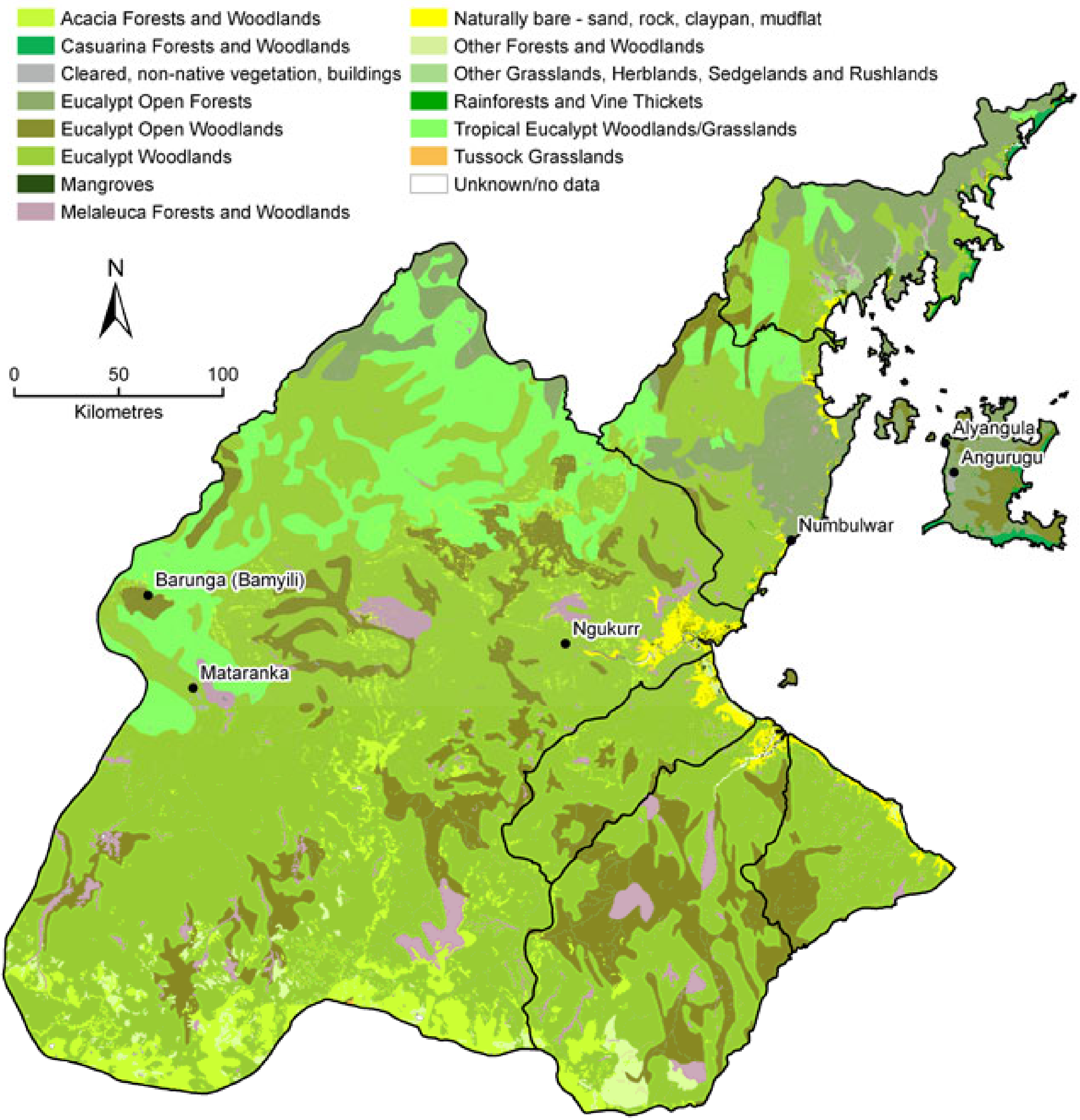



Figure RO-7. Map of current vegetation types across the Roper region (source DEWR, 2005)

The majority of land is held under pastoral lease or Indigenous land trusts as private freehold (Figure RO-8). Crown leases contain covenants that control their usage or development and can be issued for any length of time, including 'in perpetuity'. Term leases are normally issued to allow developments to proceed and can often be converted to freehold title or perpetual leasehold once the development is complete. Pastoral leases are for broadacre areas specifically used for pastoral purposes.

Pastoralism has been the main industry in the Gulf region since European settlement, but it is considered 'low key' when compared to other rangelands in the Australian tropics (CCNT, 1994) because of the limited extent of suitable pastoral land resources in the region (Dept of Lands and Housing, 1991). The Gulf region has been described as having low pastoral productivity in relation to carrying capacity, with only 2.5 head per km$^2$ live weight of cattle (Holmes, 1986).

Indigenous lands support a variety of uses, mainly as traditional or semi-traditional living areas with some areas being utilised for pastoralism (e.g. Elsey Station). Other industries include mining, tourism and conservation, and recreational and commercial fishing. The major mining lease within the Roper River catchment is the Mataranka Lime Mine located on Elsey Station. The mine is owned by Northern Cement Limited and has operated since 1991. Limestone is mined and processed at the nearby plant to produce quicklime, which is sold within the Northern Territory.

The tourist industry is a small but significant part of the local economy and visitation to the region is highly seasonal with most occurring during the May through October dry season (Dept of Lands and Housing, 1991). Primary attractions include remote camping, river fishing, four wheel driving and access to the sea (Dept of Lands and Housing, 1991). Station and outback tours, including game hunting, also are offered. Of the attractions, recreational barramundi fishing (or freshwater fishing) is the primary tourist activity within the Roper River catchment (op cit.).

The fishing industry is very significant within the region. Prawning is the largest single fishery in the Gulf and accounted for 96 percent of the value of the Gulf fisheries catch in 1990 (Dept of Lands and Housing, 1991). The prawn industry operates up to 60 nautical miles offshore. An unloading facility on the Roper River is used to tranship prawns from the Gulf. An aquaculture farm for prawns operated at Port Roper until 1995.

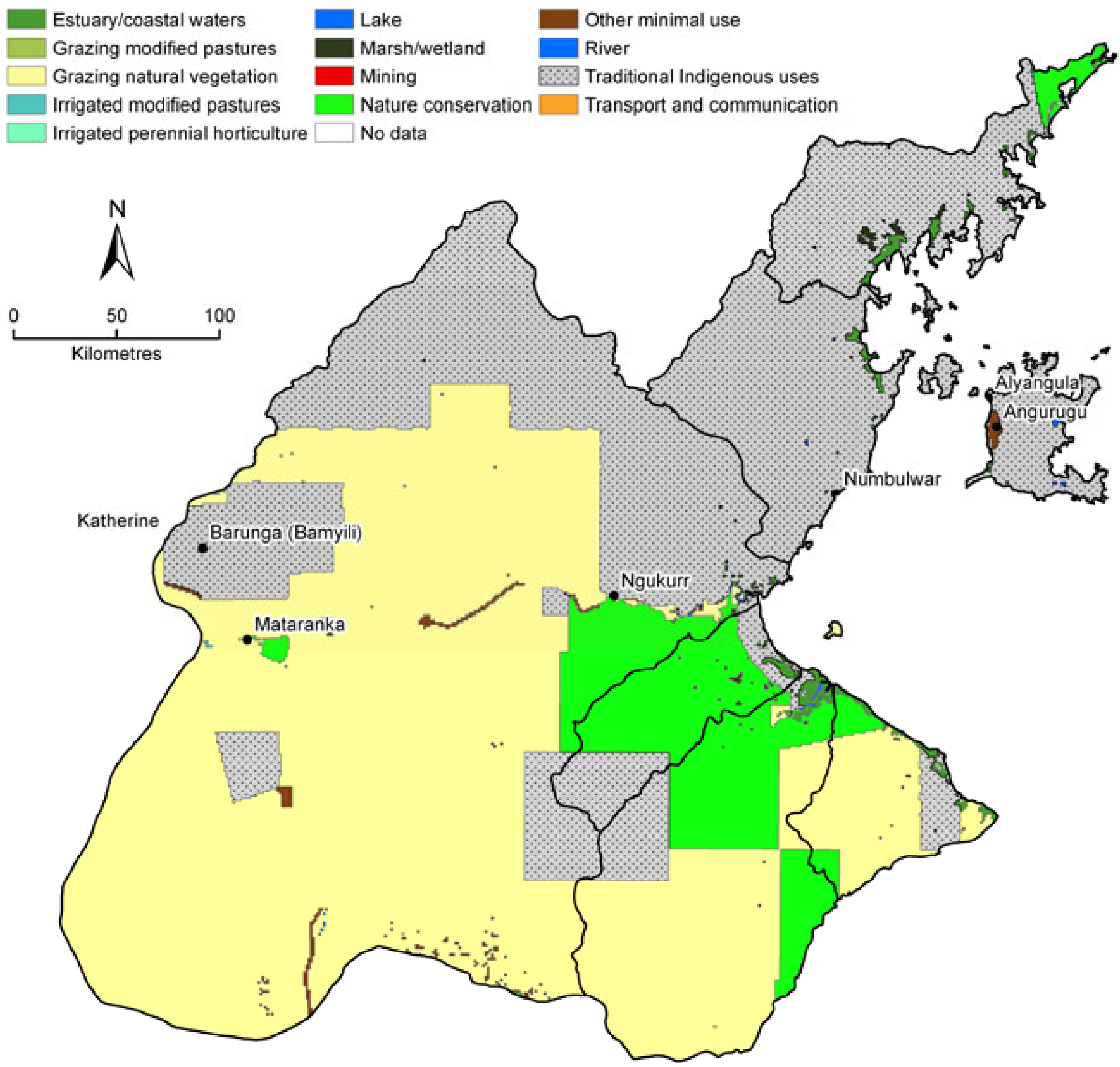



Figure RO-8. Map of dominant land uses of the Roper region (after BRS, 2002)

## RO-2.1.3 Regional environmental asset description

Environmental assets were chosen from wetlands which are listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001). From this directory, environmental assets were shortlisted for assessing changes to the hydrological regime under the climate and development scenarios. The selection of this shortlist was undertaken in consultation with state governments and the Australian Government through direct discussions and through internal reviews (see Section 1.3 in the division-level Chapter 1 for further detail).

All nationally, or internationally, important wetlands listed for the Roper region in the Directory of Important Wetlands in Australia (Environment Australia, 2001) are detailed in Table RO-2, with asterisks identifying the two shortlisted assets: Limmen Bight (Port Roper) Tidal Wetlands System and Mataranka Thermal Pools. The location of these shortlisted wetlands is shown in Figure RO-1. There are no wetlands classified as Ramsar sites in this region. Wetlands may be nationally or regionally significant depending on more locally specific criteria. All wetlands are important for a variety of ecological reasons or because they bear historical significance or have high cultural value, particularly to Indigenous people.

Table RO-2. List of Wetlands of National Significance located within the Roper region

| Site code | Name | Area | Ramsar site |
|---|---|---|---|
| | | ha | |
| NT007* | Limmen Bight (Port Roper) Tidal Wetlands System | 185,000 | No |
| NT003* | Mataranka Thermal Pools | <10 | No |

* Asterisk against the site code identifies those assets which are shortlisted for assessment of changes to flow regime.

The following section characterises these shortlisted wetlands and is based largely on the description of these assets as outlined by (Environment Australia, 2001). Chapter ID-3 presents the assessment of those shortlisted assets, and reports hydrological regime metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis.

## Limmen Bight (Port Roper) Tidal Wetlands System

The Limmen Bight (Port Roper) Tidal Wetland System (Figure RO-9) 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. It is the second largest area of saline coastal flats in the Northern Territory. The site has an area of 185,000 ha and an elevation ranging between zero and 10 m above sea level (Environment Australia, 2001).

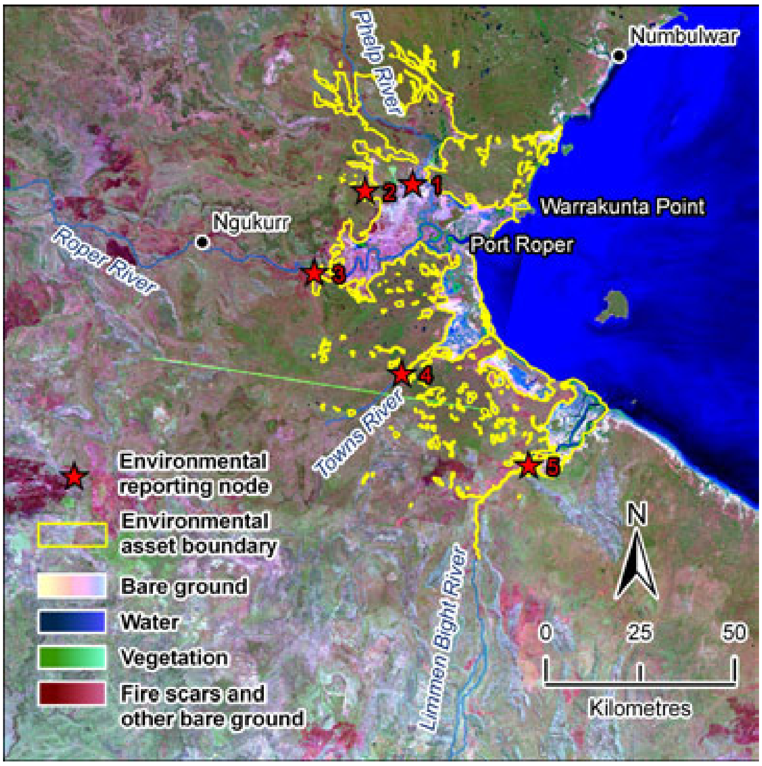



Figure RO-9. False colour satellite image of the Limmen Bight (Port Roper) Tidal Wetlands System (derived from ACRES, 2000). Clouds may be visible in image

The site, especially the Port Roper mudflats, is among the most important coastal areas for shorebirds in the Northern Territory. The maintenance of populations of commercially harvested Tiger Prawn in the Gulf is linked to their utilisation of inshore seagrass areas in this area (Environment Australia, 2001). Dugong occur offshore of the whole site in the wet season. Medium densities of Saltwater Crocodile occur in the Roper River estuary. Marine turtles use nest sites on offshore islands associated with the site.

Much of the site is Indigenous land and Indigenous communities are located outside the site. Traditional use of the wetlands is still practised. A sacred site occurs near Warrakunta Point. The near-coastal waters and estuaries support a major commercial barramundi and salmon fishery; major harvest of crabs occurs at Port Roper; and aquaculture is maintained near the Roper River (Environment Australia, 2001).

## Mataranka Thermal Pools

The Mataranka Thermal Pools (Figure RO-10) are one of the best known examples of tropical springs and associated permanent pools in the Northern Territory. The site is a popular tourist destination attracting more the 150,000 visitors annually, which results in significant support for local businesses (Environment Australia, 2001). The site has an area of less than 10 ha and an elevation of approximately 115 m above sea level (Environment Australia, 2001). The thermal pools provide a permanent source of water in a seasonally dry environment.

The surrounding woodland includes a *Livistona rigida* palm community which has a restricted distribution in the Top End Region (Wilson et al., 1990). The Little Red Flying-Fox roost in the area in large numbers, sometimes exceeding 200,000, and often use the site as a maternity colony.

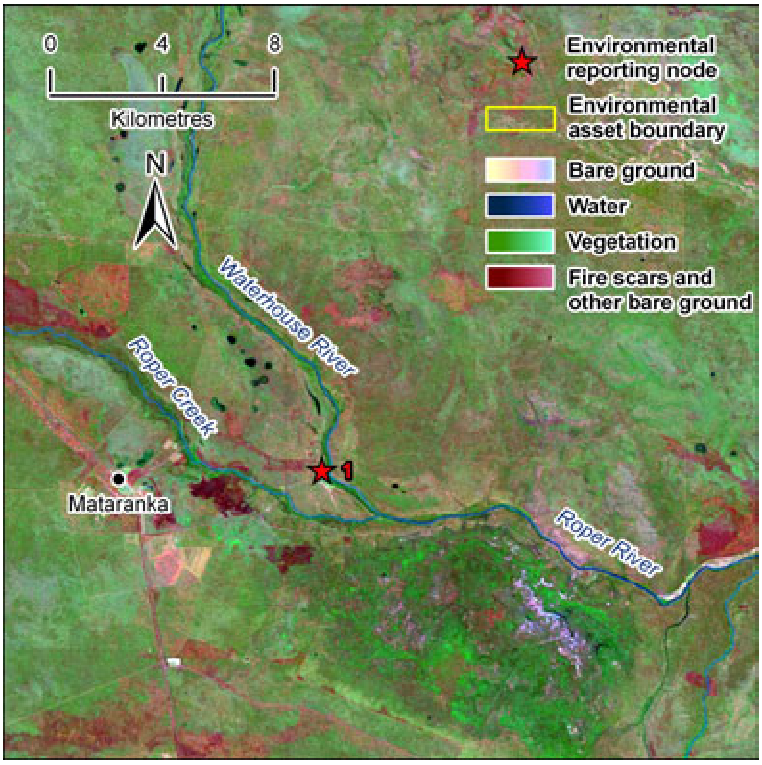



Figure RO-10. False colour satellite image of the Mataranka Thermal Pools (derived from ACRES, 2000). Clouds may be visible in image

## RO-2.2 Data availability

### RO-2.2.1 Climate

The rainfall-runoff modelling uses historical daily climate data (Scenario A) from the SILO database for the period 1 September 1930 to 31 August 2007 at 0.05 x 0.05 degree (~ 5 x 5 km) grid cells. Full details and characterisation of the SILO database are provided at the division level in Section 2.1 of Chapter 2. Scenario B and Scenario C climate data are rescaled versions of the Scenario A data; this is also discussed in Section 2.1 of Chapter 2.

### RO-2.2.2 Surface water

Streamflow gauging stations are or have been located at 22 locations within the Roper region. Twelve of these gauging stations either (i) are flood warning stations which measure stage height only; or (ii) have less than ten years of measured data. Of the remaining ten stations, one recorded more than half of its total volume of flow during events that exceed the maximum gauged stage height (MGSH). Figure RO-11 shows the spatial distribution of good quality data (duration) and the percentage of flow above MGSH (this assessment was only undertaken on stations with ten years or more of data).

In Figure RO-11 the productive aquifer layer for the Northern Territory includes key dolostone and limestone formations and Cretaceous sandstone formations. Consequently these ‘productive’ aquifers exhibit a wide range of bore yields. The location of gauging stations in the Roper is not representative of the broader region. Many gauging stations are located within or downstream of productive aquifers (Figure RO-11). Hence the extrapolation of streamflow values recorded at these gauges to the broader region can be misleading.

There are six gauging stations currently operating in the Roper region at density of one gauge for every 21,400 km$^2$. For the 13 regions the median number of current gauging stations per region is 12 and the median density of current gauging stations per region is one gauge for every 9,700 km$^2$. The Roper region has a low density of gauging stations relative to other regions in northern Australia, and the density is considerably lower than the MDB average. The mean density of current stream gauging stations across the entire MDB is one gauge for every 1,300 km$^2$.

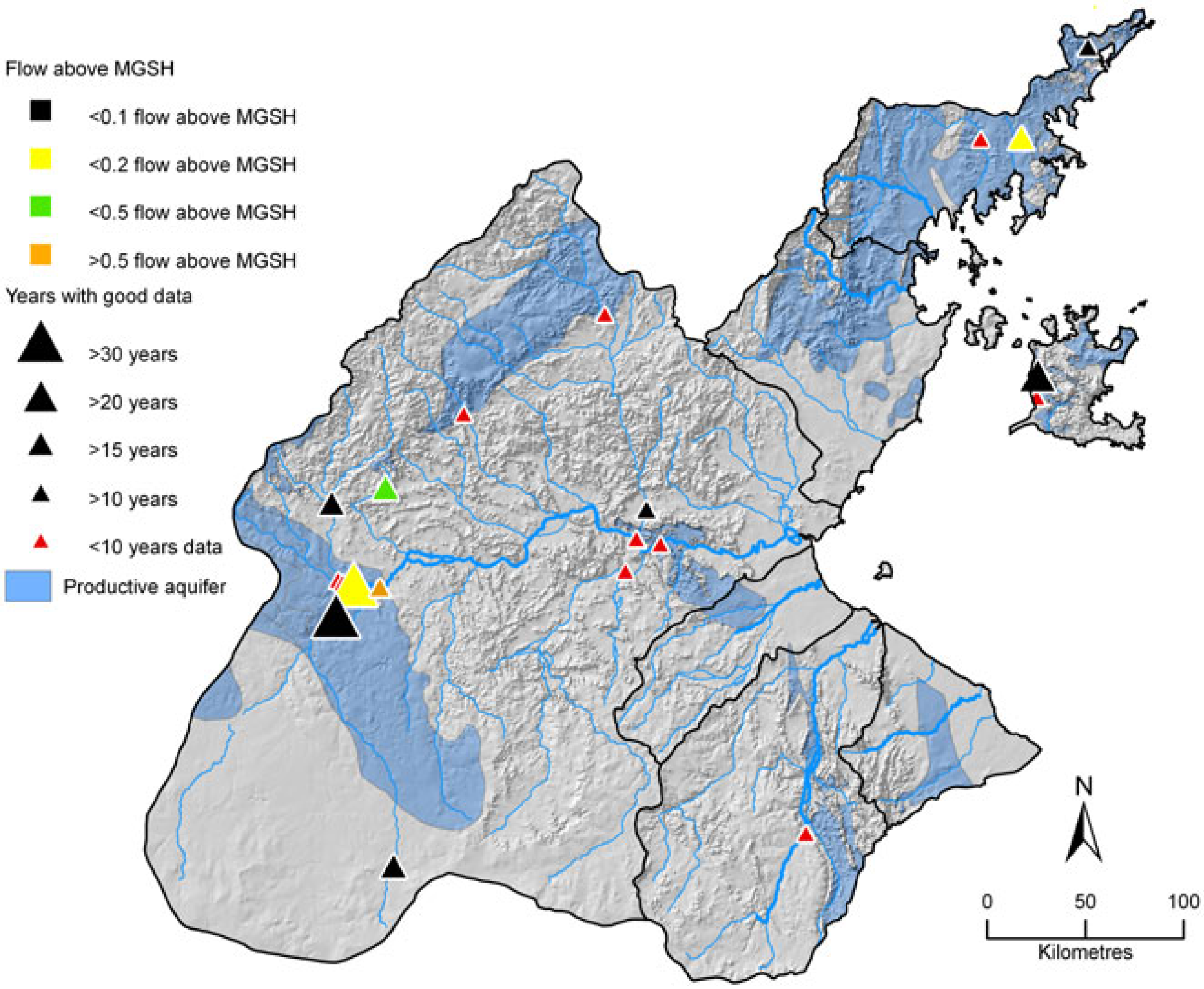



Figure RO-11. Location of surface water gauging stations overlaid on a relative relief surface showing the proportion of gauges with flow above maximum gauged stage height across the Roper region. Productive aquifer layer includes key dolostone, limestone and Cretaceous sandstone formations.

### RO-2.2.3 Groundwater

The Roper region contains a total 1656 registered groundwater bores. 122 of these bores have surveyed elevations that could enable watertable surfaces to be constructed for the main aquifers. However these bores are not necessarily monitored on a regular basis. There are 96 water level monitoring bores in the region; 65 are historical and 31 are current (Figure RO-12).

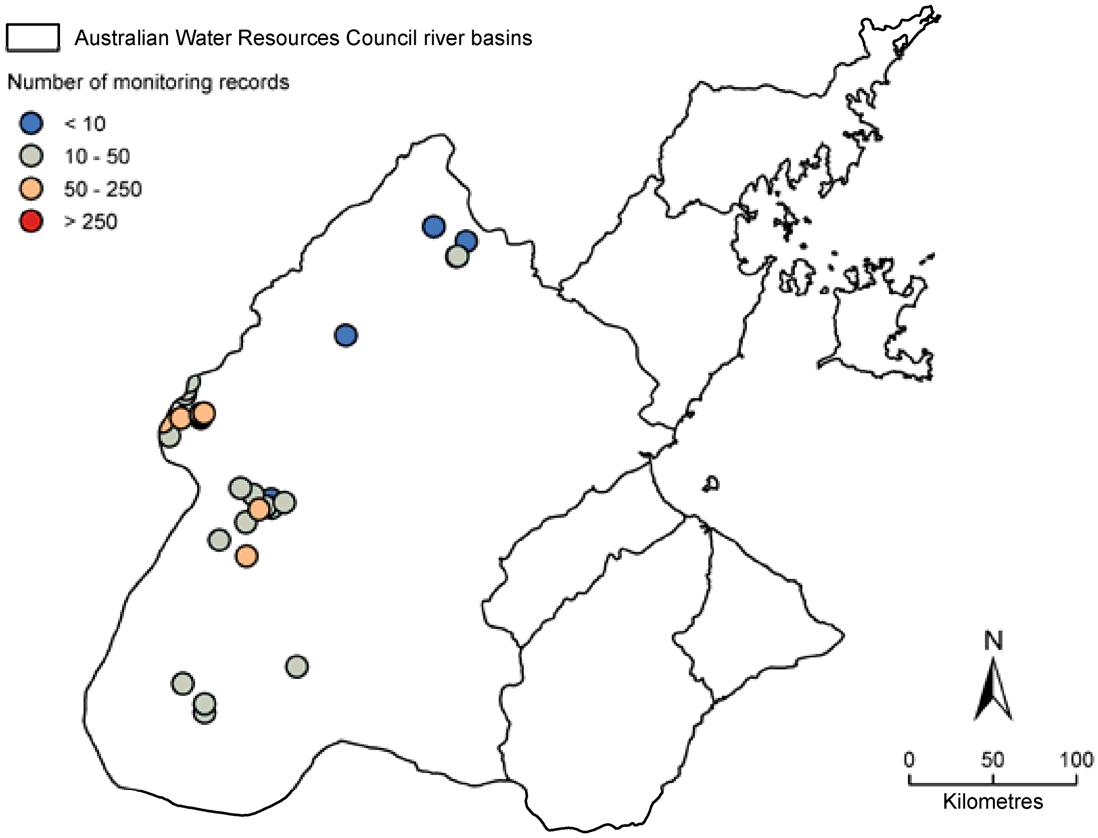



Figure RO-12. Current groundwater monitoring bores in the Roper region

### RO-2.2.4 Data gaps

The aquifer in the karstic Dook Creek Formation is the source of dry season flow in perennial reaches of a number of tributaries of the Roper River. Insufficient data exist for both the aquifer and the rivers to enable the development of any models of this interaction. Given the mineral potential of this region, it is important that a representative network of gauging stations and groundwater monitoring sites is established so that the impact of future mining developments can be adequately assessed.

## RO-2.3 Hydrogeology

This section describes the key sources of groundwater in the Roper region. The description is primarily based on reports and water bore data held by the Northern Territory Government Department of Natural Resources, Environment, The Arts and Sports (NRETAS). The distribution of water bores in the region in 2008 is shown in Figure RO-13.

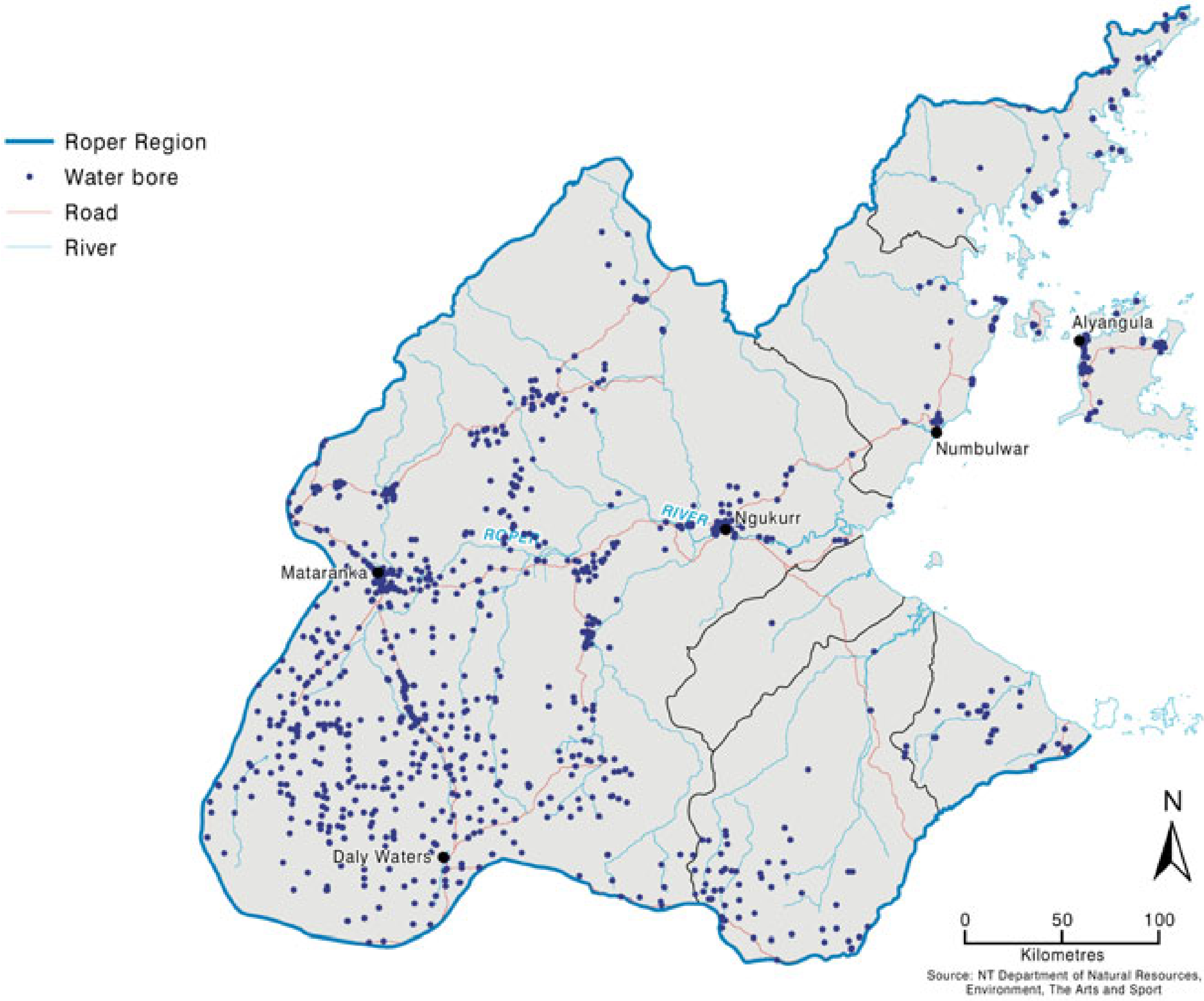



Figure RO-13. Location of groundwater bores in the Roper region (map provided by the Northern Territory Department of Natural Resources, Environment, The Arts and Sport)

### RO-2.3.1 Aquifer types

There are three major aquifer types in the Roper region. These types are fractured rocks, karstic carbonate rocks and Cretaceous sediments, all of which are briefly described below and their areal extent is shown in Figure RO-2.

#### Fractured rocks

A variety of Precambrian (older than 500 million years) rocks form the bedrock of the area. These are mainly sedimentary but also include granite and volcanic rocks. Sandstone, siltstone and greywacke are the main sedimentary rock types. In some areas they are flat-lying while in other areas they have been folded and faulted and show low grade metamorphism.

In the Early Cambrian (500 million years ago) volcanic eruptions produced an extensive sheet of basalt flows, now known as the Antrim Plateau Volcanics. These underlie the Daly, Wiso and Georgina basins.

Water is usually intersected in weathered fractured zones within the fractured rocks. Groundwater yields are controlled by the degree of fracturing of these units and are likely to be greater in areas located along large-scale joints and fault zones.

### Karstic carbonate rock – Tindall Limestone, Jinduckin Formation and Proterozoic carbonates (includes the Dook Creek Formation)

The major aquifers in the region occur within the carbonate rocks of the Daly and Georgina basins and the Dook Creek Formation. These carbonate rocks are part of an extensive area of carbonate rocks that extend across a large part of the Northern Territory and into Queensland (Figure RO-14). The Tindall Limestone and its equivalents (the Montejinni Limestone in the Wiso Basin and the Gum Ridge Formation in the northern part of the Georgina Basin) host widespread karstic aquifers. These aquifers have very high permeabilities due to an extensive network of interconnected solution cavities. The Jinduckin Formation and its equivalent (the Anthony Lagoon Beds in the northern part of the Georgina Basin) is mainly composed of siltstone. The formation contains thin, local aquifers in isolated limestone beds.

Lauritzen and Karp (1993) concluded that the Tindall Limestone karst aquifer developed before the Cretaceous period. The permeability of the karst aquifer has been further enhanced since then by the movement of acidic groundwater from the aquifer developed in the basal Cretaceous sandstone where it overlies the limestone. It is believed that the karst aquifer in the Oolloo Dolostone developed in a similar way.

The Tindall Limestone karst aquifer is the main contributor to dry season flow in the Roper River. The Dook Creek Formation contributes significant dry season flow to the upper reaches of the Wilton and Mainoru rivers and Flying Fox Creek, all of which are tributaries of the Roper River. The Tindall Limestone is the aquifer of most interest to irrigators as it occurs beneath land suitable for irrigation and can yield high flow rates (greater than 50 L/second per bore) from relatively shallow depths.

### Cretaceous sediments

The Cretaceous sediments form a mantle of lateritised claystone and sandstone covering much of the area. On Figure RO-2 the sediments have only been mapped where it is expected that they form the major aquifer at that locality. However they overlay the karstic rock aquifers over much of the region. The beds are sub-horizontal and may be divided into an upper claystone and siltstone unit and a basal sandstone unit. Outcrop is generally sparse due to the soft nature of the rock but in places silicification has altered them to porcellanite and quartzite.

In the Wiso and Georgina basins (Figure RO-14) the formation may be up to 75 m thick with the clayey upper unit comprising 60 m of its thickness. The thickness of the sandy unit is variable and ranges from less than 5 m to up to 25 m (cross-section in Figure RO-2). Where the upper claystone is thin and eroded, the potential recharge to the underlying limestone aquifer is increased. In most places within the basins the sediments lie above the regional water level.

In the north-east the formation may be over 100 m thick with most of that thickness being permeable sandstone. The Cretaceous sandstone aquifer contributes significant dry season flows to many rivers in the north-east of the region.

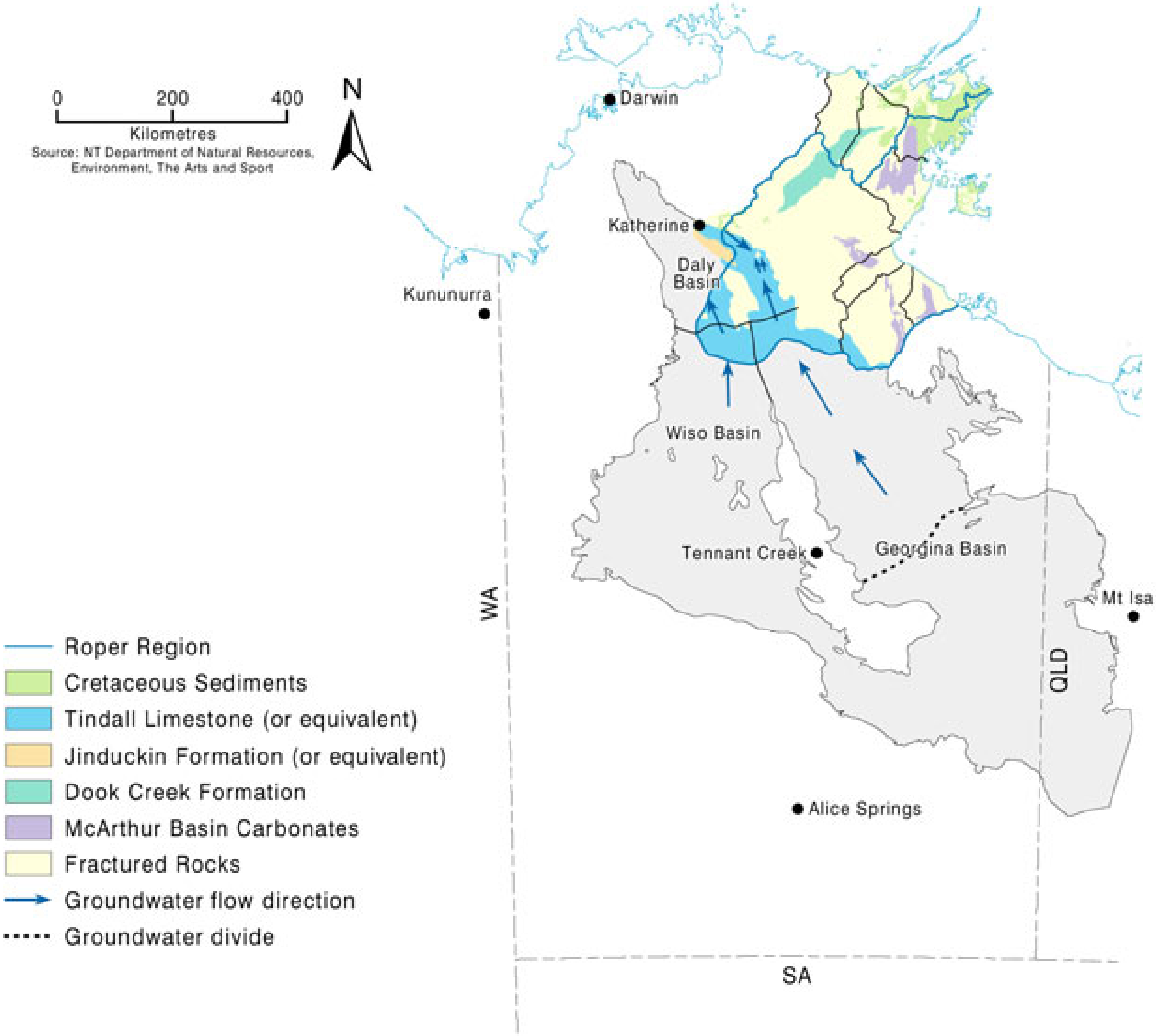



Figure RO-14. Location of the Roper region in relation to the Daly, Wiso and Georgina basins (map provided by the Northern Territory Department of Natural Resources, Environment, The Arts and Sport)

### RO-2.3.2 Inter-aquifer connection and leakage

The only aquifers in the region that may be in hydraulic connection are the fractured rock aquifers and the basal sandstone of the Cretaceous sediments in some locations.

### RO-2.3.3 Recharge, discharge and groundwater storage

Recharge occurs only in the wet season when rainfall intensity and duration is sufficient. Recharge leads to a rise in groundwater levels. In the dry season the levels naturally fall as groundwater is either transpired or discharged to wetlands and rivers where it evaporates or is discharged to the sea. The amount and rate at which the groundwater levels rise and fall depends on the type, size and other physical properties of the aquifer as well as the amount of recharge. The recharge/discharge cycle that applies in the Roper region is summarised in Figure RO-15.

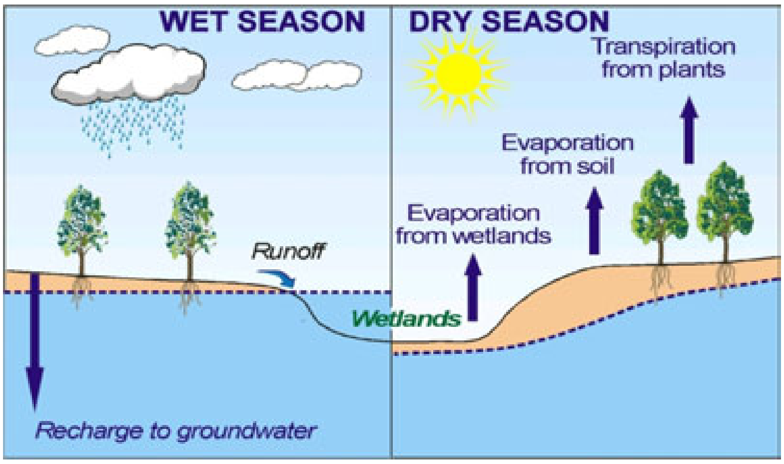



Figure RO-15. Schematic of the recharge/discharge cycle that applies in the Roper region

Recharge beneath native vegetation is dominated by bypass flow and not diffuse movement through soil horizons. The most likely mechanism for this is via stream sinks, sinkholes and/or macropores such as cracks and root holes in the soil. Sinkholes and stream sinks have been located over the Tindall Limestone and the Proterozoic carbonates.

Jolly et al. (2004) estimated the average annual recharge rate to the area within the Roper region providing spring flow to the upper reaches of the Roper River. The estimates were based on chloride concentrations and dry season gauged discharge data for the Roper River. The mean annual recharge rate was estimated to be between 3 and 16 mm/year. It was estimated that half of the recharge evaporates or transpires from the wetlands that occur in and around Elsey National Park, before it discharges to the Roper River.

Groundwater discharge occurs across the region mostly as evaporation and transpiration. Groundwater discharges that maintain perennial reaches of rivers within the region are important. The most visible of these discharges take the form of springs on or adjacent to the banks of perennial rivers such as the Roper, Durabudboi, Koolatong and Rosie rivers and Wonga and Walker creeks on the mainland; and the Angurugu, Emerald and Amagula rivers on Groote Eylandt. However the majority of discharge occurs as diffuse discharge through the beds of rivers. The Northern Territory Government maintains six river gauging stations in the region – five on the Roper River and one on the Angurugu River on Groote Eylandt.

Specific comments relating to recharge and discharge for each of the three major aquifer types follows. The locations of monitoring bores and river gauging stations in the Roper region that are referenced in the following sections are shown in Figure RO-2.

## Fractured rock aquifers

A variety of Precambrian rocks (older than 500 million years) form the bedrock of the area. These are mainly sedimentary but also include granite and volcanic rocks. Sandstone, siltstone and greywacke are the main sedimentary rock types. In some areas they are flat-lying while in other areas they have been folded, faulted and show low grade metamorphism.

Fractured rock aquifers developed in Proterozoic sandstone have been developed as a water supply source for a number of small communities in the region. Insufficient data on water levels is available to provide comment on annual water level variations.

## Cretaceous sediments

Regional groundwater discharge from the Cretaceous sediments provides the dry season flow for Wonga Creek and the Durabudboi, Angurugu, Emerald and Amagula rivers.

Changes in dry season streamflow rates occur in response to changes in the amount of rainfall that recharges the aquifer during the preceding wet season. The changing recharge rate is reflected in the variation in water level measured in monitoring bores intersecting the aquifer. Figure RO-16 plots time series groundwater level data for bore RN022220 which is located on Groote Eylandt. The data indicates that annual groundwater rises due to recharge during the wet season vary from minimal during the 1989/90 wet season to 4.5 m in 1993/94 and 1998/99. Prowse et al. (1999) demonstrated that periods of relatively low groundwater levels correspond to periods when streamflows are relatively lower in the perennial rivers of Groote Eylandt; likewise higher groundwater levels correspond with higher flows.

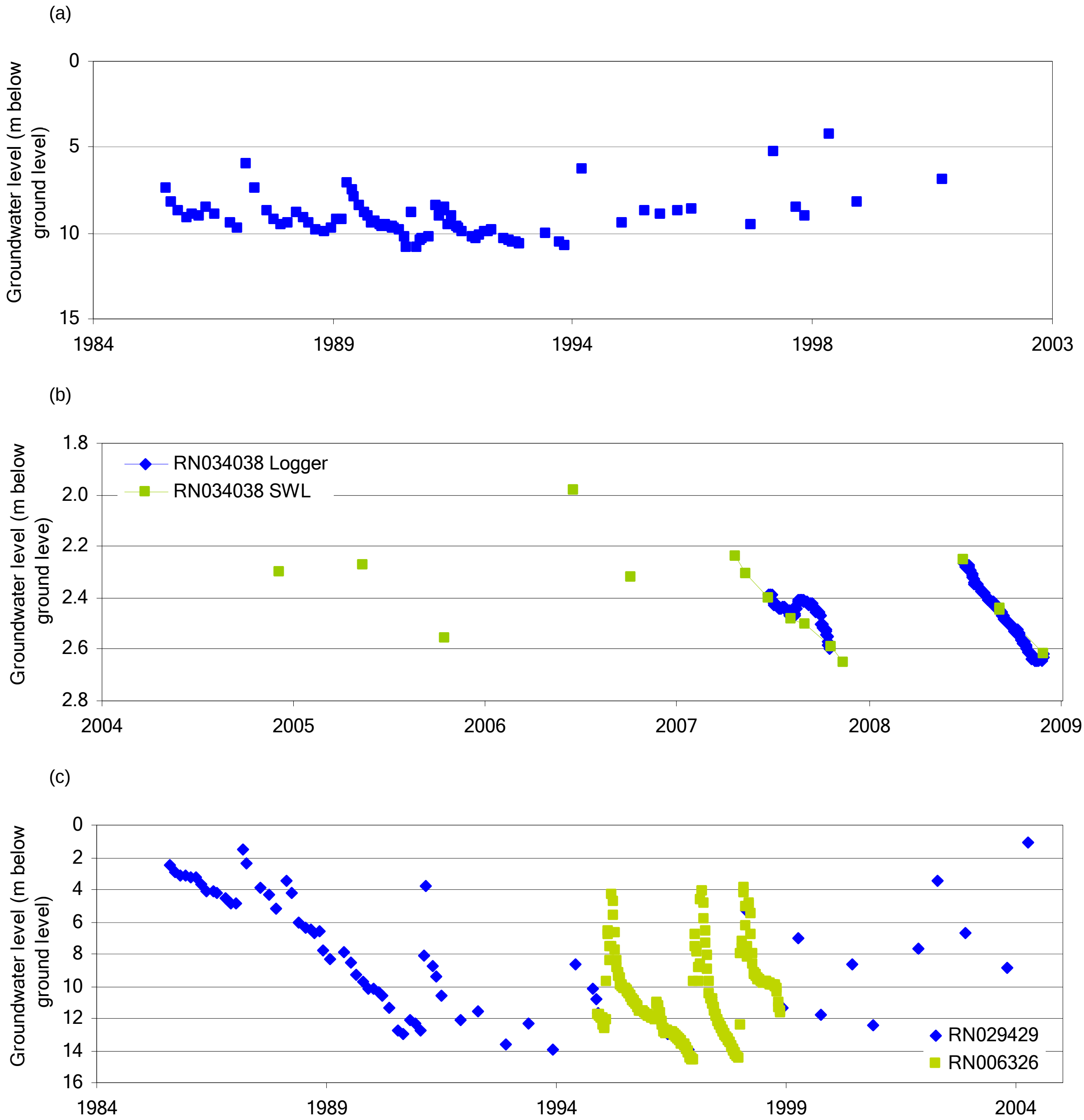



Figure RO-16. Observed groundwater levels in bores in the (a) Cretaceous Sandstone at Angurugu, (b) Tindall Limestone near Mataranka and (c) Proterozoic carbonates near Beswick

## Tindall Limestone (and equivalents)

Regional groundwater discharges from the karst aquifer developed in the Tindall Limestone (and equivalents) provide most of the dry season flow for the Roper River. The groundwater catchment of the Roper River extends into the Georgina Basin for more than 400 km outside of the surface water catchment of the Roper River (Tickell, 2005).



The aquifer developed in the Tindall Limestone that lies beneath the Wiso Basin in the Roper River catchment also provides a significant proportion of the flow in the Flora River which is located in the Daly region. In dry periods such as the 1960s and early 1970s discharge from the Tindall Limestone into the Flora River was critical to maintaining the perenniality of all of the Daly River.

As the Tindall Limestone aquifer underlies such a large area, its recharge rate can vary significantly due both to the areal variability in rainfall and the presence or absence of Cretaceous sediments overlying it. Knapton (2006) modelled the Tindall Limestone aquifer across those parts of the Daly, Wiso and Georgina basins that discharge either to the Daly River or Roper River. The average annual recharge rate to the area within the Roper River catchment providing spring flow to the upper reaches of the Roper River ranged from a low of less than 1 mm in the south to a high of 73 mm in the vicinity of the Roper River.

Limited water level monitoring data exists for the Tindall Limestone in the Roper region. Data for monitoring bore RN034038 located near the discharge zone of the aquifer are given in Figure RO-16.

#### Proterozoic carbonates

There are only limited data available for groundwater levels in the Proterozoic carbonates. The data shown in Figure RO-16 for bore RN021689 located in an outlier of the Dook Creek Formation near Beswick indicates that significant recharge occurred in 75 percent of wet seasons during the 20-year period when water levels were measured. In the remaining 25 percent of wet seasons minimal recharge appears to have occurred.

Groundwater discharge from the Dook Creek Formation provides the dry season flow for the Mainoru and Wilton Rivers and Flying Fox Creek. The Dook Creek Formation is also the source of dry season flow in the Goyder River which flows into the Arafura Swamp. (Williams et al., 2003) estimated a mean annual recharge rate of 90 mm/year (1884 to 1999) for the area of the Dook Creek Formation that provides the source of dry season flows in the Goyder River.

### RO-2.3.4 Groundwater quality

The quality of most groundwater from the fractured rock aquifers across the Roper region falls within acceptable drinking water guidelines (ADWG, 2004). The only exception is groundwater beneath the internal floodouts of the Roper River, as extensive concentration by evapotranspiration has resulted in very high salinities.

Groundwaters in the Tindall Limestone and Proterozoic carbonates (for locations see Figure RO-2) are slightly alkaline on average but pH can range from 6.4 to 8. Calcium, magnesium and bicarbonate are the dominant ions, while salinity (as electrical conductivity) is generally in the range 300 to 2000 µS/cm (Figure RO-17). However, beneath the diffuse groundwater discharge zone in Elsey National Park groundwater salinity regularly exceeds 10,000 µS/cm. Calcium, magnesium and bicarbonate concentrations are similar throughout the carbonate aquifers because these ions dissolve relatively easily from the limestone and dolomite matrix and, once saturation with respect to these minerals is reached, the ionic concentrations stabilise. Hardness is normally high and will cause scale build-up in water delivery infrastructure.

The Jinduckin Formation is known to contain the evaporite mineral anhydrite (calcium sulphate) and, to a lesser degree, halite (sodium chloride). Accordingly, groundwater in this formation generally has calcium and sulphate as the dominant ions. Salinity is mostly in the range 300 to 3000 µS/cm.

Groundwaters in the Cretaceous sediments are acidic with pH values of approximately 5. The salinity mostly ranges between 50 and 100 µS/cm.

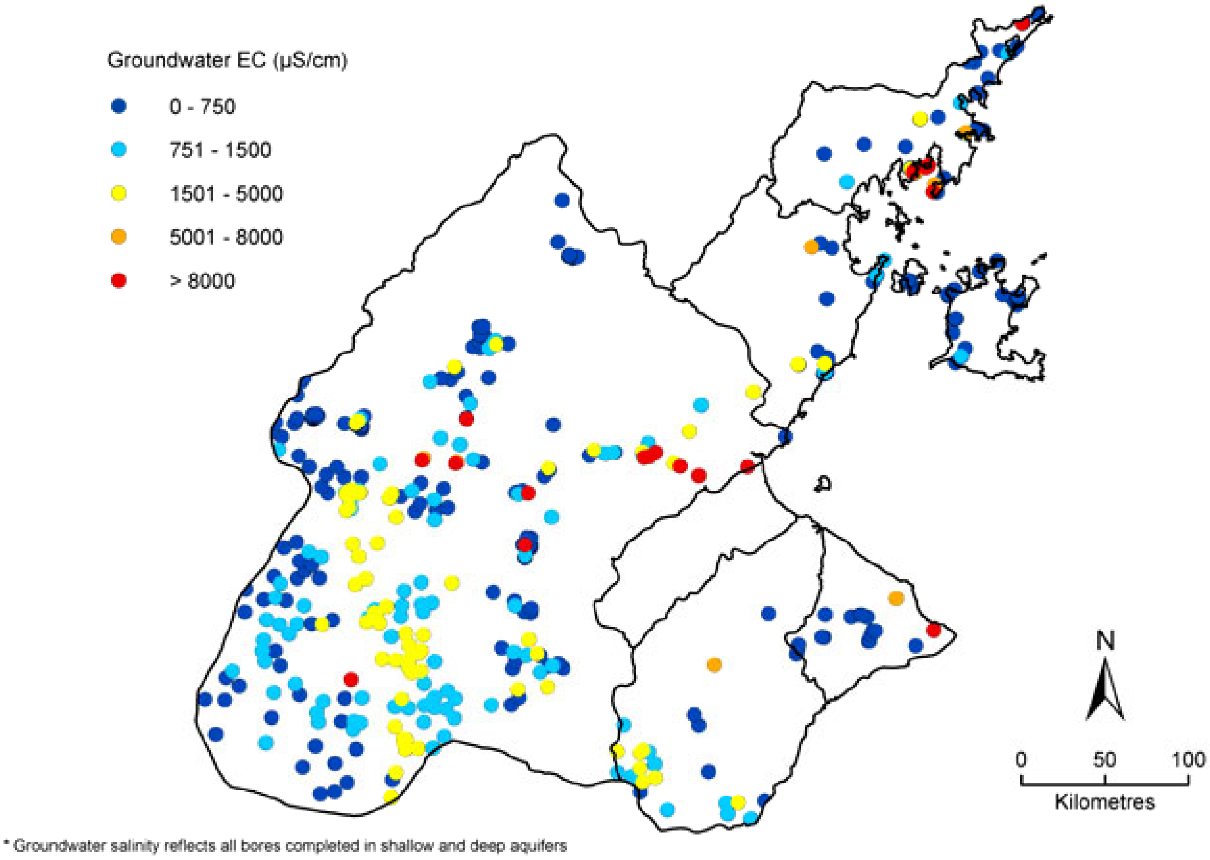



Figure RO-17. Groundwater salinity distribution for all bores drilled in the Roper region

# RO-2.4 Legislation, water plans and other arrangements

## RO-2.4.1 Legislated water use, entitlements and purpose

Unlike other states, the Northern Territory has no Integrated Catchment Management (ICM) framework in place. Currently, the responsibility for river management lies predominantly with the Northern Territory government. The *Northern Territory Water Act 1992* has been the major legislative framework for managing rivers. The *Water Act* was amended in 2000 in accordance with Council of Australian Governments (COAG) requirements for water reform. The Act provides a process for the allocation of water resources to beneficial uses, including the environment, and to enable trade in water licences. The legislative framework sets targets for cost recovery and pricing, institutional reform, water allocation (including the development of regional water allocation plans) and trading, environment and water quality, and public consultation and education. The *Water Act 1992* restricts and controls the way in which water quality can be affected. According to the *Water Act 1992*, the Crown owns all surface water and groundwater – a situation unique to Australian water law (O'Donnell, 2002).

The water policy framework in the Northern Territory is not well developed and the legislation has no objects or principles to guide the development of a water allocation plan. Sustainability is introduced through the concept of 'beneficial use'. 'Beneficial uses', or preferred uses, are determined for natural waterways under the Act. The uses include: (i) protection of aquatic ecosystem; (ii) recreation and aesthetics; (iii) raw water for drinking water supply; (iv) agricultural water supply; and (v) industrial water supply. Beneficial uses have not been declared for waterways within the Roper River catchment.

Other Northern Territory legislation that has relevance to river management includes:

- *Aboriginal Sacred Sites Act 1989*
- *Environmental Assessment Act 1982*
- *Fisheries Act 1996*
- *Heritage Conservation Act 1991*
- *Mining Act 1990*
- *Noxious Weeds Act 1994*
- *Pastoral Land Act 1992*
- *Planning Act 1999*
- *Soil Conservation and Land Utilisation Act 1992*
- *Waste Management and Pollution Control Act 1998.*

Management plans currently in place include:

- Elsey National Park Plan of Management (CCNT, 1995).

Within the Roper region there are several small towns and communities, of which Mataranka is the regional centre. Others towns and communities include Barunga, Beswick (Wugular), Bulman, Daly Waters, Larrimah, Hodgson Downs, Roper Bar, Ngukurr and Numbulwar on the mainland, and Angurugu, Umbakumba and Alyangula on Groote Eylandt. The total population living within the region is probably less than 25,000.

Surface water entitlements amount to less than 500 ML/year, with the only substantive entitlement (340 ML/year) being for the Yugul Mangi Community of Ngukurr. There are no urban or rural water restrictions on water use.

Currently, only two groundwater extraction licences have been issued in the Mataranka area, totalling 580 ML/year <http://www.nt.gov.au/nreta/water/manage/register/pdf/GWRegister_Dec08.pdf>. A surface water extraction licence for 1900 ML has been issued to GEMCO to extract water from the Angurugu River. Most of this volume would be extracted from the dry season groundwater fed flows.

#### Future

Currently there are applications for groundwater extraction licences in the Mataranka area for a further 13,923 ML/year. A significant proportion of this amount is for irrigated agriculture that is already occurring without an extraction licence.

### RO-2.4.2 Groundwater use and entitlements

Groundwater use figures for the Roper region were not calculated for the Australian Water Resources 2000 Assessment. Small volume (less than 5 ML/year) groundwater users are not required to be licensed in accordance with a pending exemption to section 47 of the Northern Territory *Water Act 1992*. Estimated use is based on 5 ML/year/property.

The largest user of groundwater in the region is the manganese mine located on Groote Eylandt which is run by GEMCO. Water is sourced for this mine from the Cretaceous sediments and the Angurugu River which is sustained by groundwater discharges from the basal sandstone of the Cretaceous sediments. While surface water extraction from the Angurugu River is licensed and metered, groundwater extraction is neither licensed nor metered. Very large quantities of groundwater are extracted to dewater the pits from which the manganese is extracted. Preliminary modelling undertaken by Aquaterra (2001) suggests the impact of pit dewatering on the Angurugu River was immeasurable, but that baseflows in the Emerald River could be influenced.

Irrigation near Mataranka is becoming an industry of increasing importance. Groundwater is extracted for irrigation from the Tindall Limestone adjacent to Elsey National Park. Use is not yet licensed nor metered. The aquifer in this area is subject to increasing stress from large irrigated agricultural developments that will have an as yet unknown impact on springs that sustain dry season flows in the Roper River. The springs include the iconic Mataranka Hot Springs.

The fractured rock and carbonate aquifers usually provide reliable groundwater supplies of good quality for the pastoral industry.

### RO-2.4.3 Rivers and storages

There are currently no large surface water storages on the Roper River or its tributaries.

### RO-2.4.4 Unallocated water

For water resources in the Northern Territory, where there has not been a detailed assessment of water availability carried out as part of a water allocation plan, a contingent water allocation guideline applies. The guideline requires that at least 80 percent of annual recharge to a groundwater system be allocated for environmental and other public benefit outcomes. Consequently, groundwater will not be allocated in a manner that allows consumptive use to exceed 20 percent of annual recharge.

### RO-2.4.5 Social and cultural considerations

Water resource assessments of West and East Arnhem Land by Zaar (2003) included a component on Indigenous knowledge of water occurrence and significance, and encompass some of the area included in this region, including Groote Island. A separate report containing Aboriginal knowledge collected during field trips was produced for both east and west Arnhem Land (Zaar and Prowse, 1999; Zaar, 2003). The data consists largely of placenames and their location. Some of these placenames, where appropriate, have been recorded on the Water Resource Map and are also included in the GIS version of the map. Stories relating to water were also recorded e.g. the rainbow serpent which is associated with billabongs and freshwater springs is responsible for the production of most water plants such as water lilies, algae and palms, found growing near water (Zaar, 2003). The roar of waterfalls in the escarpment country is said to be the sound of the serpent’s voice. The East Arnhem Land Study includes transcribed narratives describing the formation of cultural water sites.

### RO-2.4.6 Changed diversion and extraction regimes

The region is in a near-pristine state, with minimal changed diversion or extraction regimes.

### RO-2.4.7 Changed land use

Minimal land use change, focussed around the town site of Mataranka, has occurred, or is expected to occur in the region.

### RO-2.4.8 Environmental constraints and implications of future development

The Mataranka Pools and part of the Roper River are listed on the Register of the National Estate for their natural values (Australian Heritage Council). There is also heavy tourist use of the region. Impact by feral animals (particularly donkeys) and weeds has become a management issue.

## RO-2.5 References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# RO-3 Water balance results for the Roper region

This chapter describes modelling results and the assessment of the water resources undertaken by this project for the Roper region. Detailed, quantified assessments are made where possible, and relevant, and confidence is estimated. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2. This chapter is sub-divided into:

- climate
- recharge estimation
- conceptual groundwater models
- groundwater modelling results
- rainfall-runoff modelling results
- river system water balance
- changes to flow regimes at environmental assets.

## RO-3.1 Climate

### RO-3.1.1 Historical climate

The Roper region receives an average of 843 mm of rainfall over the September to August water year (Figure RO-18), most of which (805 mm) falls in the November to April wet season (Figure RO-19). Across the region there is a strong north–south gradient in annual rainfall (Figure RO-20), ranging from 1357 mm in the north to 592 mm in the south. Over the first half of the historical (1930 to 2007) period, annual rainfall was relatively constant at around 750 mm. Conversely, in the second half of the period mean annual rainfall increased to approximately 950 mm. The highest yearly rainfall received was 1477 mm in 2001, and the lowest was 347 mm in 1952.

Areal potential evapotranspiration (APET) is very high across the region, averaging 1928 mm over a water year (Figure RO-18), and varies moderately across the seasons (Figure RO-19). APET generally remains higher than rainfall hroughout the year resulting in year-round water-limited conditions.

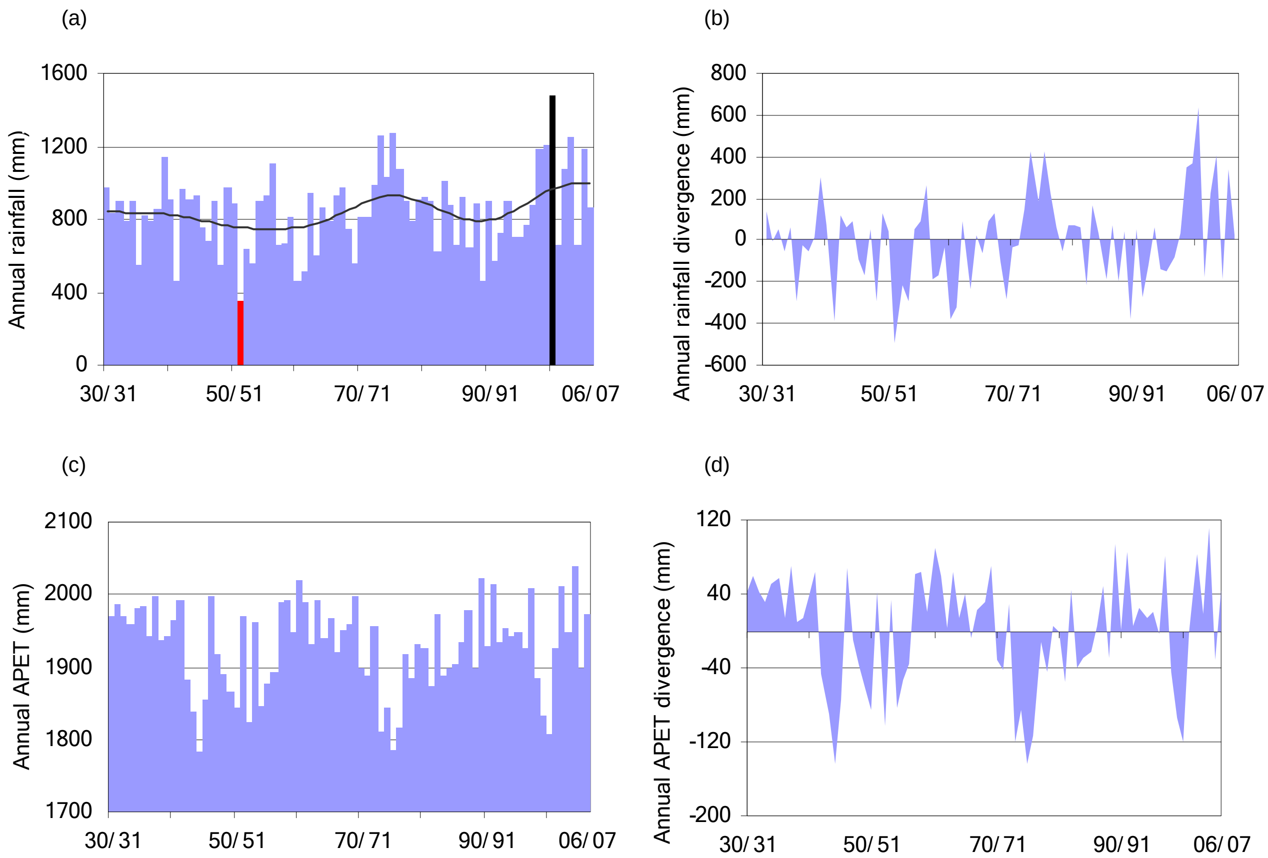



Figure RO-18. (a) Historical annual rainfall and (b) its divergence from the long-term mean; and (c) historical annual areal potential evapotranspiration and (d) its divergence from the long-term mean averaged over the Roper region. The low-frequency smoothed line in (a) indicates longer term variability.

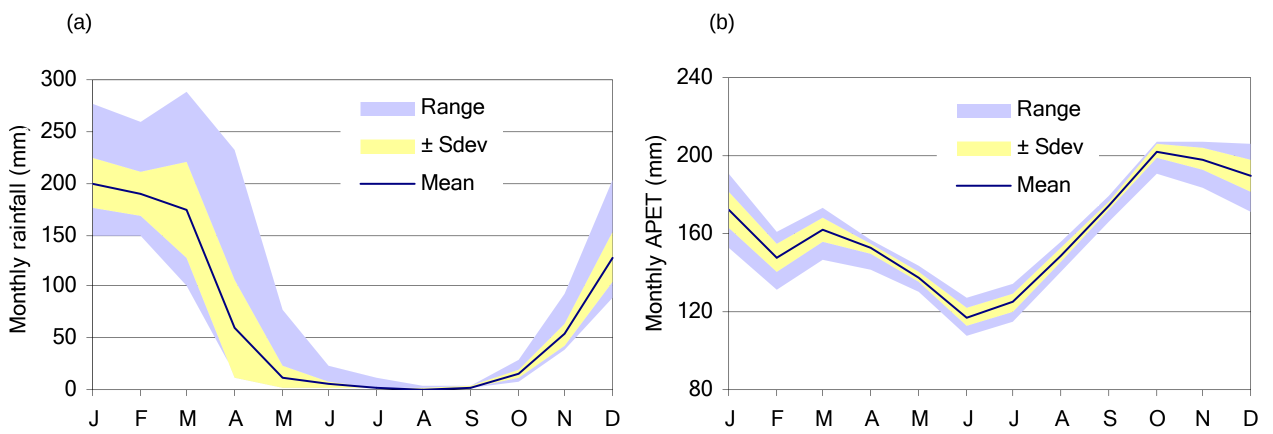



Figure RO-19. Historical mean monthly (a) rainfall and (b) areal potential evapotranspiration and their temporal variation (range and ± one standard deviation) averaged over the Roper region

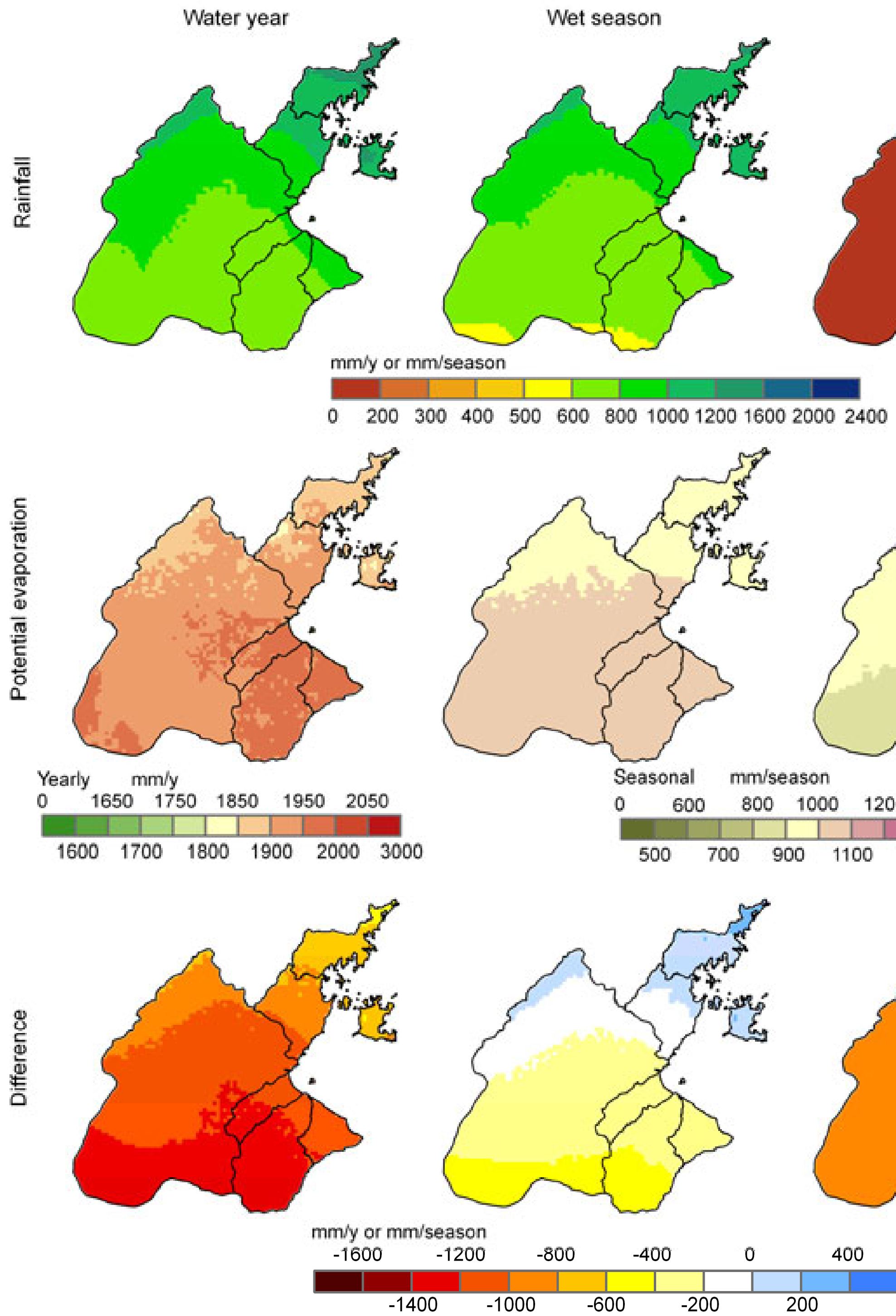



Figure RO-20. Spatial distribution of historical mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration (potential evaporation) and their difference (rainfall less areal potential evapotranspiration) across the Roper region

### RO-3.1.2 Recent climate

Figure RO-21 compares recent (1996 to 2007) to historical (in this case the 66-year period 1930 to 1996) mean annual rainfall for the Roper region. Across the whole region, recent rainfall is between 10 and 40 percent higher than historical rainfall – a statistically significant difference for the majority of the region.

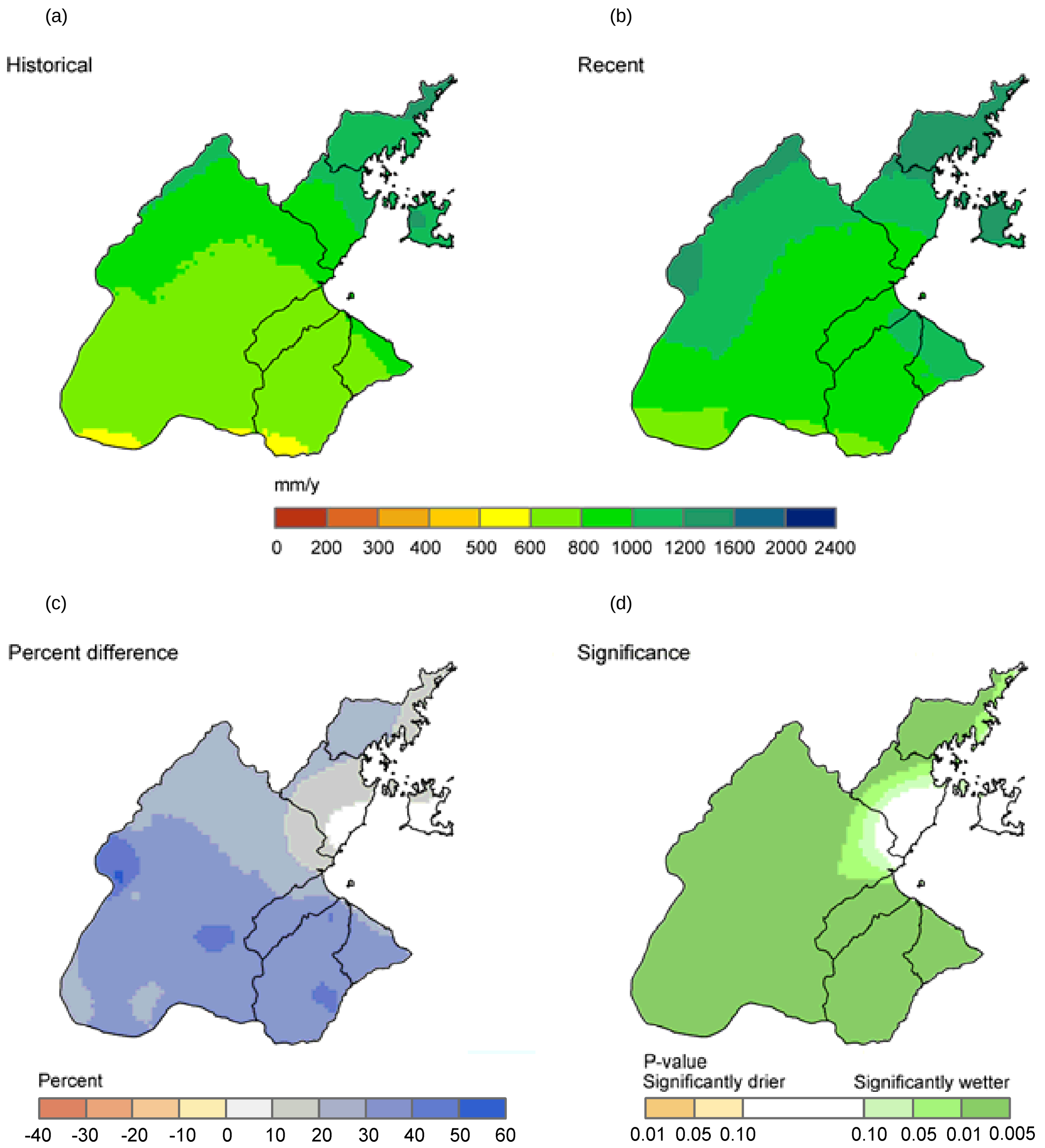



Figure RO-21. Spatial distribution of (a) historical and (b) recent mean annual rainfall; and (c) their relative percent difference and (d) the statistical significance of these differences across the Roper region. (Note that historical in this case is the 66-year period 1930 to 1996)

### RO-3.1.3 Future climate

Under Scenario C annual rainfall varies between 765 and 932 mm (Table RO-3) compared to the historical mean of 843 mm. Similarly, APET ranges between 1959 and 2001 mm compared to the historical mean of 1928 mm.

A total of 45 variants of Scenario C were modelled (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). Subsequently, results from a wet extreme, median and dry extreme variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet annual rainfall and APET increase by 11 percent and 2 percent, respectively. Under Scenario Cmid annual rainfall is the same as the historical mean and APET increases by 4 percent. Under Scenario Cdry annual rainfall decreases by 9 percent and APET increases by 4 percent.

Under Scenario Cmid long-term monthly averages of rainfall and APET do not differ much from historical values (Figure RO-22). Under Scenario Cmid rainfall lies well within the predicted range in values from all 45 Scenario C variants for all months. The seasonality of rainfall is expected to change slightly only in that any changes in rainfall will occur in the wet season. In contrast, the seasonality of APET is likely to remain the same as changes occur uniformly across the year. Under Scenario Cmid APET is slightly higher than the historical mean, which lies at the lower end of the range in values derived from all 45 Scenario C variants.

The spatial distributions of rainfall and APET under Scenario C are compared to the historical distribution in Figure RO-23 and Figure RO-24. Under Scenario C the strong north–south gradient in rainfall is retained, but with a southwards shift under Scenario Cwet and a northwards shift under Scenario Cdry. The spatial distribution of APET under Scenario C is similar to the highly regionalised historical distribution.

Table RO-3. Mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration averaged over the Roper region under historical climate and Scenario C

| | Water year * | Wet season | Dry season |
|---|---|---|---|
| | mm/y | mm/season | |
| Rainfall | | | |
| Historical | 843 | 805 | 38 |
| Cwet | 932 | 882 | 41 |
| Cmid | 843 | 797 | 38 |
| Cdry | 765 | 724 | 34 |
| Areal potential evapotranspiration | | | |
| Historical | 1928 | 1023 | 906 |
| Cwet | 1959 | 1030 | 928 |
| Cmid | 2001 | 1061 | 937 |
| Cdry | 1996 | 1060 | 934 |

* Note that the sum of the wet season and dry season values does not always equal the water year values because the combined wet season and dry season period (November to October) is different to the water year period (September to August).

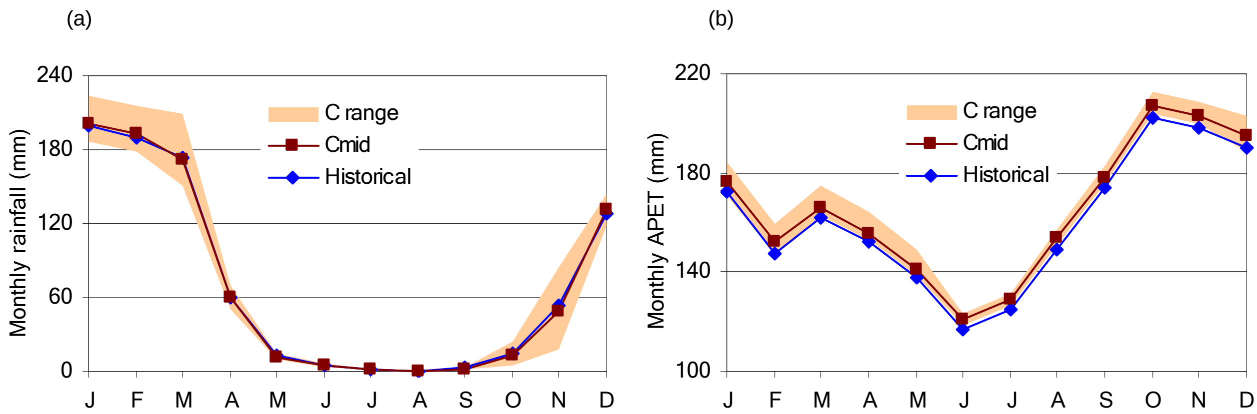



Figure RO-22. Mean monthly (a) rainfall and (b) areal potential evapotranspiration across the Roper region under historical climate and Scenario C. (C range is the range in potential evapotranspiration pooled from all global climate model outputs from all three emission scenarios – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

## RO-3.1.4 Confidence levels

Analysis of confidence of the climate data is presented at the division level and is reported in Section 2.1.4.

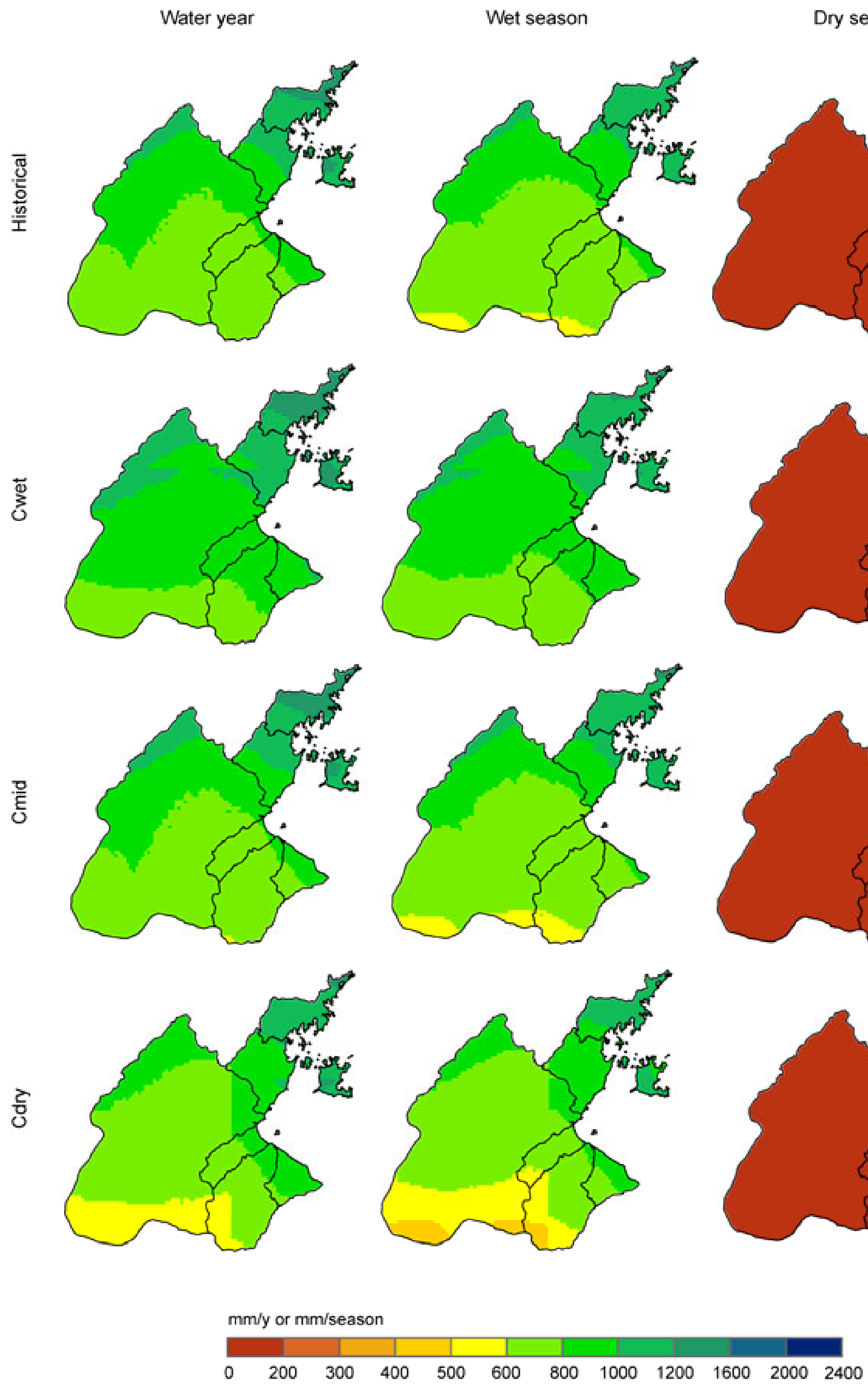



Figure RO-23. Spatial distribution of mean annual (water year), wet season and dry season rainfall across the Roper region under historical climate and Scenario C

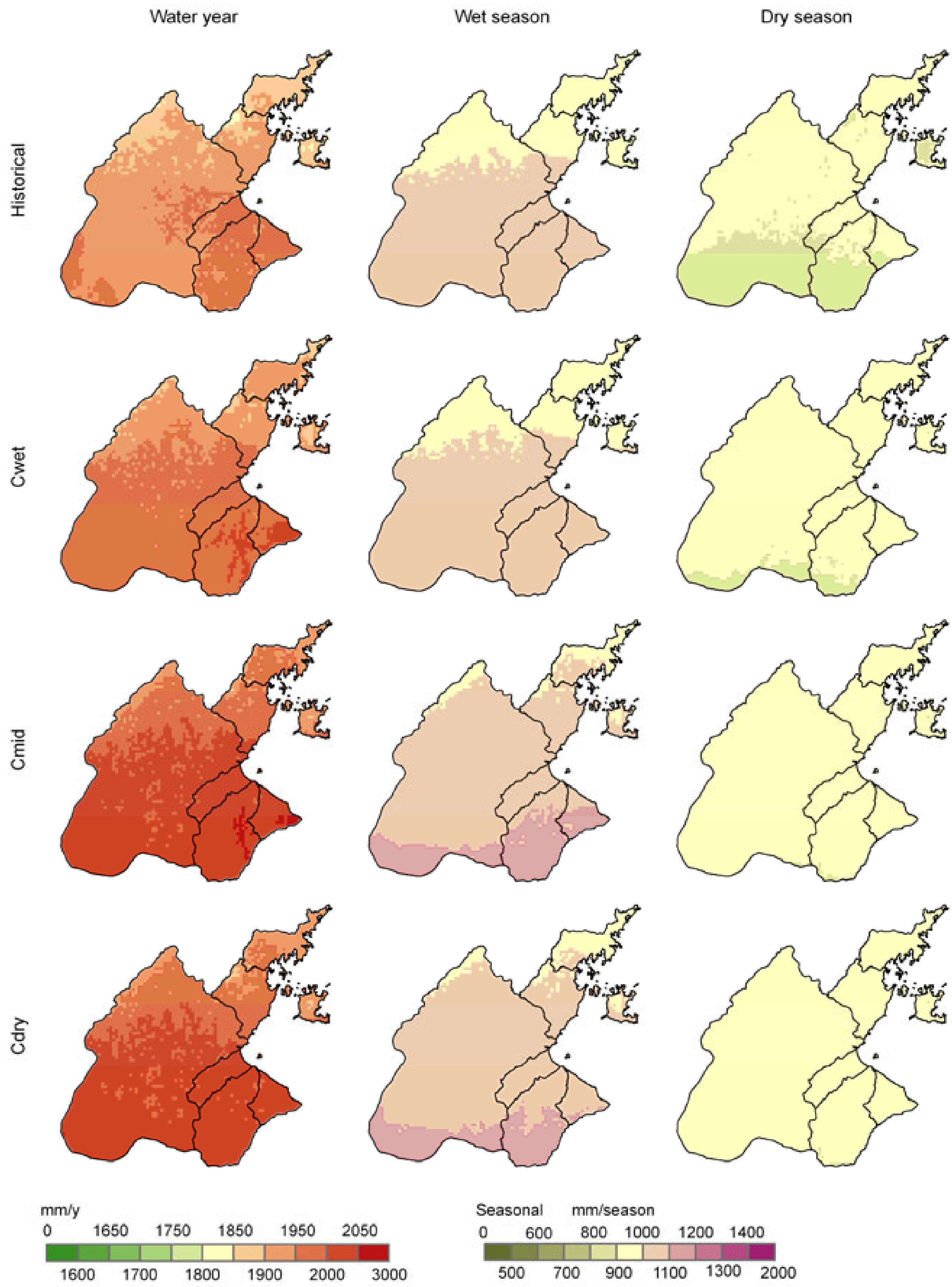



Figure RO-24. Spatial distribution of mean annual (water year), wet season and dry season areal potential evapotranspiration across the Roper region under historical climate and Scenario C

## RO-3.2 WAVES potential diffuse recharge estimations

The WAVES model (Zhang and Dawes, 1998) was used to estimate the change in groundwater recharge across the Roper region under a range of different climate scenarios. WAVES is a vertical recharge flux model that can model plant physiological feedbacks in response to increased $CO_2$, as well as model the water balance of different soil, vegetation and climate regimes. It was chosen for its balance in complexity between plant physiology and soil physics. It was also used to assess recharge for the Murray-Darling Basin Sustainable Yields Project (Crosbie et al., 2008).

### RO-3.2.1 Under historical climate

Under Scenario A the calculated recharge for the Roper region is greatest in the north and decreases progressively to the south following the rainfall gradient. The historical record was assessed to establish any difference between wet and dry periods of recharge. A 23-year period was used, which allows projections of recharge estimates to 2030 – in other words, to estimate recharge in 2030 assuming future climate is similar to historical climate (Scenario A). Under a wet historical climate (Scenario Awet) recharge increases 12 percent uniformly across the region. Under a median historical climate (Scenario Amid) recharge decreases 3 percent. Under a dry historical climate (Scenario Adry) recharge decreases 14 percent.

Where unweathered bedrock outcrops occur, confidence in the modelled results is reduced. The locations of these outcrops in the Roper region are shown on the historical recharge map in Figure RO-25.

Table RO-4. Recharge scaling factors in the Roper region under scenarios A, B and C

| Region | Awet | Amid | Adry | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| Roper | 1.12 | 0.97 | 0.86 | 1.43 | 1.48 | 1.13 | 0.98 |

### RO-3.2.2 Under recent climate

Under the recent (1996 to 2007) climate the Roper region has been wetter than the historical (1930 to 2007) average and consequently the calculated recharge is 43 percent higher under Scenario B relative to Scenario A (Table RO-4). This increase has not been uniform across the region with the greatest increase in the south of the region and some areas of the east showing almost no change from the historical period (Figure RO-25). The non-linear relationship between increase in rainfall and increase in recharge reflects the importance of climate variables other than total rainfall in determining recharge (e.g. rainfall intensity and temperature).

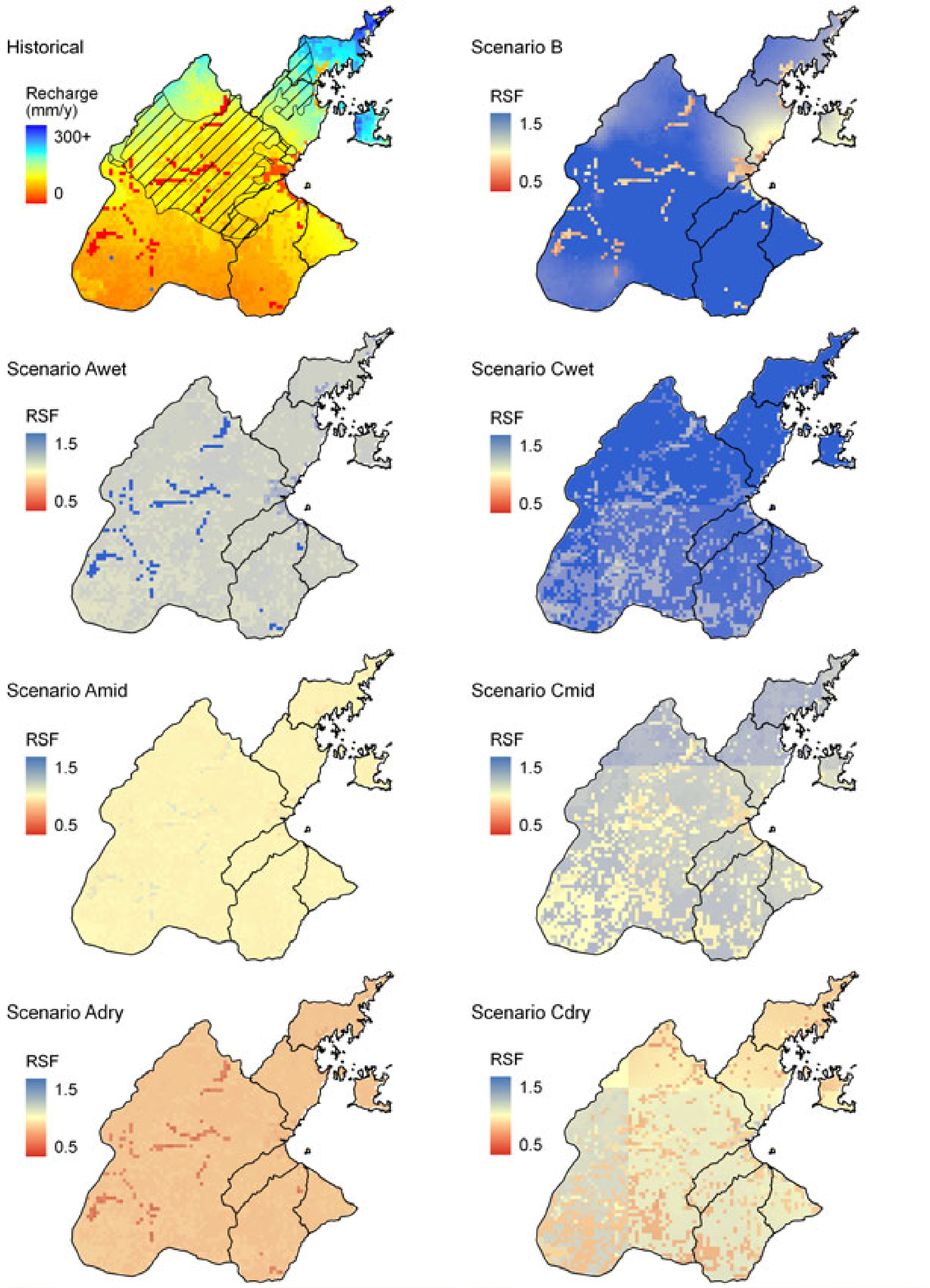



Figure RO-25. Spatial distribution of historical mean recharge rate and recharge scaling factors across the Roper region for scenarios A, B and C. The hatched region on the historical recharge map identifies where unweathered bedrock outcrops occur

### RO-3.2.3 Under future climate

Figure RO-26 shows the percentage change in mean annual recharge averaged over the Roper region under the 45 Scenario C variants (15 GCMs for each of the high, medium and low global warming scenarios) relative to Scenario A.

The percentage change in the mean annual rainfall and recharge from the corresponding GCMs are also tabulated in Table RO-5. In some scenarios the recharge is projected to increase despite a decrease in rainfall. This is because total rainfall is not the only climate variable that has an influence over recharge. Daily rainfall intensity, temperature and $CO_2$ concentration are also important drivers (see Section 2.3.3 in the division-level Chapter 2), and specific situations can result in this counter-intuitive result. In particular, rainfall intensity is seen as a significant factor in this relationship.

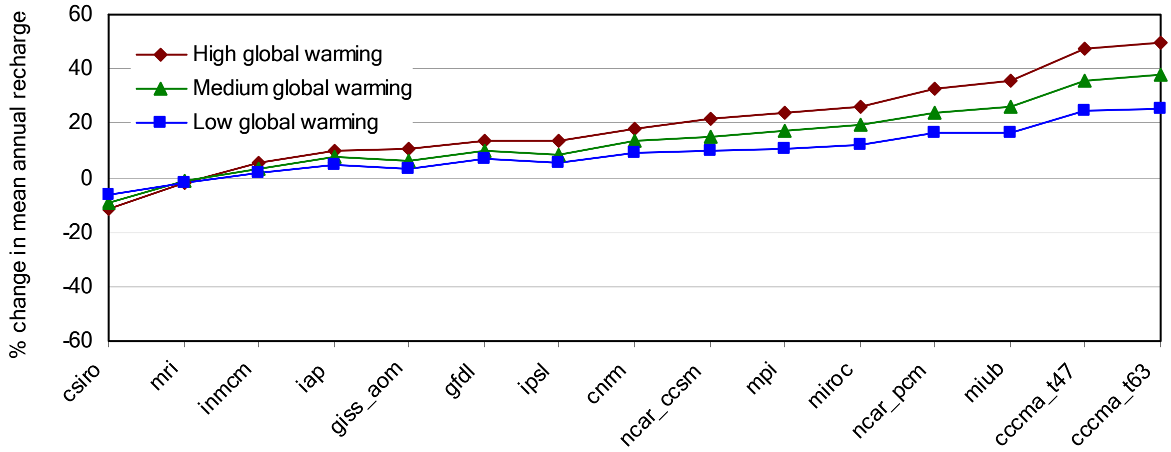



Figure RO-26. Percentage change in mean annual recharge under the 45 Scenario C variants (15 global climate models and three global warming scenarios) relative to Scenario A

Table RO-5. Summary results under 45 Scenario C variants (numbers show percentage change in mean annual rainfall and recharge under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Recharge | GCM | Rainfall | Recharge | GCM | Rainfall | Recharge |
| csiro | -14% | -11% | csiro | -10% | -9% | csiro | -7% | -6% |
| **mri** | **-5%** | **-2%** | mri | -4% | -1% | mri | -3% | -2% |
| inmcm | 0% | 6% | inmcm | 0% | 3% | inmcm | 0% | 2% |
| iap | -2% | 10% | iap | -1% | 8% | iap | -1% | 5% |
| giss_aom | -3% | 10% | giss_aom | -2% | 6% | giss_aom | -1% | 3% |
| gfdl | -9% | 14% | gfdl | -7% | 10% | gfdl | -5% | 7% |
| ipsl | 0% | 14% | ipsl | 0% | 8% | ipsl | 0% | 5% |
| cnrm | 0% | 18% | **cnrm** | **0%** | **13%** | cnrm | 0% | 9% |
| ncar_ccsm | 5% | 22% | ncar_ccsm | 4% | 15% | ncar_ccsm | 3% | 10% |
| mpi | 1% | 24% | mpi | 1% | 17% | mpi | 1% | 10% |
| miroc | 5% | 26% | miroc | 4% | 20% | miroc | 3% | 12% |
| ncar_pcm | 9% | 33% | ncar_pcm | 7% | 24% | ncar_pcm | 5% | 17% |
| miub | 5% | 35% | miub | 4% | 26% | miub | 3% | 17% |
| **cccma_t47** | **11%** | **48%** | cccma_t47 | 9% | 35% | cccma_t47 | 6% | 25% |
| cccma_t63 | 11% | 50% | cccma_t63 | 9% | 38% | cccma_t63 | 6% | 25% |

Under Scenario Cwet recharge increases 48 percent with the greatest increase in the north. Under Scenario Cmid recharge increases 13 percent with the greatest increase in the north. Under Scenario Cdry recharge decreases 2 percent with increases in the west of the region and decreases in the north.

## RO-3.2.4 Confidence levels

The estimation of recharge from (Zhang and Dawes, 1998) is only indicative of the actual recharge and has not been validated with field measurements. A chloride mass balance has been conducted as an independent measure of recharge. The results in the Roper region show that estimate of recharge under Scenario A using (Zhang and Dawes,



1998) (95 mm/year) is greater than the best estimate using the chloride mass balance (72 mm/year) but it is within the confidence limits of the chloride mass balance (7 to 168 mm/year).

## RO-3.3 Conceptual groundwater models

### RO-3.3.1 Fractured rocks

Relatively low annual rainfall and high potential evapotranspiration means that recharge to the groundwater is likely to only occur after prolonged periods of intense rainfall in the wet season. Recharge is more effective through sandy soils than black clay soils, the latter only permitting significant infiltration early in the wet season through cracks and preferential pathways before the clays swell. Aquifers are also locally recharged through either small alluvial aquifers or directly from the river when high flows or flooding occurs. The main groundwater discharge process is through evapotranspiration. For rivers draining fractured rock aquifers in the region flows are reduced to disconnected semi-permanent pools and then dry river beds as the dry season progresses.

### RO-3.3.2 Karstic carbonate rocks

Processes occurring in karstic carbonate rocks are similar to those for the fractured rocks, except that groundwater flow is primarily through solution cavities rather than fractures. The main groundwater discharge processes are through evapotranspiration and spring discharge to rivers. River flows are maintained to varying degrees by the spring discharge.

Groundwater discharging from the Proterozoic carbonates maintains perennial flows in the Mainoru, Wilton, Koolatong, Walker and Rosie rivers and Flying Fox Creek (Figure RO-2). A conceptual model for the interconnection between the Proterozoic carbonate aquifer and the Mainoru River is shown in Figure RO-27 whereby groundwater discharge to the river is focussed along a fault.

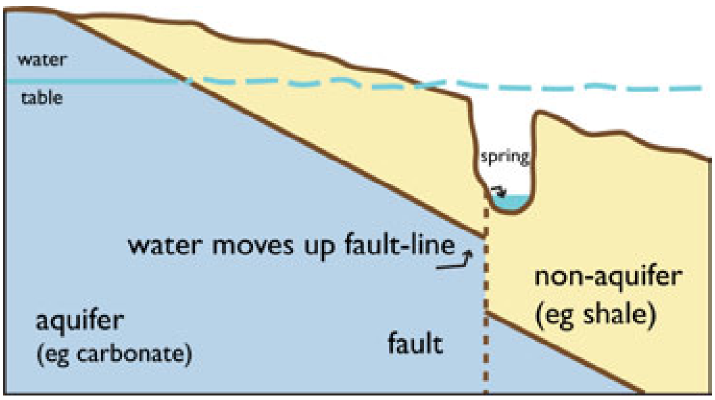



Figure RO-27. Schematic of hydrogeological cross-section showing groundwater discharge to the Mainoru River

Groundwater discharge from the Tindall Limestone maintains permanent flows in the Roper River. The generalised regional groundwater flow directions are shown in Figure RO-14 (in Chapter RO-2). Interactions between the Tindall Limestone and Roper River are generally controlled by solution cavities intersecting the river (Figure RO-28).

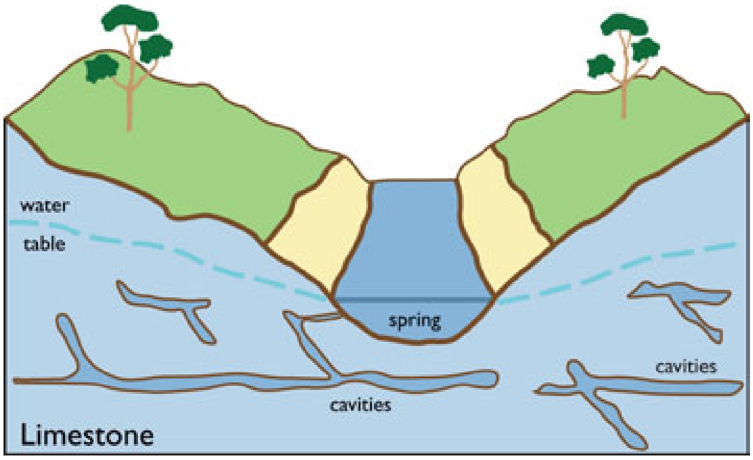



Figure RO-28. Schematic of hydrogeological cross-section showing groundwater discharge to the Roper River

### RO-3.3.3 Cretaceous sediments

Processes occurring in the Cretaceous sediments are similar to those for the fractured rocks. The main groundwater discharge processes are through evapotranspiration and spring discharge to rivers. River flows are maintained to varying degrees by the spring discharge.

Springs from the Cretaceous sediments mainly occur in the centre and east of the region. They occur where a layer of porous and permeable sandstone overlies a low permeability rock such as shale or granite (Figure RO-29). Water stored in the upper layer seeps out at the contact between the two rock types, generally in the form of a seepage zone or swampy area. Examples of where this spring type occurs are the Durabudboi River and Wonga Creek on the mainland and the Angurugu, Emerald and Amagula rivers on Groote Eylandt (Figure RO-2 in Chapter RO-1).

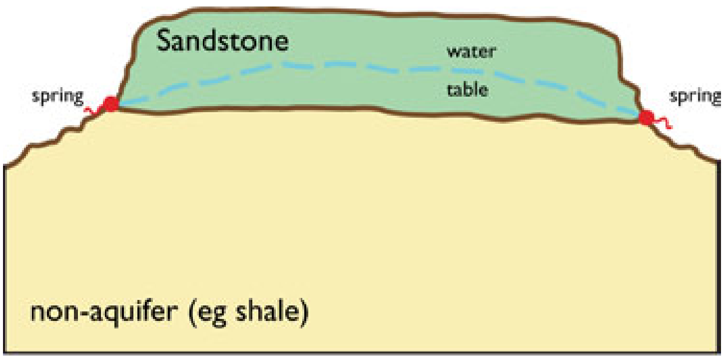



Figure RO-29. Schematic of hydrogeological cross-section showing groundwater discharge that provides the dry season flow for Wonga Creek

# RO-3.4 Groundwater modelling results

## RO-3.4.1 Historical groundwater balance

No attempt has been made to develop a detailed groundwater balance for the region due to the lack of data. However the following general comments can be made:

- The main hydrological characteristic of the region is the great variability in rainfall from year to year, within a single year and over periods of years. This variability results in a similar great variability in both surface water runoff and groundwater recharge.
- The period of record for the few river gauging stations and groundwater monitoring points within the catchment is biased towards a period of above average rainfall (based on the existing rainfall data). This needs to be taken into consideration when analysing flow and recharge data.
- Data acquired by (Hutley et al., 2001) suggest total evapotranspiration during the wet season in the Katherine area is 3.1 mm/day. Annual tree water use was estimated in the same report to be approximately 150 mm/year. Wet season pan evaporation rates averaged about 5.5 mm/day.
- Jolly et al. (Jolly et al., 2000a) trialled a range of values for evapotranspiration from the recharge area for the Tindall Limestone aquifer in developing a model to predict historical groundwater-fed flows in the Katherine River. A range of values was trialled for wet season daily losses (primarily due to evapotranspiration) and a value of 5 mm/day was chosen in the model as it yielded the best correlation between gauged and predicted groundwater-fed river flows.
- Potential annual (water year) recharge rates have been determined for three areas that cover the variability in rainfall, vegetation and terrain likely to be encountered across the region. These localities are:
    - Katherine (Jolly et al., 2000a)
    - Victoria River Downs (Jackson and Jolly, 2004)
    - Darwin (Jolly et al., 2000b).

However, in all of these studies surface runoff was included in the estimate of potential recharge rate. Subsequent modelling work in the Daly Basin (Knapton, 2006) has identified that of the potential recharge rate, where water levels do not rise above ground level during the wet seasons, approximately 60 percent will be surface runoff and 40 percent recharge. Assuming recharge is 40 percent of the potential recharge rate and combining the datasets for the three localities yields a useful relationship between recharge and rainfall for the region (Figure RO-30).

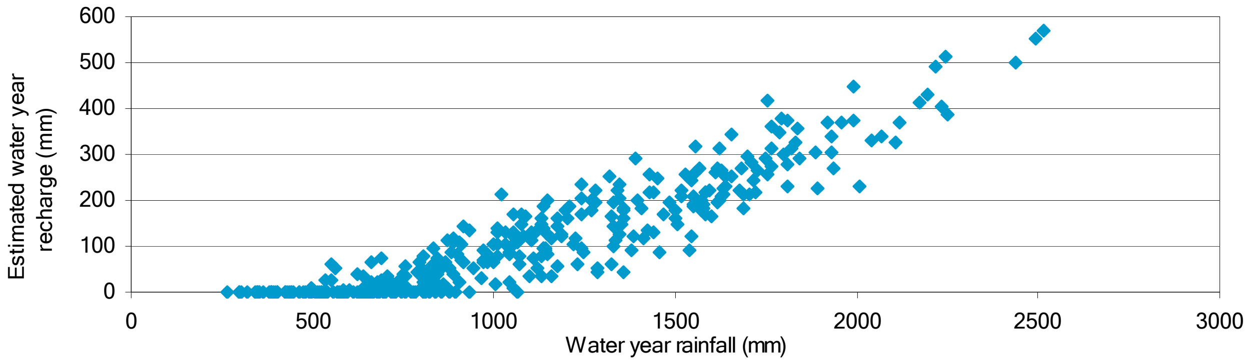



Figure RO-30. Estimated annual (water year) recharge for the Roper region

### RO-3.4.2 Surface–groundwater interaction

In this section, the impact of groundwater extractions on surface water yields is considered. The impact is to stream depletion whereby pumped groundwater eventually is sourced from a nearby river. The distance between a groundwater pump and a nearby river greatly affects the timing of its impacts on that river. Licensed groundwater extraction within the Roper region is currently limited to two licences totalling only 0.58 GL/year. Hence, this section will focus on hypothetical analyses that can be used for managing future groundwater developments. It is worth noting however, that the following analysis assumes a homogeneous aquifer in which groundwater flow is distribyed throughout the porous limestone. It does not account for groundwater flow through dissolution features (e.g., caves) and therefore may provide misleading results for extraction close to the river.

Figure RO-31 shows results of stream depletion calculations for hypothetical scenarios in the unconfined carbonate aquifers to provide some insight into the potential impacts of further groundwater development. The calculations assume an aquifer transmissivity of 400 $m^2$/day and specific yield of 0.2.

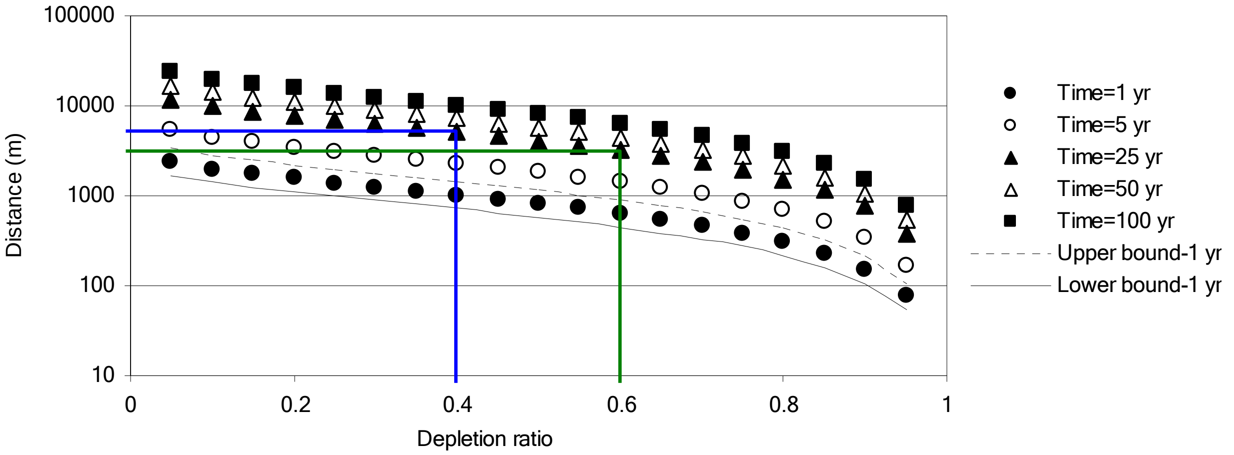



Figure RO-31. Impact of hypothetical scenarios in an unconfined aquifer on stream depletion

Figure RO-31 can be used as a management tool in two different ways:

- locating bores to minimise stream depletion. For example, if a proponent wanted to pump groundwater at 10,000 $m^3$/day and was not allowed to deplete the river by more than 4,000 $m^3$/day (i.e. depletion ratio = 0.4) on any occasion during the next 25 years, the pumping bores would need to be located no closer than 5 km from the river (see blue lines in Figure RO-31).
- determining maximum groundwater pumping rates at specified distances from the stream. For example, if a proponent wanted to pump groundwater from a bore located 3 km from a river and was not permitted to deplete the river by more than 4000 $m^3$/day on any occasion during the next 25 years, the corresponding depletion ratio would be 0.6 (see green lines in Figure RO-31) and the maximum pumping rate is 4,000/0.6 = 6666 $m^3$/day.

There is a great uncertainty in estimating representative aquifer parameters for this analysis. Upper and lower limits for this uncertainty can be defined and hence an estimate corresponding to upper and lower bounds for impacts. The example curves shown in Figure RO-31 represent the likely impacts (after 1 year) for a 100 percent uncertainty in aquifer transmissivity.

Given the importance of carbonate aquifers in providing dry season flows to perennial rivers in the region, any new groundwater developments should be located as far as possible from rivers to minimise the short-term (seasonal) impact, which can potentially reduce flow during the dry season. By locating developments away from the river, the impacts would be delayed, but the aquifer is depleted (rather than the river). However, the aquifer is likely to be recharged during the wet season.

## RO-3.5 Rainfall-runoff modelling results

In this section the term runoff is the sum of overland flow, interflow and baseflow. It is equivalent to streamflow expressed as a mm depth equivalent. All plots show data averaged over the modelled subcatchments of the Roper region. For this reason rainfall reported in this section may vary slightly from that reported elsewhere due to differences between the catchment boundaries (shown in Figure RO-1) and the DEM-derived catchment boundaries used here. In this section, where annual data are reported years are represented by numbers 1 through 77. Consistently throughout this report, annual data are based on the water year (1 September to 31 August) and the dry season is defined as 1 May to 31 October. Unless stated otherwise scenarios Cwet, Cmid and Cdry are selected on the basis of the ranked mean annual runoff. For more details on methods refer to Section 2.2 of the division-level Chapter 2.

### RO-3.5.1 Regional synopsis

The rainfall-runoff modelling estimates runoff in 0.05 degree grid cells in 39 subcatchments (Figure RO-32). Optimised parameter values from eight calibration catchments are used. Four of these calibration catchments are in the Roper region. The remaining calibration catchments are in the South-West Gulf region (two) and the Arafura Sea region (two). In the Roper catchment the gauging stations are predominantly located in the upper reaches.

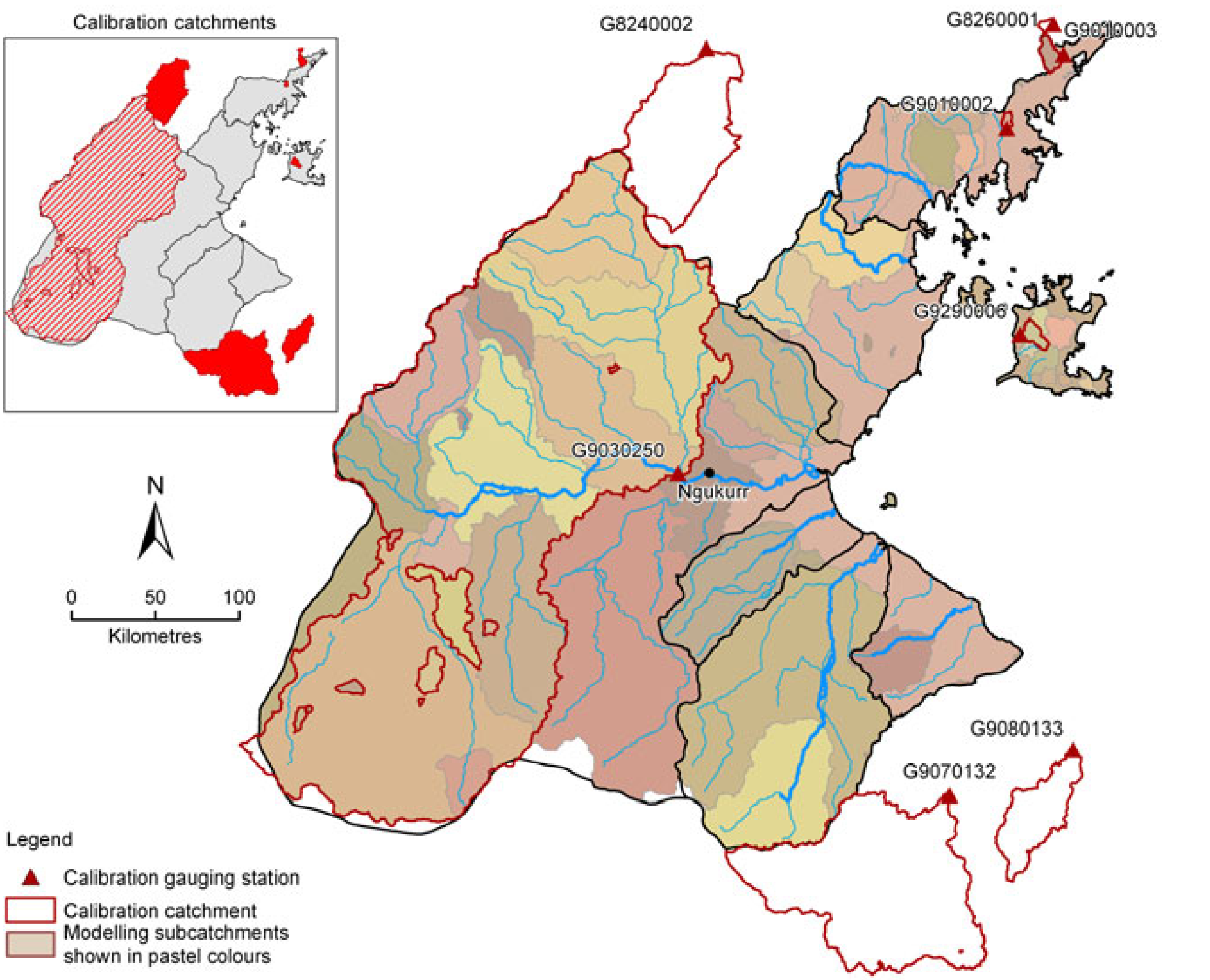



Figure RO-32. Map of the modelling subcatchments, calibration catchments and calibration gauging stations used for the Roper region with inset highlighting (in red) the extent of the calibration catchments. Notes: (i) gauge G8240002 is in the Arafura region while gauges G9070132 and G9080133 are in the South-west Gulf region; and (ii) the area of the rainfall-runoff catchments is slightly different from the Australian Water Resources Council boundary as it is based on a more recent version of the digital elevation model

## RO-3.5.2 Model calibration

Figure RO-33 compares the modelled and observed monthly runoff and the modelled and observed daily flow duration curves for the ten calibration catchments. Nash-Sutcliffe efficiency (NSE) values provide a quantitative measure of how well simulated values match observed values. NSE values are described in more detail in Section 2.2.3 of the division-level Chapter 2. On the monthly plots NSE is the monthly Nash-Sutcliffe efficiency value and NSE (dry season) is the dry season monthly Nash-Sutcliffe efficiency value. On the daily flow exceedance plots, NSE is the daily flow exceedance curve Nash-Sutcliffe efficiency value and NSE (50 to 100 percent) is the lower half of the daily flow exeedance curve Nash-Sutcliffe efficiency value.

The results indicate that the ensemble calibration of the rainfall-runoff models Sacramento and IhacresClassic does not reproduce the observed monthly runoff series (monthly NSE values generally greater than 0.6) and the daily flow duration characteristic (NSE values generally greater than 0.85) well. However, it should be noted that the volumetric constraint used in the model calibration also ensures that the total modelled runoff is within 5 percent of the total observed runoff.

The calibration method places more importance on the simulation of high runoff, and therefore rainfall-runoff modelling of the medium and high runoff is considerably better than the modelling of low runoff. It should be noted, however, that while the relative difference between the observed and simulated low flow values may be large (which is what gives rise to the low monthly dry season NSE values for example), the absolute difference between the observed and simulated low flow values is generally small because both values are small. This is demonstrated by the relatively low NSE values for the monthly dry season and lower half of the daily flow duration characteristic. Nevertheless, an optimisation to reduce overall error variance can result in some underestimation of high runoff and overestimation of low runoff. This is evident in some of the scatter plots comparing the modelled and observed monthly runoff and many of the daily flow duration curves. For the majority of calibration catchments the disagreement between the modelled and observed daily runoff characteristics is discernable for runoff that is exceeded less than 1 percent of the time. This is accentuated in the plots because of the linear scale on the y-axis and normal probability scale on the x-axis. In any case, the volumetric constraint used in the model calibration ensures that the total modelled runoff is always within 5 percent of the total observed runoff. As indicated by the relatively low NSE values for the lower half of the daily flow exceedance curve and monthly dry season there may be considerable disagreement between observed and modelled low flow values (i.e. cease-to-flow).

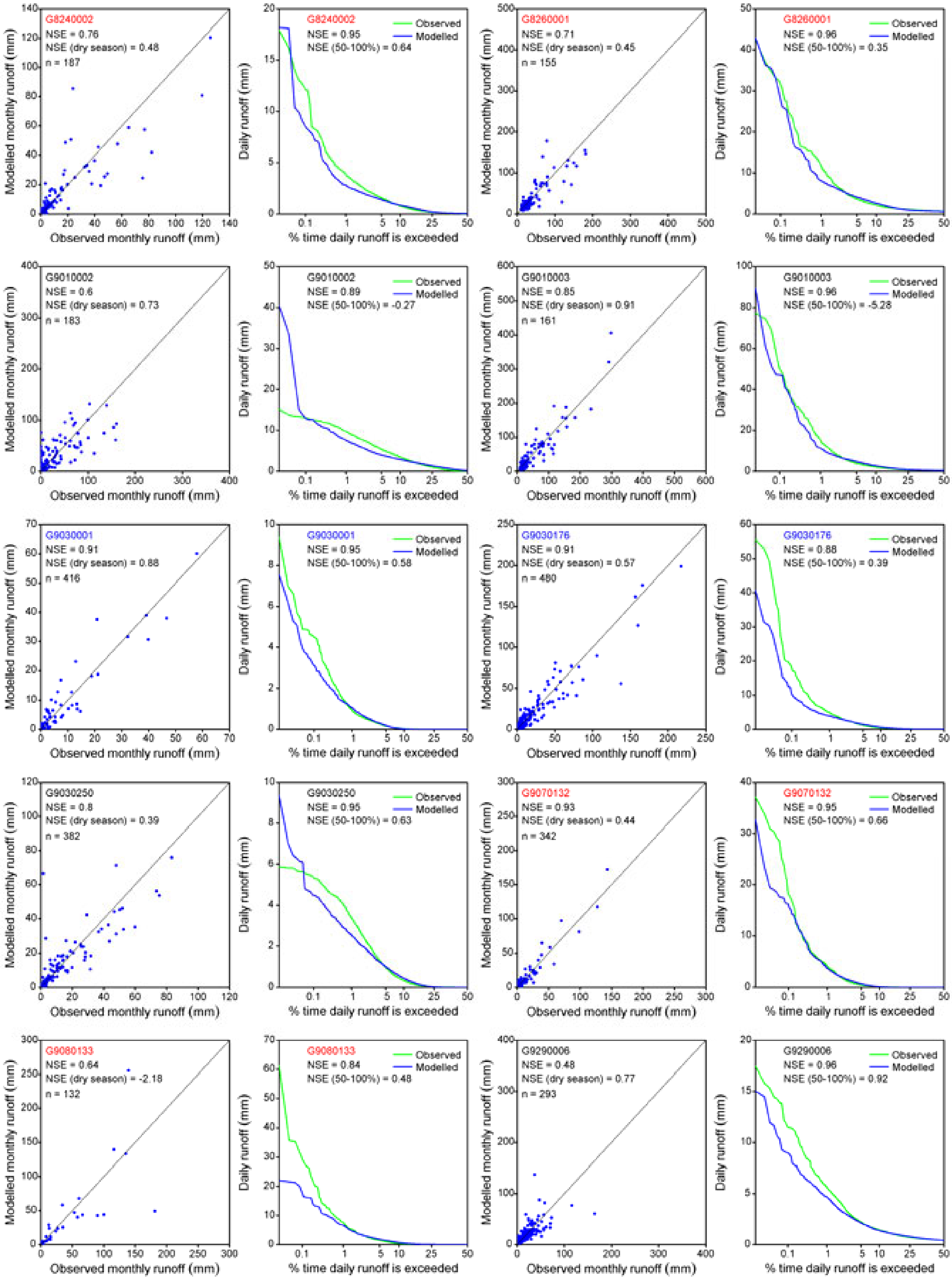



Figure RO-33. Modelled and observed monthly runoff and daily flow exceedance curve for each calibration catchment in the Roper region. (Red text denotes gauges located outside the region; blue text denotes gauges used to predict streamflow only)

### RO-3.5.3 Under historical climate

Figure RO-34 shows the spatial distribution of mean annual rainfall and runoff under Scenario A (averaged over 1930 to 2007) across the Roper region. Figure RO-34 shows the mean annual rainfall and runoff averaged over the region.

The mean annual rainfall and runoff averaged over the modelled Roper region are 839 mm and 112 mm respectively. The mean wet season and dry season runoff averaged over the Roper region are 103 mm and 8 mm respectively.

In this project, all runoff grids are presented as long-term mean annual values. However the distributions of monthly and annual runoff data in northern Australia can be highly skewed; consequently the median and additional percentile values spatially averaged over the region are also reported. The 10$^{th}$ percentile, median and 90$^{th}$ percentile annual runoff values across the Roper region are 194, 101 and 31 mm respectively. The median wet season and dry season runoff averaged over the Roper region are 94 mm and 7 mm respectively.

The mean annual rainfall varies from over 1300 mm in the north-east tip to about 600 mm in the south. The mean annual runoff varies from over 400 mm in the north-east to under 20 mm in the south-west (Figure RO-34) and runoff coefficients vary from less than 4 to greater than 35 percent. The majority of rainfall and runoff occurs during the wet season months December to April. Rainfall and runoff can vary considerably from year to year with long periods over several years or decades that are considerably wetter or drier than others (Figure RO-35 and Figure RO-36). The coefficients of variation of annual rainfall and runoff averaged over the Roper region are 0.25 and 0.67 respectively.

The Roper is one of 13 regions which cover the three divisions studied in this project. Mean annual rainfall and runoff, as well as coefficients of variation, have been calculated for all of these 13 regions, and it is useful to compare the Roper results to results across all 13 regions. Across all 13 regions in this project 10$^{th}$ percentile, median and 90$^{th}$ percentile values are 1371, 936 and 595 mm respectively for mean annual rainfall and 374, 153 and 78 mm respectively for mean annual runoff. The mean annual rainfall (839 mm) and runoff (112 mm) averaged over the Roper region fall in the mid to lower end of this range. Across all 13 regions in this project the 10$^{th}$ percentile, median and 90$^{th}$ percentile values are 0.34, 0.26 and 0.19 respectively for the coefficient of variation of annual rainfall and 1.39, 0.69 and 0.48 for the coefficient of variation of runoff. The coefficients of variation of annual rainfall (0.25) and runoff (0.67) averaged over the Roper region are in the middle of the range of the 13 reporting regions.

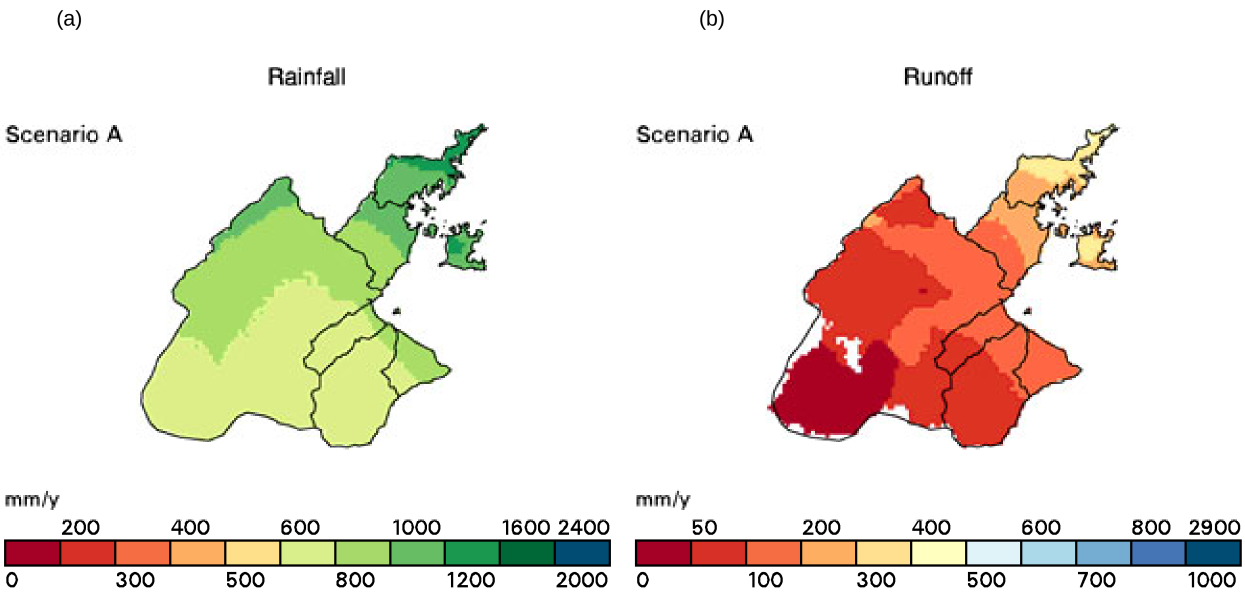



Figure RO-34. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the Roper region under Scenario A

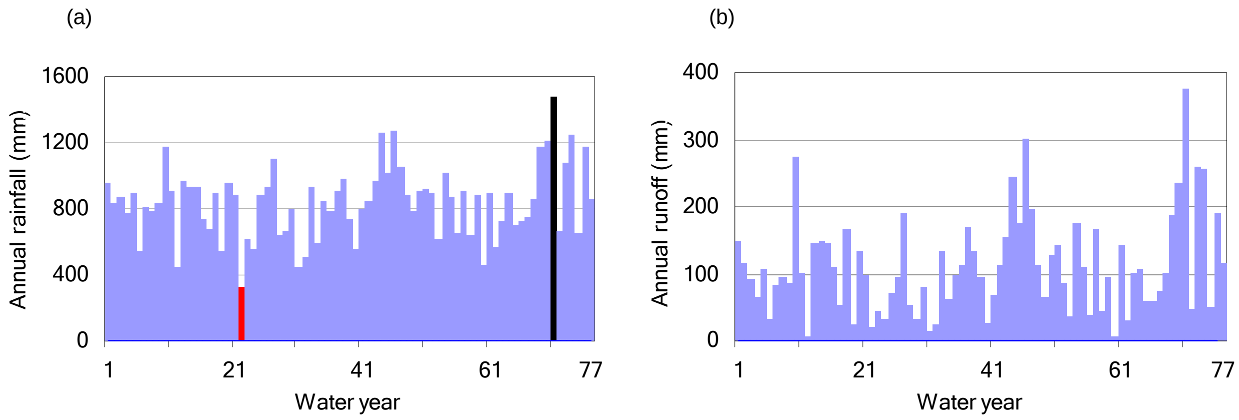



Figure RO-35. Annual (a) rainfall and (b) modelled runoff in the Roper region under Scenario A

Figure RO-36(a,b) shows the minimum and maximum monthly rainfall and runoff and the range of values between the 25th and 75th percentile monthly rainfall and runoff. Figure RO-36(c,d) shows the mean and median monthly flows and the range of values between the 25th and 75th percentile monthly rainfall and runoff. The large difference in the mean and median wet season monthly runoff values indicates that the distribution of monthly runoff in the Roper region is highly skewed.

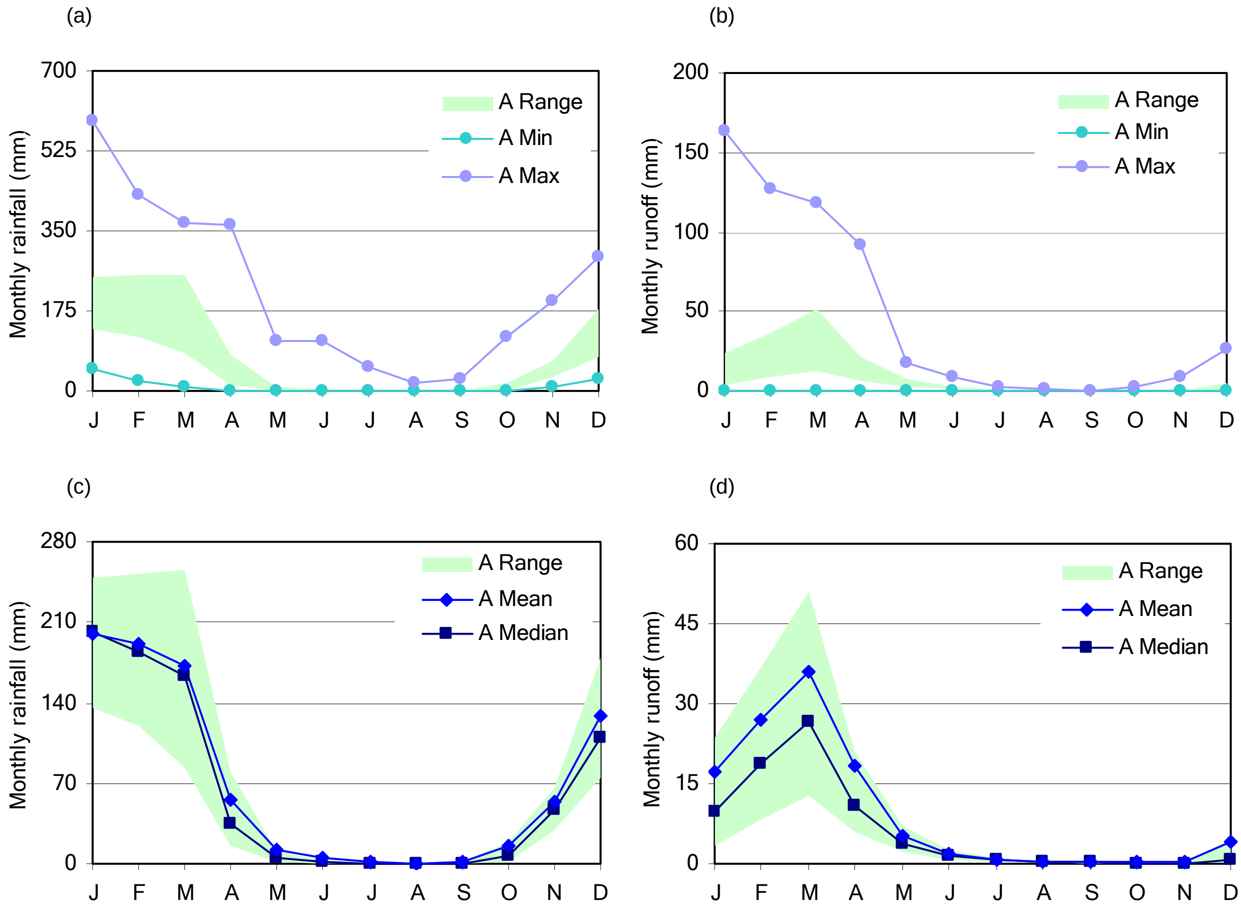



Figure RO-36. Minimum, maximum and A range monthly (a) rainfall and (b) modelled runoff; and mean, median and A range monthly (c) rainfall and (d) modelled runoff in the Roper region under Scenario A (A range is the 25th to 75th percentile monthly rainfall or runoff)

### RO-3.5.4 Under recent climate

The mean annual rainfall and runoff under Scenario B (1996 to 2007) are 20 percent and 54 percent higher respectively than the historical (1930 to 2007) mean values. The spatial distribution of rainfall and runoff across the Roper region under Scenario B is shown in Figure RO-37.

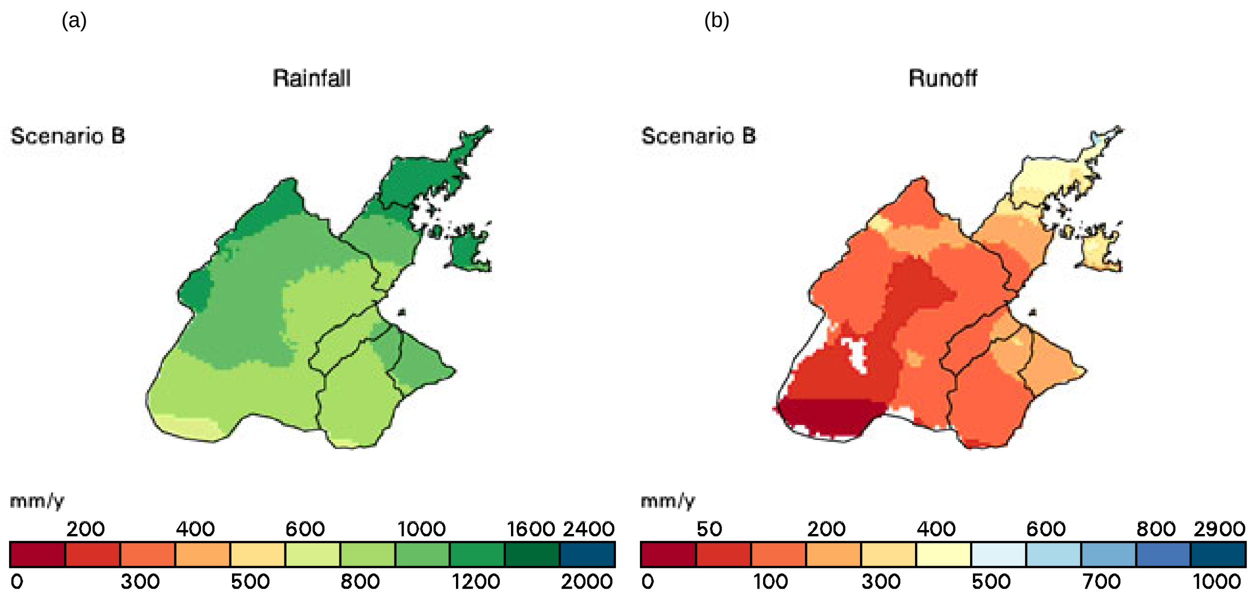



Figure RO-37. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the Roper region under Scenario B

### RO-3.5.5 Under future climate

Figure RO-38 shows the percentage change in the mean annual runoff averaged over the Roper region under Scenario C relative to Scenario A for the 45 scenarios (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). The percentage change in the mean annual runoff and rainfall from the corresponding GCMs are also tabulated in Table RO-6.

The figure and table indicate that the potential impact of climate change on runoff can be very significant. Although there is considerable uncertainty in the estimates, the results indicate that runoff in ~2030 in the Roper region is more likely to decrease than increase. Rainfall-runoff modelling with climate change projections from three-fifths of the GCMs shows a reduction in mean annual runoff, while rainfall-runoff modelling with climate change projections from two-fifths of the GCMs shows an increase in mean annual runoff. The wide range of mean annual runoff values shown in Figure RO-38 and Table RO-6 is primarily due to the wide range of future projections of rainfall by the 15 GCMs.

Because of the large variation between GCM simulations and the method used to obtain the climate change scenarios, the biggest increase and biggest decrease in runoff comes from the high global warming scenario. For the high global warming scenario, rainfall-runoff modelling with climate change projections from two of the GCMs indicates a decrease in mean annual runoff greater than 10 percent while rainfall-runoff modelling with climate change projections from four of the GCMs indicates an increase in mean annual runoff greater than 10 percent.

In subsequent reporting here and in other sections, only results from a wet extreme, median and dry extreme variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet, results from the second highest increase in mean annual runoff from the high global warming scenario are used. Under Scenario Cdry, results from the second highest reduction in mean annual runoff from the high global warming scenario are used. Under Scenario Cmid, the median mean annual runoff results from the medium global warming scenario are used. These are shown in bold in Table RO-6.

Under scenarios Cwet, Cmid and Cdry, mean annual runoff changes by 33, -2 and -18 percent relative to Scenario A. By comparison, the range based on the low global warming scenario is a 17 to -10 percent change in mean annual runoff.

Figure RO-39 shows the mean annual runoff across the Roper region under scenarios A and C. The linear discontinuities that are evident in Figure RO-39 are due to GCM grid cell boundaries.

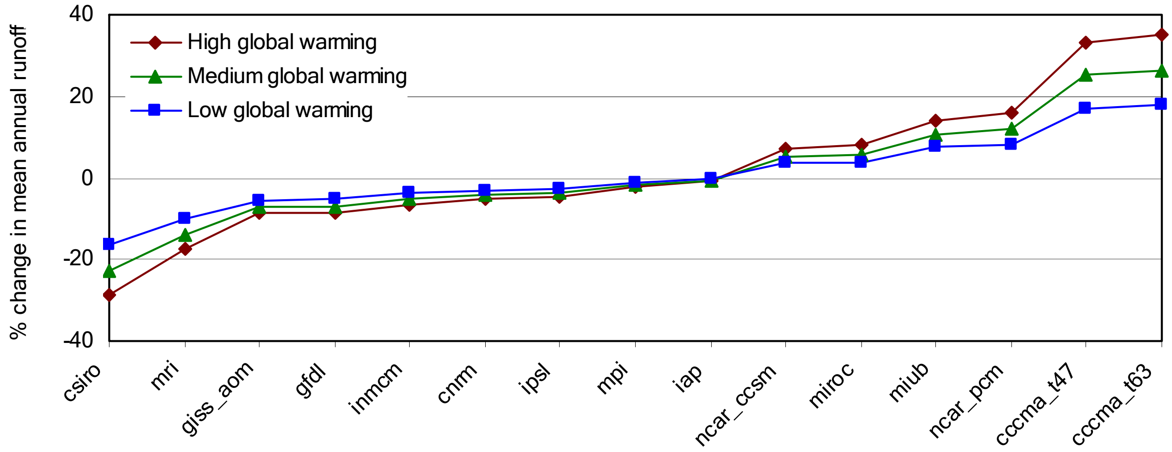



Figure RO-38. Percentage change in mean annual modelled runoff under the 45 Scenario C variants (15 global climate models and three global warming scenarios) relative to Scenario A

Table RO-6. Summary results under the 45 Scenario C simulations for the modelling subcatchments in the Roper region (numbers show percentage change in mean annual rainfall and modelled runoff under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Runoff | GCM | Rainfall | Runoff | GCM | Rainfall | Runoff |
| csiro | -14% | -29% | csiro | -11% | -23% | csiro | -8% | -17% |
| **mri** | **-6%** | **-18%** | mri | -5% | -14% | mri | -3% | -10% |
| giss_aom | -4% | -9% | gfdl | -7% | -7% | gfdl | -5% | -5% |
| gfdl | -10% | -9% | giss_aom | -3% | -7% | giss_aom | -2% | -5% |
| inmcm | 0% | -7% | inmcm | 0% | -5% | inmcm | 0% | -4% |
| cnrm | 0% | -5% | cnrm | 0% | -4% | cnrm | 0% | -3% |
| ipsl | -1% | -5% | ipsl | -1% | -4% | ipsl | 0% | -3% |
| mpi | 0% | -2% | **mpi** | **0%** | **-2%** | mpi | 0% | -1% |
| iap | -2% | -1% | iap | -2% | -1% | iap | -1% | 0% |
| ncar_ccsm | 5% | 7% | ncar_ccsm | 4% | 5% | ncar_ccsm | 3% | 4% |
| miroc | 4% | 8% | miroc | 3% | 6% | miroc | 2% | 4% |
| miub | 4% | 14% | miub | 3% | 11% | miub | 2% | 7% |
| ncar_pcm | 9% | 16% | ncar_pcm | 7% | 12% | ncar_pcm | 5% | 8% |
| **cccma_t47** | **11%** | **33%** | cccma_t47 | 8% | 25% | cccma_t47 | 6% | 17% |
| cccma_t63 | 10% | 35% | cccma_t63 | 8% | 26% | cccma_t63 | 6% | 18% |

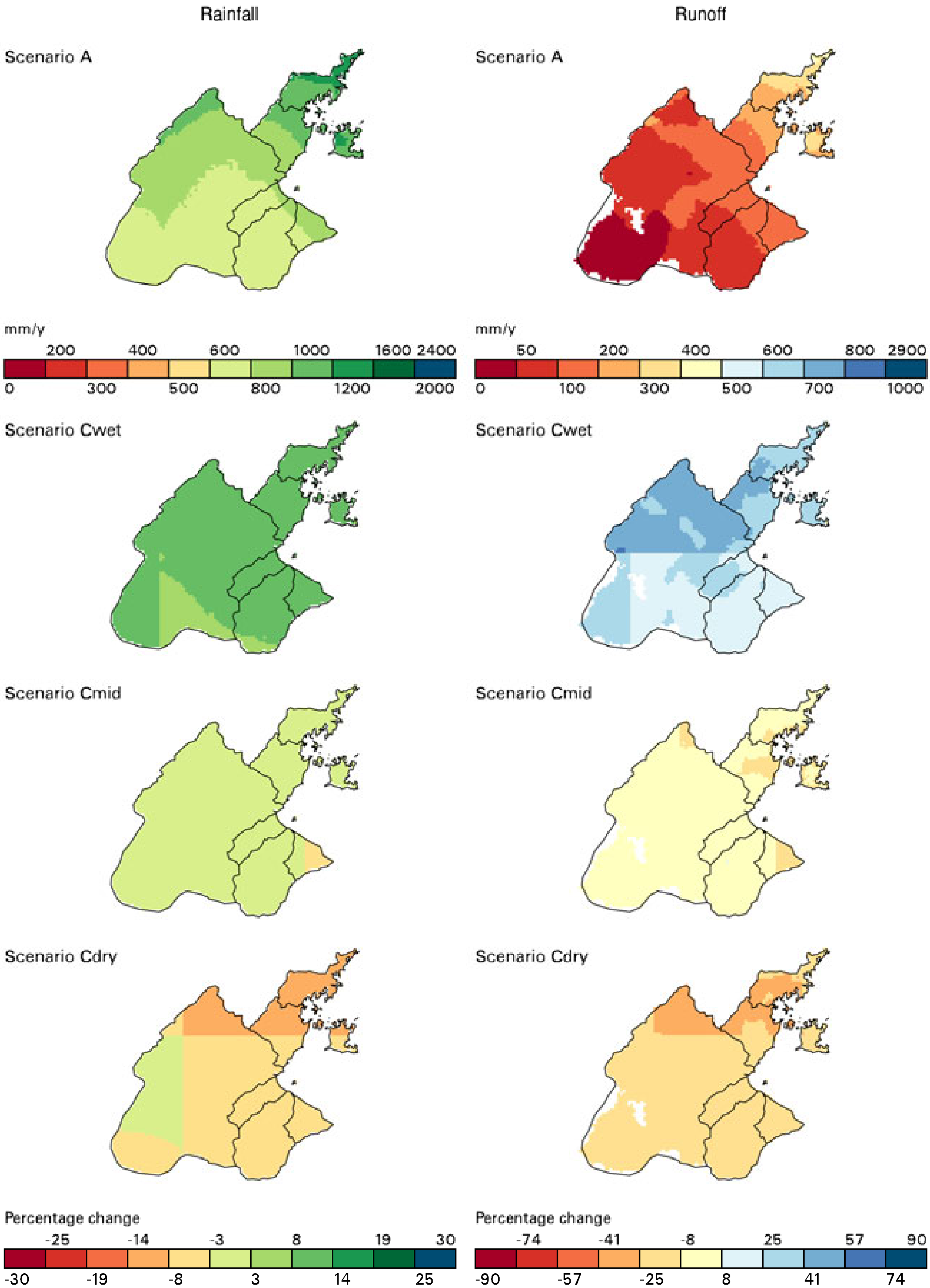



Figure RO-39. Spatial distribution of mean annual rainfall and modelled runoff across the Roper region under Scenario A and under Scenario C relative to Scenario A

## RO-3.5.6 Summary results for all scenarios

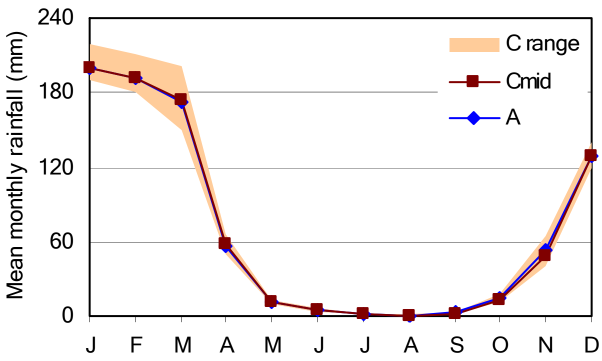
Table RO-7 shows the mean annual rainfall, runoff and actual evapotranspiration under Scenario A averaged over the Roper region, and the percentage changes in the rainfall, runoff and actual evapotranspiration under scenarios B and C relative to Scenario A. The Cwet, Cmid and Cdry results are based on the mean annual runoff, and the rainfall changes shown in Table RO-7 are the changes in the mean annual value of the rainfall series used to obtain the runoff under scenarios Cwet, Cmid and Cdry. The changes in mean annual rainfall do not necessarily translate directly to the changes in mean annual runoff because of changes in seasonal and daily rainfall distributions and the relationship between rainfall and runoff is non-linear. The latter factor usually results in small changes in rainfall to be amplified in runoff (Table RO-6).

Figure RO-40 shows the mean monthly rainfall and runoff under scenarios A and C averaged over 1930 to 2007 for the region. Figure RO-41 shows the daily rainfall and flow duration curves under scenarios A and C averaged over the region. Figure RO-41 shows that the daily flow characteristic curve for Scenario B is greater than C range. In Figure RO-40 Cwet, Cmid and Cdry are selected on a month-by-month basis, while in Figure RO-41 Cwet, Cmid and Cdry are selected for every day of the daily flow exceedance curve.

Table RO-7. Water balance over the entire Roper region under Scenario A and under scenarios B and C relative to Scenario A

| Scenario | Rainfall | Runoff | Evapotranspiration |
|---|---|---|---|
| | mm | | |
| A | 839 | 112 | 727 |
| | percent change from Scenario A | | |
| B | 21% | 54% | 16% |
| Cwet | 11% | 33% | 7% |
| Cmid | 0% | -2% | 0% |
| Cdry | -6% | -18% | -4% |

(a)




(b)

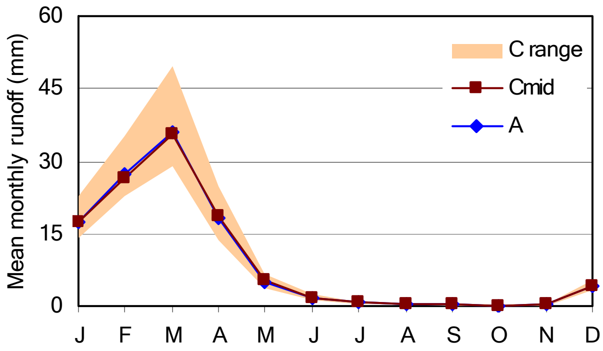



Figure RO-40. Mean monthly (a) rainfall and (b) modelled runoff in the Roper region under scenarios A and C (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

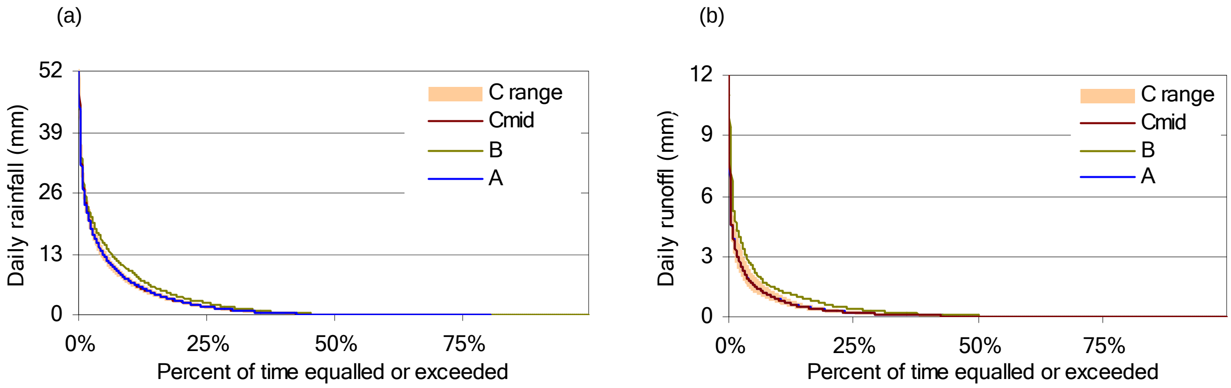



Figure RO-41. Daily flow exceedance curves for (a) rainfall and (b) modelled runoff in the Roper region under scenarios A, B and C (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

## RO-3.5.7 Confidence levels

The level of confidence of the runoff estimates for the Roper region is low because there are few catchments with high quality gauging station data. NSE values for monthly runoff and daily flow duration curve characteristic are low relative to other regions. This may be due to a combination of factors, including poor rainfall records in the region (Figure RO-5), gauging stations may be sited in ‘open systems’ (i.e. flow may bypass the gauge), and variable quality streamflow records due to the difficulty of operating and maintaining stations in remote areas. Low flow records from areas of carbonate rock can be affected by the formation of Tufa dams. This appears to be the case at several stations within the Roper (e.g. 9030176 and G9030013) and this further reduces the level of confidence in the dry season flow calibrations at these sites.

The rainfall-runoff model verification analysis with data from 123 catchments from across all of northern Australia indicates that the mean annual runoff for ungauged catchments are under estimated or over estimated, when using optimised parameter values from a nearby catchment, by less than 20 percent in 40 percent of catchments and by less than 50 percent in 80 percent of the catchments.

Transposing parameter sets in the Roper region is problematic because of the distances between donor and target subcatchments and some areas of the Roper have complex surface–groundwater interactions. Consequently there is a low level of confidence associated with predictions of runoff in ungauged subcatchments in the Roper region. No gauges are sited on the coastal area of the Roper and parameter sets for these regions were donated from far away calibration catchments. Extrapolating runoff values recorded at gauging stations to the broader Roper region is confounded by problems of bias, with a disproportionate number of stations sited within or downstream of areas of productive aquifer systems (Figure RO-7). There is also considerable uncertainty about catchment areas as there are distributary channels and sinkholes in the upper reaches. Diagrams in (Petheram, 2009) illustrate which calibrated rainfall-runoff model parameter sets are used to model streamflow in which ungauged subcatchments in the Roper region.

Figure RO-42 illustrates the level of confidence in modelling the mid to high runoff events (i.e. peak flows) and dry season runoff (respectively) for the subcatchments of the Roper region. It should be noted that these maps of level of confidence are not statistical confidence levels and are intended to only convey a broad reliability of prediction. Except in three small calibration catchments in the north-west, there is a low level of confidence associated with gridded predictions for mid to high and dry season runoff events in the Roper region. The level of confidence in streamflow predictions will vary slightly from the level of confidence in runoff predictions shown below and as discussed in Section 2.2.6 of the division-level Chapter 2.

There is a high degree of confidence that dry season runoff in the Roper region is low because it is known that rainfall and baseflow are low during the dry season. The map of level of confidence for dry season flow shown in Figure RO-42 provides a relative indication of how well dry season metrics, such as cease-to-flow, are simulated.

In summary the level of confidence in the long-term average monthly and annual results for the Roper region are low relative to other regions in this study. As shown in Figure RO-42, in many areas of the Roper region localised studies will require more detailed analysis than undertaken and reported here and would most likely require the site to be visited and additional field measurements made.

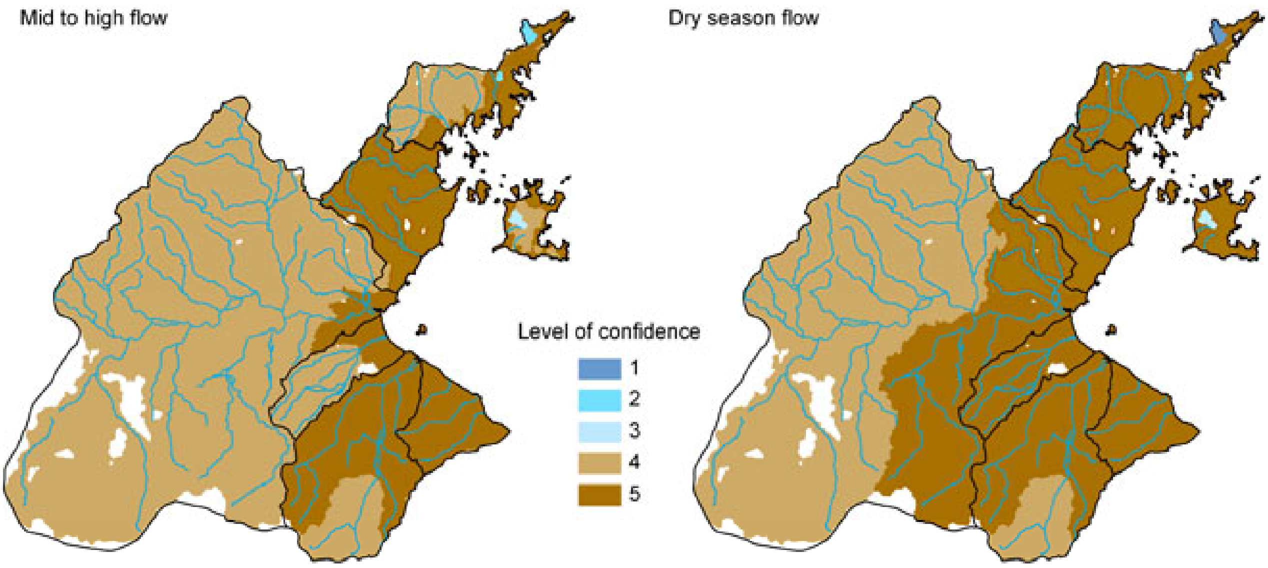



Figure RO-42. Level of confidence in the modelling of runoff for (a) mid- to high flow events and (b) monthly dry season flow events for the modelling subcatchments of the Roper region. 1 is the highest level of confidence, 5 is the lowest

## RO-3.6 River system water balance

The Roper region is comprised of seven AWRC river basins and has an area of 128,518 km$^2$. Under the historical climate the mean annual runoff across the region is 112 mm (Section RO-3.5.3), which equates to a mean annual streamflow across the region of 14,394 GL.

No information on infrastructure, water demand, water management, sharing rules or future development were available, and consequently there is no river modelling section to the Roper region report. Streamflow time series have been generated for each streamflow reporting node (SRN) based on the upstream grid cell rainfall-runoff simulations, as described in Section 2.2.5 of the division-level Chapter 2. The locations of these nodes are shown in Figure RO-43. Summary streamflow statistics for each SRN are reported in (Petheram, 2009). In addition to the streamflow time series generated by the rainfall-runoff model ensemble, a range of hydrological metrics computed using regression analysis are also available for each SRN (as described in Section 2.2.7 of the division-level Chapter 2). The complete set of results for the multiple regression analysis is reported in SKM (2009). The merit of each approach is discussed in Section 2.2.7 of the division-level Chapter 2.

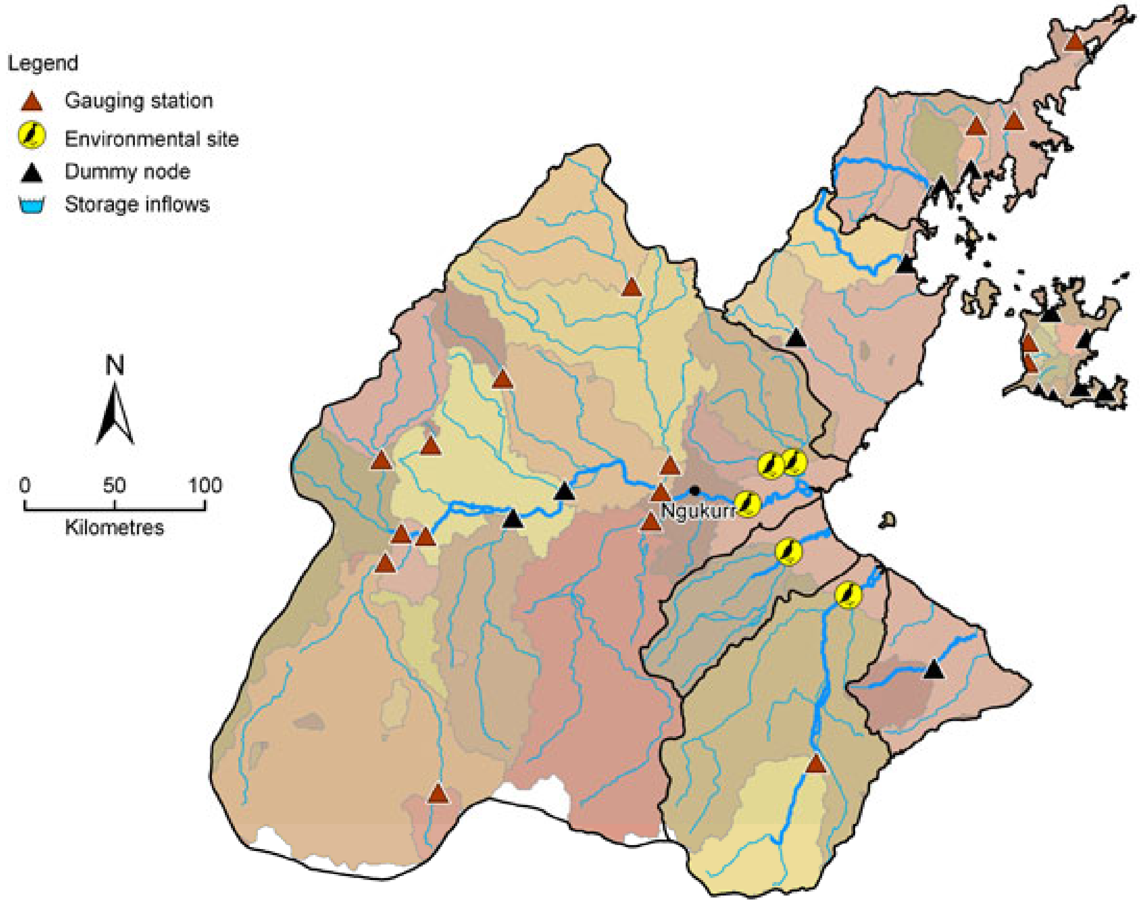



Figure RO-43. Map of streamflow reporting nodes (gauging stations, environmental sites, dummy nodes and storage inflows) in the Roper region. (No storage inflows are reported for this region)

# RO-3.7 Changes to flow regimes at environmental assets

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Two environmental assets have been shortlisted in the Roper region: Limmen Bight (Port Roper) Tidal Wetlands System and Mataranka Thermal Pools. The locations of these assets is shown in Figure RO-1 and the assets are characterised in Chapter RO-2.

This section presents the assessment of these shortlisted assets and reports metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis. Confidence in results for low flows and high flows was calculated separately on a scale of 1 to 5, with 1 indicating results with the highest confidence (as described in Section 2.2.6 of the division-level Chapter 2). Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are 1, 2 or 3. If confidence levels in the low flows or high flows are ranked 4 or 5, results are not reported and are labelled NR (not reported).

Some of the assets in this region have multiple nodes at which streamflow modelling results are available. When reporting hydrological regime metrics for such assets a single node was selected. The selected node was that with the highest streamflow confidence level and the largest proportion of streamflow to the asset. Results for all nodes are presented in (McJannet et al., 2009).

In the absence of site-specific metrics for the Roper region a set of standard metrics related to high and low flows have been utilised. However the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and ecology.

## RO-3.7.1 Standard metrics

### Limmen Bight (Port Roper) Tidal Wetlands System

The surface water flow confidence levels for both high and low flows for this asset within the Roper region (see location on Figure RO-9) are ranked unreliable (4 or 5); therefore model data are of insufficient quality to allow environmental flow metrics to be calculated.

### Mataranka Thermal Pools

The Mataranka Thermal Pools (see location on Figure RO-10) are fed by perennial groundwater springs in the upper reaches of the Roper River however there is currently not enough confidence in existing groundwater models to report and results for different scenarios. In addition, the surface water flow confidence levels for both high and low flows for the asset within the Roper region are ranked unreliable (4 or 5); therefore model data are of insufficient quality to allow environmental flow metrics to be calculated.

# RO-3.8 References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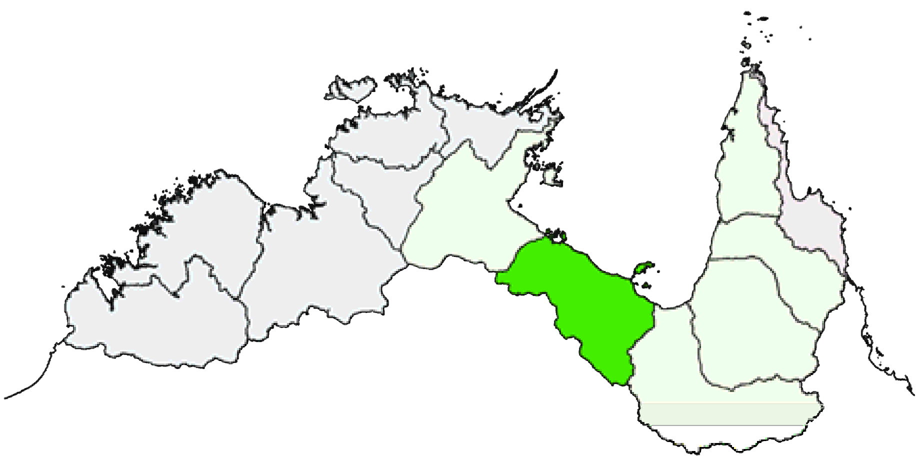
# Water in the South-West Gulf region



# SW-1 Water availability and demand in the South-West Gulf region

The first part of this report (the Preamble, Chapter 1 and Chapter 2) reports at the division level, including division-wide descriptions of climate and geology and methods which apply to all regions. Subsequent chapters report at the region level. In particular, Chapters SW-1, SW-2 and SW-3 focus on the South-West Gulf region (Figure SW-1).

This chapter summarises the water resources of the South-West Gulf region, using information from Chapter SW-2 and Chapter SW-3, and directly addresses the Terms of Reference, specifically terms 3, 4 and 5 as listed in the Preamble. Essentially, this chapter provides a synoptic view of the region and covers:

- regional observations
- water resource assessment
- seasonality of water resources
- surface–groundwater interaction
- changes to flow regime at environmental assets
- water storage options
- data and knowledge gaps.

For further details on the context of the region (physical and climate descriptions, hydrogeology and legislation) see Chapter SW-2. Region-specific methods and results are provided in Chapter SW-3. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2.

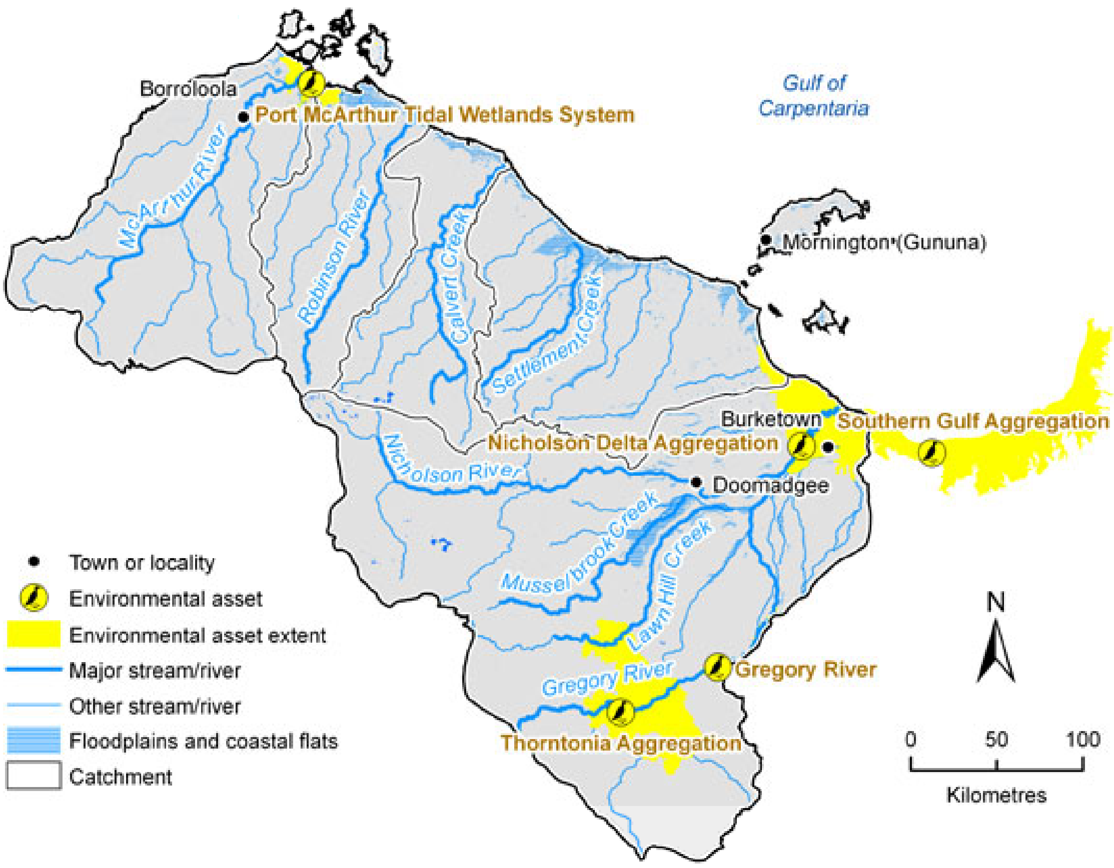



Figure SW-1. Major rivers, towns and location of environmental assets selected for assessment of changes to hydrological regime in the South-West Gulf region

## SW-1.1 Regional summary

This section summarises key modelling results and provides other relevant water resource information as context about water availability and demand in the South-West Gulf region.

The historical (1930 to 2007) mean annual rainfall for the region is 670 mm. Mean annual areal potential evapotranspiration (APET) is 1961 mm. The mean annual runoff averaged over the modelled area of the South-West Gulf region is 89 mm, 13 percent of rainfall. Rainfall and runoff generation both decline with distance from the coast but otherwise show little spatial variation. Under the historical climate the mean annual streamflow over the South-West Gulf region is estimated to be 9,958 GL.

The South-West Gulf region has a very high inter-annual variability of rainfall and hence also runoff and groundwater recharge. Coefficients of variation are 0.34 and 1.0 for rainfall and runoff, respectively. These are among the highest of the regions across northern Australia and reflect multiple years of significantly below average and above average rainfall.

Seasonality is extreme. Ninety-four percent of rainfall falls between November and May. The region has a relatively high rainfall intensity and hence rapid runoff and short lag between rainfall and runoff. There has been a slight increase in rainfall intensity over the historical (1930 to 2007) period.

There is a strong north–south rainfall gradient across the region and runoff varies from 20 to 4 percent of rainfall across the region. Lower reaches are flood determined and dominated.

APET is high throughout the year and exceeds rainfall in all but a few months. Thus the landscape is water-limited: there is more energy available to remove water from the landscape than there is water available to be removed.

The South-West Gulf region has a recent (1996 to 2007) climate record that is 27 percent wetter than the historical climate. This has resulted in a 78 percent increase in runoff for the past 11 years compared to the historical mean. Modelling suggests that the future (~2030) climate conditions will be slightly drier than the historical climate and drier than the recent climate. Under the wet and dry extreme future climates, conditions are wetter and drier, respectively.

There is minimal and unregulated use of surface water in the region.

The major aquifers in the region with potential for development for irrigated agriculture occur in the karstic rocks of the Camooweal Dolostone and Thorntonia Limestone. Potential for groundwater development of the karstic rock areas of the region is limited by their low recharge rates and the environmental significance of the aquatic ecosystems they maintain. The perennial rivers in the region – the Gregory, Calvert and Robinson rivers and Lawn Hill Creek – source their dry season (May to October) flow from karstic rock aquifers.

Current rates of extraction from the aquifers in the region are poorly constrained. Mining water use from the karstic rock aquifers (e.g. Thorntonia Limestone) is locally expected to be large, but precise extraction and re-cycling figures across the region are not available.

Significant contributions of water from the Gregory River to shallow aquifers play an important role in supporting coastal wetland environments. For all environmental assets, there has been significantly more flow recently and therefore there are fewer low flow days and more high flow days. Annual and seasonal flows do not change much under the median future climate, hence there is little change in the high and low flow threshold exceedance. There are moderate changes to the high flow threshold exceedance under wet and dry extreme future climates which may have negative environmental impacts.

The region is extremely datapoor and only a water resource assessment can be made. No models exist to determine a water availability assessment.

## SW-1.2 Water resource assessment

Term of Reference 3a

### SW-1.2.1 Under historical climate and current development

Term of Reference 3a (i)

Mean annual rainfall for the South-West Gulf region is 670 mm, with a standard deviation of 161 mm. Maximum recorded rainfall was 1460 mm in 2001; the lowest was 289 mm in 1952. Mean annual areal potential evapotranspiration (APET) is 1961 mm, with a relatively small variation (standard deviation of 19 mm). Highest APET occurred in 1992 (2067 mm); lowest in 1974 (1814 mm). The mean annual runoff averaged over the modelled area of the South-West Gulf region is 89 mm, 13 percent of rainfall. Rainfall and runoff generation both decline with distance from the coast but otherwise show little spatial variation.

Rainfall is very seasonal, with 94 percent falling during the wet season (November to April), and runoff is highest in February and March.

Current groundwater extraction in the South-West Gulf region, both for licensed and unlicensed purposes, is unknown but expected to be minimal. Natural groundwater discharge from the karstic carbonate aquifers plays an important role in providing dry season surface water flows in the perennial Gregory, Calvert and Robinson rivers and Lawn Hill Creek (Table SW-1).

Table SW-1. Estimated groundwater contribution (baseflow) to streamflow, modelled diffuse recharge and groundwater extraction for the South-West Gulf region under historical climate

| Station | River | Station name | Annual BFI * | Dry season BFI * | Dry season baseflow * |
|---|---|---|---|---|---|
| | | | | GL | |
| 912101A | Gregory | Gregory Downs | 0.26 | 0.86 | 58.3 |
| 912103A | Lawn Hill Ck | Lawn Hill No 2 | 0.17 | 0.74 | 8.3 |
| 912104A | Widdallion Ck | Lawn Hill | 0.25 | 0.80 | 12.7 |
| 912105A | Gregory | Riversleigh No.2 | 0.30 | 0.86 | 57.9 |
| 912106A | Musselbrook Ck | Stockyard Ck | 0.07 | 0.08 | 0.2 |
| G9070132 | McArthur | M. I. M. Pump | 0.09 | 0.52 | 7.2 |
| | | Historical recharge ** | Estimated groundwater extraction | | |
| | | GL/y | | | |
| Entire South-West Gulf region | | 6030 | unknown | | |

* BFI (baseflow index) and baseflow volume derived from gauged data.
** Aggregated recharge from Zhang and Dawes (1998).

Under a continued historical climate, mean annual groundwater recharge to the watertable aquifers in the South-West Gulf region is likely to be similar to the historical (1930 to 2007) average rate. When coupled with the assumed current low level of groundwater development in the region, this means that average groundwater levels and fluxes would be unlikely to change by 2030.

### SW-1.2.2 Under recent climate and current development

Term of Reference 3a (ii)

The mean annual rainfall and runoff over 1996 to 2007 were 27 percent and 78 percent higher, respectively, than the historical (1930 to 2007) mean values. Rainfall increased across the entire region relative to the historical pattern.

Under a continued recent climate, mean annual groundwater recharge to the watertable aquifers of the South-West Gulf region is likely to be significantly higher than historical average rate. Without a detailed groundwater model for the region it is not possible to quantify the impacts of increased recharge to the various aquifers. However, if current groundwater extraction is as low as expected, the increased recharge will ultimately result in higher groundwater levels and increased discharge to rivers and watercourses.

### SW-1.2.3 Under future climate and current development

Term of Reference 3a (iii)

Future climate is expected to be similar to historical climate. Under the wet extreme, median and dry extreme future climates, annual rainfall is 732, 668 and 632 mm, respectively. Corresponding APET values under these scenarios are 2002, 2009 and 2041 mm, respectively.

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the South-West Gulf region is more likely to decrease than increase. Rainfall-runoff modelling from two-thirds of the global climate models (GCMs) shows a reduction in mean annual runoff, while one-third of the GCMs show an increase in mean annual runoff. For the high global warming scenario, rainfall-runoff modelling with climate change projections from six of the GCMs indicates a decrease in mean annual runoff greater than 10 percent while four of the GCMs indicate an increase in mean annual runoff greater than 10 percent.

The median estimate is a 3 percent decrease in mean annual runoff by 2030. The extreme estimates range from an increase of 19 percent to a decrease of 18 percent in mean annual runoff. By comparison, the range based on the low global warming scenario is a 10 to -10 percent change in mean annual runoff.

Under the future climate, mean annual groundwater recharge to the watertable aquifers of the South-West Gulf region is likely to be slightly higher than the historical average rate. Whilst the impacts of slightly higher recharge on the groundwater balance cannot be quantified without a groundwater model, they are likely to be insignificant around 2030.

### SW-1.2.4 Under future climate and future development

Term of Reference 3a (iv)

Projecting impacts of future climate and future development is not possible without detailed river and groundwater models for the main rivers and aquifers in the region. However, any future groundwater development located within several kilometres of the perennial rivers is likely to have a detrimental (though possibly delayed) impact on dry season flows in those rivers.

## SW-1.3 Changes to flow regime at environmental assets

Term of Reference 3b

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Five environmental assets were shortlisted for the South-West Gulf region: Gregory River, Nicholson Delta Aggregation, Port McArthur Tidal Wetland System, Southern Gulf Aggregation and the Thorntonia Aggregation. These assets are characterised in Chapter SW-2.

In deciding whether it is feasible to report hydrological regime metrics for these shortlisted assets, it is important to consider the confidence levels in modelled streamflow (as described in Section 2.2.6 of the division-level Chapter 2). Confidence in results for low flows and high flows was calculated separately. Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are sufficiently high. If confidence in the low flow or high flow is too low, metrics are not reported, and hence an important gap in our knowledge is identified.

Some of the assets in this region have multiple nodes at which streamflow modelling results are available. When reporting hydrological regime metrics for such assets a single node was selected. The selected node was that with the highest streamflow confidence level and the largest proportion of streamflow to the asset. The location of nodes for each asset are shown on satellite images in Section SW-2.1.3. Results for all nodes are presented in McJannet et al., (2009).

For the South-West Gulf region, high (wet season) flows for nodes at three assets were considered reliable. Thus metrics are reported in the final section of Chapter SW-3 for these assets: Gregory River, Port McArthur Tidal Wetlands System and the Thorntonia Aggregation.

Confidence in low (dry season) flows was not sufficiently reliable for reporting metrics at any asset. Thus, only general comments can be made about changes to average annual and low flow conditions under the different scenarios.



At all assets under the recent climate, flows are significantly (>20 percent) greater than the historical average, resulting in more frequent exceedance of high flow thresholds. The number of days above the high flow threshold increases from 18 days/year to more than 23 days/year at all sites.

Under the median future climate there is no significant change from the historical regime, but there are moderate increases and decreases under the wet and dry extreme future climates.

## SW-1.4 Seasonality of water resources

Term of Reference 4

The rivers have a marked seasonal flow regime of high water levels during the wet season (November to April) and minimal flow during the dry season (May to October). Approximately 95 percent of rainfall and 97 percent of runoff occurred during the wet season months under the historical and recent climates. Very similar seasonal percentages (±2 percent) of rainfall and runoff are projected to occur at 2030.

The South-West Gulf region experiences low dry season flow (equivalent to 2 to 3 percent of total runoff on average) under historical, recent and future climates.

## SW-1.5 Surface–groundwater interaction

Term of Reference 4

Small springs occur in some parts of the region after average to above average rainfall years. Some have a small flow (<10 L/second) throughout the year. Most cease-to-flow early in the dry season. These springs often drain a very small area (less than 10 $km^2$) and, while they may be ecologically significant, are outside the scope of this discussion.

Reaches of rivers where significant groundwater discharge is known to occur are shown in Figure SW-2. The data used to compile this map represent spot gauged flows (measured in cumecs, i.e. cubic metres per second) after a series of both below average and above average wet seasons. These flows are sustained by significant regional groundwater discharge from aquifers developed in karstic rocks. The Robinson and Calvert rivers source their dry season flow from Proterozoic carbonates. The Gregory River and Lawn Hill Creek source their dry season flow from the Camooweal Dolostone and Thorntonia Limestone.

Monthly streamflow data exists for gauging stations 912101A and 912105A on the Gregory River and 912103A on Lawn Hill Creek. Evaluation of this data has revealed the accuracy of historical flows measured at gauges 912105A and 912103A has been reduced due to the formation of tufa dams during the dry season. Tufa dams are formed naturally through the localised precipitation of carbonate minerals on in-stream rock bars as surface water is progressively concentrated by evaporation. As these dams build the gauged river height upstream increases, leading to an overestimate of the actual streamflow rate. The data at gauge 912101A, however, is thought to be less affected by tufa formations and gives a more reliable indication of the long-term variability in dry season flow conditions in the Gregory River (Figure SW-3). This figure demonstrates a lag time of at least 2 years between when annual rainfall (not shown) peaks and dry season (in this case August) streamflow peaks, suggesting there is significant inertia and hence storage within the surrounding aquifer.

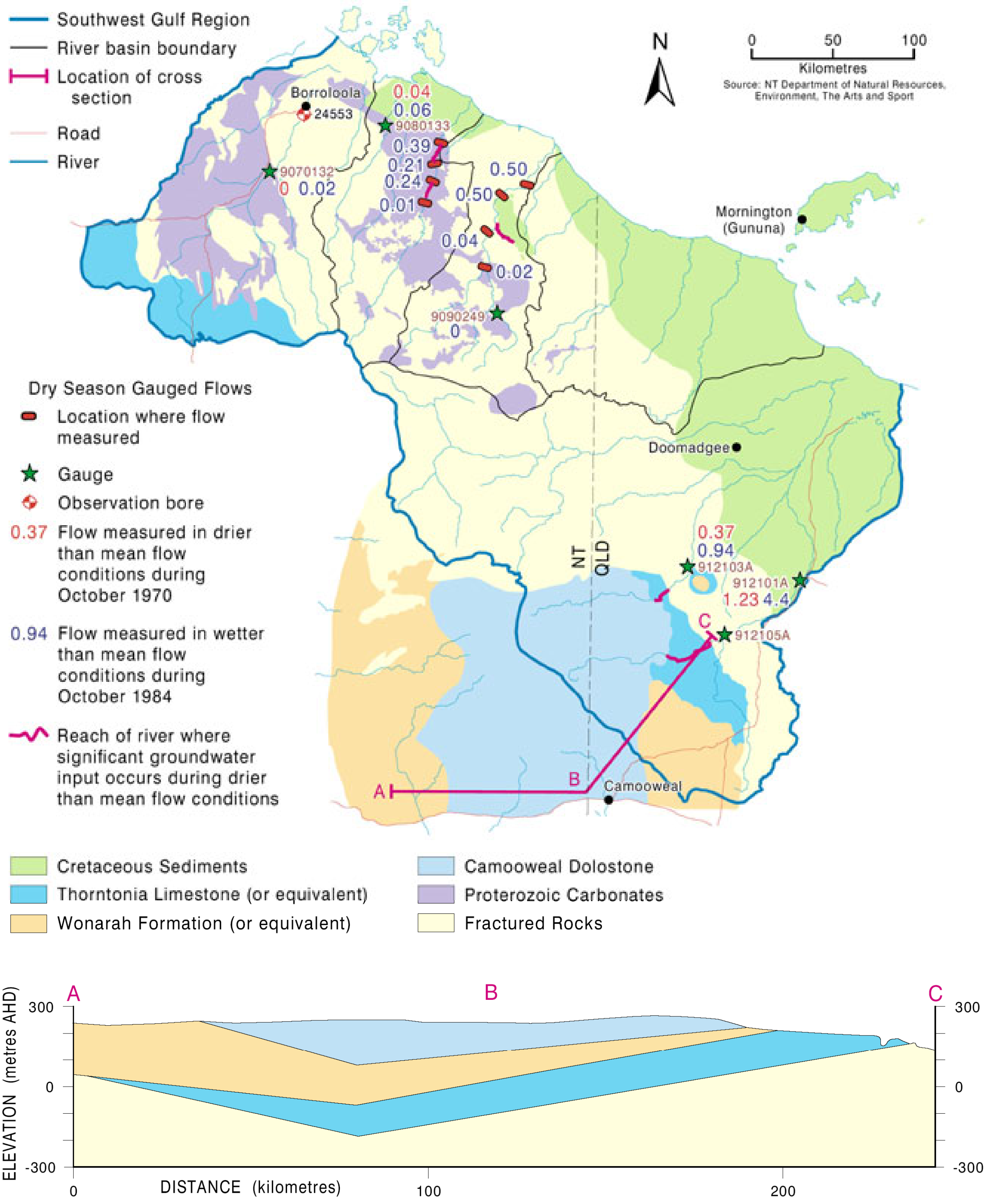



Figure SW-2. Hydrogeology of the South-West Gulf region (map provided by the Northern Territory Department of Natural Resources, Environment, The Arts and Sport)

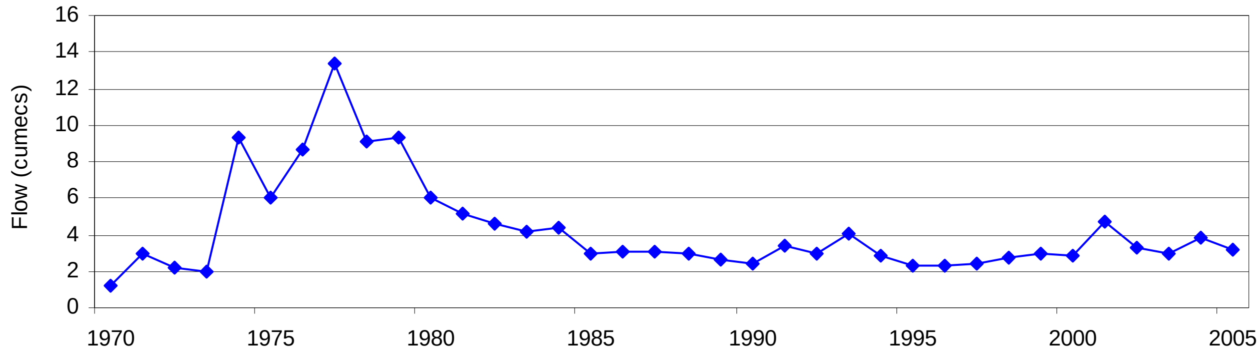



Figure SW-3. Mean August flow at gauging station G912101A on the Gregory River

# SW-1.6 Water storage options

Term of Reference 5

## SW-1.6.1 Surface water storages

There are currently no large surface water storages in this region.

## SW-1.6.2 Groundwater storages

Groundwater development in the South-West Gulf region is small and the largest volume of extraction for a purpose other than stock and domestic use is associated with mine dewatering. Under current development managed aquifer recharge (MAR) would have limited applicability as storages in the local carbonate aquifers (e.g., Camooweal Dolostone or Thorntonia Limestone) are likely to be at full capacity towards the end of the wet season when surface water is available for injection. Section SW-2.1.2 indicates that potential evaporation is generally higher than rainfall for most of the year resulting in almost year-round water-limited conditions, with the exceptions being January to March. When water is not limited aquifers are expected to be at full capacity.

# SW-1.7 Data gaps

Term of Reference 1e

There are only five weather stations in the region that have better than 80 percent record completeness, and three that pass 90 percent. Interpolation of climate data, therefore, relies on the assumption that these are representative of the region as a whole and that infilling of the temporal sequences used in SILO and other analyses is also representative.

Across the region, all stream gauges are located in the upper reaches and there are few gauges against which to calibrate the rainfall-runoff models. There are no calibration gauges in the floodplains. We do not have sufficient confidence in the low flow streamflow estimations to report low flow hydrological regime change at environmental assets.

Rates of groundwater extraction from the Camooweal Dolostone and Thorntonia Limestone, and surface water diversion from the Gregory River, are not known. The collection of such data is required to address concerns of local residents who have reported a decline in dry season flows in the Gregory River.

# SW-1.8 Knowledge gaps

Term of Reference 1e

None of the environmental assets in this region have any site-specific metrics by which to gauge the potential impacts of future changes in climate and development. In the absence of site-specific metrics a set of standard metrics related to high and low flows have been utilised. However, the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and specific ecological entities (for example, macrophyte populations, fish passage, faunal and floral habitats, etc.).

Flooding is an important factor that sustains many environmental assets and this occurs when the stream breaks out of it's banks (a level known as bankfull stage or discharge). However, bank full discharge is not known for many streams, nor is the dependence of area flooded on increasing stream depth, so it is difficult to predict when assets are inundated. Further information about bank full stage and discharge are needed for most environmental assets.

Water balance across the floodplains is not well known. No gauging has taken place and estimates of flood extent using remote sensing should be carried out.

Many environmental assets depend not simply on duration above or below certain flow levels, but on triggers (e.g. for reproduction or migration) set by the rate of change of flow. In addition, some environmental assets depend on the frequency and duration of events that occur less than annually (i.e. once every 5, 10 or 20 years or more). Further analysis is therefore required to look at how the timing, duration and rate of rise and fall in flow rates at critical times of the season will vary under the various scenarios.

Dry season flows are poorly understood in this region therefore the ability to predict the potential impacts of the various scenarios on low or zero flows at environmental assets is very limited. Improved monitoring of low streamflow conditions is needed along with the development of hydrological models that combine surface and groundwater regimes. Further monitoring of groundwater levels is also required so that the potential impacts of future changes in climate and development on groundwater-dependent ecosystems can be better understood.

A detailed numerical groundwater flow model may be required for the Camooweal Dolostone and Thorntonia Limestone to evaluate the causes of anecdotal evidence of declines in dry season flow in the Gregory River.

## SW-1.9 References

McJannet DL, Wallace JW, Henderson A and McMahon J (2009) High and low flow regime changes at environmental assets across northern Australia under future climate and development scenarios. A report to the Australian Government from the CSIRO Northern Australian Sustainable Yields Project. CSIRO Water for a Healthy Country National Research Flagship, Division of Land and Water, Canberra. *In prep.*

Zhang L and Dawes W (1998) WAVES - An integrated energy and water balance model. Technical Report No. 31/98, CSIRO Land and Water.

# SW-2 Contextual information for the South-West Gulf region

This chapter summarises the background information for the region, outlining existing knowledge of water resources and prior and current investigations relevant to the water resources of the region. This chapter also outlines the current and potential future legislation, water plans and other water resource management arrangements. This chapter is arranged into four sections:

- physical and climate descriptions
- data availability
- hydrogeology
- legislation, water plans and other arrangements.

# SW-2.1 Overview of the region

## SW-2.1.1 Geography and geology

Five major river systems drain the South-West Gulf region into the Gulf of Carpentaria. The McArthur River, Robinson River and Calvert River drain the low-lying country of eastern Northern Territory. Settlement Creek and Nicholson River (which includes the Gregory River) drain the open floodplains of Queensland. The low relief results in high tidal reaches, extending over 100 km inland from the coast. Highly braided, anastomosing channels dominate the landscape making gauging of streamflow difficult with channels migrating under annual floods.

The region's terrain sweeps in parallel bands away from the coastline. Almost flat coastal terraces give way to gentle slopes that, in turn, abut a series of linear sandstone ridges that cut across the direction of drainage, imposing a strong structural control and causing local accumulation of sediment. Further inland, high, level rocky plateaux and ridges of resistant sandstone and igneous rock define the landscape, where escarpments, low hills and gentle plains of lateritic cap rocks have been incised, exposing softer underlying sediments. Along the inland division boundary, the divide comprises intact areas of mature laterite on old stable surfaces of the Barkly Tableland.

The geological history of the area is complex. The McArthur Basin underlies the centre and north of the region. It unconformably overlies the Murphy Inlier to the south. The Murphy Inlier was probably a palaeogeographical high separating the McArthur Basin from the South Nicholson Basin. The Georgina and Carpentaria basins unconformably overlie the McArthur Basin succession. McArthur Basin strata apparently continue beneath these basins.

The McArthur Basin succession comprises sandstone, shale, carbonate, and interbedded volcanic and intrusive igneous rocks. The McArthur River lead-zinc-silver mine is located inland of Borroloola halfway up the McArthur River. This is one of the world's largest zinc mines, providing 70 percent of global demand for zinc in concentrate form.

The Georgina Basin contains a relatively thin stratigraphic succession, up to 450 m thick, deposited on a tectonically quiescent platform. Deposition commenced with a marine transgression in the early Middle Cambrian and may have extended into the Late Cambrian.

The Carpentaria Basin is a broad north–south trending intracratonic basin and is the most northerly tectonic unit within the Great Artesian Basin. The basin formed in the Middle Jurassic and contains mainly Mesozoic clastic sediments. These onlap Proterozoic metamorphic basement rocks and unmetamorphosed Proterozoic sediments of the McArthur Basin in the region. Middle to Late Jurassic strata comprise sandstone, and minor siltstone and conglomerate. Deposition was initially restricted to pre-existing structural lows, and was mainly fluvial. By the Early Cretaceous, fluvial sandstone deposition was widespread. In the Middle Cretaceous, a widespread transgression brought coastal swamp conditions and then shallow marine conditions across the basin, with the deposition of a thick mudstone succession.

The current drainage system probably came into existence in the Cretaceous when uplift in the north of the Northern Territory resulted in a drainage divide between inland draining streams to the south and streams draining to the sea in the north.

The alluvial plains that cover an extensive area along the coastal eastern edge of the region are underlain by primarily marine sediments that have been deposited in the last 10,000 years since the end of the last ice age.



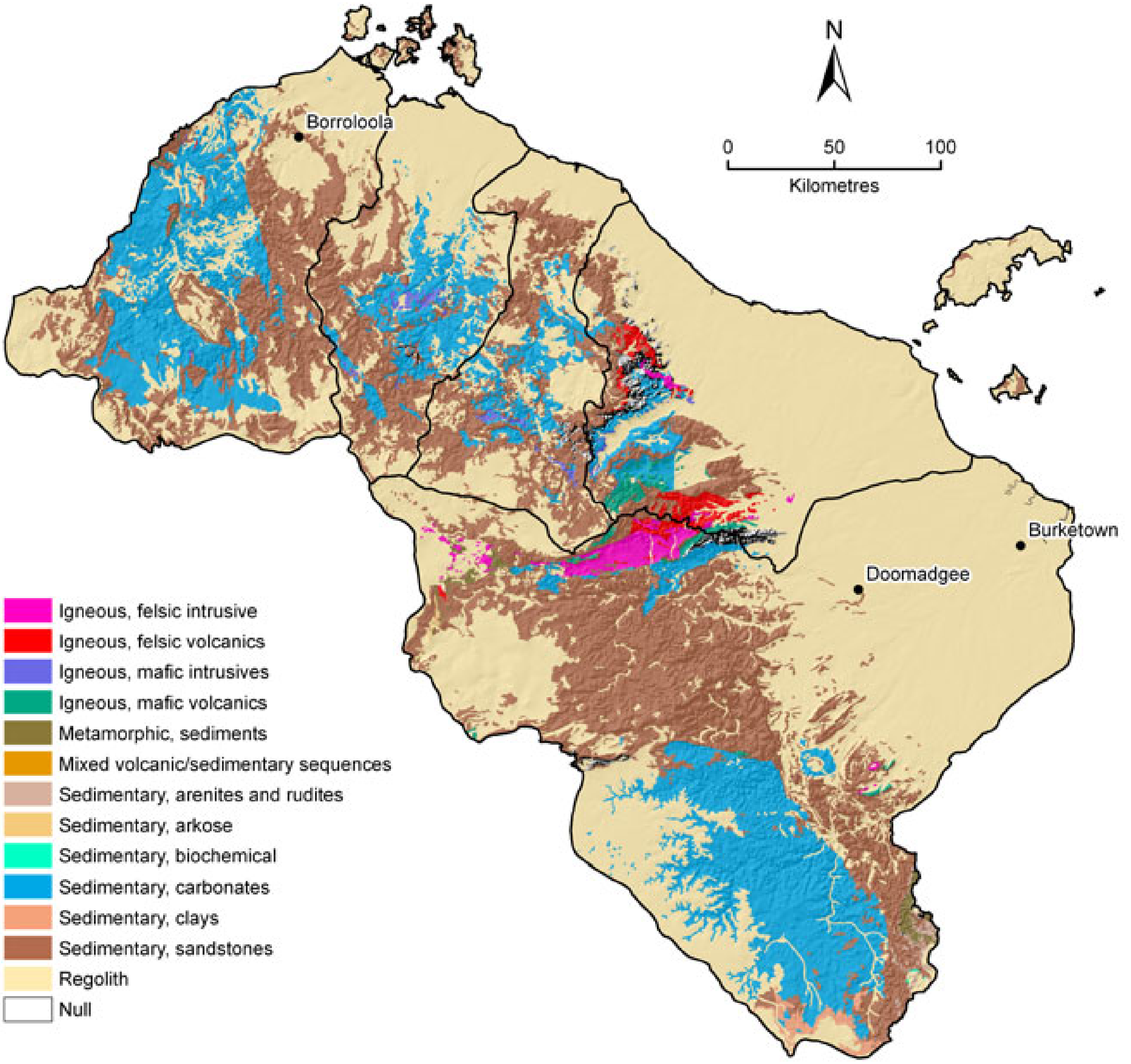



Figure SW-4. Surface geology of the South-West Gulf region overlaid on a relative relief surface



## SW-2.1.2 Climate, vegetation and land use

The South-West Gulf region receives an average of 670 mm of rainfall over a water year (September to August), most of which (631 mm) falls in the November to April wet season (Figure SW-5). Across the region there is a strong north–south gradient in annul rainfall, ranging from 1168 mm in the north to 405 mm in the south. Over the historical (1930 to 2007) period, rainfall has generally remained constant but with the 1970s and post-2000 being wetter than average. The highest yearly rainfall was 1460 mm in 2001, and the lowest was 289 mm in 1952.

Areal potential evapotranspiration (APET) is very high across the region, averaging 1961 mm over a water year, and varies moderately across the seasons. APET generally remains higher than rainfall for most of the year resulting in near-year-round water-limited conditions. The exceptions to this are the months January to March, when more rain falls than can potentially be evaporated.

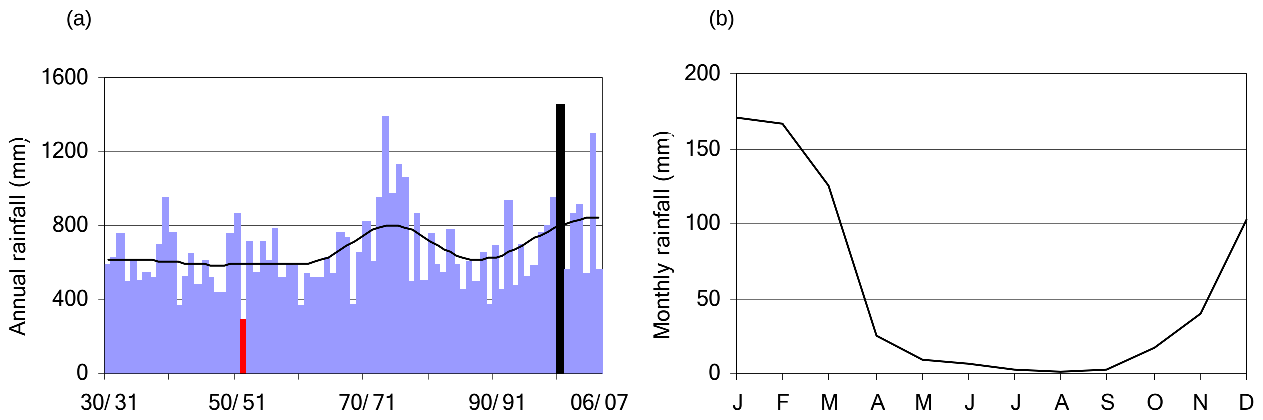



Figure SW-5. Historical (a) annual and (b) mean monthly rainfall averaged over the South-West Gulf region. The low-frequency smoothed line in (a) indicates longer term variability

The South-West Gulf region lies within the 'Humid Zone' and 'Semi-Arid Zone', and Eucalypt woodland with grass understorey is the dominant vegetation type, grading into grassland towards the south (Figure SW-6).

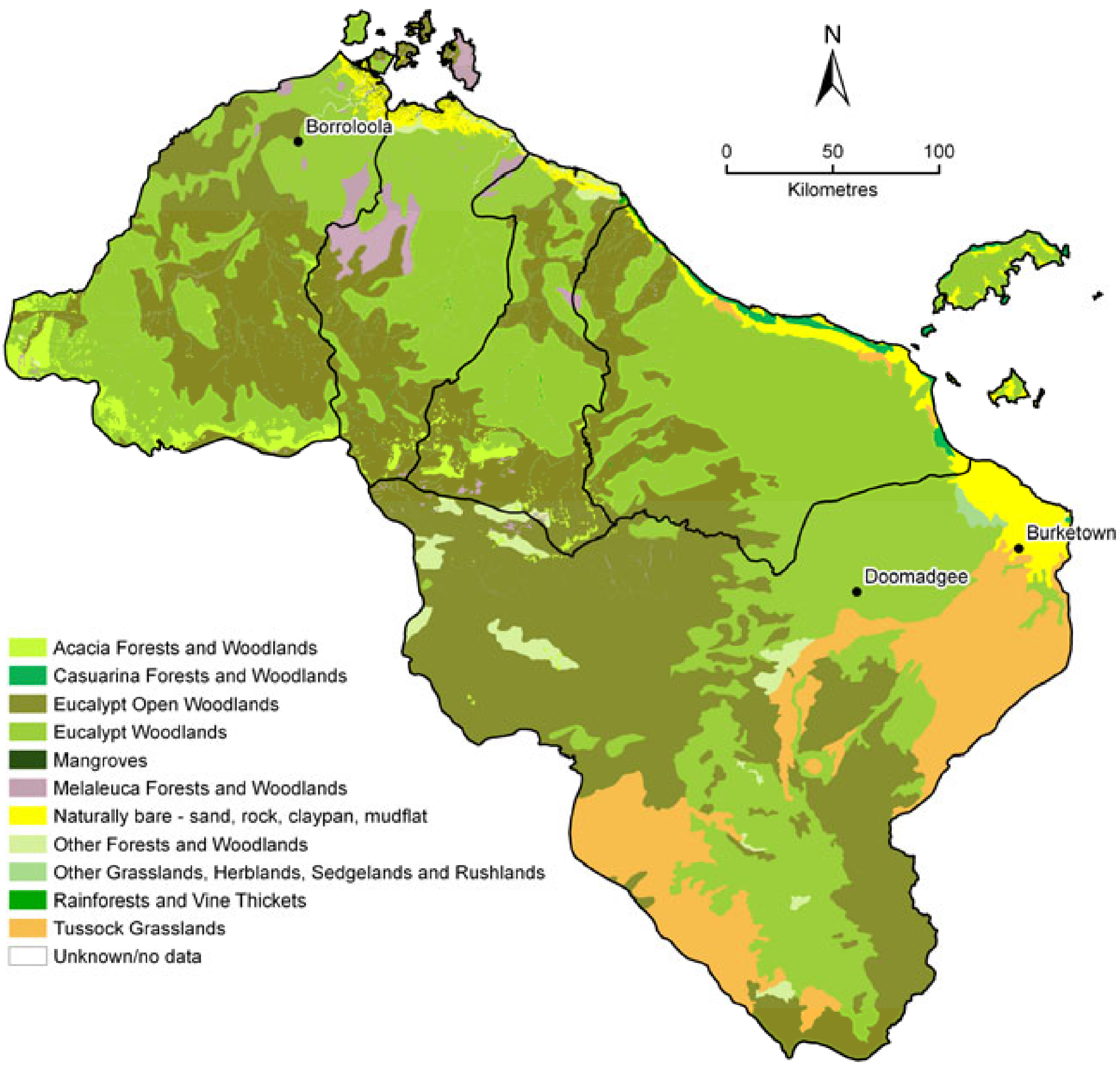



Figure SW-6. Map of current vegetation types across the South-West Gulf region (source DEWR, 2005)



The majority of land is held under pastoral lease or Indigenous land trusts as private freehold (Figure SW-7). Crown leases contain covenants that control their usage or development and can be issued for any length of time, including ‘in perpetuity’. Term leases are normally issued to allow developments to proceed and can often be converted to freehold title or perpetual leasehold once the development is complete. Pastoral leases are for broadacre areas specifically used for pastoral purposes.

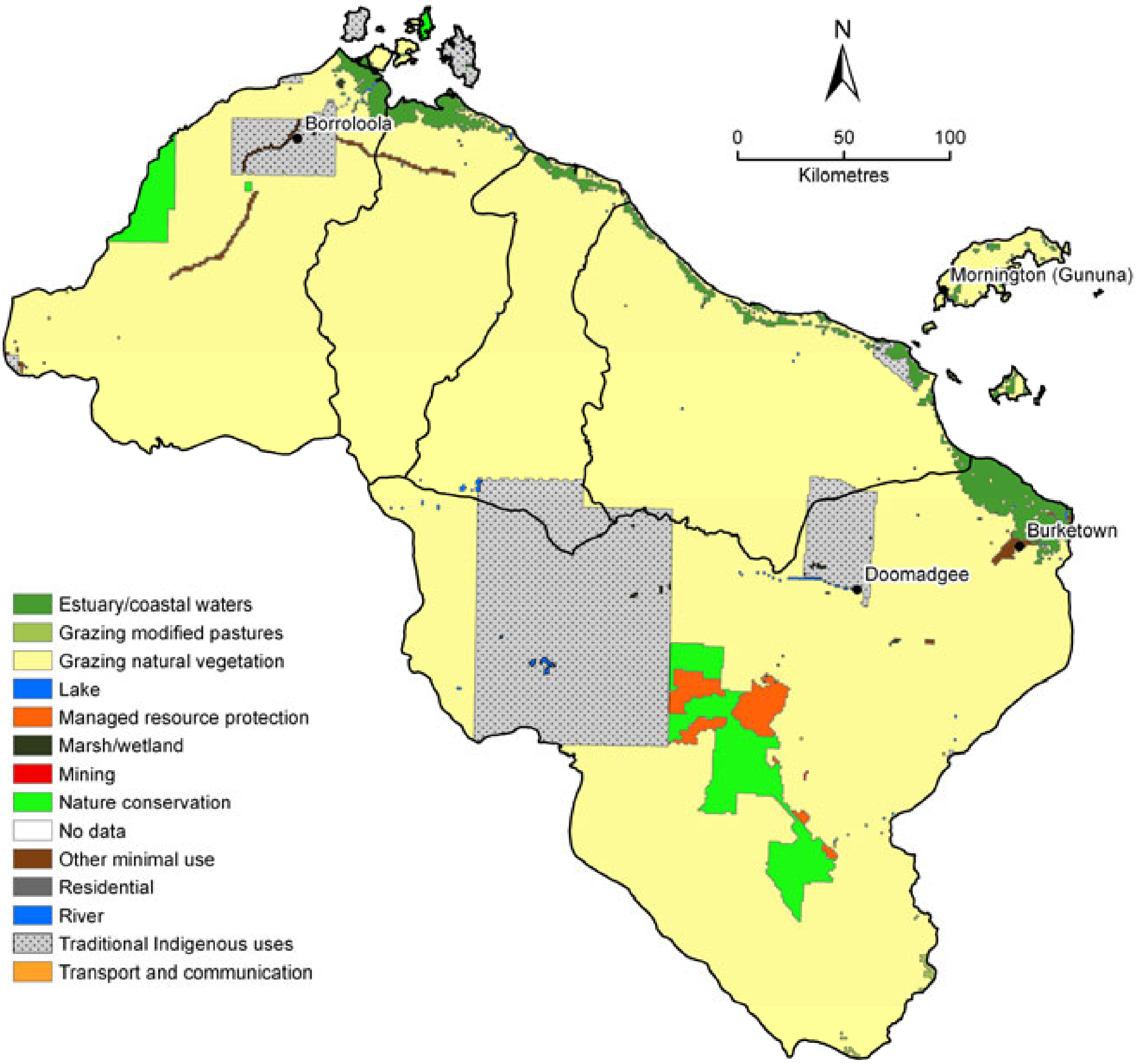



Figure SW-7. Map of dominant land uses of the South-West Gulf region (source BRS, 2002)

Pastoralism has been the main industry in the Gulf region since European settlement, but it is considered ‘low key’ when compared to other rangelands in the Australian tropics (CCNT, 1994) because of the limited extent of suitable pastoral land resources in the region (Department of Lands and Housing, 1991). The Gulf region has been described as having low pastoral productivity in relation to carrying capacity, with only 2.5 head per km$^2$ live weight of cattle (Holmes, 1986).

Indigenous lands support a variety of uses, mainly as traditional or semi-traditional living areas with some areas being utilised for pastoralism. Other industries include mining, tourism and conservation, and recreational and commercial fishing.

The fishing industry is very significant within the region. Prawning is the largest single fishery in the Gulf and accounted for 96 percent of the value of the Gulf fisheries catch in 1990 (Department of Lands and Housing, 1991). The prawn industry operates up to 60 nautical miles offshore.

Significant mines operate in the region, with the McArthur zinc-lead-silver mine in the north near Boroloola and the Century lead-zinc mine in the south near Doomadgee.

### SW-2.1.3 Regional environmental asset description

Environmental assets were chosen from wetlands which are listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001). From this directory, environmental assets were shortlisted for assessing changes to the hydrological regime under the climate and development scenarios. The selection of this shortlist was undertaken in consultation with state governments and the Australian Government through direct discussions and through internal reviews (see Section 1.3 in the division-level Chapter 1 for further detail).

All nationally, or internationally, important wetlands listed for the South-West Gulf region in the Directory of Important Wetlands in Australia (Environment Australia, 2001) are detailed in Table SW-2, with asterisks identifying the five shortlisted assets: Gregory River, Nicholson Delta Aggregation, Port McArthur Tidal Wetlands System, Southern Gulf Aggregation and Thorntonia Aggregation. The location of these shortlisted wetlands is shown in Figure SW-1. There are no wetlands classified as Ramsar sites in this region. Wetlands may be nationally or regionally significant depending on more locally specific criteria. All wetlands are important for a variety of ecological reasons or because they bear historical significance or have high cultural value, particularly to Indigenous people.

The following section characterises these shortlisted wetlands and is based largely on the description of these assets as outlined by (Environment Australia, 2001). Chapter ID-3 presents the assessment of those shortlisted assets, and reports hydrological regime metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis.

Table SW-2. List of Wetlands of National Significance located within the South-West Gulf region

| Site code | Name | Area | Ramsar site |
|---|---|---|---|
| | | ha | |
| QLD102 | Bluebush Swamp | 879 | No |
| NT006 | Borroloola Bluebush | 70 | No |
| QLD105 | Forsyth Island Wetlands | 6,390 | No |
| QLD119 * | Gregory River | 26,600 | No |
| QLD101 | Lawn Hill Gorge | 1,130 | No |
| QLD108 | Marless Lagoon Aggregation | 167,000 | No |
| QLD110 | Musselbrook Creek Aggregation | 45,100 | No |
| QLD111 * | Nicholson Delta Aggregation | 63,600 | No |
| NT008 * | Port McArthur Tidal Wetlands System | 119,000 | No |
| QLD114 * | Southern Gulf Aggregation | 546,000 | No |
| QLD122 * | Thorntonia Aggregation | 299,000 | No |
| QLD116 | Wentworth Aggregation | 82,300 | No |

* Asterisk against the site code identifies those assets which are shortlisted for assessment of changes to flow regime.



## Gregory River

Gregory River (Figure SW-8) is the largest perennial river in arid and semi-arid Queensland. The area encompasses the nationally significant Riversleigh fossil beds associated with the Carl Creek Limestone Formation. The site comprises an extensive perennial riverine complex in a semi-arid environment. All of the major streams of this catchment are spring fed. The site has an area of 26,600 ha and an elevation ranging between 65 m and 150 m above sea level (Environment Australia, 2001).

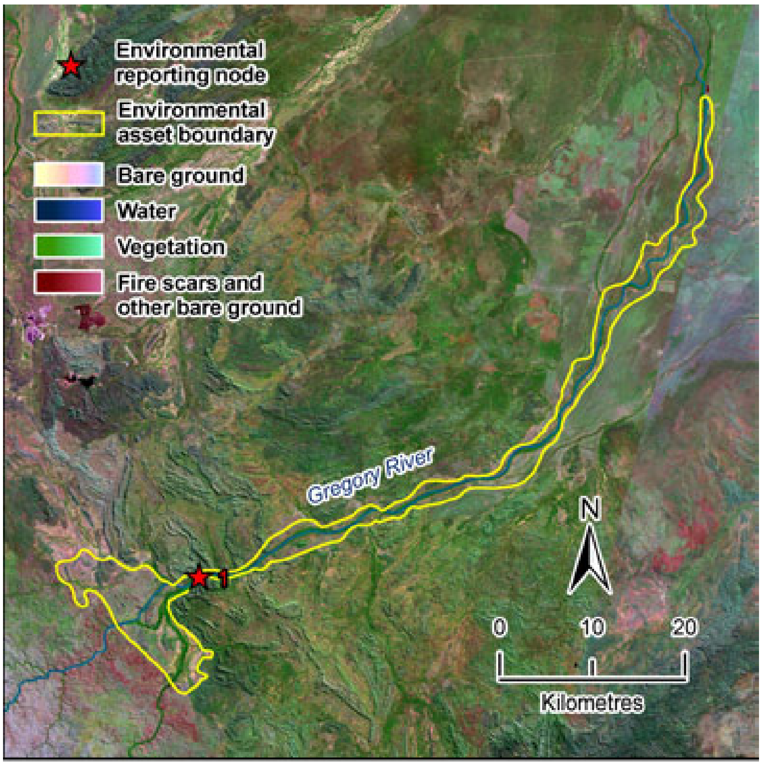



Figure SW-8. False colour satellite image of Gregory River (derived from ACRES, 2000). Clouds may be visible in image

Aquatic beds and occasional sedge emergents occur in still water areas in the lower reaches and forested wetland communities occur on the narrow levees. Estuarine crocodiles occur occasionally in the lower reaches. Levees of the Gregory River are of considerable significance to the local Indigenous community (Environment Australia, 2001).

## Nicholson Delta Aggregation

The Nicholson Delta Aggregation (Figure SW-9) is the best example of a deltaic, alluvial system in the south-western portion of the southern Gulf of Carpentaria. The aggregation comprises a complex disjunct wetland aggregation (Blackman et al., 1992) of closed depressions in impeded drainage lines, flood-outs, back-plains and riverine channels merging with an extensive estuarine system of saline clay pans and tidal channels. The site has an area of 63,600 ha and an elevation ranging between 5 m and 10 m above sea level (Environment Australia, 2001).

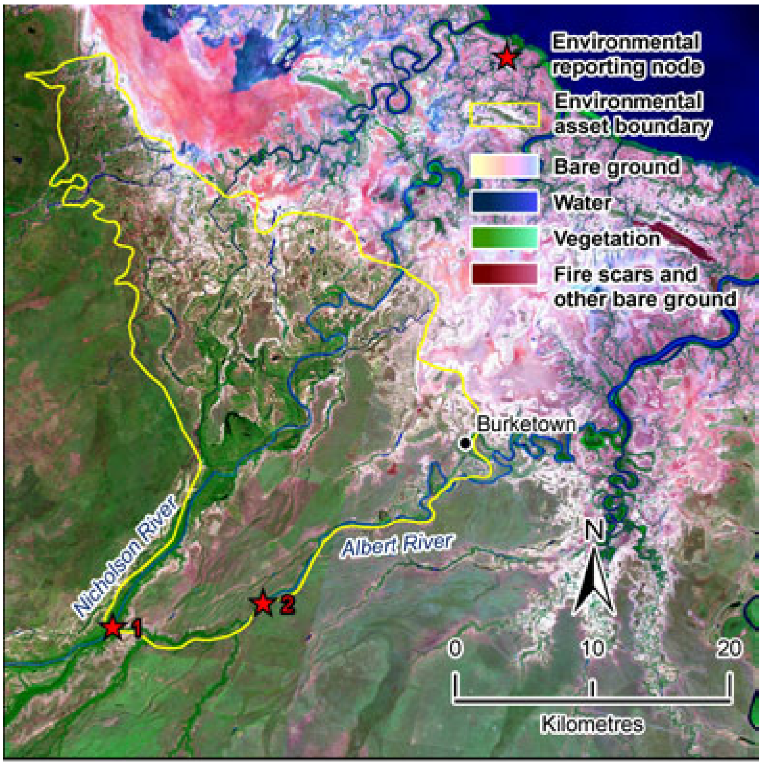



Figure SW-9. False colour satellite image of the Nicholson Delta Aggregation (derived from ACRES, 2000). Clouds may be visible in image

The rich array of permanent, semi-permanent and seasonal wetlands provides drought refuge for waterbirds as well as breeding, roosting, feeding and moulting habitat. Australian freshwater and estuarine crocodiles are common in the area as are large numbers of waterbirds. Parts of this site are frequented by tourists (Environment Australia, 2001).



## Port McArthur Tidal Wetland System

The Port McArthur Tidal Wetland System (Figure SW-10) is a good example of a tidal wetland system of the Gulf of Carpentaria, including the only substantial area of mangrove swamp, and the widest and largest area of intertidal mudflats, in the south-west of the Gulf. Lake Eames is the only sizeable, permanent freshwater lake in the south-west of the Gulf. The site has an area of 119,000 ha and an elevation at or near sea level (Environment Australia, 2001).

Twenty-six mangroves, including 15 tree species, are known to occur in the area (Environment Australia, 2001). Fifty-five species of waterbird have been recorded, 26 of which are listed under treaties (JAMBA, CAMBA, BONN) (Environment Australia, 2001). The 55 include ten herons and allies, 27 shorebirds and eight terns. At least two substantial waterbird breeding rookeries are located at the site, supporting a total of more than 3000 adult birds (egrets, cormorants and Pied Herons) (Environment Australia, 2001). At least 24 seabird breeding rookeries support more than 300,000 adult birds.

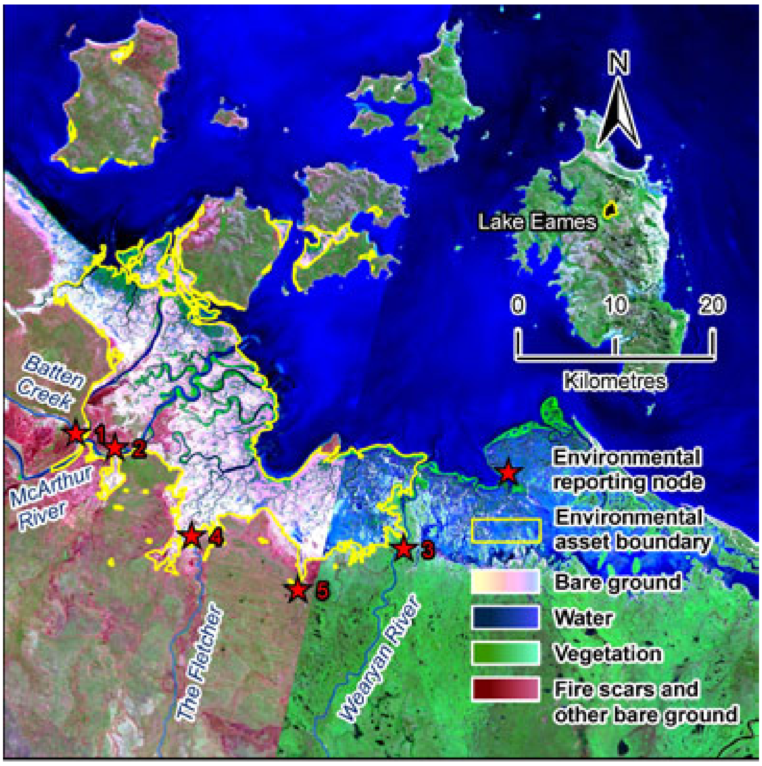



Figure SW-10. False colour satellite image of the Port McArthur Tidal Wetland System (derived from ACRES, 2000). Clouds may be visible in image

The site's marine and estuarine habitats are known to support at least 132 fish species (Environment Australia, 2001). The mangroves contain most of the bird species that have adapted to this habitat and probably are an important link between Top End and Cape York bird populations. Turtles occur on most of the islands offshore with all species known to breed regularly in the Northern Territory nesting here.

The islands are occupied by Indigenous people and many sacred sites exist on the islands and some occur on the mainland. Commercial fishing occurs around most of the estuaries and the site supports a major mud crab fishery (Environment Australia, 2001).

## Southern Gulf Aggregation

This huge coastal aggregation covers an area of 546,000 ha and ranges in elevation from zero to 10 m above sea level (Figure SW-11). This wetland area extends across three of the regions defined for this project: the Flinders-Leichhardt, South-West Gulf and South-East Gulf regions. In the South-West Gulf region we consider reporting node 1. The Southern Gulf Aggregation is a complex continuous wetland aggregation (Blackman et al., 1992) that also encompasses several complex disjunct aggregations of closed depressions. Seaward to landward it comprises a continuum of extensive marine intertidal flats, beaches and foredunes, secondary dunes and swales, saline clay plains, seaward margins of saline clay plains, margins and levees of tidal channels, low elevated plains, and depressions within low elevated plains. The area is under the dominating influence of estuarine tides and massive freshwater flooding during wet season events.

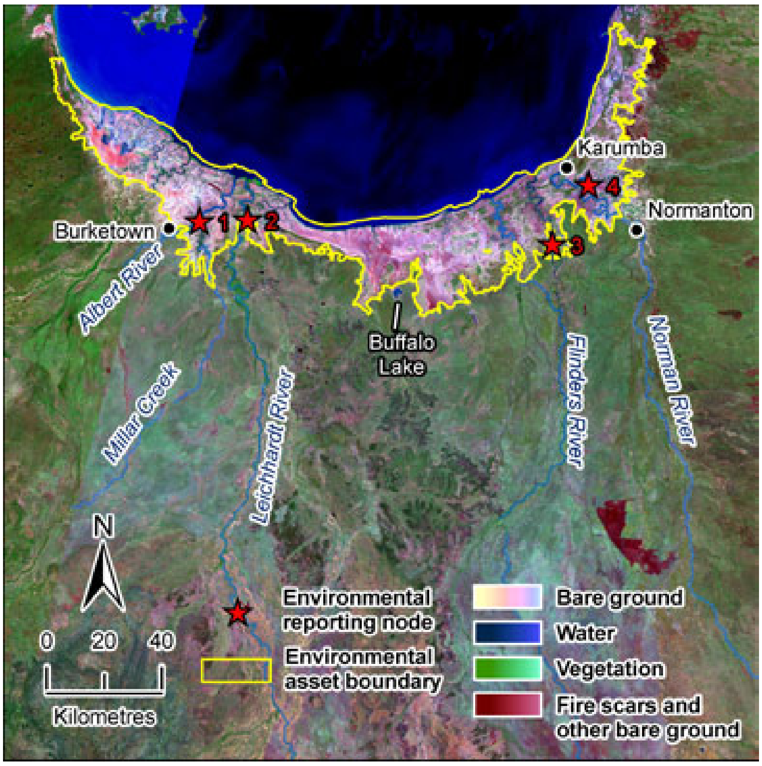



Figure SW-11. False colour satellite image of the Southern Gulf Aggregation 9derived from ACRES, 2000). Clouds may be visible in image

Marine and estuarine tidal waters permanently inundate or regularly flood much of the area, with wet season flooding by freshwater from the streams and rivers of the inland catchment combined with local runoff from the plains of the Gulf Fall. The wetlands occurring along the inland margins of the area are brackish and all are seasonal. The aggregation has a major influence on nutrient flow into the Gulf of Carpentaria (Wolanski, 1993).The Southern Gulf Aggregation is the largest continuous estuarine wetland aggregation of its type in northern Australia. It is one of the three most important areas for shorebirds in Australia (Watkins, 1993).



## Thorntonia Aggregation

The Thorntonia Aggregation (Figure SW-12) is a good example of a pristine wetland system with permanent deep water in a semi-arid environment. Probably the only perennial streams in arid Queensland also occur at the site. The area includes a large part of the Carl Creek Limestone Formation containing the internationally significant Riversleigh fossil field. The site has an area of 299,000 ha and an elevation ranging between 150 and 250 m above sea level (Environment Australia, 2001).

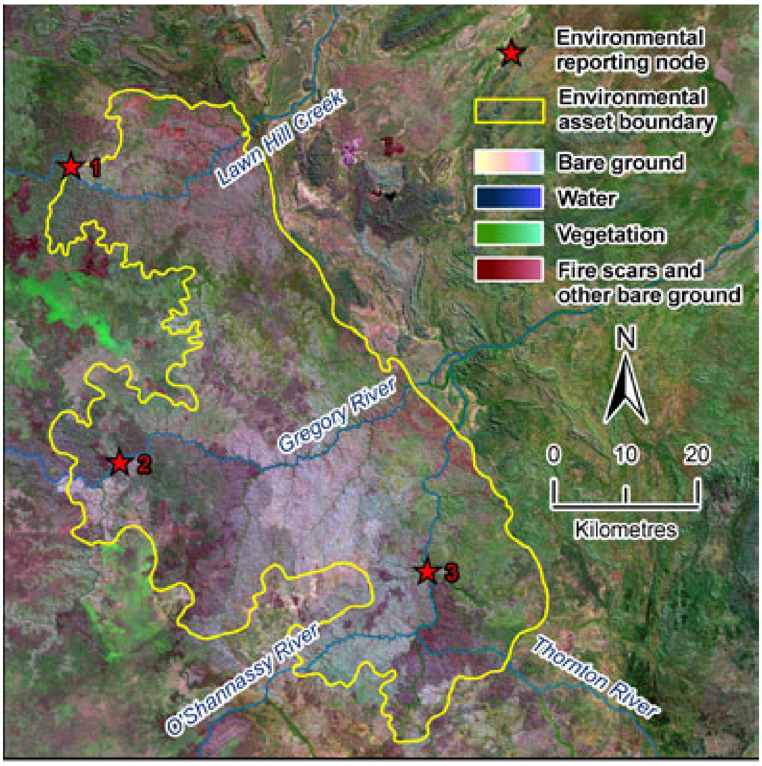



Figure SW-12. False colour satellite image of the Thorntonia Aggregation (derived from ACRES, 2000). Clouds may be visible in image

Forested and shrub-scrub palustrine wetlands occur on well-developed levees and in the shallower seasonal channels. Aquatic vegetation beds occur in the riverine wetlands. A notable aspect of the flora is the rainforest influence and marked differences between the fringing communities of the gorges and channels and the surrounding semi-arid country. The perennial streams are considered to provide a refuge environment during the May to October dry season (Environment Australia, 2001).

## SW-2.2 Data availability

### SW-2.2.1 Climate

The rainfall-runoff modelling uses historical daily climate data (Scenario A) from the SILO database for the period 1 September 1930 to 31 August 2007 at 0.05 x 0.05 degree (~ 5 x 5 km) grid cells. Full details and characterisation of the SILO database are provided at the division level in Section 2.1 of Chapter 2. Scenario B and Scenario C climate data are rescaled versions of the Scenario A data; this is also discussed in Section 2.1 of Chapter 2.

### SW-2.2.2 Surface water

Streamflow gauging stations are, or have been, located at 25 locations within the South-West Gulf region. Seven of these gauging stations either (i) are flood warning stations which measure stage height only; or (ii) have less than ten years of measured data. Of the remaining 18 stations, nine recorded more than half of their total volume of flow during events that exceed the maximum gauged stage height. Figure SW-13 shows the spatial distribution of good quality data (duration) and the percentage of flow above maximum gauged stage height (MGSH) (this assessment was only undertaken on stations with ten or more years of data).

In Figure SW-13 the productive aquifer layer for the Northern Territory includes key dolostone and limestone formations and Cretaceous sandstone formations. Consequently these productive aquifers exhibit a wide range of bore yields. The locations of gauging stations in the South-West Gulf region are biased to being located within or downstream of ‘productive’ aquifers in the Nicholson and McArthur catchments (Figure SW-13).

There are five gauging stations currently operating in the South-West Gulf region at density of one gauge for every 22,400 km$^2$. For the 13 regions the median number of current gauging stations per region is 12 and the median density of current gauging stations per region is one gauge for every 9700 km$^2$. The South-West Gulf region has a low density of current gauging stations relative to the other 12 regions in northern Australia, and the density of stations is considerably lower than the Murray-Darling Basin average. The mean density of current stream gauging stations across the entire Murray-Darling Basin is one gauge for every 1300 km$^2$.

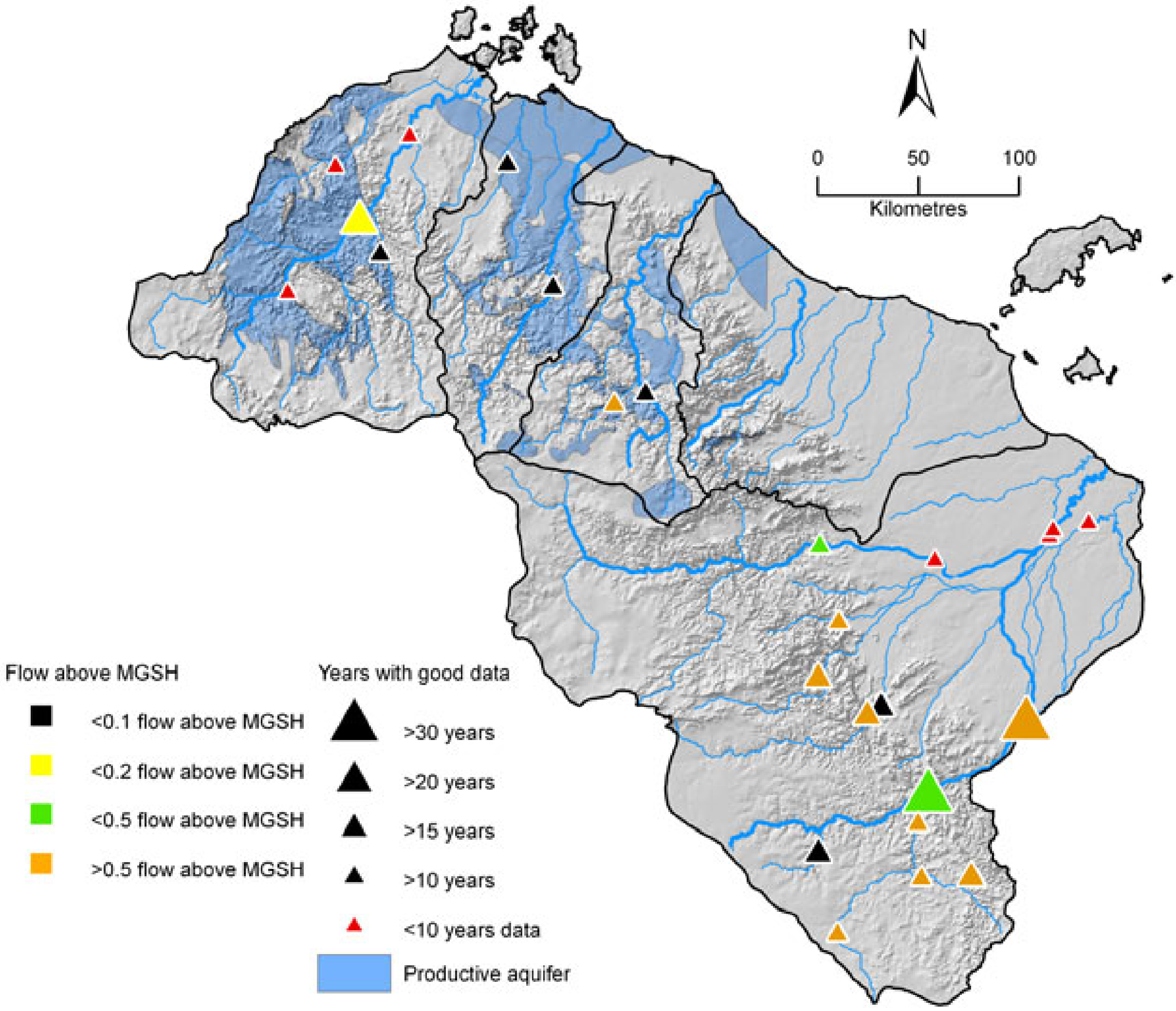



Figure SW-13. Location of streamflow gauging stations overlaid on a relative relief surface showing the proportion of gauges with flow above maximum gauged stage height across the South-West Gulf region. Productive aquifer layer for the Northern Territory includes key dolostone, limestone and Cretaceous sandstone formations

## SW-2.2.3 Groundwater

The South-West Gulf region contains a total 752 registered groundwater bores. Very few (21) of these bores have surveyed elevations that could enable watertable surfaces to be constructed for the main aquifers. However these bores are not necessarily monitored on a regular basis. There are 15 water level monitoring bores in the region; 14 are historical and one is current.

## SW-2.2.4 Data gaps

Rates of groundwater extraction from the Camooweal Dolostone and Thorntonia Limestone, and surface water diversion from the Gregory River, are currently not known. The collection of such data is required to address concerns of local residents who have reported a decline in dry season flows in the Gregory River. Additional stream gauging, particularly focusing on low flow conditions, and groundwater level and water quality measurements would be beneficial for understanding surface-groundwater interactions.

## SW-2.3 Hydrogeology

This section describes the key sources of groundwater in the South-West Gulf region. The description is based primarily on reports and water bore data held by the Northern Territory Government Department of Natural Resources, Environment, The Arts and Sport (NRETAS) and the Queensland Department of Environment and Resource Management (DERM). The distribution of recorded water bores in the region at 2004 is shown in Figure SW-14.

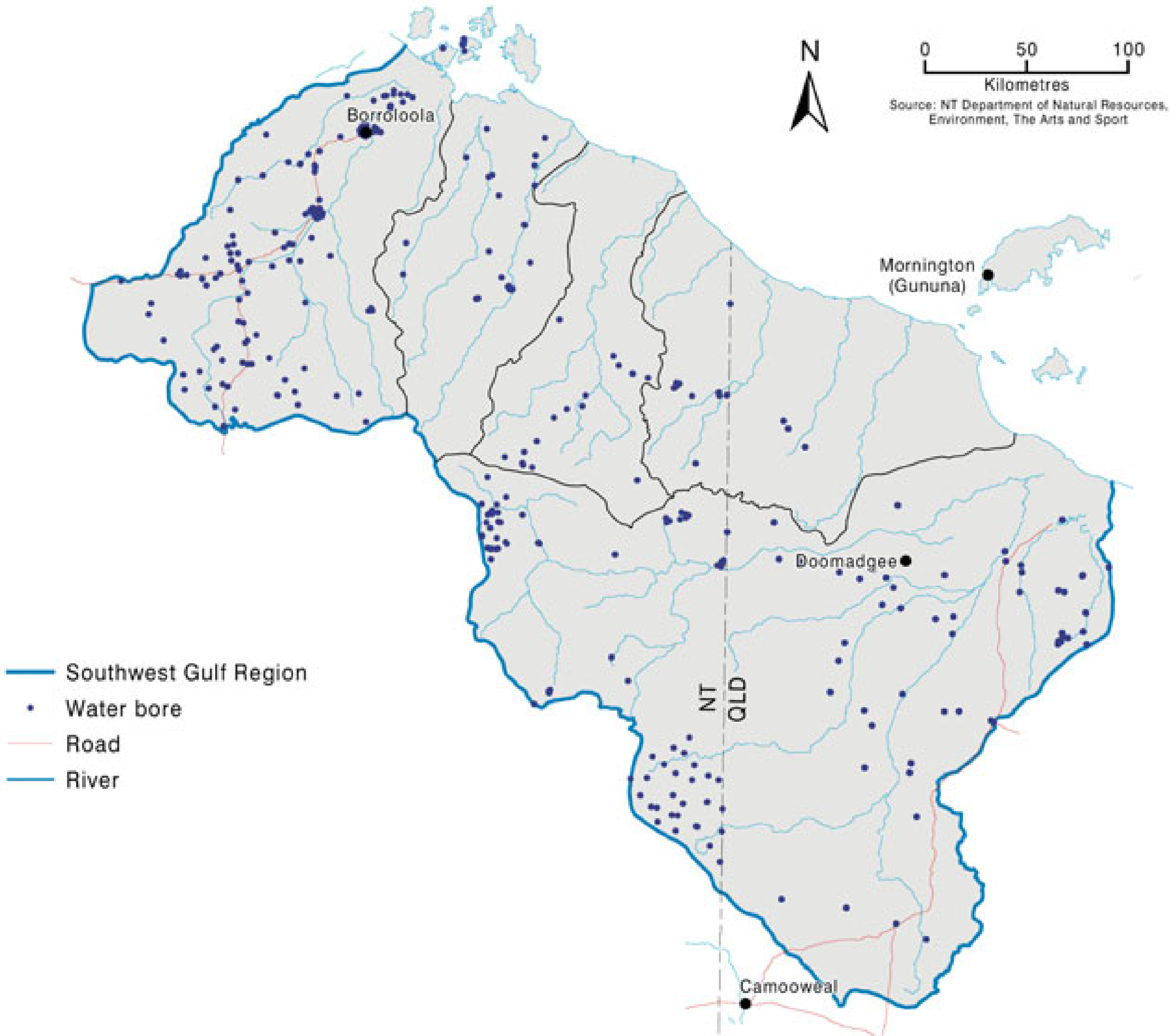



Figure SW-14. Location of groundwater bores in the South-West Gulf region (map provided by the Northern Territory Department of Natural Resources, Environment, The Arts and Sport)

### SW-2.3.1 Aquifer types

There are three major aquifer types in the South-West Gulf region. These types are fractured rocks, karstic carbonate rocks and Cretaceous sediments, all of which are briefly described below with their areal extent shown in Figure SW-2 (in Chapter SW-1). Alluvial aquifers also exist along current and historical drainage paths of the major rivers, however these resources are very localised and often only have a few metres of basal sands and gravels that actually constitute an aquifer (e.g., McArthur River (URS, 2005)).



### Fractured rocks

A variety of Precambrian (older than 500 million years) rocks form the bedrock of the area. These are mainly sedimentary but also include granite and volcanic rocks. Sandstone, siltstone and greywacke are the main sedimentary rock types. In some areas they are flat-lying while in other areas they have been folded and faulted and show low grade metamorphism. Water is usually intersected in weathered fractured zones within the fractured rocks. Groundwater yields are controlled by the degree of fracturing of these units and are likely to be greater in areas located along large-scale joints and fault zones.

### Karstic carbonate rocks – Thorntonia Limestone (or equivalent), Wonarah Formation (or equivalent), Camooweal Dolostone and Proterozoic carbonates

The sediments of the McArthur Basin are the oldest within the region. Significant aquifers occur within the Proterozoic carbonate rocks of the basin. Groundwater levels in these carbonate rock aquifers typically fluctuate by 5 to 6 m between wet and dry seasons (URS, 2005). Small but significant baseflow is generated from these aquifers in the lower reaches of the Calvert and Robinson rivers.

The major aquifers in the region occur within carbonate rocks of the Georgina Basin, part of an extensive area of carbonate rocks that extend across the Northern Territory – Queensland border (Figure SW-15). The Georgina Basin contains a relatively thin stratigraphic succession, up to 450 m thick, deposited on a tectonically quiescent platform. The succession is similar to that of the Daly Basin. The basal Thorntonia Limestone is similar to the Tindall Limestone, the Wonarah Formation to the Jinduckin Formation and the Camooweal Dolostone to the Oolloo Dolostone. The Camooweal Dolostone and Thorntonia Limestone host widespread karstic aquifers. These aquifers have very high permeability due to an extensive network of interconnected solution cavities. The Wonarah Formation is mainly composed of siltstone. The formation contains thin, local aquifers in isolated limestone beds.

### Cretaceous sediments

In the Early Cretaceous the sea transgressed across the region, depositing a thin sheet of predominantly sandy sediments (Gilbert River Formation) followed by a much thicker layer of predominantly clayey sediments (Rolling Downs Group). That period was short lived and erosion again dominated until the present day. These sediments underlay approximately one-quarter of the region and comprise the Carpentaria Basin of the more extensive Great Artesian Basin (GAB). The Gilbert River Formation aquifer is confined by the Rolling Downs Group and is known to have artesian conditions in some areas.

The Cretaceous Sandstone aquifer in the north-eastern portion of the region may contribute a small amount of baseflow to the upper reaches of some rivers.

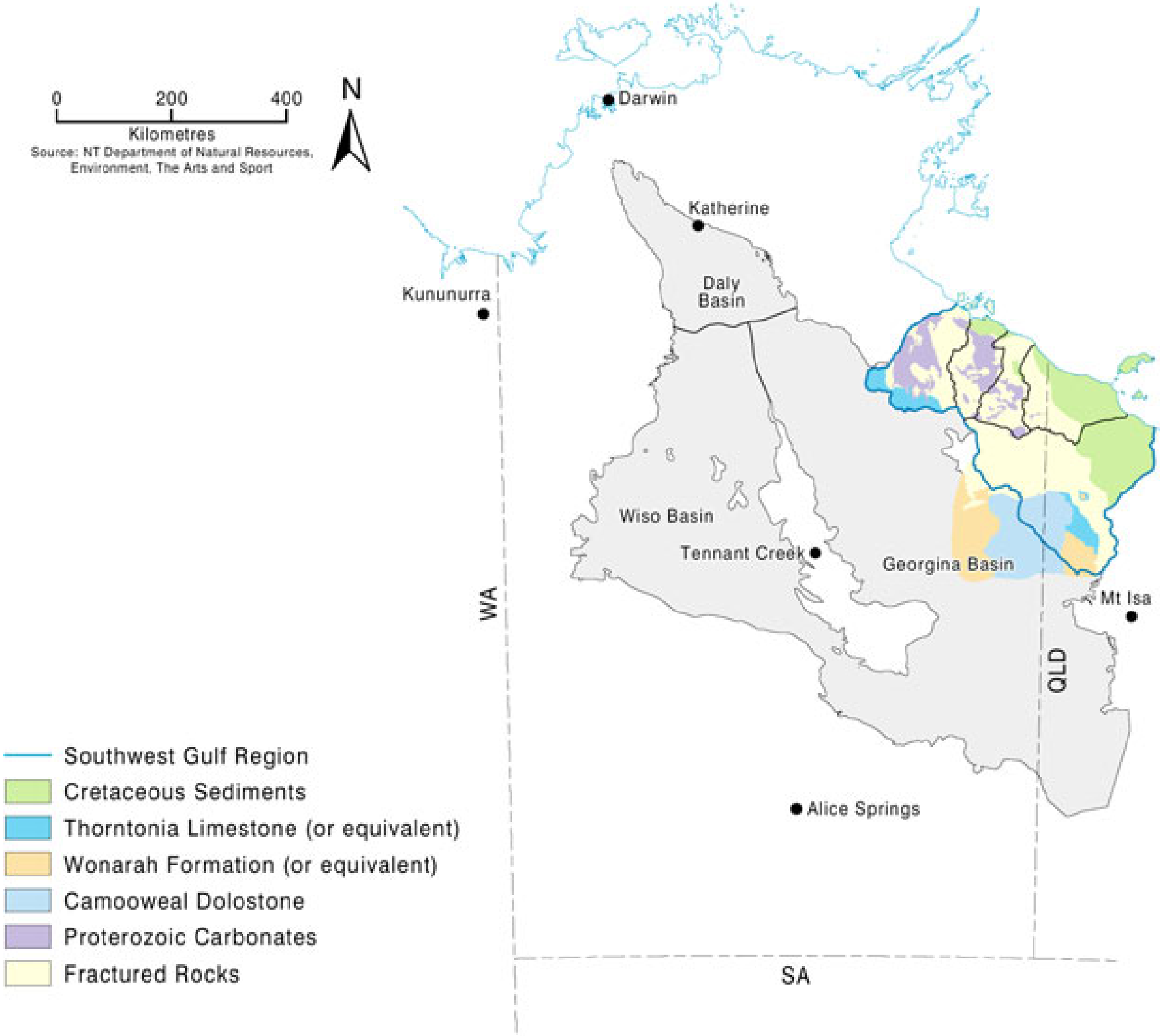



Figure SW-15. Location of the South-West Gulf region in relation to the Daly, Wiso and Georgina basins (map provided by the Northern Territory Department of Natural Resources, Environment, The Arts and Sport)

### SW-2.3.2 Inter-aquifer connection and leakage

The major aquifers in the South-West Gulf region are usually not in hydraulic connection because they are separated by siltstone, claystone or shale (Figure SW-2).

The one important exception occurs in the headwaters of the Gregory River and Lawn Hill Creek. In this area throughflow from the regionally extensive aquifer developed in the karstic rocks of the Camooweal Dolomite recharges the underlying Thorntonia Limestone. Normally the siltstone of the Wonarah Formation (or equivalent) separates these two formations (Figure SW-2).

A historical study of Gregory River streamflow (Whitehouse and Ogilvie, 1949) showed that as the river traversed the alluvial Gulf Plains there was a decline in streamflow such that it was reduced significantly by the time it had reached its endpoint. The major component of this loss was considered to occur as seepage loss to groundwater. However, an investigation into this hypothesis, which involved the drilling of 21 bores in the Gregory River catchment, did not support this assumption (McEniery, 1980). The results of the drilling found that the alluvial deposits were strongly channelled to depths of about 40 m and saturated sediments only occurred in the channels. Hence streamflow losses were considered the result of evapotranspiration from the belt of trees that bordered the river to about 800 m either side and were not attributed to leakage to aquifers.

The thinning of riparian vegetation as the Nicholson River approaches the mouth of the Gulf of Carpentaria means that evapotranspiration processes are likely to be greatly reduced and river leakage may account for a more significant volume of groundwater recharge. This is supported by (Davis and Dowe, 2005) who concluded that groundwater recharge via leakage from the permanently flowing streams plays an important role in supporting coastal wetland environments.

### SW-2.3.3 Recharge, discharge and groundwater storage

Recharge occurs only in the wet season when rainfall intensity and duration is sufficient. Recharge leads to a rise in groundwater levels and in the dry season the levels naturally fall as groundwater is either transpired or discharged to wetlands and rivers where it evaporates or is discharged to the sea. The amount and rate at which the groundwater levels rise and fall depends on the type, size and other physical properties of the aquifer, as well as the amount of recharge. The recharge/discharge cycle that applies in the South-West Gulf region is summarised in Figure SW-16.

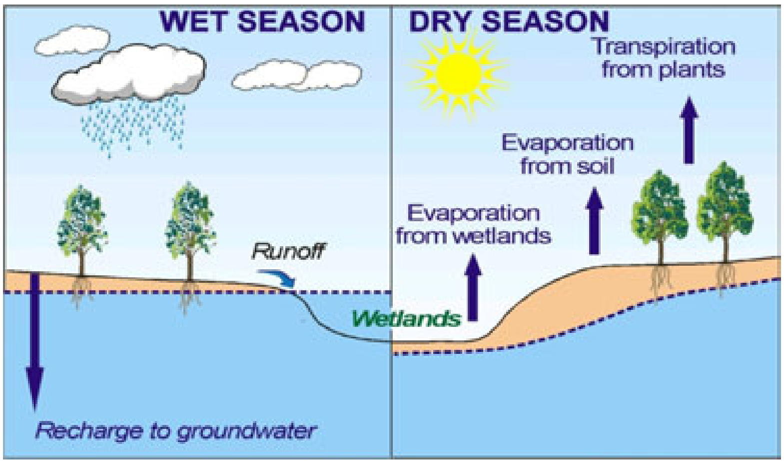



Figure SW-16. Schematic of the recharge and discharge cycle that applies in the South-West Gulf region

Recharge beneath native vegetation is dominated by bypass flow and not diffuse movement through soil horizons. The most likely mechanism for this is via macropores such as cracks and remnant tree root holes in the soil.

Recharge rates will be higher in the north of the region due to higher rainfall. River recharge and leakage from thin alluvial aquifers may also be significant mechanisms for recharging the fractured rock aquifers in drier periods.

Evapotranspiration is thought to be the primary discharge mechanism.

Springs that discharge from aquifers in either fractured rocks, Proterozoic carbonates or Cretaceous sediments usually have small flows. Comparatively higher spring discharge occurs where Cretaceous sandstones aquifers are underlain by either Proterozoic carbonates or low permeability fractured rocks such as occurs for the Robinson and Calvert rivers (Figure SW-2). Prior to 1988, the Northern Territory Government maintained river gauging stations on the Calvert and Robinson rivers. However recent work has shown that they were situated upstream of areas where significant groundwater discharges occurred.

Small quantities of groundwater flow either into or out of the South-West Gulf region across its boundary. It would be expected that over most of the region the inflows will balance the outflows and the net impact will not be significant. The only exception to this is the aquifer system that occurs in the equivalent of the Thorntonia Limestone located adjacent to the north-western boundary of the region. This aquifer system discharges to the Roper River to the north-west of the South-West Gulf region.

Specific comments relating to recharge to and discharge from each of the three major aquifer types follows. The locations of monitoring bores and river gauging stations in the region that are referenced in the following sections are shown on Figure SW-2.

## Fractured rocks

A fractured rock aquifer in the Proterozoic sandstone has been developed as a water supply for Borroloola. Data from a bore monitoring water levels in that aquifer have been plotted in Figure SW-17. From 1987 to 1995 it is evident that very little recharge occurred to the aquifer and/or pumping was slowly depleting the resource at this location. In the period from 1996 to 1999 water levels appear to have recovered to above their 1987 levels possibly in response to the above average rainfall that occurred in the region over this period.

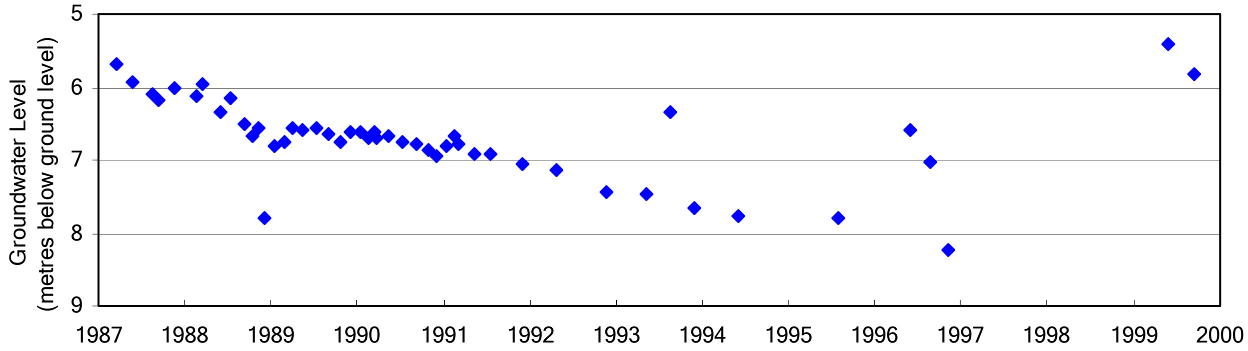



Figure SW-17. Water level fluctuations in bore RN024453 located near Borroloola

## Karstic carbonate rocks – Thorntonia Limestone (or equivalent), Wonarah Formation (or equivalent) and Proterozoic carbonates

With the exception of localised monitoring around the Phosphate Hill mine (data not available to this project), there is no time series groundwater level data available for the karstic carbonate rocks of the region.

Regional groundwater discharges from the aquifer developed in Proterozoic carbonates provide the dry season flow for the Calvert and Robinson rivers and numerous small springs across the region.

Regional groundwater discharges from the aquifer developed in the Camooweal Dolostone and Thorntonia Limestone provide the dry season flow for the Gregory River and Lawn Hill Creek.

Read (2003) estimated recharge to the Camooweal Dolostone to be between 2 and 6 mm/year using a groundwater chloride mass balance technique. He estimated the same range of recharge rates for the Camooweal Dolostone and Thorntonia Limestone by evaluating dry season flow data for Lawn Hill Creek and the Gregory River.

In the Australian Water Resource Assessment 2000 (ANRA, 2008a) total annual recharge to the Thorntonia Limestone aquifer was estimated to be between 19 and 30 GL/year. This volume equates to a mean annual recharge rate of between 6 and 9.5 mm/year.

Discharge from the Thorntonia Limestone aquifer also occurs in the form of dewatering for the Century Zinc Mine. It has been estimated that if the dewatering continues for the 22-year life of the mine, an estimated 420 GL will discharge from the aquifer over this period. The impact of dewatering will be a loss in storage that is expected to take more than 50 years to refill (ANRA, 2008b).

## Cretaceous sediments

There is no time series groundwater level data available for the Cretaceous sediments in the region. Regional groundwater discharges from the aquifer developed in the Cretaceous sediments provides part of the dry season flow for the Calvert River.

Tickell (2003) commented on the mass death of mature trees (including *Corymbia polycarpa*) during 2001 on Pungalina Station, 130 km south-east of Borroloola in an area where the Cretaceous sediments overlie fractured rocks. The trees were fringing what was historically an ephemeral lake. A study of the growth rings in one of the trees indicated that it was at least 98 years old. The death of the trees, presumably as a result of prolonged water logging, indicates that recent rainfall has been exceptionally high compared to the last one hundred years. This interpretation is supported by the

Calvert Hills station rainfall record, where annual rainfall has been consistently above the historical mean value since the late 1990s (Figure SW-18).

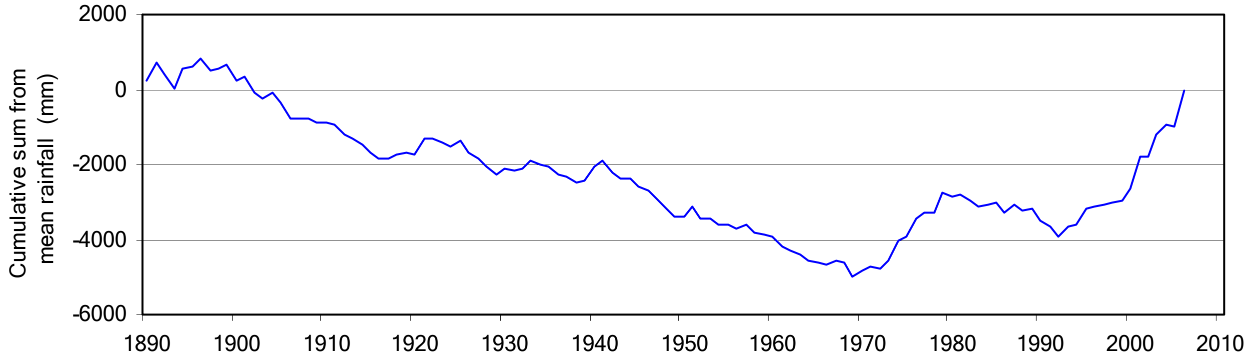



Figure SW-18. Cumulative deviation from mean annual rainfall at Calvert Hills

Groundwater recharge to the aquifers of the Great Artesian Basin in this region is expected to be small. This is suggested because drilling of the basal sandstone aquifer in coastal regions of the Northern Territory adjacent to the Queensland border has encountered brackish to saline water, as did deep drilling beneath Mornington Island. Discharge from the Cretaceous sediments is likely to be to adjacent creeks and wetlands.

### SW-2.3.4 Groundwater quality

The quality of most groundwater sourced from the fractured rock aquifers across the South-West Gulf region falls within the drinking water guidelines (ADWG, 2004). Occasionally elevated levels of arsenic pose a human and animal health risk.

Groundwaters in the Thorntonia Limestone (and equivalent) and Proterozoic carbonates (for locations see figure SW-2) are slightly alkaline on average but pH can range from 6.4 to 8. Calcium, magnesium and bicarbonate are the dominant ions, while salinity (as electrical conductivity) is mostly in the range 300 to 1500 µS/cm (Figure SW-19). Calcium, magnesium and bicarbonate concentrations show neglible geographic variation across the carbonate aquifers. They dissolve relatively easily from the limestone and dolomite matrix and once saturation is reached with respect to these minerals their concentrations rarely change. Hardness is normally high and will cause scale build-up in plumbing.

Groundwaters in the Wonarah Formation (and equivalent) are known to contain the evaporite minerals halite (NaCl) and anhydrite (calcium sulphate). These minerals were deposited at the time that the sediments were being laid down. Calcium and sulphate are thus the dominant ions, while salinity (as electrical conductivity) mostly ranges between 1000 and 5000 µS/cm (Figure SW-19).

The Queensland Department of Environment and Resource Management records groundwater quality information for only three bores constructed in Great Artesian Basin aquifers in the South-West Gulf region. Two of these bores are screened in the Gilbert River Formation. Electrical conductivity values of 2210 and 2600 µS/cm were recorded in 1994 and 1999 respectively. The third value is from a bore constructed in the Wallumbilla Formation (of the Rolling Downs Group) with an electrical conductivity of 3500 µS/cm, last recorded in 1983.

Groundwater quality of the carbonate aquifers is typically good, however the geomorphology of the karst systems mean that they are particularly susceptible to contamination via pollutants. The effect of catchment activities in the vicinity of the karstic aquifers on subsequent groundwater quality remains virtually unknown. The DNRW records groundwater quality information for two bores constructed in the Thorntonia Limestone. The latest groundwater electrical conductivities recorded for these bores were 390 µS/cm (in 2001) and 460 µS/cm (in 1973).

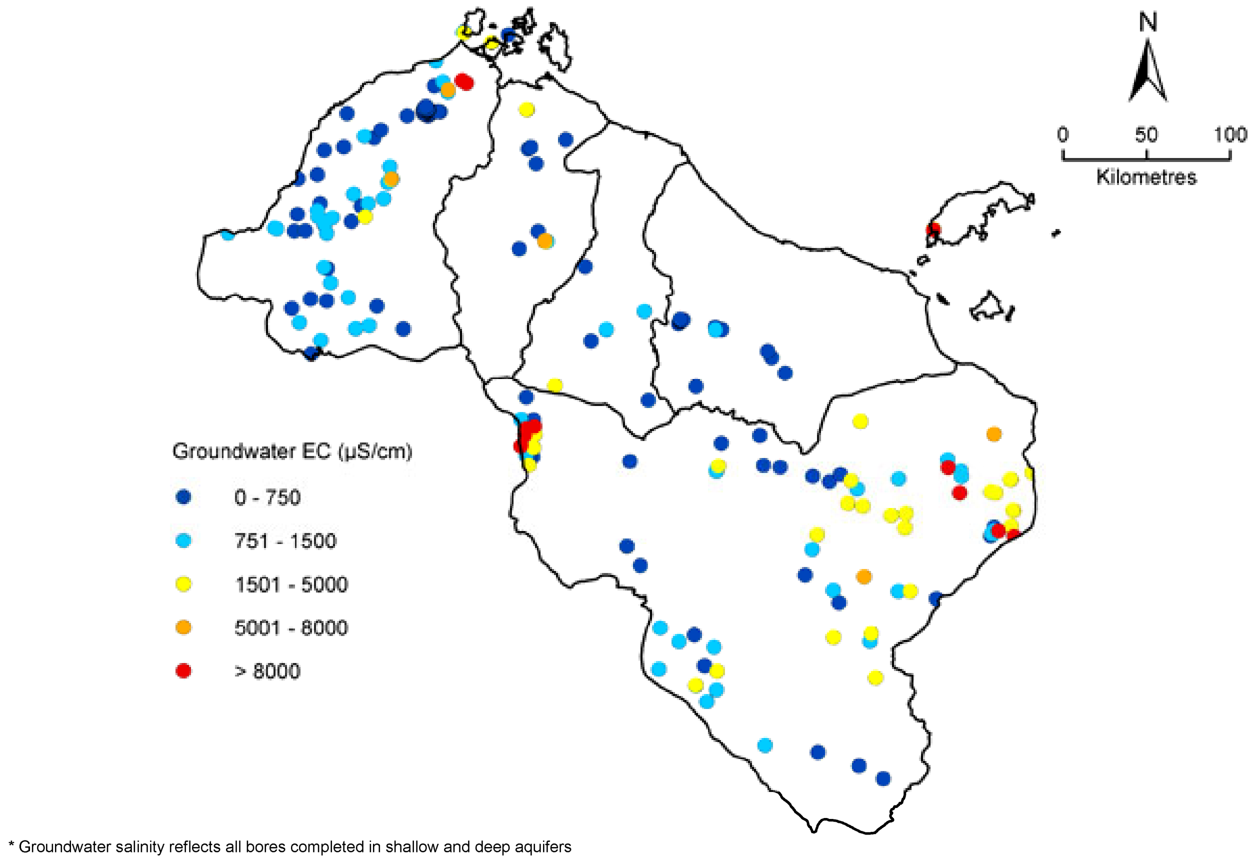



Figure SW-19. Groundwater salinity distribution for all bores in the South-West Gulf region

# SW-2.4 Legislation, water plans and other arrangements

## SW-2.4.1 Legislated water use, entitlements and purpose

The South-West Gulf region straddles the Northern Territory and Queensland border. The only towns in the region are Borroloola, Doomadgee and Burketown. The total population living within the region is probably less than 10,000, and the main activities are mining, the pastoral industry and tourism. The predominant land use in the region is pastoral activity in the form of cattle grazing.

Those catchments in the Northern Territory are administered through the Northern Territory government, guided by the *Northern Territory Water Act 1992*. The Act provides a process for the allocation of water resources to beneficial uses, including the environment, and to enable trade in water licences. The legislative framework sets targets for cost recovery and pricing, institutional reform, water allocation (including the development of regional water allocation plans) and trading, environment and water quality and public consultation and education. The *Water Act 1992* restricts and controls the way in which water quality can be affected. According to the *Water Act 1992*, the Crown owns all surface water and groundwater, a situation unique to Australian water law (O'Donnell, 2002).

The water policy framework in the Northern Territory is not well developed and the legislation has no objects or principles to guide the development of a water allocation plan. Sustainability is introduced through the concept of 'beneficial use'. 'Beneficial uses', or preferred uses, are determined for natural waterways under the Act. The uses include: (i) protection of aquatic ecosystems; (ii) recreation and aesthetics; (iii) raw water for drinking water supply; (iv) agricultural water supply; and (v) industrial water supply. Beneficial uses have not been declared for any waterways within the region.

Water resources on the Queensland side of the border are administered through the *Water Resources (Gulf) Plan 2007*. Water resources in the GAB in Queensland are also administered through the *Water Resources (Great Artesian Basin) Plan 2006*. The Settlement Basin and the Gregory River catchment (including the lower Nicholson River from its confluence with the Gregory) are declared wild river areas. The *Wild Rivers Act 2005* includes a process for the Minister for Environment and Resource Management to declare wild river areas. The intent of the *Settlement Wild River Declaration 2007* and the *Gregory Wild River Declaration 2007* is to preserve the natural values of wild rivers in the Settlement and Gregory wild river areas. The declarations do this by regulating most future development activities and resource allocations within the wild river areas. Water allocations for these wild river areas are dealt with under the *Water Resource (Gulf) Plan 2007*. In the wild river areas new development activities will be regulated through existing development assessment processes with wild river requirements applied through the wild river declarations or the wild rivers code. Developments and authorisations in place at the time the declarations were made are not affected.

There are currently no surface water entitlements in the Settlement catchment. The Nicholson catchment has two main subcatchments: Nicholson and Gregory. The Nicholson has 2950 ML/year surface water allocated for use. Of this 2420 L/year is allocated for irrigation use; 500 ML/year is allocated to town water supply for Doomadgee; and 30 L/year is allocated to non-riparian stock and domestic entitlements (Figure SW-20).

Groundwater use figures for the South-West Gulf region were not calculated for the Australian Water Resources 2000 Assessment. However, there are a number of groundwater and surface water entitlements which total 1.2 and 3.5 GL/year respectively for town water supplies and watering livestock from reliable supplies of good quality groundwater from the carbonate aquifers (DNRW, 2008). There is limited or no information about the actual use from these entitlements and hence it is difficult to assess the potential impacts of this extraction. Depending on vicinity to the rivers (in the case of groundwater entitlements) and timing of extraction, these entitlements are likely to have a direct impact on dry season river flows and environmental health of dependent ecosystems if they are utilised.

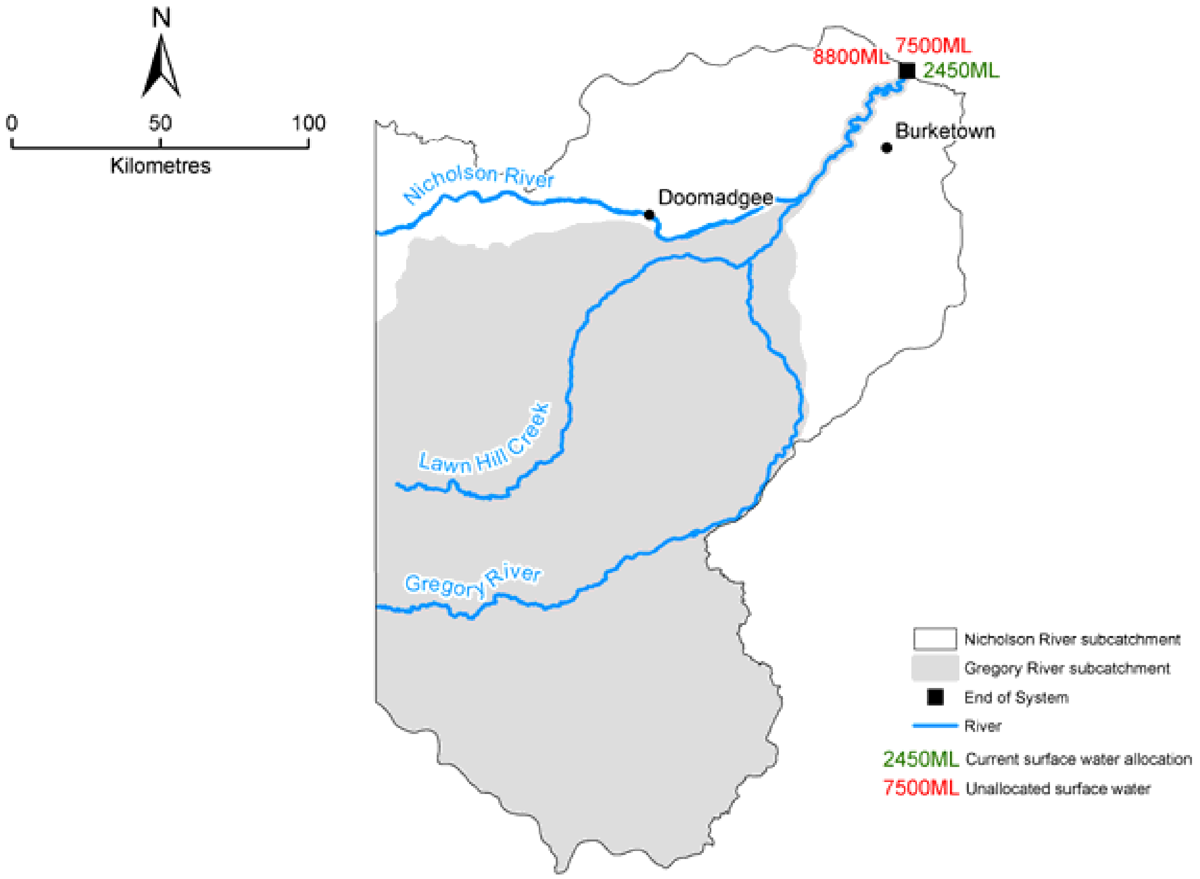



Figure SW-20. Assignment of water allocations in the Nicholson Catchment. Allocations are green, unallocated water in red (after *Water Resource (Gulf) Plan 2007*)

### SW-2.4.2 Groundwater use and entitlements

Substantial parts of the region lie within the North West Minerals Province, which is considered one of the most prospective regions in the world for metals, industrial minerals and gemstones. There is limited or no information for groundwater extraction for either dewatering or processing purposes in a number of mines in the region. The Century Zinc Mine, for example, is thought to extract approximately 19 GL/year (ANRA, 2008b) which is of the same order of magnitude as estimated recharge volumes to the major aquifers (Thorntonia Limestone was estimated to be between 19 and 30 GL/year in (ANRA, 2008a)). The impact of dewatering will be a loss in storage that is expected to take more than 50 years to refill (ANRA, 2008b). It is likely that this extraction has and will continue to draw water from rivers dependant on baseflow and spring discharges in the area. As dewatering continues, it is possible that significant depletion in the flow of Lawn Hill Creek could occur where it is underlain by the Thorntonia Limestone.

A small portion of the South-West Gulf region resides within the Great Artesian Basin and is represented by the Carpentaria Management Area. This management area is responsible for the groundwater resources of the Rolling Downs Group, the Gilbert River Formation and Eulo Queen Group. The base of the Wallumbilla Formation (of the Rolling Downs Group) contains sandier layers that (when combined with weathered basement rocks) provide locally important sources of artesian water. These units are mainly developed for stock usage, due to poor quality and low yields, typically less than 5 L/second (DNRM, 2005). The Gilbert River Formation is the main artesian aquifer in this management area, as to a large extent it lies directly on basement rocks. However, water quality (including salinity and fluoride content), bore yields and aquifer thickness varies considerably and hence development is restricted to stock and domestic use only. Burketown previously sourced water from the Gilbert River Formation; however the availability of better quality surface water has reduced the need to extract groundwater from this Great Artesian Basin aquifer.

### SW-2.4.3 Rivers and storages

There are two storages on the Nicholson River that provide water for Mount Isa Mines. These have a total storage capacity of 17,820 ML.

### SW-2.4.4 Unallocated water

Unallocated water is water that is identified as water potentially available for future allocation. In Queensland it has a specific definition and may be held as one of three reserves:

- General Reserve (general unallocated water), which may be granted for any purpose;
- Strategic Reserve (strategic unallocated water) which may only be granted for a state purpose. This might be:
    - a project of state significance; or
    - a project of regional significance; or
    - town water supply; or
    - eco-tourism in a wild river area.

Under the *Water Resources (Gulf) Plan* there is 0.4 GL/yr unallocated water in general reserve in the Carpentaria management area of the GAB, and 10 GL/yr unallocated State reserve across the whole of the basin. There is no distinction between surface water and groundwater within this unallocated water. The allocation limit is given for combined extraction. Three assumptions are implicit:

- The vast majority of water will be taken from surface water: utilising flood harvesting and extraction from major surface water sources.
- Any groundwater extractions taken close to a major surface water source are treated as if they came from the surface water supply.
- For the purposes of documentation, all unallocated water is taken to be surface water extraction.

Further, no specific location can be assigned to this water, as it applies to the entire catchment, or a region within it. The temporary assignment is to the downstream point of the region's catchment. Unlicensed extraction in all catchments is expected to remain insignificant.

Groundwater under the *Water Resource (Great Artesian Basin) Plan (2006)* is however separated from surface water. There is unallocated water from the GAB which is separate and not considered a surface water extraction.

Unallocated water in the South-West Gulf region is listed in Table SW-3. Under the *Water Resource (Great Artesian Basin) Plan 2006*, 400 ML/yr in unallocated groundwater is specified as general reserve in the Carpentaria Management Area and there is potential access to 10,000 ML/yr unallocated State reserve across the entire basin.

Table SW-3. Unallocated water reserves in the South-West Gulf region (Queensland catchment only)

| Catchment | General | Strategic | Indigenous | TOTAL |
|---|---|---|---|---|
| | ML/y | | | |
| Settlement | - | 1000 | - | 1000 |
| Nicholson | 4400 | 4400 | - | 8800 |
| Gregory | 2500 | 5000 | - | 7500 |

### SW-2.4.5 Social and cultural considerations

Jackson et al. (2008) found that focus group participants at Mount Isa placed a high value on particular rivers. A negative response to a hypothetical future dam on the Gregory was explained in the following terms:

> "The Gregory is one of the only permanent rivers in the area – it's VERY special – you could dam any of the other 19 rivers in the area and people would feel differently. Some rivers you don't touch, Gregory is one. Everyone loves it."

The Maga-Kutana, Wakabunga, Nguburinjo, Ganggalida and Mingin people are the traditional owners of the Gregory River catchment area and the Ganggalida and Gananggallanda people are the traditional owners of the Settlement Creek catchment area. All Indigenous groups maintain strong cultural and spiritual connections with the land and rivers.

### SW-2.4.6 Changed diversion and extraction regimes

Very low population and remoteness is likely to result in minimal future change to water regimes.

### SW-2.4.7 Changed land use

Ongoing mineral prospecting and development of any new exploration targets are the only land use change envisaged and these will have minimal impact at a regional scale. Low agricultural suitability has meant that only a few zones in the Gregory area have been used for pastoral agriculture and these have been affected by some erosion and pasture degradation associated with grazing. The most contentious development in the area is the Dutch Century Zinc mine, only 30 km from the river. Expansion of mining for minerals such as zinc and copper are a threat to the Gregory's wild river values. Wild river protection will restrict instream mining in the area, as well as help manage the growing threat of invasive weeds in the region.

The Settlement Creek is remote and currently there is little human demand for water extraction in this area. The major present threat in this area is cattle grazing; if not managed sustainably, cattle can cause major soil erosion, trample vegetation and pollute river systems. Wild river protection, as well as the Indigenous Wild River Ranger program, will help address these impacts.

### SW-2.4.8 Environmental constraints and implications of future development

Fed by limestone springs, the immense Gregory River is one of few rivers in this region that flow all year round thanks to a strong groundwater influence in the area from Australia's largest karst terrain. It is bordered by white sandy beaches in some places and limestone cliffs in others and is recognised by canoeists as one of Australia's best courses.

In the dry season, when most other rivers in the Gulf Savannah are baked into cracked red earth, Wallabies, Wallaroos, Bats, Olivine Python, Fairy Martins, Wedge-Tailed Eagles and a multitude of birds rely on the Gregory for water.

The Gregory River and its wetlands are part of the Thorntonia Aggregation, a system of wetlands in which more than half of Queensland's international migratory birds can be found. The Gregory's year round flow is essential to the survival of these wetlands and is also critical to the health of the Gulf of Carpentaria's seagrass beds and dugong populations. There is also a direct relationship between the river's annual flows and the abundance of prawns available to the Gulf's lucrative fishing industry.

The Gregory River makes up the Southern border of the Riversleigh World Heritage Area, established to protect fossils preserved over millions of years by its lime-rich waters.

Similar importance can be ascribed to perennial reaches of the Calvert and Robinson rivers, further to the west. For the Queensland portion of the region, the *Water Resource (Gulf) Plan 2007* ensures that total consumptive extractions will be limited to around 0.5 percent of the total mean annual flow for these catchments.

# SW-2.5 References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# SW-3 Water balance results for the South-West Gulf region

This chapter describes modelling results and the assessment of the water resources undertaken by this project for the South-West Gulf region. Detailed, quantified assessments are made where possible, and relevant, and confidence is estimated. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2. This chapter is sub-divided into:

- climate
- recharge estimation
- conceptual groundwater models
- groundwater modelling results
- rainfall-runoff modelling results
- river system water balance
- changes to flow regimes at environmental assets.

## SW-3.1 Climate

### SW-3.1.1 Historical climate

The South-West Gulf region receives an average of 670 mm of rainfall over the September to August water year (Figure SW-21), most of which (631 mm) falls in the November to April wet season (Figure SW-22). Across the region there is a strong north–south gradient in annual rainfall (Figure SW-23), ranging from 1168 mm in the north to 405 mm in the south. Over the historical (1930 to 2007) period, rainfall has generally remained constant but with the 1970s and post-2000 wetter than average. The highest regionally averaged yearly rainfall received was 1460 mm which fell in 2001, and the lowest was 289 mm in 1952.

Areal potential evapotranspiration (APET) is very high across the region, averaging 1961 mm over a water year (Figure SW-21), and varies moderately across the seasons (Figure SW-22). APET generally remains higher than rainfall for most of the year resulting in near-year-round water-limited conditions. The exceptions to this are the months January to March, when more rain falls than can potentially be evaporated.

 

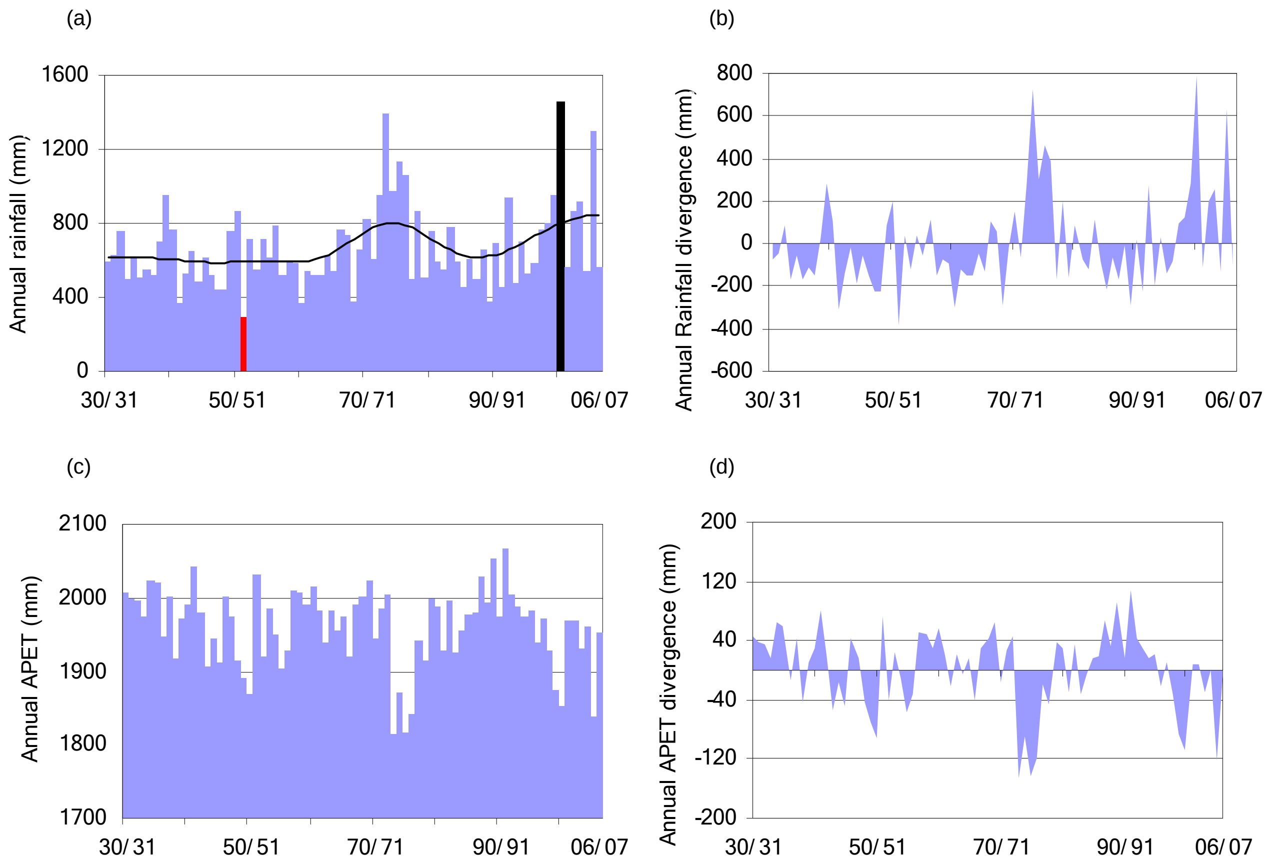


Figure SW-21. (a) Historical annual rainfall and (b) its divergence from the long-term mean; and (c) historical annual areal potential evapotranspiration and (d) its divergence from the long-term mean averaged over the South-West Gulf region. The low-frequency smoothed line in (a) indicates longer term variability

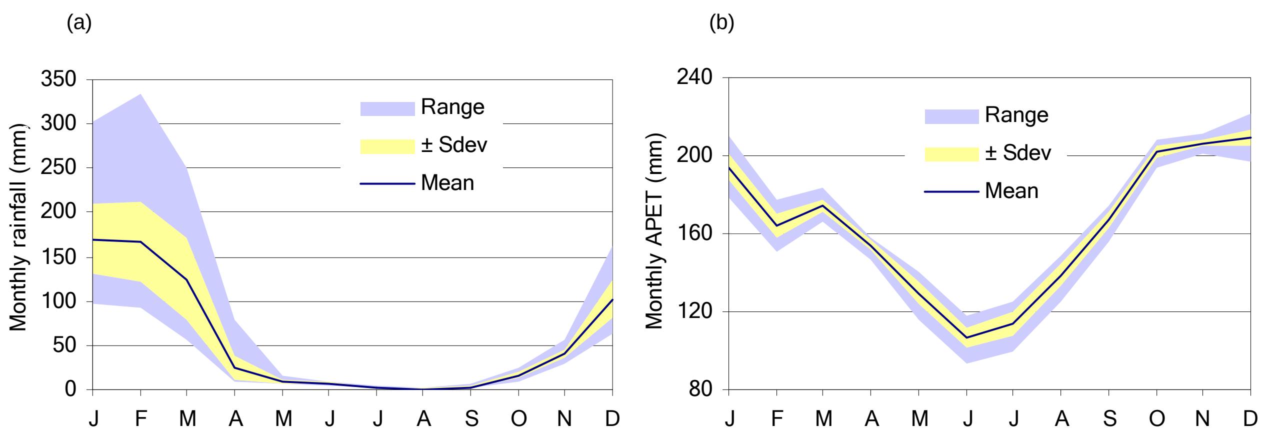


Figure SW-22. Historical mean monthly (a) rainfall and (b) areal potential evapotranspiration and their temporal variation (range and ± one standard deviation) averaged over the South-West Gulf region

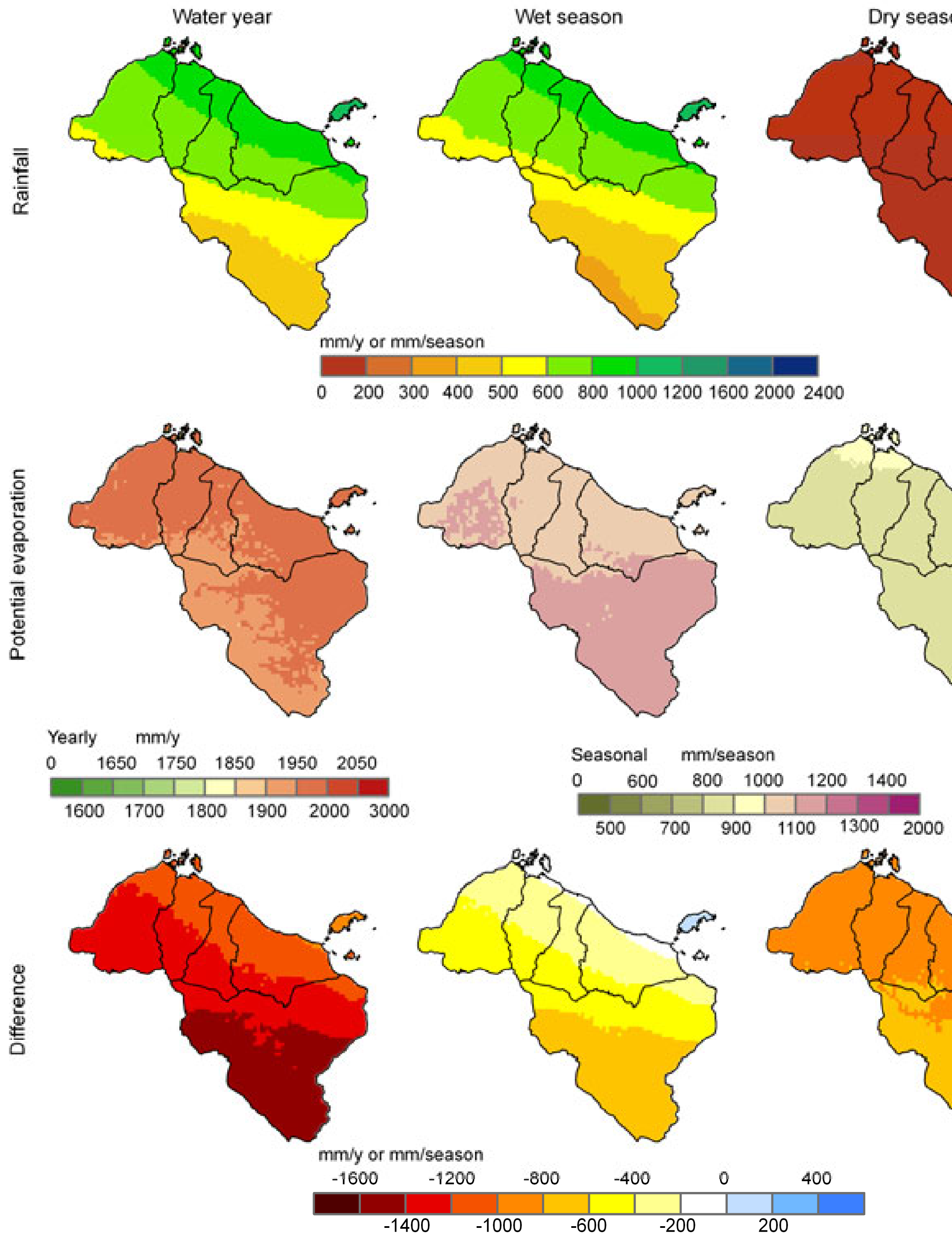


Figure SW-23. Spatial distribution of historical mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration (potential evaporation) and their difference (rainfall less areal potential evapotranspiration) across the South-West Gulf region

### SW-3.1.2 Recent climate

Figure SW-24 compares recent (1996 to 2007) to historical (in this case the 66-year period 1930 to 1996) mean annual rainfall for the South-West Gulf region. Across the whole region, recent rainfall is between 10 and 60 percent higher than historical rainfall – a statistically significant difference for the majority of the region.

 

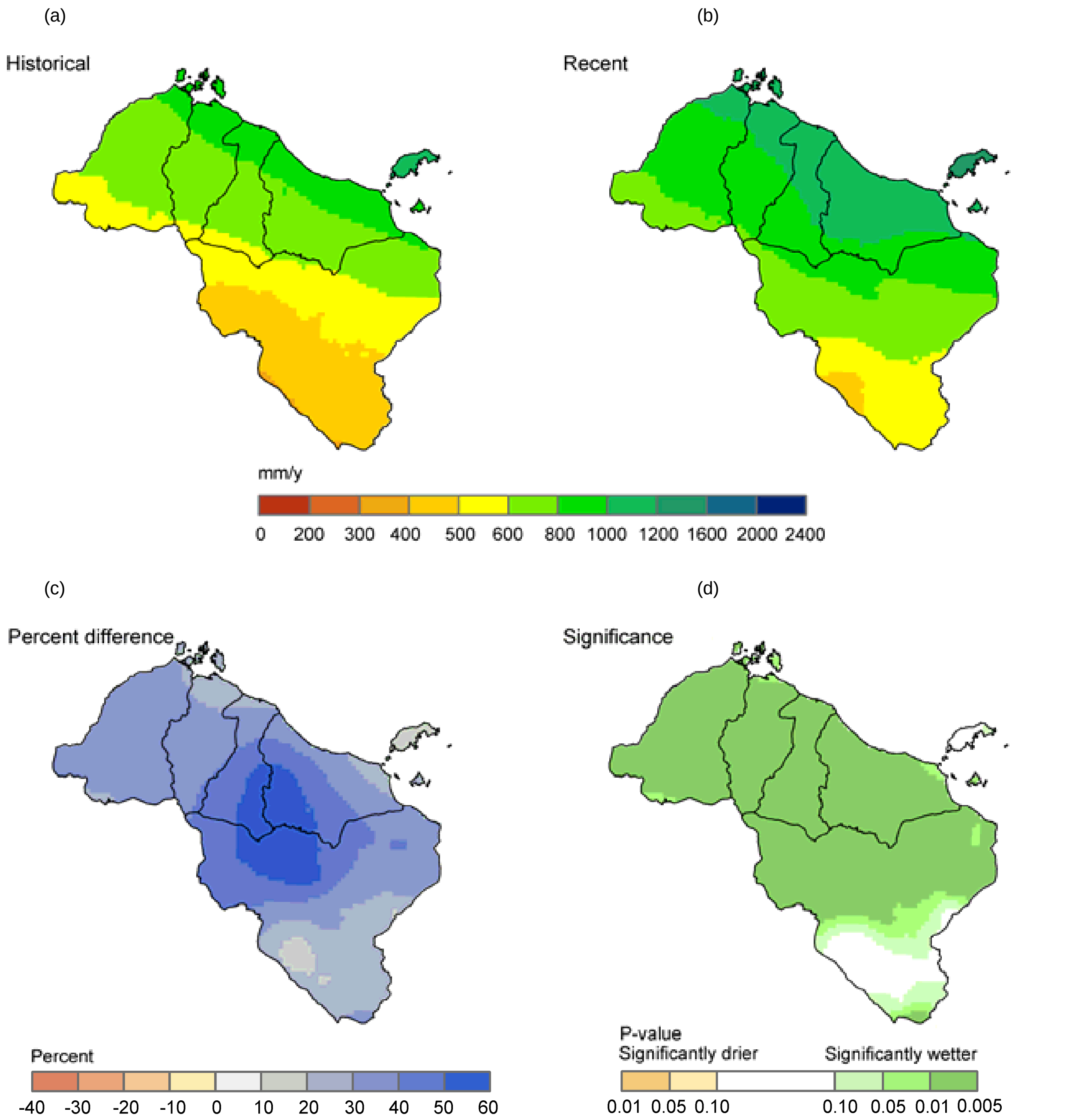


Figure SW-24. Spatial distribution of (a) historical and (b) recent mean annual rainfall; and (c) their relative percent difference and (d) the statistical significance of these differences across the South-West Gulf region. (Note that historical in this case is the 66-year period 1930 to 1996)

### SW-3.1.3 Future climate

Under Scenario C annual rainfall varies between 632 and 732 mm (Table SW-4) compared to the historical mean of 670 mm. Similarly, APET ranges between 2009 and 2041 mm compared to the historical mean of 1961 mm.

A total of 45 variants of Scenario C were modelled (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). Subsequently, results from an extreme 'wet', median and extreme 'dry' variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet annual rainfall and APET increase by 9 percent and 3 percent, respectively. Under Scenario Cmid annual rainfall is the same as the historical mean and APET increases by 2 percent. Under Scenario Cdry annual rainfall decreases by 6 percent and APET increases by 4 percent.

Under Scenario Cmid long-term monthly averages of rainfall do not differ much from historical values, while APET is higher for all months (Figure SW-25). The historical APET values are at the lower bound of the range of the 45 Scenario

C variants. Under Scenario Cmid rainfall and APET lie within the range in values from all 45 Scenario C variants. The seasonality of both rainfall and APET remain generally unchanged.

The spatial distributions of rainfall and APET under Scenario C are compared to the historical distribution in Figure SW-26 and Figure SW-27. Under Scenario C the strong north–south gradient in rainfall is retained, but with a southwards shift under Scenario Cwet and a northwards shift under Scenario Cdry. The spatial distribution of APET under Scenario C is similar to the highly regionalised historical distribution. The greatest changes to APET occur in the east of the region.

Table SW-4. Mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration averaged over the South-West Gulf region under historical climate and Scenario C

| | Water year* | Wet season | Dry season |
|---|---|---|---|
| | mm/y | mm/season | |
| Rainfall | | | |
| Historical | 670 | 631 | 39 |
| Cwet | 732 | 683 | 40 |
| Cmid | 668 | 624 | 37 |
| Cdry | 632 | 593 | 32 |
| Areal potential evapotranspiration | | | |
| Historical | 1961 | 1103 | 858 |
| Cwet | 2022 | 1134 | 884 |
| Cmid | 2009 | 1125 | 880 |
| Cdry | 2041 | 1143 | 894 |

* Note that the sum of the wet season and dry season values does not always equal the water year values because the combined wet season and dry season period (November to October) is different to the water year period (September to August).

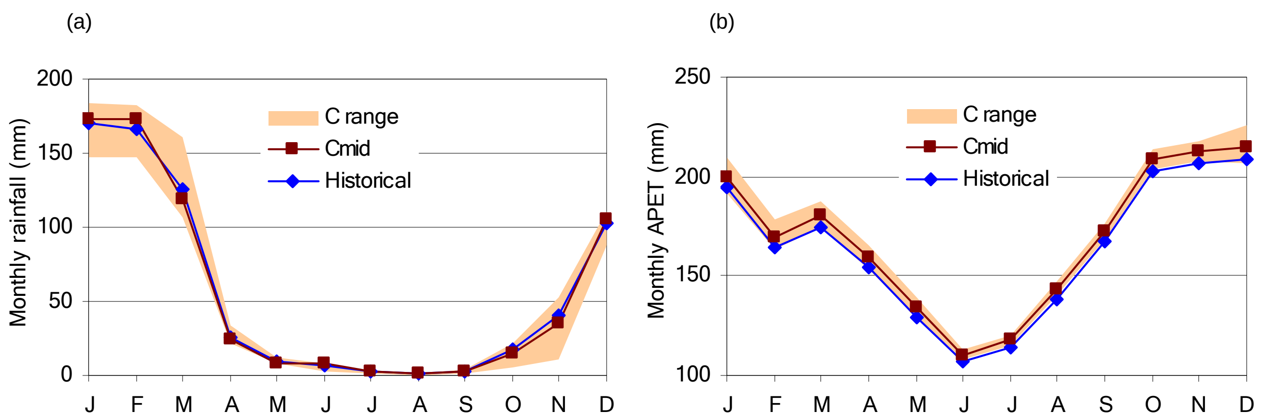


Figure SW-25. Mean monthly (a) rainfall and (b) areal potential evapotranspiration averaged over the South-West Gulf region under historical climate and Scenario C. (C range is the range under the 45 Scenario C simulations – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

## SW-3.1.4 Confidence levels

Analysis of confidence of the climate data is presented in Section 2.1.4 of the division-level Chapter 2.

 

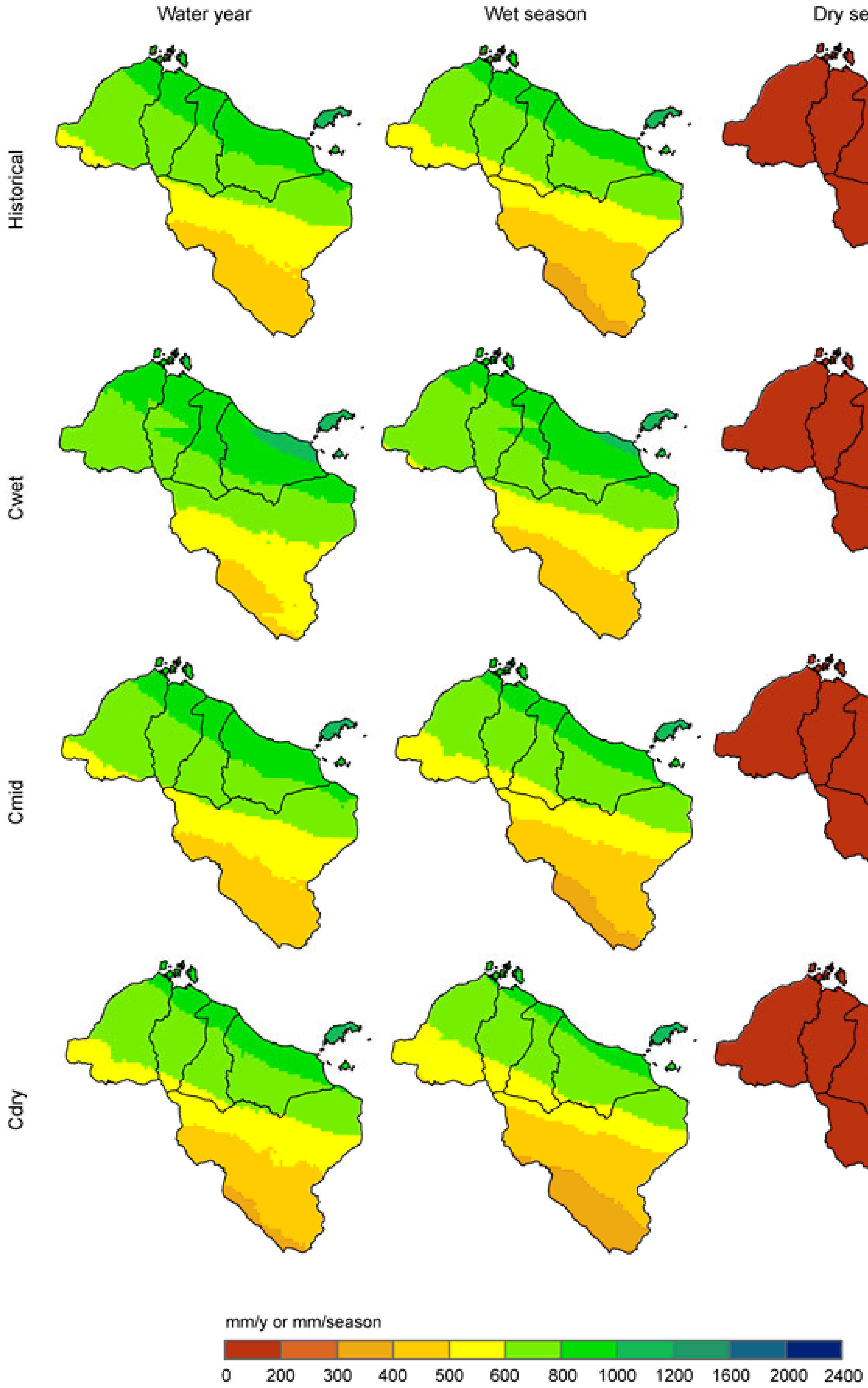


Figure SW-26. Spatial distribution of mean annual (water year), wet season and dry season rainfall across the South-West Gulf region under historical climate and Scenario C

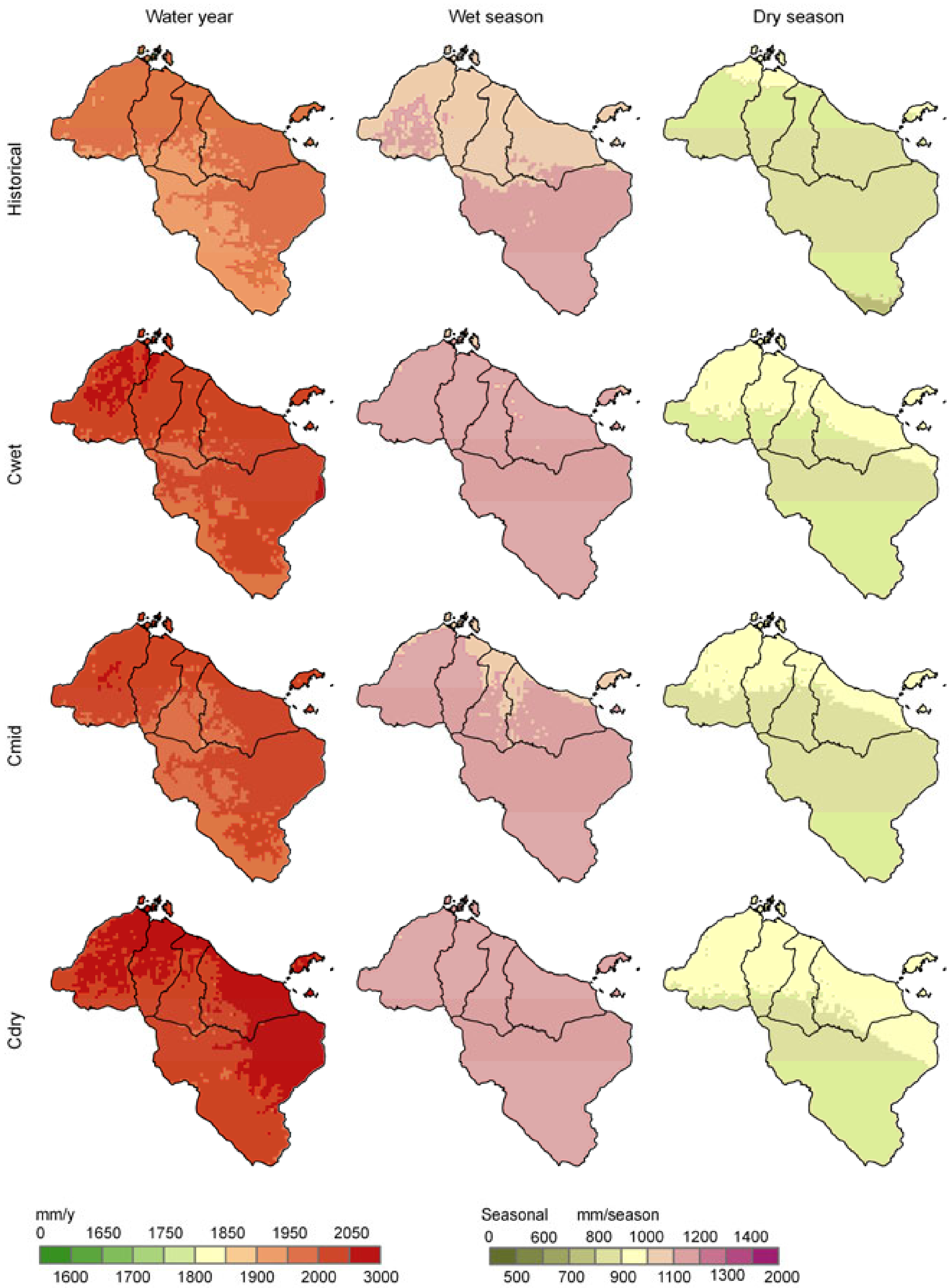


Figure SW-27. Spatial distribution of mean annual (water year), wet season and dry season areal potential evapotranspiration across the South-West Gulf region under historical climate and Scenario C

 

## SW-3.2 WAVES potential diffuse recharge estimations

The WAVES model (Zhang and Dawes, 1998) was used to estimate the change in groundwater recharge across the South-West Gulf region under a range of different climate scenarios. WAVES is a vertical recharge flux model that can model plant physiological feedbacks in response to increased $CO_2$, as well as modelling the water balance of different soil, vegetation and climate regimes. It was chosen for its balance in complexity between plant physiology and soil physics. It was also used to assess recharge for the Murray-Darling Basin Sustainable Yields Project (Crosbie et al., 2008).

### SW-3.2.1 Under historical climate

The calculated historical recharge for the South-West Gulf region shows that recharge is low when compared to the other regions. The historical record is used to establish any difference between wet and dry periods of recharge. A 23-year period allows projections of recharge estimates to 2030 – in other words, to estimate recharge in 2030 assuming future climate is similar to historical climate (Scenario A). Under a wet historical climate (Scenario Awet) recharge increases 12 percent. Under the median estimate of historical climate (Scenario Amid) recharge decreases 3 percent. Under a dry historical climate (Scenario Adry) recharge decreases 14 percent.

Table SW-5. Recharge scaling factors in the South-West Gulf region for scenarios A, B and C

| Region | Awet | Amid | Adry | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| South-West Gulf | 1.12 | 0.97 | 0.86 | 1.60 | 1.39 | 1.09 | 0.99 |

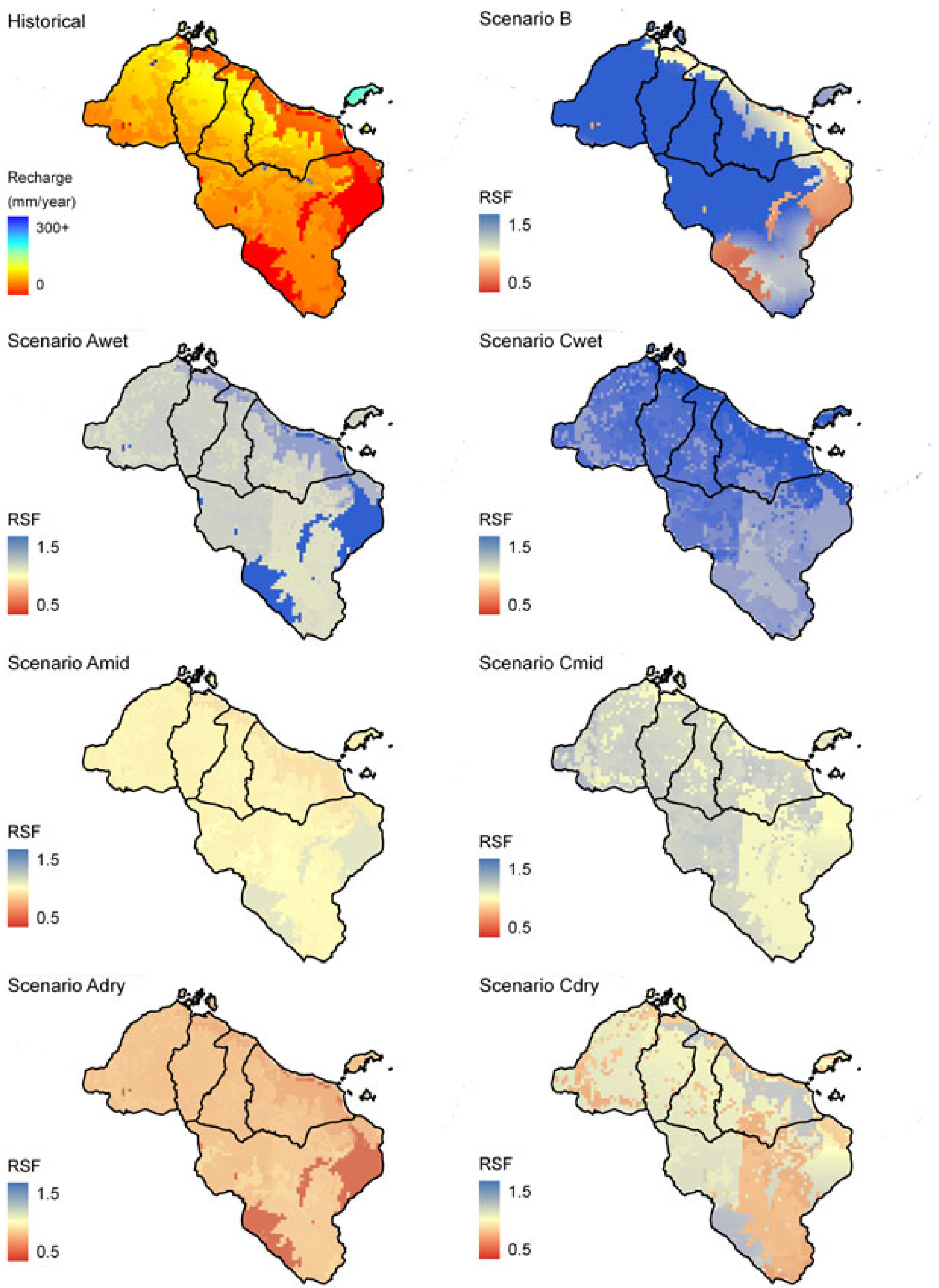


Figure SW-28. Spatial distribution of historical mean recharge rate ; and recharge scaling factors for scenarios A, B and C in the South-West Gulf region

 

## SW-3.2.2 Under recent climate

The recent (1996 to 2007) climate in the South-West Gulf region has been wetter than the historical (1930 to 2007) average and consequently the calculated recharge has increased 60 percent under Scenario B relative to Scenario A (Table SW-5). This increase has not been uniform across the region with areas near the coast being close to the historical recharge and some areas in the east of the region showing a decrease in recharge (Figure SW-28).

## SW-3.2.3 Under future climate

Figure SW-29 shows the percentage change in modelled mean annual recharge averaged over the South-West Gulf region under Scenario C relative to Scenario A for the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The percentage change in the mean annual rainfall and recharge from the corresponding GCMs are also tabulated in Table SW-6. Under some scenarios the recharge is projected to increase despite a decrease in rainfall. This is because total rainfall is not the only climate variable that influences recharge. Daily rainfall intensity, temperature and $CO_2$ concentration are also important drivers (see Section 2.3.3 in the division-level Chapter 2), and specific situations can result in this counter-intuitive result. In particular, rainfall intensity is seen as a significant factor in this relationship.

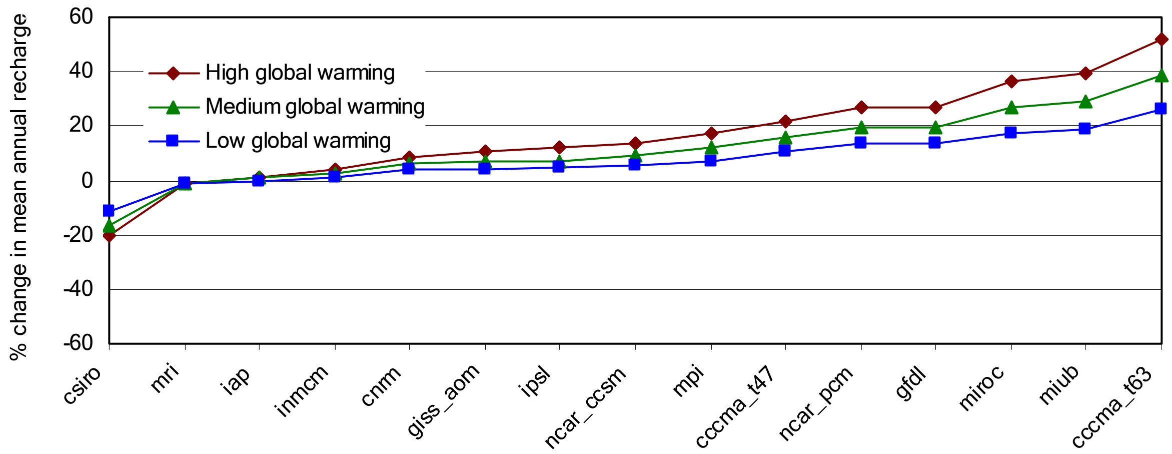


Figure SW-29. Percentage change in mean annual recharge under the 45 Scenario C simulations (15 global climate models and three global warming scenarios relative to Scenario A recharge

Table SW-6. Summary results under 45 Scenario C simulations (numbers show percentage change in mean annual rainfall and recharge under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Recharge | GCM | Rainfall | Recharge | GCM | Rainfall | Recharge |
| csiro | -20% | -20% | csiro | -15% | -16% | csiro | -10% | -11% |
| **mri** | **-6%** | **-1%** | mri | -4% | -1% | mri | -3% | -1% |
| iap | -5% | 1% | iap | -3% | 1% | iap | -2% | 0% |
| inmcm | -1% | 4% | inmcm | 0% | 2% | inmcm | 0% | 1% |
| cnrm | -4% | 9% | cnrm | -3% | 6% | cnrm | -2% | 4% |
| giss_aom | -1% | 11% | giss_aom | 0% | 7% | giss_aom | 0% | 4% |
| ipsl | 0% | 12% | ipsl | 0% | 7% | ipsl | 0% | 4% |
| ncar_ccsm | 1% | 14% | **ncar_ccsm** | **1%** | **9%** | ncar_ccsm | 1% | 6% |
| mpi | -1% | 17% | mpi | 0% | 12% | mpi | 0% | 7% |
| cccma_t47 | 1% | 22% | cccma_t47 | 1% | 16% | cccma_t47 | 1% | 11% |
| ncar_pcm | 7% | 27% | ncar_pcm | 5% | 19% | ncar_pcm | 4% | 13% |
| gfdl | 0% | 27% | gfdl | 0% | 20% | gfdl | 0% | 13% |
| miroc | 10% | 36% | miroc | 7% | 27% | miroc | 5% | 18% |
| **miub** | **8%** | **39%** | miub | 6% | 29% | miub | 4% | 19% |
| cccma_t63 | 10% | 52% | cccma_t63 | 8% | 39% | cccma_t63 | 6% | 26% |

Under Scenario Cwet recharge increases 39 percent; this is less than under Scenario B. Under Scenario Cmid recharge increases 9 percent. Under Scenario Cdry recharge decreases 1 percent decrease across the region, but with some areas showing an increase in recharge and others a decrease.

### SW-3.2.4 Confidence levels

The estimation of recharge from WAVES is only indicative of the actual recharge and has not been validated with field measurements. A chloride mass balance (CMB) has been conducted as an independent measure of recharge (Crosbie et al., 2009). The results in the South-West Gulf region show that the historical estimate of recharge using WAVES (54 mm/year) is less than the best estimate using the CMB (72 mm/year) but it is within the confidence limits of the CMB (6 to 171 mm/year).

## SW-3.3 Conceptual groundwater models

### SW-3.3.1 Fractured rocks

Relatively low rainfall and high potential evaporation means that recharge to the groundwater is likely to only occur after prolonged periods of intense rainfall in the wet season. Recharge is more effective through sandy soils than the black clay soils where recharge is only significant early in the wet season through cracks and preferential pathways before the clays swell. Aquifers are also locally recharged through either small alluvial aquifers or directly from the river when high flows or flooding occurs. The main groundwater discharge process is through evapotranspiration. For rivers draining fractured rock aquifers in the region flows are reduced to disconnected semi-permanent pools and then dry river beds as the dry season (in May to October) progresses.

### SW-3.3.2 Karstic carbonate rocks

Processes occurring in karstic carbonate rocks are similar to those for the fractured rocks. The main groundwater discharge processes are through evapotranspiration and spring discharge to rivers. River flows are maintained to varying degrees by the spring discharge.

Groundwater discharging from the Proterozoic carbonates in the catchments of the Robinson and Calvert rivers maintain perennial flows in the lower reaches of those rivers (Figure SW-16 in Chapter SW-2). There are three general conceptual models which describe the interaction between the carbonate aquifers and their discharge to rivers.

The first type describes the interconnection between the Proterozoic carbonate aquifer and the Robinson River and is given in Figure SW-30, where groundwater discharges from an underlying carbonate aquifer through a fault to the river.

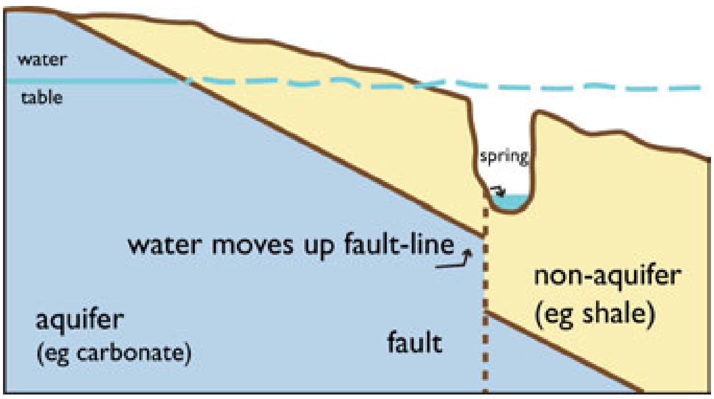


Figure SW-30. Schematic of conceptual model for groundwater discharge to the Robinson River of the South-West Gulf region

Groundwater discharge from the Camooweal Dolomite and Thorntonia Limestone maintains permanent flows in the Gregory River and Lawn Hill Creek. The conceptual model for this interaction is shown schematically in Figure SW-31.

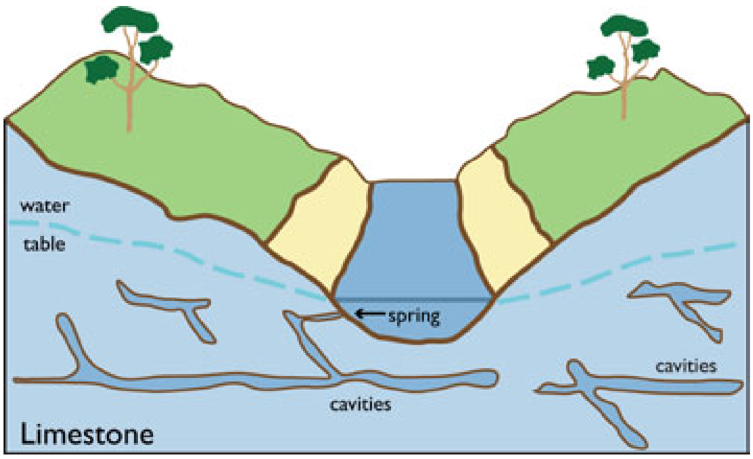


Figure SW-31. Schematic of conceptual model for groundwater discharge to the Gregory River and Lawn Hill Creek of the South-West Gulf region

The third conceptual model for the carbonate aquifers is described in the second part of the following section, and shown in the left hand side of Figure SW-32.

### SW-3.3.3 Cretaceous sediments

The dominant processes of recharge and discharge for the Cretaceous sediments are similar to those for the fractured rock aquifers and karstic carbonate aquifers. There are two types of spring discharge in the centre of the South-West Gulf region. The first occurs where a layer of porous and permeable sandstone overlies a low permeability rock such as shale or granite, as shown on the right hand side of Figure SW-32. Water stored in the upper layer seeps out at the contact between the two rock types. This is generally in the form of a seepage zone or swampy area at the contact. If the sandstone is underlain by carbonates (the third conceptual model for carbonate related springs) then discharge will be more focussed (eg the springs on Pungalina Station in the Calvert River Catchment). The karst features of carbonate rocks in this sequence are thought to have been enhanced by the more acidic groundwater recharging through the overlying sandstone aquifer, expanding the existing solution cavities.

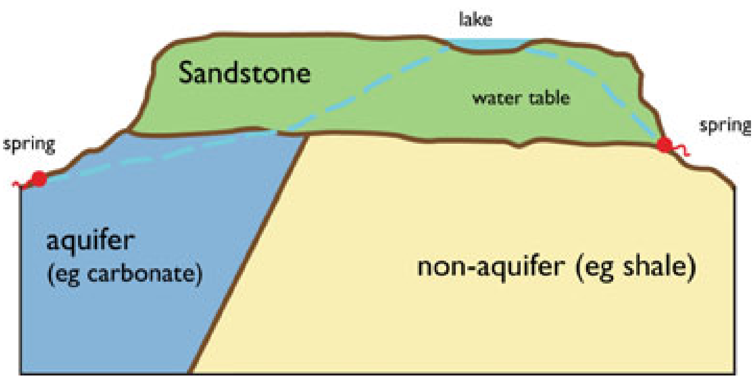


Figure SW-32. Schematic of conceptual model for groundwater discharge that provides the dry season flow for the Calvert River of the South-West Gulf region

 

### SW-3.3.4 Baseflow index analysis

The results of the baseflow analysis for suitable gauges in the South-West Gulf region are provided in Table SW-1 (in Chapter SW-1). The annual baseflow index (BFI) values range from 0.07 to 0.30 (n=6, median = 0.25). Figure SW-2 (in Chapter SW-1) shows the surface geology of the South-West Gulf region and the average volume of dry season baseflow to rivers. This figure indicates that dry season baseflow is strongly correlated with the geology at or above the gauge; high baseflow volumes correspond to areas of carbonate aquifers, while lower baseflow volumes correspong to areas of fractured rock aquifers.

## SW-3.4 Groundwater modelling results

### SW-3.4.1 Historical groundwater balance

No attempt has been made to develop a detailed groundwater balance for the South-West Gulf region due to the lack of data. However the following general comments can be made.

- The main hydrological characteristic of this catchment is the great variability in rainfall from year to year, within a single year and over periods of years. This variability results in a similar great variability in both surface water runoff and groundwater recharge.
- The period of record for the few gauging stations and groundwater monitoring points within the catchment is biased towards a period of above average rainfall (based on the existing rainfall data). This needs to be taken into consideration when analysing flow and recharge data.

## SW-3.5 Rainfall-runoff modelling results

In this section the term runoff is the sum of overland flow, interflow and baseflow. It is equivalent to streamflow expressed as a mm depth equivalent. All plots show data averaged over the modelled subcatchments of the South-West Gulf region. For this reason rainfall reported in this section may vary slightly from that reported elsewhere due to differences between the catchment boundaries (shown in Figure SW-1) and the DEM-derived catchment boundaries used here. In this section, where annual data are reported years are represented by numbers 1 through 77. Consistently throughout this report, annual data are based on the water year (1 September to 31 August) and the dry season is defined as 1 May to 31 October. Unless stated otherwise scenarios Cwet, Cmid and Cdry are selected on the basis of the ranked mean annual runoff. For more details on methods refer to Section 2.2 of the division-level Chapter 2.

### SW-3.5.1 Regional synopsis

The rainfall-runoff modelling estimates runoff in 0.05 degree grid cells in 44 subcatchments (Figure SW-33). Optimised parameter values from ten calibration catchments are used. Nine of these calibration catchments are within the region and the remaining calibration catchment is to the east in the Flinders-Leichhardt region. The calibration catchments tend to be located in the south-east and north-west of the region.

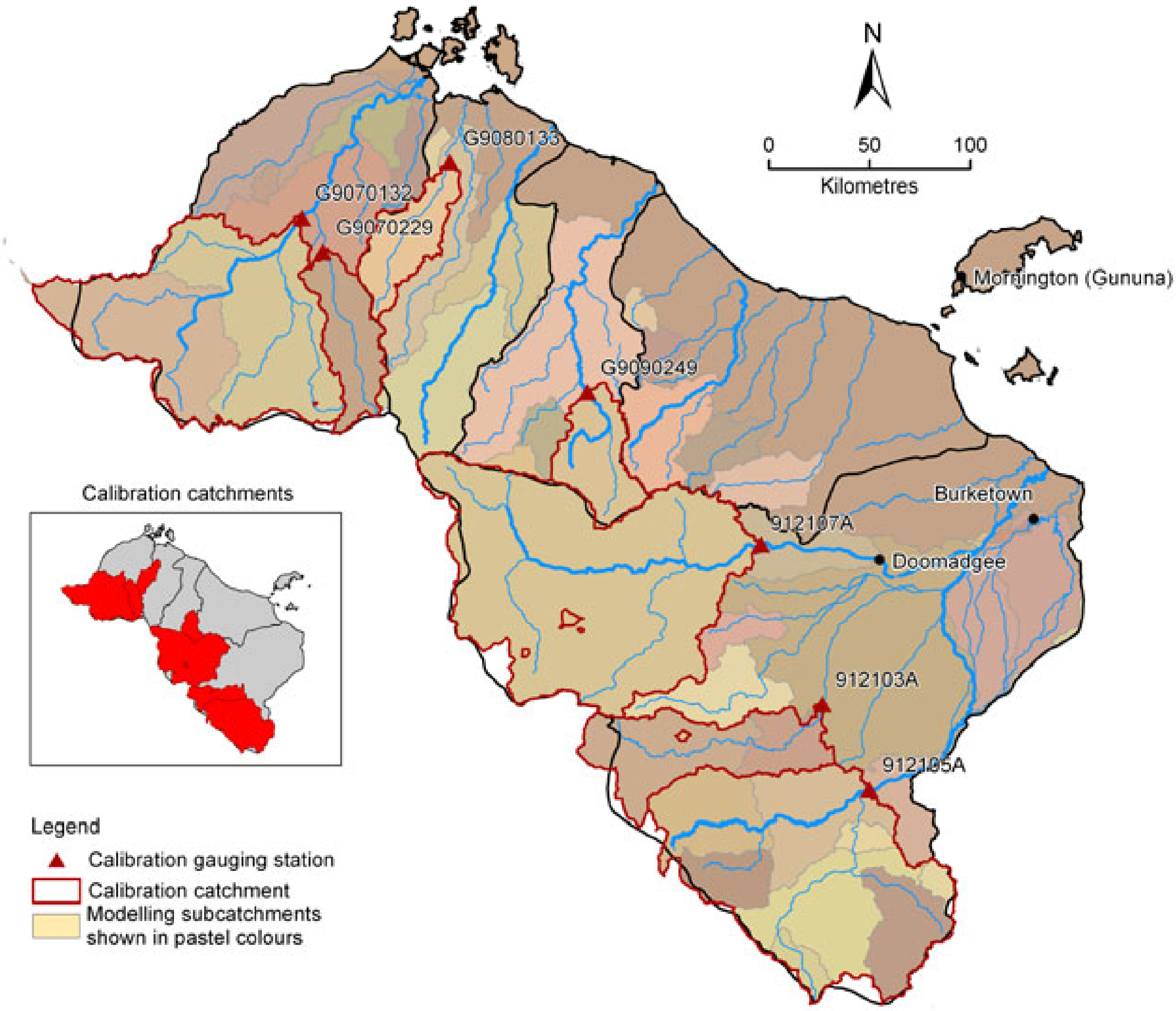


Figure SW-33. Map of the modelling subcatchments, calibration catchments and calibration gauging stations used for the South-West Gulf region with inset showing the extent (in red) of the calibration catchments

 

## SW-3.5.2 Model calibration

Figure SW-34 compares the modelled and observed monthly runoff and the modelled and observed daily flow exceedance curves for the ten calibration catchments. Nash-Sutcliffe efficiency (NSE) values provide a quantitative measure of how well simulated values match observed values. NSE is described in more detail in Section 2.2.3 in the division-level Chapter 2. On the monthly plots NSE is the monthly Nash-Sutcliffe efficiency value and NSE (dry season) is the dry season monthly Nash-Sutcliffe efficiency value. On the daily flow exceedance plots, NSE is the daily flow exceedance curve Nash-Sutcliffe efficiency value and NSE (50 to 100 percent) is the lower half of the daily flow exeedance curve Nash-Sutcliffe efficiency value.

The results indicate that the ensemble calibration of the rainfall-runoff models Sacramento and IhacresClassic reasonably reproduces the observed monthly runoff series (NSE values generally greater than 0.7) and the daily flow exceedance curve (NSE values generally greater than 0.8) for the general purpose of estimating long-term annual runoff. The volumetric constraint used in the model calibration also ensures that the total modelled runoff is within 5 percent of the total observed runoff.

The calibration method places more importance on the simulation of high runoff, and therefore rainfall-runoff modelling of the medium and high runoff is considerably better than the modelling of low runoff. It should be noted, however, that while the relative difference between the observed and simulated low flow values may be large (which is what gives rise to the low monthly dry season NSE values for example), the absolute difference between the observed and simulated low flow values is generally small because both values are small. This is demonstrated by the relatively low NSE values for the monthly dry season and lower half of the daily flow exceedance curve. Nevertheless, an optimisation to reduce overall error variance can result in some underestimation of high runoff and overestimation of low runoff. This is evident in some of the scatter plots comparing the modelled and observed monthly runoff and many of the daily flow exceedance curves. For the majority of calibration catchments the disagreement between the modelled and observed daily runoff curves is discernable for runoff that is exceeded less than 1 percent of the time. This is accentuated in the plots because of the linear scale on the y-axis and normal probability scale on the x-axis. In any case, the volumetric constraint used in the model calibration ensures that the total modelled runoff is always within 5 percent of the total observed runoff. As indicated by the relatively low NSE values for the lower half of the daily flow exceedance curve and monthly dry season there may be considerable disagreement between observed and modelled low flow values (i.e. cease-to-flow).

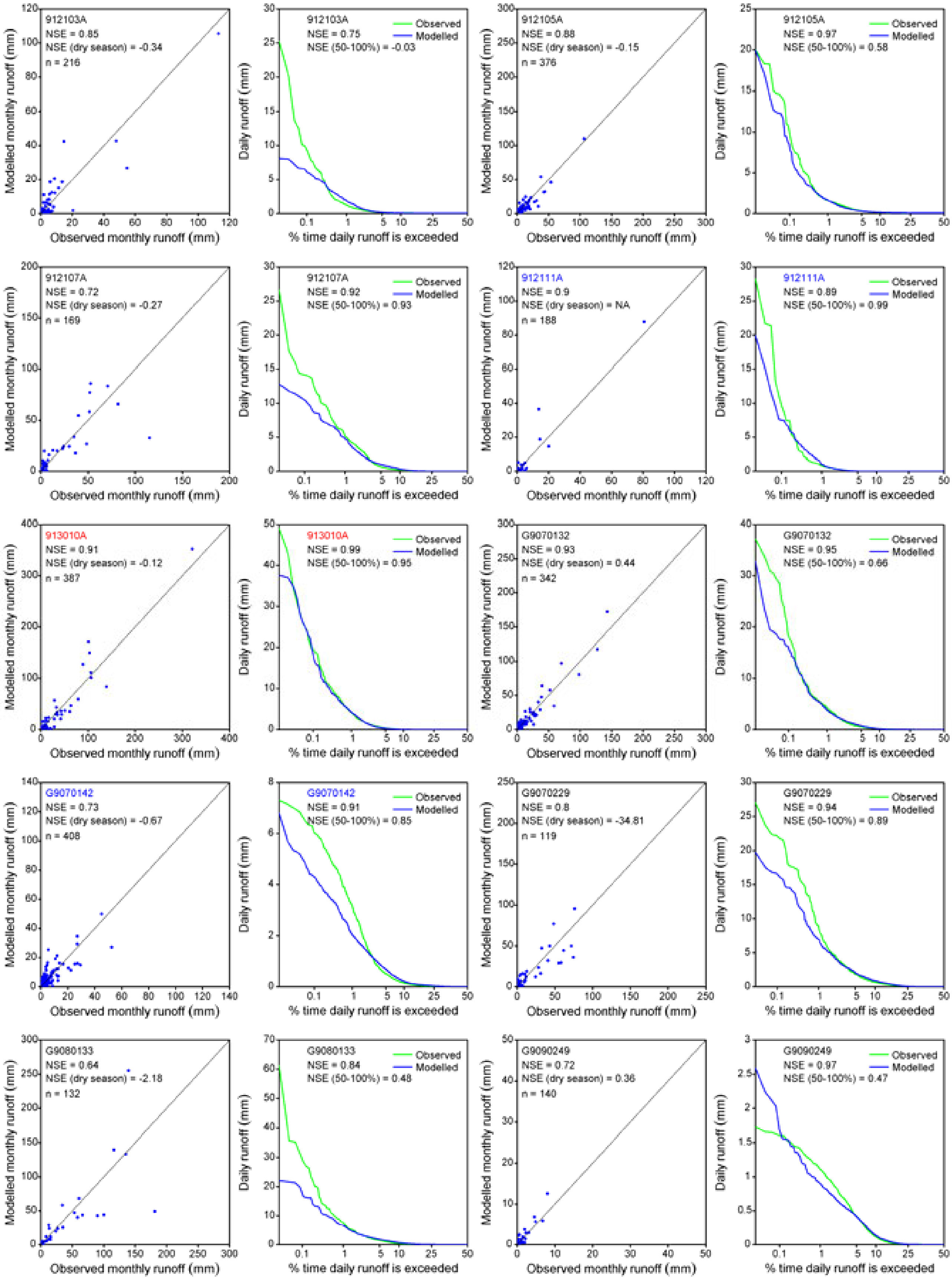


Figure SW-34. Modelled and observed monthly runoff and daily flow exceedance curve for each calibration catchment in the South-West Gulf region. (Red text denotes catchment s outside the region; blue text denotes catchments used for streamflow modelling only)

### SW-3.5.3 Under historical climate

Figure SW-35 shows the spatial distribution of mean annual rainfall and runoff under Scenario A (averaged over 1930 to 2007) across the South-West Gulf region. Figure SW-36 shows the mean annual rainfall and runoff averaged over the region.

The mean annual rainfall and runoff averaged over the South-West Gulf region are 666 mm and 89 mm respectively. The mean wet season and dry season runoff averaged over the South-West Gulf region are 87 mm and 2 mm respectively.

In this project all runoff grids are presented as long-term mean annual values. However the distributions of monthly and annual runoff data in northern Australia can be highly skewed, consequently the median and additional percentile values spatially averaged over the region are also reported. The 10$^{th}$ percentile, median and 90$^{th}$ percentile annual runoff values across the South-West Gulf region are 200, 59 and 17 mm respectively. The median wet season and dry season runoff averaged over the South-West Gulf region are 57 mm and 1 mm respectively.

The mean annual rainfall varies from about 900 mm in the north to about 400 mm in the south-east. The mean annual runoff varies from about 180 mm in the north to less than 15 mm in the south-east (Figure SW-35) and subcatchment runoff coefficients vary from 4 to 20 percent of rainfall. The majority of rainfall and runoff occurs during the wet season months December to April (Figure SW-37). Rainfall and runoff can vary considerably from year to year with long periods over several years or decades that are considerably wetter or drier than others (Figure SW-36). The coefficients of variation of annual rainfall and runoff averaged over the South-West Gulf region are 0.34 and 1.00 respectively.

The South-West Gulf is one of 13 regions which cover the three divisions studied in this project. Mean annual rainfall and runoff, as well as coefficients of variation, have been calculated for all of these 13 regions, and it is useful to compare the South-West Gulf results to results across all 13 regions. Across all 13 regions in this project 10$^{th}$ percentile, median and 90$^{th}$ percentile values are 1371, 936 and 595 mm respectively for mean annual rainfall and 374, 153 and 78 mm respectively for mean annual runoff. The mean annual rainfall (666 mm) and runoff (89 mm) averaged over the South-West Gulf region fall in the lower end of this range. Across all 13 regions in this project the 10$^{th}$ percentile, median and 90$^{th}$ percentile values are 0.34, 0.26 and 0.19 respectively for the coefficient of variation of annual rainfall and 1.39, 0.69 and 0.48 for the coefficient of variation of runoff. The coefficients of variation of annual rainfall (0.34) and runoff (1.00) averaged over the South-West Gulf region are among the highest of the 13 reporting regions.

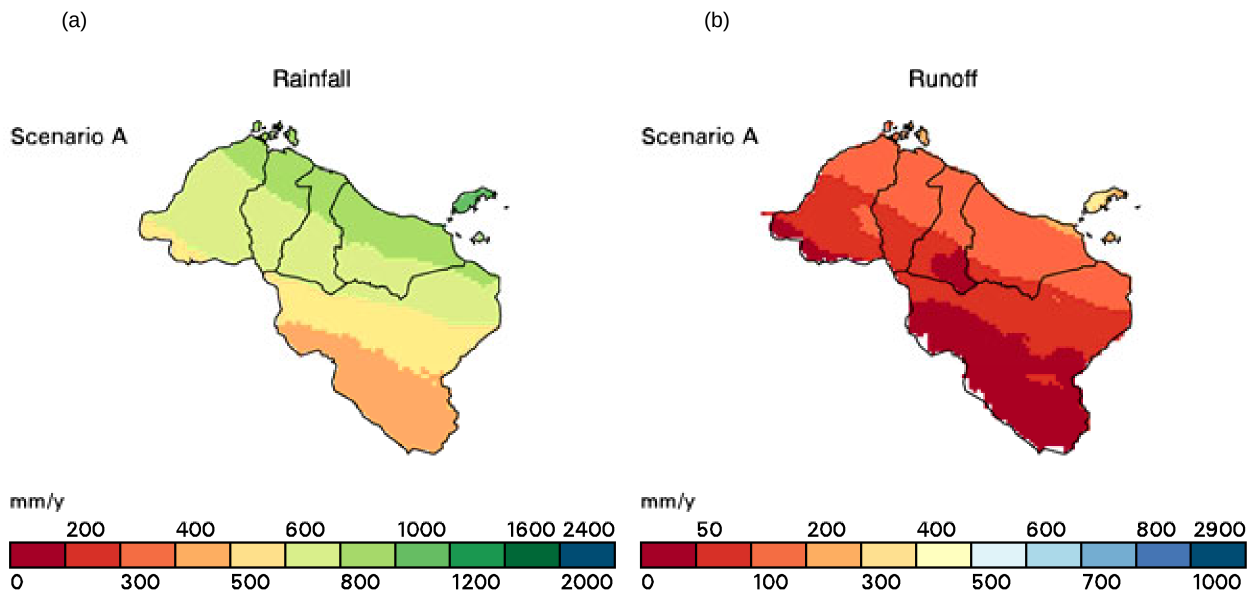


Figure SW-35. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the South-West Gulf region under Scenario A

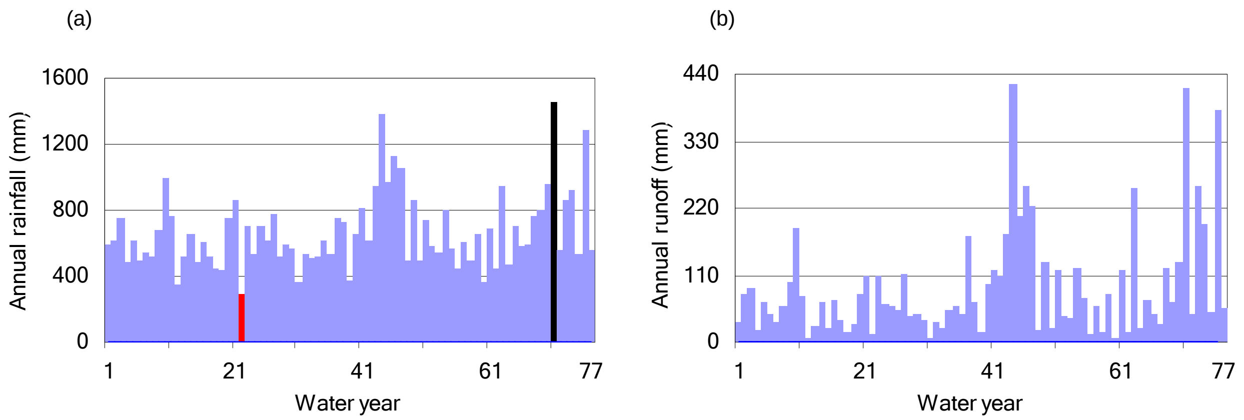


Figure SW-36. Annual (a) rainfall and (b) modelled runoff in the South-West Gulf region under Scenario A

Figure SW-37 (a, b) shows the minimum and maximum monthly rainfall and runoff and the range of values between the 25th and 75th percentile monthly rainfall and runoff. Figure SW-37 (c, d) shows the mean and median monthly flows and the range of values between the 25th and 75th percentile monthly rainfall and runoff. The large difference in the mean and median wet season monthly runoff values indicates that the distribution of monthly runoff in the South-West Gulf region is highly skewed.

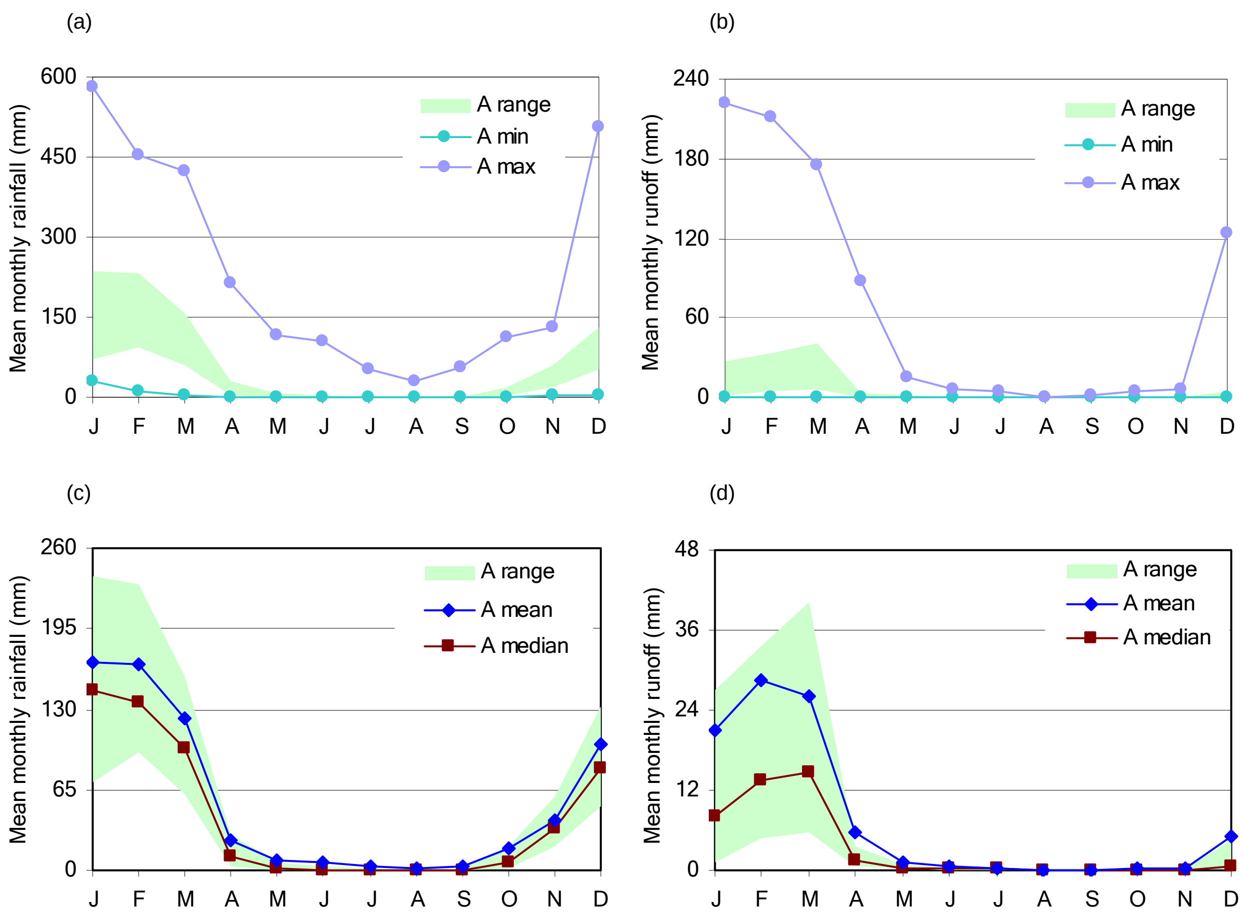


Figure SW-37. Minimum, maximum and A range monthly (a) rainfall and (b) modelled runoff; and mean, median and A range monthly (c) rainfall and (d) modelled runoff in the South-West Gulf region under Scenario A (A range is the 25th to 75th percentile monthly rainfall or runoff)

 

### SW-3.5.4 Under recent climate

The mean annual rainfall and runoff under Scenario B (1996 to 2007) are 27 percent and 78 percent higher respectively than the historical (1930 to 2007) mean values. The spatial distribution of rainfall and runoff across the South-West Gulf region under Scenario B is shown in Figure SW-38.

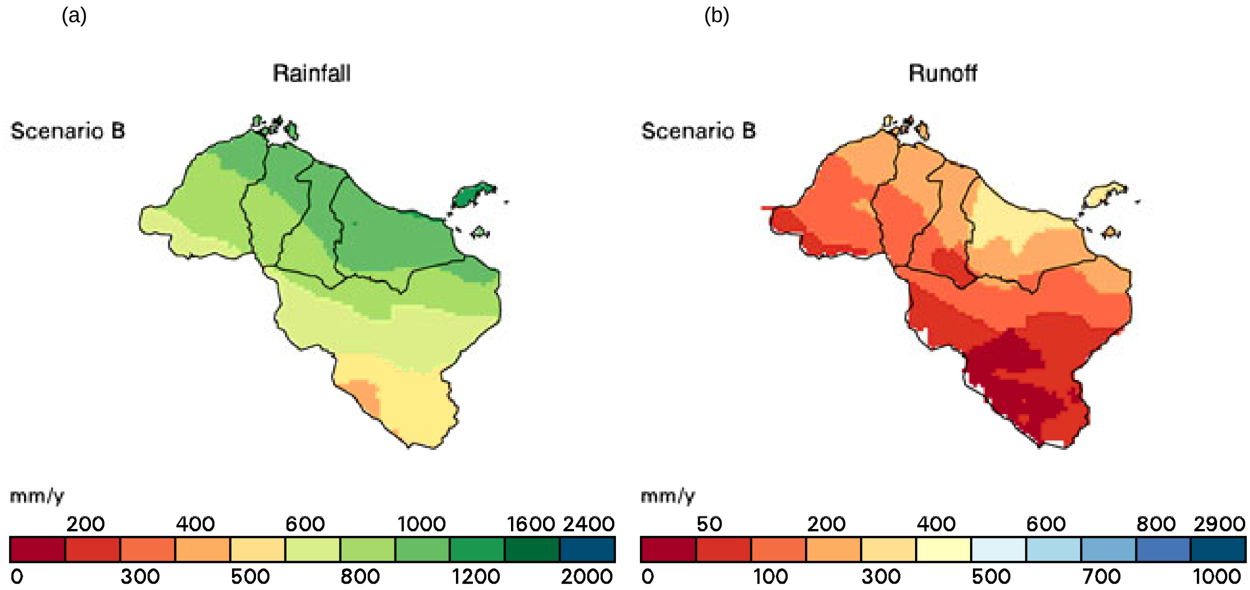


Figure SW-38. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the South-West Gulf region under Scenario B

### SW-3.5.5 Under future climate

Figure SW-39 shows the percentage change in the mean annual runoff averaged over the South-West Gulf region under Scenario C relative to Scenario A for the 45 scenarios (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). The percentage change in the mean annual runoff and rainfall from the corresponding GCMs are also tabulated in Table SW-7.

The figure and table indicate that the potential impact of climate change on runoff can be very significant. Although there is considerable uncertainty in the estimates, the results indicate that runoff in ~2030 in the South-West Gulf region is more likely to decrease than increase. Rainfall-runoff modelling with climate change projections from two-thirds of the GCMs show a reduction in mean annual runoff, while rainfall-runoff modelling with climate change projections from one-third of the GCMs shows an increase in mean annual runoff. The wide range of mean annual runoff values shown in Figure SW-39 and Table SW-7 is primarily due to the wide range of future projections of rainfall by the 15 GCMs.

Because of the large variation between GCM simulations and the method used to obtain the climate change scenarios, the biggest increase and biggest decrease in runoff come from the high global warming scenario. For the high global warming scenario, rainfall-runoff modelling with climate change projections from six of the GCMs indicates a decrease in mean annual runoff greater than 10 percent while rainfall-runoff modelling with climate change projections from four of the GCMs indicates an increase in mean annual runoff greater than 10 percent.

In subsequent reporting here and in other sections, only results from an extreme ‘wet’, ‘mid’ and extreme ‘dry’ variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet, results from the second highest increase in mean annual runoff from the high global warming scenario are used. Under Scenario Cdry, results from the second highest reduction in mean annual runoff from the high global warming scenario are used. Under Scenario Cmid, the median mean annual runoff results from the medium global warming scenario are used. These are shown in bold in Table SW-7.

Under scenarios Cwet, Cmid and Cdry, mean annual runoff increases by 19 percent and decreases by 3 and 18 percent relative to Scenario A. By comparison, the range based on the low global warming scenario is a 10 to -10 percent change in mean annual runoff. Figure SW-40 shows the mean annual runoff across the South-West Gulf region under scenarios A and C. The linear discontinuities that are evident in Figure SW-40 are due to GCM grid cell boundaries.

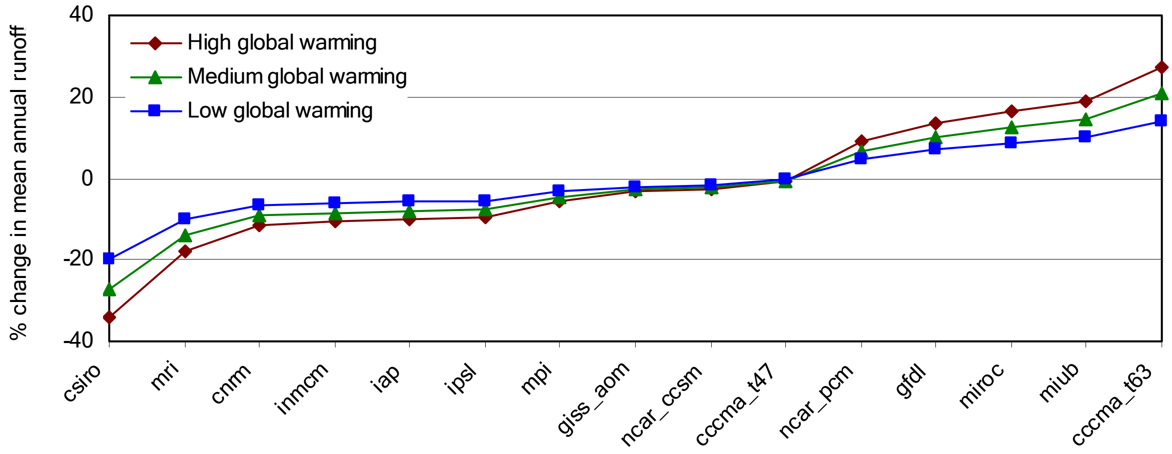


Figure SW-39. Percentage change in mean annual modelled runoff under the 45 Scenario C simulations (15 global climate models and three global warming scenarios) relative to Scenario A

Table SW-7. Summary results under the 45 Scenario C simulations (numbers show percentage change in mean annual rainfall and runoff under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Runoff | GCM | Rainfall | Runoff | GCM | Rainfall | Runoff |
| csiro | -20% | -34% | csiro | -16% | -27% | csiro | -11% | -20% |
| **mri** | **-6%** | **-18%** | mri | -5% | -14% | mri | -3% | -10% |
| cnrm | -5% | -12% | cnrm | -4% | -9% | cnrm | -2% | -6% |
| inmcm | -1% | -11% | inmcm | -1% | -8% | inmcm | -1% | -6% |
| iap | -5% | -10% | ipsl | -1% | -8% | ipsl | 0% | -6% |
| ipsl | -1% | -10% | iap | -4% | -8% | iap | -3% | -5% |
| mpi | -1% | -6% | mpi | -1% | -4% | mpi | -1% | -3% |
| giss_aom | -1% | -3% | **giss_aom** | **-1%** | **-3%** | giss_aom | -1% | -2% |
| ncar_ccsm | 1% | -3% | ncar_ccsm | 1% | -2% | ncar_ccsm | 0% | -2% |
| cccma_t47 | 1% | -1% | cccma_t47 | 1% | -1% | cccma_t47 | 1% | 0% |
| ncar_pcm | 6% | 9% | ncar_pcm | 5% | 7% | ncar_pcm | 3% | 5% |
| gfdl | 0% | 13% | gfdl | 0% | 10% | gfdl | 0% | 7% |
| miroc | 9% | 16% | miroc | 7% | 12% | miroc | 5% | 8% |
| **miub** | **7%** | **19%** | miub | 5% | 14% | miub | 4% | 10% |
| cccma_t63 | 10% | 27% | cccma_t63 | 7% | 21% | cccma_t63 | 5% | 14% |

 

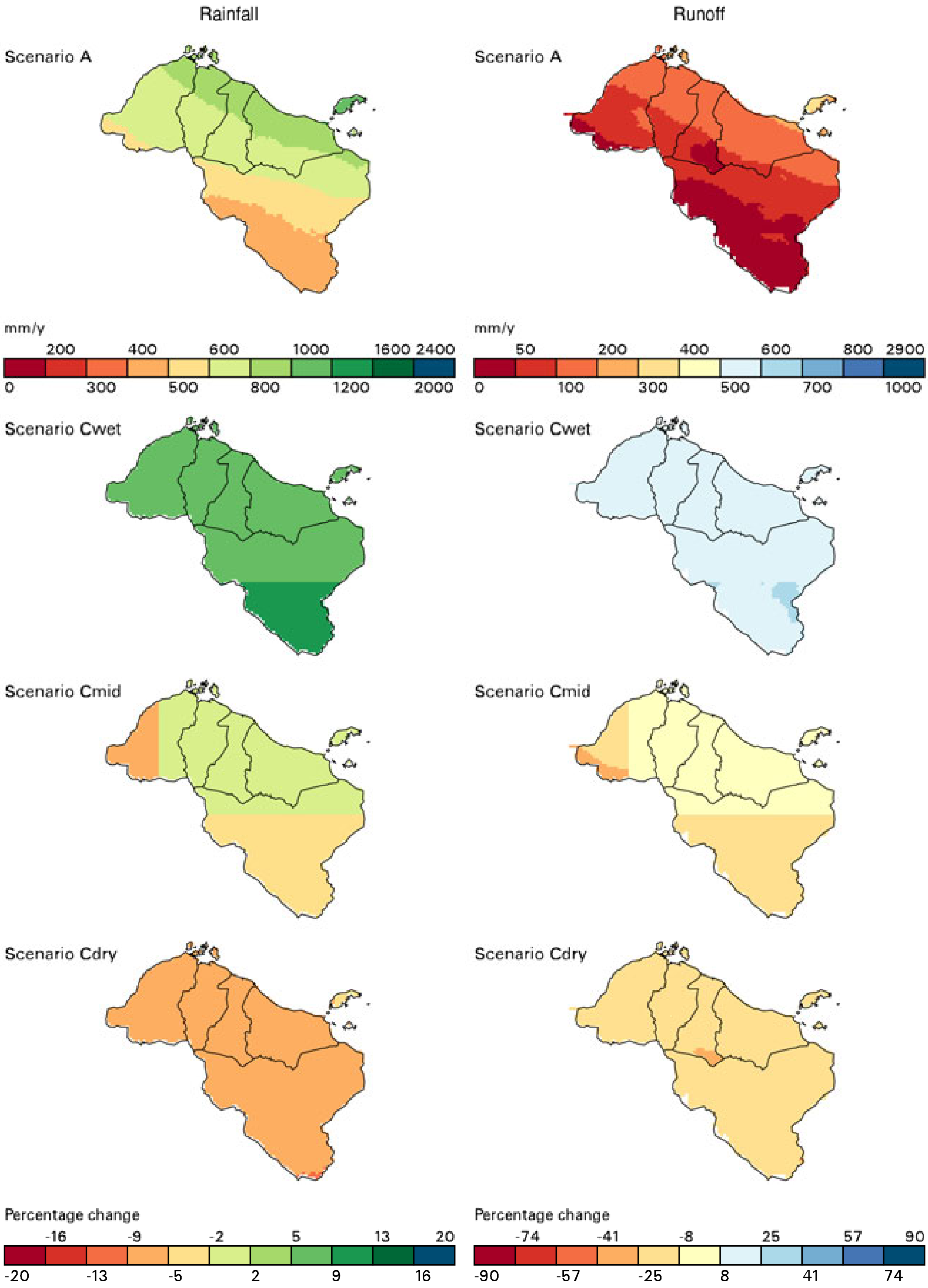


Figure SW-40. Spatial distribution of mean annual rainfall and modelled runoff across the South-West Gulf region under Scenario A and under Scenario C relative to Scenario A

### SW-3.5.6 Summary results for all scenarios

Table SW-8 shows the mean annual rainfall, runoff and actual evapotranspiration under Scenario A averaged over the South-West Gulf region, and the percentage changes in the rainfall, runoff and actual evapotranspiration under scenarios B and C relative to Scenario A. The Cwet, Cmid and Cdry results are based on the mean annual runoff, and the rainfall changes shown in Table SW-8 are the changes in the mean annual value of the rainfall series used to obtain the runoff under scenarios Cwet, Cmid and Cdry. The changes in mean annual rainfall do not necessarily translate directly to the changes in mean annual runoff because of changes in seasonal and daily rainfall distributions and the relationship between rainfall and runoff is non-linear. The latter factor usually results in small changes in rainfall to be amplified in runoff (Table SW-7).

Figure SW-41 shows the mean monthly rainfall and runoff under scenarios A and C averaged over the 77-year period for the region. Figure SW-42 shows the daily rainfall and flow exceedance curves under scenarios A and C averaged over the region. Figure SW-42 shows that the daily flow curve under Scenario B is considerably greater than under C range. In Figure SW-41 scenarios Cwet, Cmid and Cdry are selected on a month-by-month basis, while in Figure SW-42 scenarios Cwet, Cmid and Cdry are selected for every day of the daily flow exceedance curve.

Table SW-8. Water balance over the entire South-West Gulf region under Scenario A and under scenarios B and C relative to Scenario A

| Scenario | Rainfall | Runoff | Evapotranspiration |
|---|---|---|---|
| | | mm | |
| A | 666 | 89 | 576 |
| | | percent change from Scenario A | |
| B | 27% | 78% | 19% |
| Cwet | 7% | 19% | 5% |
| Cmid | -1% | -3% | -1% |
| Cdry | -6% | -18% | -4% |

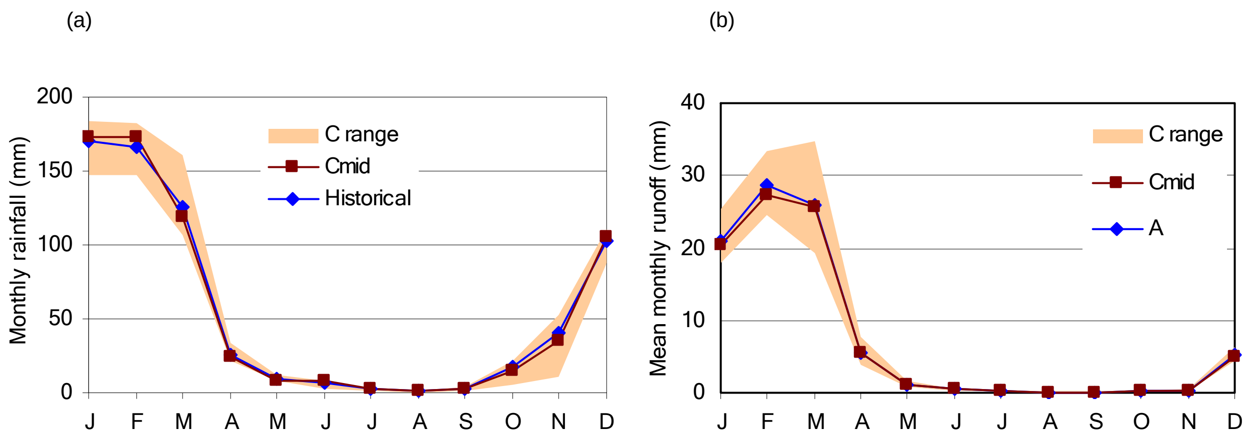


Figure SW-41. Mean monthly (a) rainfall and (b) modelled runoff in the South-West Gulf region under scenarios A and C (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

 

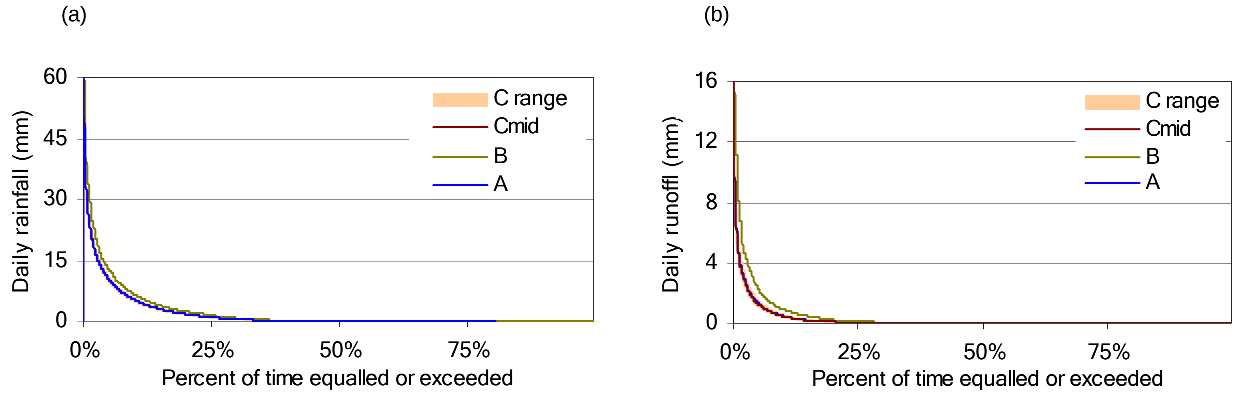


Figure SW-42. Daily flow exceedance curves for (a) rainfall and (b) modelled runoff in the South-West Gulf region under scenarios A and C

## SW-3.5.7 Confidence levels

The level of confidence of the runoff estimates for the South-West Gulf region is variable. The Nicholson and McArthur catchments have the majority of gauging stations, although many of these were excluded from this analysis because of low confidence in the quality of the data. Elsewhere gauging stations are sparse. Low flow records from areas of carbonate rock can be affected by the formation of Tufa dams. This appears to be the case at several stations within the South-West Gulf region (e.g. 912103A and 901105A) and this further reduces the level of confidence in the dry season flow calibrations at these sites.

The rainfall-runoff model verification analysis with data from 123 catchments from across all of northern Australia, indicates that the mean annual runoff for ungauged catchments are under estimated or over estimated, when using optimised parameter values from a nearby catchment, by less than 20 percent in 40 percent of catchments and by less than 50 percent in 80 percent of the catchments. In general there is a low level of confidence in transposing parameters from gauged calibration catchments to ungauged subcatchments is the South-West Gulf region. The level of confidence in the runoff predictions along the coastal floodplain is also low, yet the coastal floodplains comprises a large proportion of the region. Diagrams in (Petheram et al., 2009) illustrate which calibrated rainfall-runoff model parameter sets are used to model streamflow in the ungauged subcatchments in the South-West Gulf region.

Figure SW-43 illustrates the level of confidence in the modelling of the mid to high runoff events (i.e. peak flows) and dry season runoff (respectively) for the subcatchments of the South-West Gulf region. It should be noted that these maps of level of confidence are not statistical confidence levels and are intended to only convey a broad reliability of prediction. The level of confidence in streamflow predictions will vary slightly from the level of confidence in runoff predictions shown below and as discussed in Section 2.2.6 of the division-level Chapter 2.

There is a high degree of confidence that dry season runoff in the Northern Coral region is low because it is known that rainfall and baseflow are low during the dry season. The level of confidence for dry season flow map shown in Figure SW-43 provides a relative indication of how well dry season metrics, such as cease-to-flow, are simulated.

Although there is uncertainty associated with annual runoff volumes for individual ungauged catchments in the South-West Gulf region, they are not all biased to one direction. The non-systematic errors therefore tend to cancel one another to some extent. However, across the South-West Gulf region level of confidence in the long-term average monthly and annual results presented in this section is low relative to other regions. As shown in Figure SW-43, in many areas of the South-West Gulf region localised studies will require more detailed analysis than undertaken and reported here and would most likely require the site to be visited and additional field measurements made.

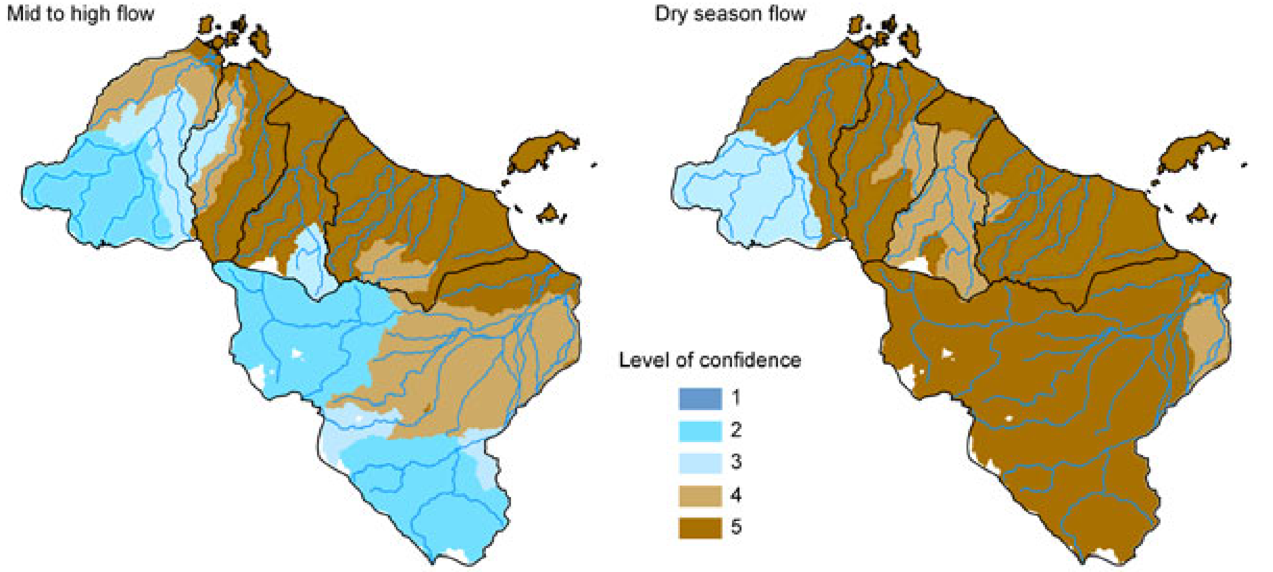


Figure SW-43. Level of confidence in the modelling of runoff for (a) mid- to high flow events and (b) monthly dry season flow events for the modelling subcatchments of the South-West Gulf region. 1 is the highest level of confidence, 5 is the lowest.

# SW-3.6 River system water balance

The South-West Gulf region is comprised of five AWRC river basins and has an area of 111,890 km$^2$. Under the historical climate the mean annual runoff across the region is 89 mm (Section SW-3.5.3), which equates to a mean annual streamflow across the region of 9,958 GL.

No information on infrastructure, water demand and water management and sharing rules or future development were available, and consequently there is no river modelling section to the South-West Gulf region report. Streamflow timeseries have been generated for each streamflow reporting node (SRN) based on the upstream grid cell rainfall-runoff simulations, as described in Section 2.2.5 of division-level Chapter 2. The locations of these nodes are shown in Figure SW-44. Summary streamflow statistics for each SRN are reported in (Petheram et al., 2009). In addition to the streamflow timeseries generated by the rainfall-runoff model ensemble, a range of hydrological metrics computed using regression analysis are also available for each SRN (as described in Section 2.2.7 of division-level Chapter 2). The complete set of results for the multiple regression analysis are reported in SKM (2009). The merit of each approach is discussed in Section 2.2.7 of division-level Chapter 2.

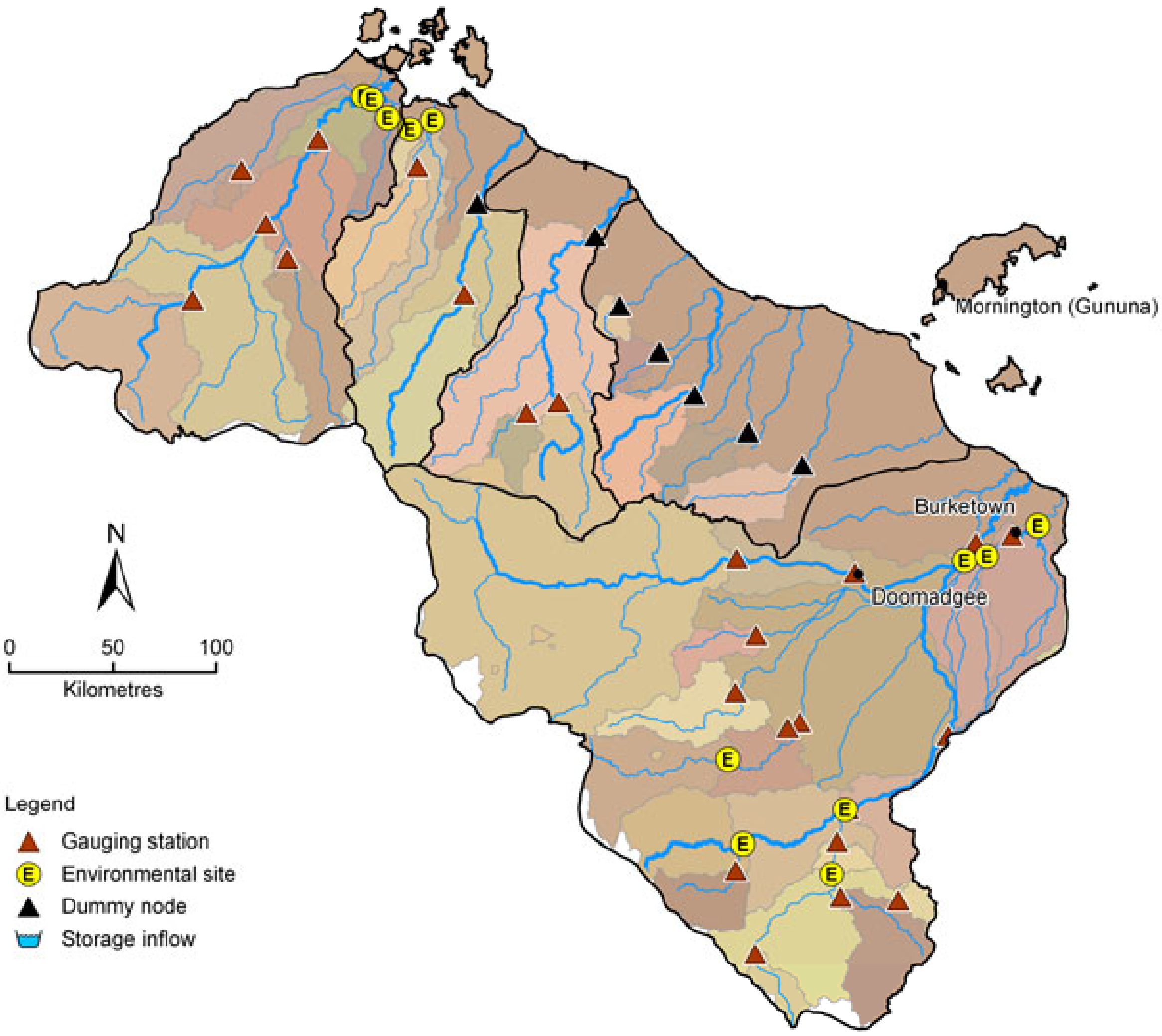


Figure SW-44. Location of streamflow reporting nodes (gauging stations, environmental sites, dummy nodes and storage inflows) in the South-West Gulf region. (Note no storage inflows are reported for this region)

## SW-3.7 Change to flow regimes at environmental assets

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Five environmental assets have been shortlisted in the South-West Gulf region: Gregory River, Port McArthur Tidal Wetlands System, Nicholson Delta Aggregation, Thorntonia Aggregation, and Southern Gulf Aggregation. The locations of these assets are shown in Figure SW-1 and the assets are characterised in Chapter SW-2.

This section presents the assessment of these shortlisted assets and reports metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis. Confidence in results for low flows and high flows was calculated separately on a scale of 1 to 5, with 1 indicating results with the highest confidence (as described in Section 2.2.6 of the division-level Chapter 2). Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are 1, 2 or 3. If confidence levels in the low flows or high flows are ranked 4 or 5, results are not reported and are labelled NR (not reported).

Some of the assets in this region have multiple nodes at which streamflow modelling results are available. When reporting hydrological regime metrics for such assets a single node was selected. The selected node was that with the highest streamflow confidence level and the largest proportion of streamflow to the asset. Results for all nodes are presented in (McJannet et al., 2009).

In the absence of site-specific metrics for the South-West Gulf region a set of standard metrics related to high and low flows have been utilised. However the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and ecology.

 

### SW-3.7.1 Standard metrics

Table SW-9. Standard metrics for changes to surface water flow regime at environmental assets in the South-West Gulf region

| Standard metrics | Units | A | B | Cwet | Cmid | Cdry | Dwet | Dmid | Ddry |
|---|---|---|---|---|---|---|---|---|---|
| | | | change from Scenario A | | | | | | |
| Gregory River - Node 1 (confidence level: low flow = 5, high flow = 1) | | | | | | | | | |
| Annual flow (mean) | GL | 455 | +19% | +24% | -3% | -18% | nm | nm | nm |
| Wet season flow (mean)* | GL | 387 | +21% | +24% | -3% | -18% | nm | nm | nm |
| Dry season flow (mean)** | GL | NR | NR | NR | NR | NR | | | |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | NR | | | | | | | |
| Number of days below low flow threshold (mean) | d/y | NR | NR | NR | NR | NR | | | |
| Number of days of zero flow (mean) | d/y | NR | NR | NR | NR | NR | | | |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | 3.1 | | | | | | | |
| Number of days above high flow threshold (mean) | d/y | 18.3 | +5.3 | +3.8 | -0.4 | -3.1 | nm | nm | nm |
| Port McArthur Tidal Wetlands System - Node 3 (confidence level: low flow = 5, high flow = 3) | | | | | | | | | |
| Annual flow (mean) | GL | 401 | +71% | +4% | -10% | -19% | nm | nm | nm |
| Wet season flow (mean)* | GL | 390 | +72% | +3% | -9% | -19% | nm | nm | nm |
| Dry season flow (mean)** | GL | NR | NR | NR | NR | NR | | | |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | NR | | | | | | | |
| Number of days below low flow threshold (mean) | d/y | NR | NR | NR | NR | NR | | | |
| Number of days of zero flow (mean) | d/y | NR | NR | NR | NR | NR | | | |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | 5.97 | | | | | | | |
| Number of days above high flow threshold (mean) | d/y | 18.3 | +10.5 | +0.3 | -1.8 | -3.4 | nm | nm | nm |
| Thorntonia Aggregation - Node 3 (confidence level: low flow = 5, high flow = 2) | | | | | | | | | |
| Annual flow (mean) | GL | 232 | +23% | +26% | -2% | -20% | nm | nm | nm |
| Wet season flow (mean)* | GL | 195 | +25% | +26% | -3% | -20% | nm | nm | nm |
| Dry season flow (mean)** | GL | NR | NR | NR | NR | NR | | | |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | NR | | | | | | | |
| Number of days below low flow threshold (mean) | d/y | NR | NR | NR | NR | NR | | | |
| Number of days of zero flow (mean) | d/y | NR | NR | NR | NR | NR | | | |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | 1.57 | | | | | | | |
| Number of days above high flow threshold (mean) | d/y | 18.3 | +6.2 | +3.9 | -0.4 | -3.4 | nm | nm | nm |

* Wet season covers the six months from November to April

** Dry season covers the six months from May to October

NR – metrics not reported because streamflow confidence level is ranked four or five
nm – not modelled

#### Gregory River

The surface water flow confidence level for the selected reporting node for the Gregory River (see location on Figure SW-8) is considered reliable (1) for wet season flows and unreliable (5) for dry season flows (Table SW-9). When the confidence level is 4 or 5 flows are too unreliable to allow environmental flow metrics to be calculated. Under Scenario A annual flow into this asset is dominated by wet season flows (85 percent) which have been 21 percent higher under Scenario B. Annual and seasonal flows do not change much under Scenario Cmid when compared to Scenario A, but there are moderate increases under Scenario Cwet (24 percent) and moderate decreases under Scenario Cdry (18 percent). There are no development scenarios for the area upstream of this asset.

Under Scenario B the high flow threshold exceedence has been more frequent than under Scenario A (Table SW-9). Under Scenario Cmid high flow threshold exceedence does not change much from Scenario A, but there are moderate increases and decreases under Cwet and Cdry respectively. There are no low flow metrics reported for this asset.

## Nicholson Delta Aggregation

The surface water flow confidence level for this asset is considered unreliable (4 or 5) for both wet season and dry season flows which is too unreliable to allow environmental flow metrics to be calculated for this asset.

## Port McArthur Tidal Wetlands System

The surface water flow confidence level for the selected reporting node for the Port McArthur Tidal Wetlands System (see location on Figure SW-10) is considered moderately reliable (3) for wet season and reliable (5) for dry season flows (Table SW-9). Under Scenario A annual flow into this asset is dominated by wet season flows (97 percent) which have been 72 percent higher under Scenario B. Annual and seasonal flows do not change much under Scenario Cmid when compared to Scenario A, but there are small increases under Scenario Cwet (3 to 4 percent) and moderate decreases under Scenario Cdry (19 percent). There are no development scenarios for the area upstream of this asset.

Under Scenario B the high flow threshold exceedence has been more frequent than under Scenario A (Table SW-9). Under Scenarios Cmid and Cwet high flow threshold exceedence does not change much from Scenario A, whereas there is a moderate decrease in high flow days under Cdry. There are no low flow metrics reported for this asset.

## Southern Gulf Aggregation

The surface water flow confidence level for this asset is considered unreliable (4 or 5) for both wet season and dry season flows which is too unreliable to allow environmental flow metrics to be calculated for this asset.

## Thorntonia Aggregation

The surface water flow confidence level for the selected reporting node for the Thorntonia Aggregation (see location on Figure SW-12) is considered fairly reliable (2) for wet season flows and unreliable (5) for dry season flows (Table SW-9). Under Scenario A annual flow into this asset is dominated by wet season flows (84 percent) which have been 25 percent higher under Scenario B. Annual and seasonal flows do not change much under Scenario Cmid when compared to scenario A, but there are moderate increases under Scenario Cwet (26 percent) and moderate decreases under Scenario Cdry (20 percent). There are no development Scenarios for the area upstream of this asset.

Under Scenario B the high flow threshold exceedance has been more frequent than under Scenario A (Table SW-9). Under Scenarios Cmid high flow threshold exceedance does not change much from Scenario A, but there are moderate increases and decreases under Cwet and Cdry respectively. There are no low flow metrics reported for this asset.

 

## SW-3.8 References


Crosbie RS, McCallum J, Walker GR and Chiew FHS (2008) Diffuse groundwater recharge modelling across the Murray-Darling Basin. A report to the Australian government from the CSIRO Murray-Darling Basin Sustainable Yields project, Water for a Healthy Country Flagship. CSIRO, Canberra. 108pp.

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McJannet DL, Wallace JW, Henderson A and McMahon J (2009) High and low flow regime changes at environmental assets across northern Australia under future climate and development scenarios. A report to the Australian Government from the CSIRO Northern Australian Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, CSIRO, Australia. *In prep.*

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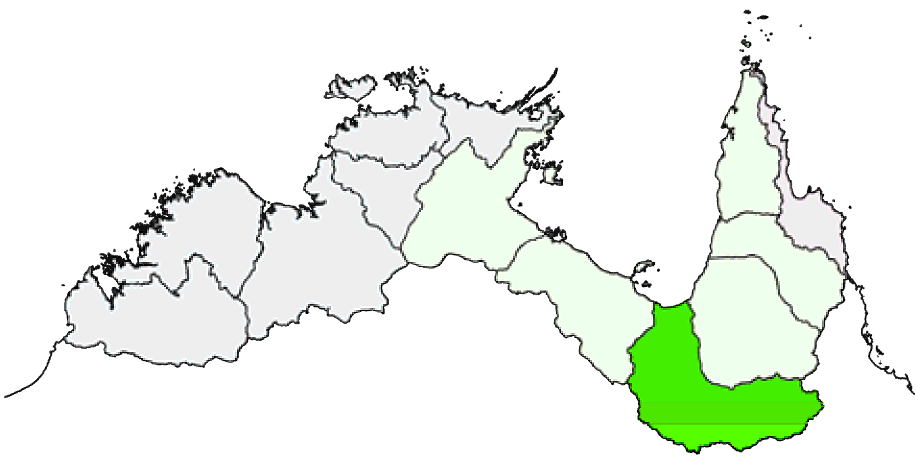
SKM (2009) Regionalisation of hydrologic indices. Northern Australia sustainable yields. A report prepared by Sinclair Knight Merz for the CSIRO Northern Australia Sustainable Yields project, Melbourne, 183 pp.

Zhang L and Dawes W (1998) WAVES - An integrated energy and water balance model. Technical Report No. 31/98, CSIRO Land and Water.

# Water in the Flinders-Leichhardt region



# FL-1 Water availability and demand in the Flinders-Leichhardt region

The first part of this report (the Preamble, Chapter 1 and Chapter 2) reports at the division level, including division-wide descriptions of climate and geology and methods which apply to all regions. Subsequent chapters report at the region level. In particular, Chapters FL-1, FL-2 and FL-3 focus on the Flinders-Leichhardt region (Figure FL-1).

This chapter summarises the water resources of the Flinders-Leichhardt region, using information from Chapter FL-2 and Chapter FL-3, and directly addresses the Terms of Reference, specifically terms 3, 4 and 5 as listed in the Preamble. Essentially, this chapter provides a synoptic view of the region and covers:

- regional observations
- water resource assessment
- seasonality of water resources
- surface–groundwater interaction
- changes to flow regime at environmental assets
- water storage options
- data and knowledge gaps.

For further details on the context of the region (physical and climate descriptions, hydrogeology and legislation) see Chapter FL-2. Region-specific methods and results are provided in Chapter FL-3. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2.

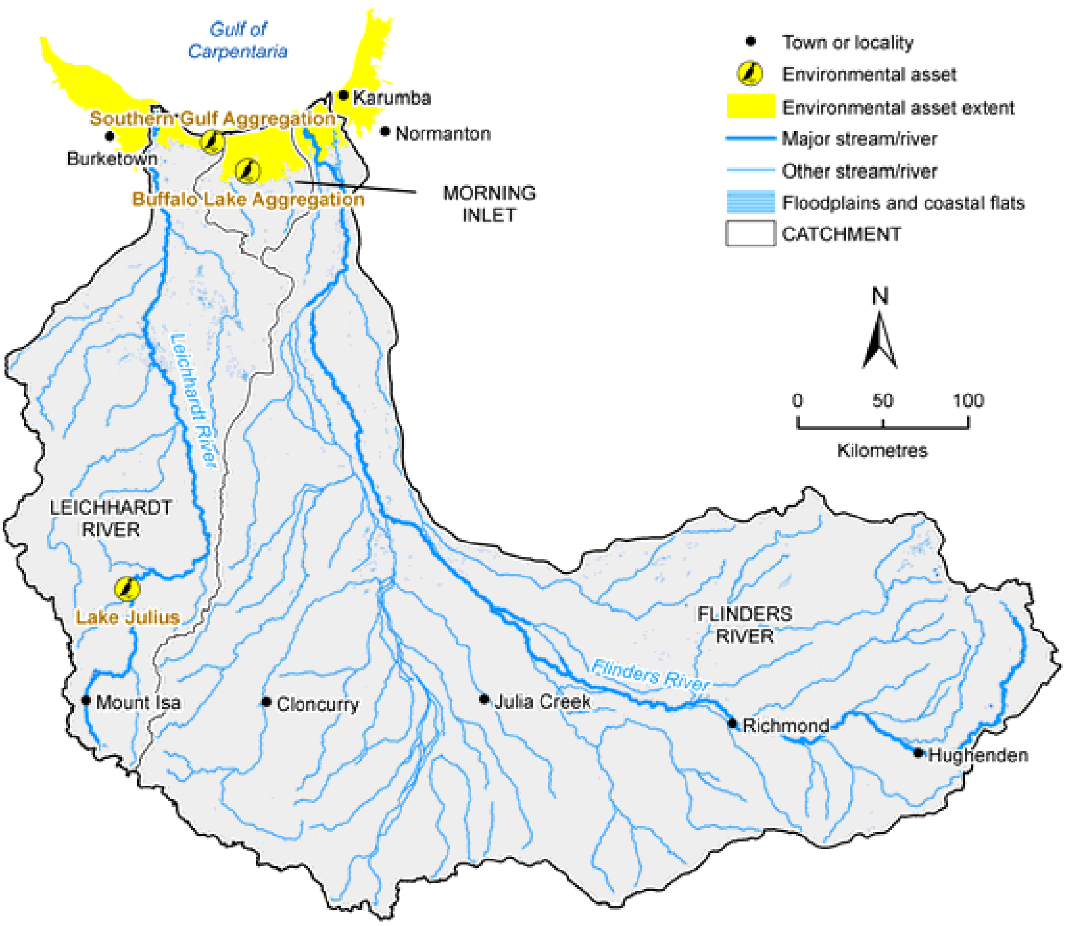



Figure FL-1. Major rivers, towns and location of assets selected for assessment of changes to hydrological regime in the Flinders-Leichhardt region

# FL-1.1 Regional summary

This section summarises key modelling results from this project and provides other relevant water resource information as context about water availability and demand in the Flinders-Leichhardt region.

The historical (1930 to 2007) mean annual rainfall for the region is 493 mm. Mean annual areal potential evapotranspiration (APET) is 1326 mm. The mean annual runoff averaged over the modelled area of the Flinders-Leichhardt region is 44 mm, 9 percent of rainfall. These values are low in comparison to other regions across northern Australia. Under the historical climate the mean annual streamflow over the Flinders-Leichhardt region is estimated to be 6,390 GL.

The Flinders-Leichhardt region has a high inter-annual variability in rainfall and hence runoff and recharge. Coefficients of variation are among the highest of the regions across northern Australia and reflect multiple years of significantly below average and above average rainfall.

There is a strong seasonality in rainfall patterns, with 89 percent of rainfall falling in the wet season, between November and May, and a very high dry season potential evapotranspiration. The region has a relatively high rainfall intensity, and this is reflected in rapid runoff and a short lag between rainfall and runoff. Ninety-eight percent of runoff occurs within the months of December and May. There has been a slightly increasing amount and intensity of rainfall from 1930 to 2007. The Flinders and Leichhardt rivers do not flow for the entire dry season.

There is a strong north–south rainfall gradient, and hence also runoff, with the runoff coefficient decreasing from 25 to 3 percent of precipitation in the same direction.

APET is annually greater than rainfall, and hence the region may be considered water-limited. The region has years when it is water-limited throughout the entire year, with APET exceeding rainfall even through the wet season.

The Flinders-Leichhardt region has a recent (1996 to 2007) climate record that is statistically significantly similar to the historical (1930 to 2007) record. Modelling suggests that future (~2030) conditions will also be similar to historical conditions, and future runoff and recharge will also be similar to historical levels.

Current average surface water availability in the Flinders system is 2023 GL/year and on average about 107 GL/year (or 5 percent) of this water is used. This is a low level of development.

Current average surface water availability in the Leichhardt system is 1368 GL/year and on average about 111 GL/year (or 8 percent) of this water is used. This is a low level of development. All five major storages in the Leichhardt River are fully utilised by the full use of existing entitlements and reserved allocations.

The aquifer of the Gilbert River Formation within the Great Artesian Basin is the most significant groundwater resource in the region. This aquifer is predominantly confined by low-permeability overlying sediments, except in the east where the formation outcrops and is recharged. 'Rejected recharge' provides baseflow to the Flinders River and is likely responsible for extending the duration of flow into the dry season.

The shallow alluvial aquifers of the region are characterised by variable thickness and groundwater quality, and are therefore a relatively undeveloped groundwater resource.

The aquifers of the Great Artesian Basin provide an important source of water in the region, including the provision of water for maintaining springs that host ecological assets.

There are few opportunities for surface water storage and most are in the southern, drier headwater areas, where potential evapotranspiration is highest within the region. Lower reaches are frequently flood inundated. Generally the region has low relief.

At environmental assets flows are highly dominated by wet season (November to April) flow, with dry season (May to October) flows only a small fraction of total annual flow. However, environmental assets depend on this strong seasonality and any significant changes in the frequency and duration of wet season high flows and dry season low flows are likely to have an environmental impact. If the future sees full allocation of entitlements, changes to the high flow threshold exceedance are likely, which could have negative environmental impacts.

The region is generally datapoor.

# FL-1.2 Water resource assessment

Term of Reference 3a

## FL-1.2.1 Under historical climate and current development

Term of Reference 3a (i)

Mean annual rainfall over the Flinders-Leichhardt region is 493 mm, with a standard deviation of 86 mm. Maximum recorded rainfall fell in 1974 with 1326 mm; the lowest was in 1952 with only 189 mm. Mean annual areal potential evapotranspiration (APET) is 1939 mm, with a relatively small variation (standard deviation of 54 mm). Highest APET occurred in 1935 (2023 mm); lowest in 1974 (1771 mm). The mean annual runoff averaged over the modelled area of the Flinders-Leichhardt region is 44 mm, 9 percent of rainfall. Rainfall declines with distance from the coast but otherwise shows little spatial variation.

Rainfall is very seasonal, with 89 percent falling during the wet season, and runoff is highest in February and March.

These values are low in comparison to other regions. Rainfall and runoff vary little across the region, in keeping with the low relief.

The current average surface water availability for the Flinders catchment is 2023 GL/year and on average about 107 GL/year (or 5 percent) of this water is allocated under full use of existing entitlements. This is a low level of development.

The current average surface water availability for the Leichhardt catchment is 1368 GL/year and on average about 111 GL/year (or 8 percent) of this water is allocated under full use of existing entitlements. This is a low level of development.

Licensed groundwater extraction with a volumetric entitlement is currently very low in the Flinders-Leichhardt region, particularly from the shallow sedimentary aquifers. Extraction from the Great Artesian Basin (GAB) aquifers for stock and domestic purposes is by far the greatest use of groundwater in the region. The combined annual extraction for all purposes is estimated to be around 73 GL/year (Table FL-1). Natural groundwater discharge from both the shallow alluvial aquifer and the Gilbert River Formation provides water for maintaining flows in the Flinders River well into the dry season; this is reflected in the relatively high dry season baseflow volume for the Flinders River compared to other gauged rivers in the region (Table FL-1).

Table FL-1. Estimated groundwater contribution (baseflow) to streamflow, modelled diffuse recharge and groundwater extraction for the Flinders-Leichhardt region under historical climate

| Station | River | Station name | Annual BFI * | Dry season BFI * | Dry season baseflow * |
|---|---|---|---|---|---|
| | | | | | GL |
| 913003A | Gunpowder Ck | White Gorge | 0.11 | 0.06 | 0.0 |
| 913004A | Leichhardt | Kajabbi | 0.11 | 0.05 | 0.1 |
| 913006A | Gunpowder Ck | Gunpowder | 0.06 | 0.02 | 0.0 |
| 913010A | Fiery Ck | 16 Mile Waterhole | 0.11 | 0.24 | 0.0 |
| 913014A | Leichhardt | Doughboy Ck | 0.06 | 0.02 | 0.0 |
| 913015A | Leichhardt | Julius Dam | 0.09 | 0.02 | 0.1 |
| 915003A | Flinders | Walkers Bend | 0.17 | 0.10 | 3.6 |
| 915008A | Flinders | Richmond | 0.05 | 0.03 | 0.5 |
| 915011A | Porcupine Ck | Mt Emu Plains | 0.09 | 0.17 | 0.1 |
| 915204A | Cloncurry | Damsite | 0.05 | 0.01 | 0.1 |
| 915206A | Dugald | Railway Crossing | 0.05 | 0.03 | 0.0 |
| 915208A | Julia Ck | Julia Ck | 0.06 | 0.04 | 0.0 |
| 915211A | Williams | Landsborough HWY | 0.04 | 0.01 | 0.0 |
| | | Historical recharge ** | Estimated groundwater extraction | | |
| | | GL/y | | | |
| Entire Flinders-Leichhardt region | | 2790 | | | 73 |

* BFI (baseflow index) and baseflow volume derived from gauged data.
** Aggregated recharge from Zhang and Dawes (1998).

Recharge to the shallow alluvial aquifer is unlikely to change under a continued historical climate and, with current levels of development, groundwater conditions are likely to remain stable in these aquifers. GAB aquifers are recharged on the western side of the Great Dividing Range around the headwaters of the Flinders River. Given the scale and inertia of this regional groundwater system, it is highly unlikely that the groundwater balance would change by 2030 under a continued historical climate. Because the resource is largely undeveloped in the Flinders-Leichhardt region, continued groundwater extraction at current levels would also be unlikely to cause adverse water level trends in the short to medium term.

### FL-1.2.2 Under recent climate and current development

Term of Reference 3a (ii)

The mean annual rainfall and runoff under the recent (1996 to 2007) climate are 12 and 9 percent higher respectively than the historical (1930 to 2007) mean values. Rainfall increases in the recent period have predominantly occurred in the north and west of the region. This increase is within the range of variability seen historically.

If future climate is similar to that experienced recently, mean annual groundwater recharge is likely to be similar to the historical value for both the shallow alluvial aquifers and the outcropping Gilbert River Formation of the GAB.

### FL-1.2.3 Under future climate and current development

Term of Reference 3a (iii)

Future climate is expected to be similar to the historical climate. Under the wet extreme future climate, mean annual rainfall is 547 mm; under the median future climate, 492 mm; and under the dry extreme future climate, 456 mm. Corresponding APET values under these scenarios are 1993, 1994 and 2038 mm, respectively.

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Flinders-Leichhardt region is equally likely to increase as decrease. Rainfall-runoff modelling with climate change projections from half of the GCMs shows a reduction in mean annual runoff, while rainfall-runoff modelling with climate change projections from the other half of the GCMs shows an increase in mean annual runoff. Under the median future climate, mean annual runoff changes by zero percent by 2030. The extreme estimates, which come from the high global warming scenario, range from a 23 percent reduction to a 28 percent increase in mean annual runoff. By comparison, the range under the low global warming scenario is a 13 percent reduction to a 15 percent increase in mean annual runoff.

Under the median future climate in the Flinders catchment there would be a 2 percent increase in water availability and total diversions decrease 2 percent.

For the Flinders catchment the climate extremes for 2030 indicate:

- under the wet extreme future climate, water availability increases 32 percent and total diversions increase 4 percent
- under the dry extreme future climate, water availability decreases 25 percent and total diversions decrease 7 percent
- under the dry extreme future climate, town water supplies decrease by 1 percent.

Under the median future climate in the Leichhardt catchment there would be a 19 percent increase in water availability and total diversions increase 2 percent.

For the Leichhardt catchment the climate extremes for 2030 indicate:

- under the wet extreme future climate, water availability increases 30 percent and total diversions increase 3 percent
- under the dry extreme future climate, water availability decreases 23 percent and total diversions decrease 5 percent
- under the dry extreme future climate, town water supplies decrease by 6 percent.

Groundwater recharge to shallow alluvial aquifers and outcropping portions of regional aquifers would on average be similar under the future climate to what has occurred historically. With future groundwater development equal to that currently occurring in the region, groundwater levels and flow processes in these aquifers would also remain similar to historical conditions.

### FL-1.2.4 Under future climate and future development

Term of Reference 3a (iv)

Without appropriate regional-scale groundwater models it is difficult to predict what changes in groundwater resource condition could be expected under this scenario, regardless of the scale of potential future development.

## FL-1.3 Changes to flow regime at environmental assets

Term of Reference 3b

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Three environmental assets were shortlisted for the Flinders-Leichhardt region: Lake Julius, the Southern Gulf Aggregation and the Lake Buffalo Aggregation. These assets are characterised in Chapter FL-2.

In deciding whether it is feasible to report hydrological regime metrics for these shortlisted assets, it is important to consider the confidence levels in modelled streamflow (as described in Section 2.2.6 of the division-level Chapter 2). Confidence in results for low flows and high flows was calculated separately. Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are sufficiently high. If confidence in the low flow or high flow is too low, metrics are not reported, and hence an important gap in our knowledge is identified.

Some of the assets in this region have multiple nodes at which streamflow modelling results are available. When reporting hydrological regime metrics for such assets a single node was selected. The selected node was that with the highest streamflow confidence level and the largest proportion of streamflow to the asset. The location of nodes for each asset are shown on satellite images in Section FL-2.1.1. Results for all nodes are presented in (McJannet et al., 2009).

Two river systems models were used in this region. Results are reported under pre-development as well as current and future conditions.

For the Lake Buffalo Aggregation, confidence levels in the gauging information are too low for analysis.

For both Lake Julius and the Southern Gulf Aggregation, confidence levels in both low flows and high flows are sufficient to report hydrological regime metrics.

For these two assets, annual flow is dominated by wet season flow. Under the recent climate, wet season flow has increased dramatically (by 87 percent for Lake Julius and by 50 percent for the Southern Gulf Aggregation). Dry season flow, however, has decreased by more than half at both sites under the recent climate.

There is little to moderate increase in flow under the future climate assuming full uptake of entitlements, with moderate increases and decreases in flow under the wet extreme and dry extreme future climates, respectively.

The low flow threshold is zero at both sites, and this occurs between a third and half of the year. This threshold is exceeded (i.e. is more frequent) under all future scenarios. The high number of threshold exceedance days does not change much under the median and dry extreme future climate, but a moderate decrease is expected under the dry extreme future climate.

The results for flow regime assessments include assets in the Leichhardt River catchment only. Under the recent climate this catchment experienced much greater streamflow increases than the adjoining Flinders River system (see Section FL-3.6).

## FL-1.4 Seasonality of water resources

Term of Reference 4

The rivers have a marked seasonal flow regime of high water levels during the wet season (November to April) and minimal flow during the dry season. Approximately 89 percent of rainfall and 98 percent of runoff occurs during the wet season under the historical climate. Under recent climate 91 percent of rainfall and 97 percent of runoff occurs during the wet season. Under future climate 89 percent of rainfall and 97 to 98 percent of runoff occurs during the wet season.

## FL-1.5 Surface–groundwater interaction

Term of Reference 4

The Leichhardt River originates south of Mount Isa and flows in a northerly direction before terminating at Kangaroo Point on the coastline. The main tributaries of the Leichhardt River include the Alexandra River, Fiery Creek, Gunpowder Creek, Mistake Creek and Rifle Creek.

The Flinders River is the longest of the Gulf rivers and rises in the Great Dividing Range, nearly 1000 km from the Gulf of Carpentaria. Other major rivers in the Flinders catchment include the Bynoe, Saxby, Cloncurry, Corella, Fullarton and McKinlay.

The Flinders and Leichhardt rivers are ephemeral, flowing only for a portion of the year following intensive summer storm events. During the wet season, water infiltrates from the river into the alluvial aquifer either laterally via the incised sediments, or vertically via diffuse recharge when overbank flooding occurs. As the wet season comes to an end river levels begin to drop and groundwater discharges from the alluvial aquifer into the river. The alluvial aquifer continues to discharge to the river thus maintaining surface water flow (albeit at a declining rate), until the groundwater level falls below the river bed. At this point the river runs dry. Permanent or near-permanent waterholes along most of the larger watercourses are likely to exist due to surface flows from the previous wet season; it is not likely that they are the result of groundwater contribution (Petheram and Bristow, 2008).

River baseflow is the low portion of streamflow mostly contributed from regional groundwater discharge. Analysis of gauged streamflow data indicates that dry season baseflow is low in this region compared with other regions in the Gulf of Carpentaria Division, and that the lower reaches of the Flinders River receive the highest dry season baseflow in the region (Table FL-1 and Figure FL-2).

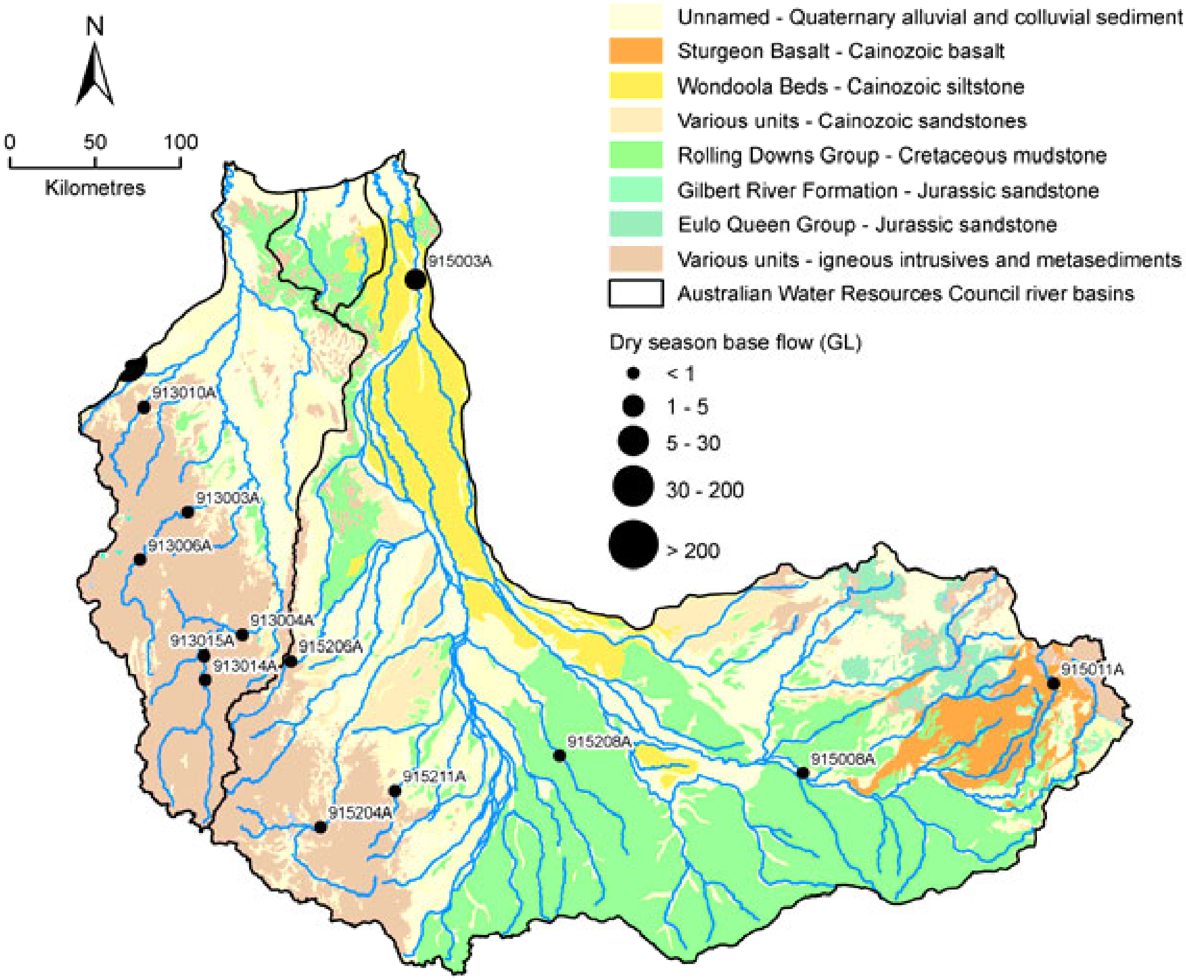



Figure FL-2. Surface geology of the Flinders-Leichhardt region and modelled mean dry season baseflow

Groundwater discharge from the GAB aquifers occurs where the streams are incised into outcropping sandstones and the watertable is high. The landscape in these areas is typically steep and dissected. A report identifying the potential areas of groundwater and surface water interaction in the GAB Water Resource Plan area was produced in 2005 (AGE, 2005). Although the report recognised limitations in its methodology, a summary of the streams identified to receive groundwater contribution from the GAB is shown in Figure FL-3. This summary included tributaries of the Flinders River, including the Woolgar River, Hampstead Creek and Porcupine Creek, all of which intersect the Gilbert River Formation. There is also potential for the Sturgeon Basalt to provide baseflow to tributaries such as Porcupine Creek.

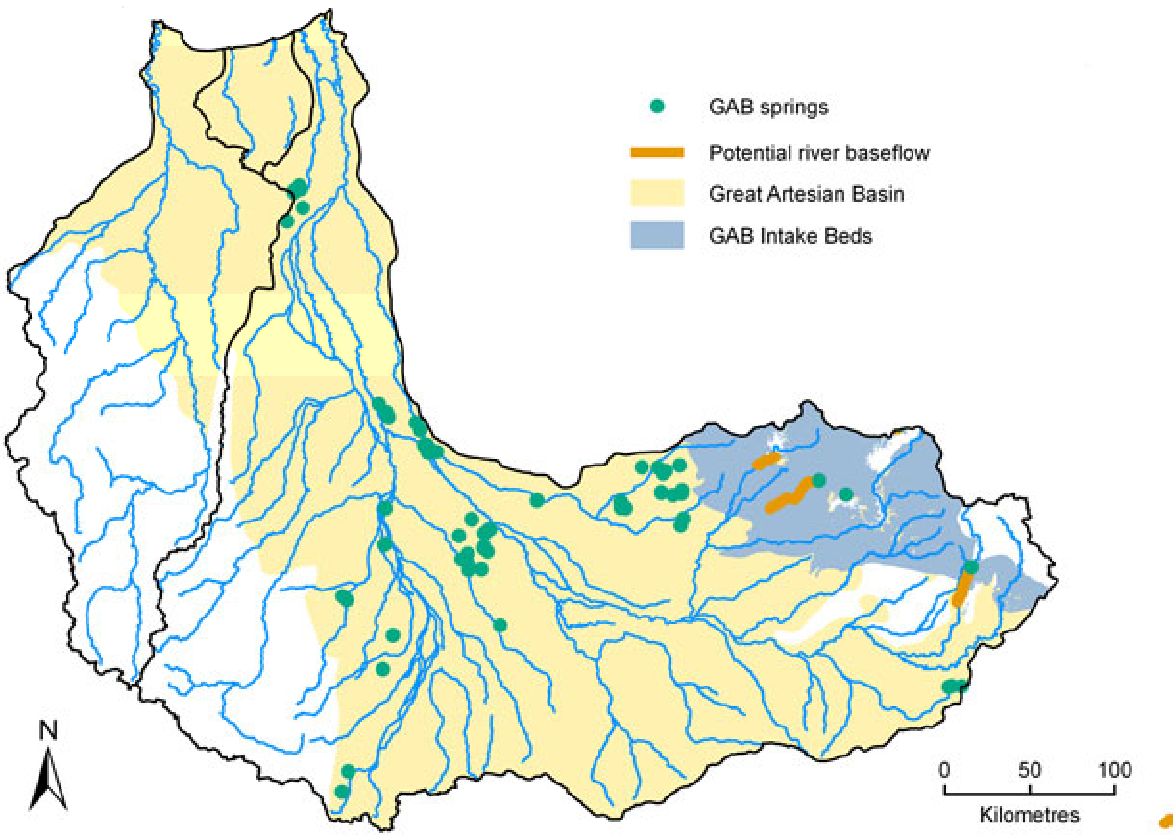



Figure FL-3. Location of spring groups of the Great Artesian Basin and potential river baseflow in the Flinders-Leichhardt region (derived from DNRM, 2005)

## FL-1.6 Water storage options

Term of Reference 5

### FL-1.6.1 Surface water storages

Significant surface water storages on the Flinders and Leichhardt rivers and their tributaries are listed in Section FL-2.4.3. The largest storages provide water supplies for urban, mining and industrial use in the upper Leichhardt catchment, around Mount Isa.

### FL-1.6.2 Groundwater storages

The main aquifer in the Flinders-Leichhardt region is the Gilbert River Formation of the GAB. Extraction from this resource for stock and domestic purposes is, by far, the greatest use of water in the region. Where the aquifer outcrops and is unconfined, recharge during the wet season fills any available storage before 'rejecting' excess recharge back into the rivers. Managed aquifer recharge (MAR) therefore has limited applicability in these areas. Further towards the north-west, the aquifer in the Gilbert River Formation becomes confined and ultimately artesian – a condition not favourable for MAR.

## FL-1.7 Data gaps

Term of Reference 1e

There are 29 weather stations in the region that have better than 80 percent record completeness, and 20 that pass 90 percent, making the Flinders-Leichhardt region the most data-rich region of northern Australia, at least for rainfall.

While the lower reaches of the Flinders and Leichhardt Rivers are gauged there is uncertainty associated with over bank events. Flood extent and volume measurements would increase the accuracy of the river system models in the lower reaches of these systems.

Time series groundwater level and salinity data is required for each of the main aquifer types in the Flinders-Leichhardt region to provide greater understanding of recharge processes and inter-aquifer leakage, particularly for the Great Artesian Basin aquifers.

## FL-1.8 Knowledge gaps

Term of Reference 1e

Flooding is an important factor that sustains many environmental assets and this occurs when the stream breaks out of its banks (a level known as bankfull stage or discharge). However, bank full discharge is not known for many streams, nor is the dependence of area flooded on increasing stream depth, so it is difficult to predict when assets are inundated. Further information about bank full stage and discharge are needed for most environmental assets.

Floodplain dynamics in general are poorly constrained. Flood extents, inundation rates and persistence are all critical factors for ecosystem health and are required to close water balance models. Remote sensing and field data would help fill this knowledge gap.

None of the environmental assets in this region have any site-specific metrics by which to gauge the potential impacts of future changes in climate and development. In the absence of site-specific metrics a set of standard metrics related to high and low flows have been utilised. However, the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and specific ecological entities (for example, macrophyte populations, fish passage, faunal and floral habitats, etc.).

Dry season flows are poorly understood in this region therefore the ability to predict the potential impacts of the various scenarios on low or zero flows at environmental assets is very limited. Improved monitoring of low streamflow conditions is needed along with the development of hydrological models that combine surface and groundwater regimes. Further monitoring of groundwater levels is also required so that the potential impacts of future changes in climate and development on groundwater-dependent ecosystems can be better understood.

Many environmental assets depend not simply on duration above or below certain flow levels, but on triggers (e.g. for reproduction or migration) set by the rate of change of flow. In addition, some environmental assets depend on the frequency and duration of events that occur less than annually (i.e. once every 5, 10 or 20 years or more). Further analysis is therefore required to look at how the timing, duration and rate of rise and fall in flow rates at critical times of the season will vary under the various scenarios.

Diffuse upward leakage of water out of the Great Artesian Basin aquifers and into overlying Cainozoic sediments is yet to be quantified. Whilst previous numerical models have inferred such leakage, further research is required to estimate these discharge fluxes so that a detailed groundwater balance can be developed for the aquifers.

## FL-1.9 References

AGE (2005) Great Artesian Basin water resource plan - potential for river baseflow from aquifers of the GAB. Prepared for the Department of Natural Resources and Mines.

DNRM (2005) Hydrogeological framework report for the Great Artesian Basin resource plan area.

McJannet DL, Wallace JW, Henderson A and McMahon J (2009) High and low flow regime changes at environmental assets across northern Australia under future climate and development scenarios. A report to the Australian Government from the CSIRO Northern Australian Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, CSIRO, Australia. *In prep.*

Petheram C and Bristow KL (2008) Towards an understanding of the hydrological opportunities and constraints to irrigation in northern Australia. North Australian Irrigation Futures Project. CSIRO Land and Water technical report No. 14/08, 111pp.

Zhang L and Dawes W (1998) WAVES - An integrated energy and water balance model. Technical Report No. 31/98, CSIRO Land and Water.

# FL-2 Contextual information for the Flinders-Leichhardt region

This chapter summarises the background information for the region, outlining existing knowledge of water resources and prior and current investigations relevant to the water resources of the region. This chapter also outlines the current and potential future legislation, water plans and other water resource management arrangements. This chapter is arranged into four sections:

- overview of the region: physical and climate descriptions
- data availability
- hydrogeology
- legislation, water plans and other arrangements.



## FL-2.1 Overview of the region

### FL-2.1.1 Geography and geology

The Flinders-Leichhardt region covers 145,223 km$^2$ and comprises the Australian Water Resources Council (AWRC, 1987) catchments of the Leichhardt (32,664 km$^2$), Morning Inlet (3679 km$^2$) and Flinders (108,192 km$^2$). The course of the Flinders River rises in the Great Dividing Range north-east of Hughenden and flows 840 km west, then north to discharge into the Gulf of Carpentaria near Karumba. At just over 1000 km, it is Australia's second longest river course outside the Murray-Darling Basin, and sixth longest overall. It does not flow year round, however. The Leichhardt River rises in the eastern edge of the Barkly Tableland, in low-lying hills (to 300 m) that provide a low watershed between streams flowing north to the Gulf and those, such as the Georgina, that flow south to Lake Eyre. A structural basin between the higher ground to the south-west and south-east is infilled with alluvial sediments from numerous streams, dissected with entrenched riverbeds. These lowland plains extend far inland to the south from the Gulf, which is itself a down-warped part of the plain. Mornington Island and South Wellesley Island (in the South-West Gulf region) represent parts not depressed below sea level.

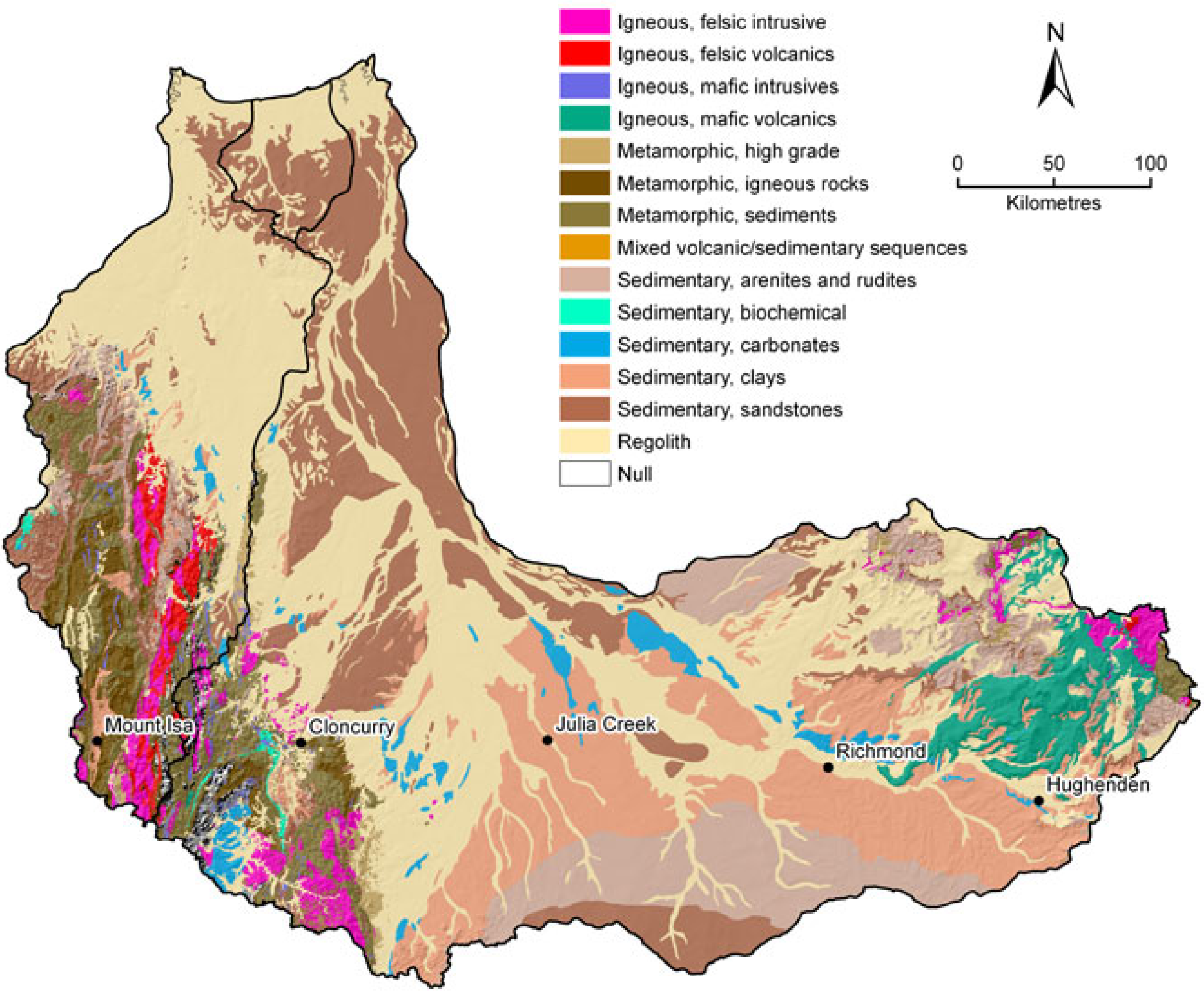



Figure FL-4. Surface geology of the Flinders-Leichhardt region overlaid on a relative relief surface

In its upper reaches, the Leichhardt River dissects the mining town of Mount Isa, with the town centre on the eastern side and mining activities mostly on the west. Rich deposits of lead, zinc and silver in metasediments of the Selwyn Range make this region one of the richest economic zones in the world.

### FL-2.1.2 Climate, vegetation and land use

The Flinders-Leichhardt region receives an average of 493 mm of rainfall over a water year (September to August), most of which (437 mm) falls in the November to April wet season (Figure FL-5). Across the region there is a strong north–south gradient in annual rainfall, ranging from 810 mm in the north to 330 mm in the south. Over the historical (1930 to 2007) period, annual rainfall has been reasonably constant overall, but with wetter than average conditions in the early 1950s and the 1970s and drier conditions through the 1960s. The highest yearly rainfall received was 1326 mm which fell in 1974, and the lowest was 189 mm in 1952. Areal potential evapotranspiration (APET) is very high across the region, averaging 1939 mm over a water year, and varies moderately across the seasons. APET generally remains higher than rainfall throughout the year resulting in year-round water-limited conditions, to which the vegetation has adapted.

Vegetation across the region is dominated by tussock grasslands on the floodplains and open eucalypt woodlands on higher ground (Figure FL-6). Grazing country dominates the landscape, except for the mining region around Mount Isa (Figure FL-7).

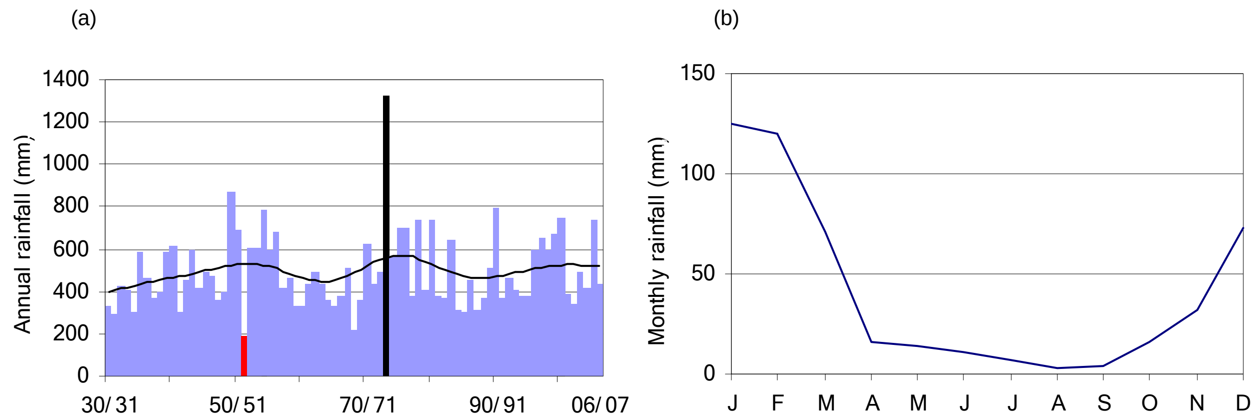



Figure FL-5. Historical (a) annual and (b) mean monthly rainfall averaged over the Flinders-Leichhardt region. The low-frequency smoothed line in (a) indicates longer term variability



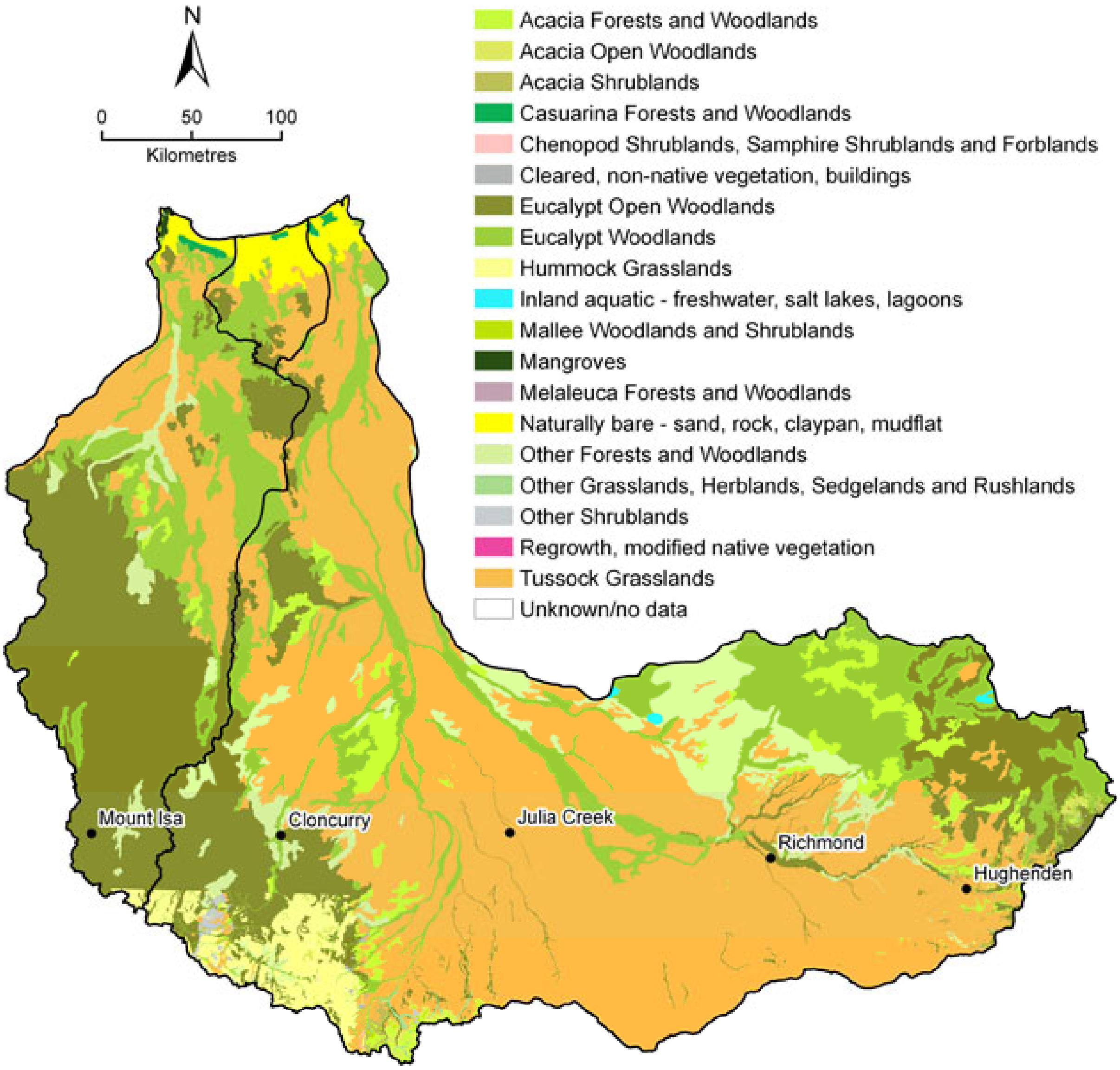



Figure FL-6. Map of current vegetation types across the Flinders-Leichhardt region (source DEWR, 2005)

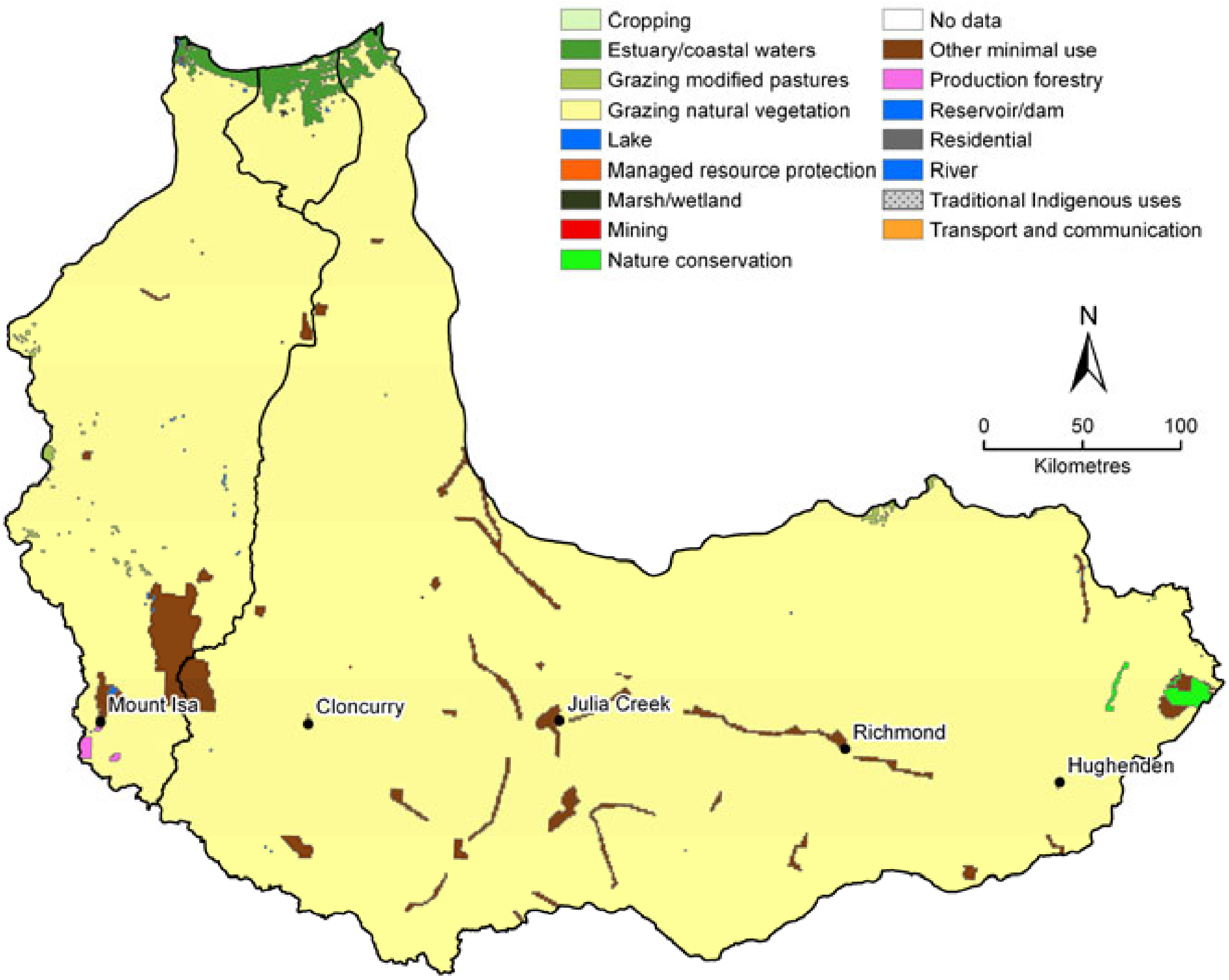



Figure FL-7. Map of dominant land uses of the Flinders-Leichhardt region (after BRS, 2002)

### FL-2.1.3 Regional environmental asset description

Environmental assets were chosen from wetlands which are listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001). From this directory, environmental assets were shortlisted for assessing changes to the hydrological regime under the climate and development scenarios. The selection of this shortlist was undertaken in consultation with state governments and the Australian Government through direct discussions and through internal reviews (see Section 1.3 in the division-level Chapter 1 for further detail).

All nationally, or internationally, important wetlands listed for the Flinders-Leichhardt region in the Directory of Important Wetlands in Australia (Environment Australia, 2001) are detailed in Table FL-2, with asterisks identifying the three shortlisted assets: Buffalo Lake Aggregation, Lake Julius and Southern Gulf Aggregation. The location of these shortlisted wetlands is shown in Figure FL-1. There are no wetlands classified as Ramsar sites in this region. Wetlands may be nationally or regionally significant depending on more locally specific criteria. All wetlands are important for a variety of ecological reasons or because they bear historical significance or have high cultural value, particularly to Indigenous people.

The following section characterises these shortlisted wetlands and is based largely on the description of these assets as outlined by (Environment Australia, 2001). Chapter FL-3 presents the assessment of those shortlisted assets, and reports hydrological regime metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis.

Table FL-2. List of Wetlands of National Significance located within the Flinders-Leichhardt region

| Site code | Name | Area | Ramsar site |
|---|---|---|---|
| | | ha | |
| QLD103 * | Buffalo Lake Aggregation | 1,910 | No |
| QLD120 * | Lake Julius | 1,940 | No |
| QLD121 | Lake Moondarra | 1,740 | No |
| QLD106 | Lignum Swamp | 283 | No |
| QLD114 * | Southern Gulf Aggregation | 546,000 | No |
| QLD115 | Stranded Fish Lake | 68 | No |

* Asterisk against the site code identifies those assets which are shortlisted for assessment of changes to flow regime.

In the Flinders-Leichhardt, the Buffalo Lake Aggregation, Lake Julius and the Southern Gulf Aggregation were chosen for assessment of changes to hydrological regime under the different scenarios. The following section characterises these wetlands and is based largely on the description of these assets as outlined by (Environment Australia, 2001).

## Buffalo Lake Aggregation

Buffalo Lake Aggregation has an area of 1910 ha and an elevation range of 5 to 15 m above sea level (Figure FL-8). The lake is flooded in extreme wet season events and during tidal surges which periodically inundate much of the coast from Burketown to Normanton. The lake is seasonal, drying out completely in most years. Depth is variable but mostly less than 1 m. Buffalo Lake is a good example of a large shallow lake typical of a suite of lacustrine systems in the Karumba Plains province. The aggregation consists of shallow lacustrine wetlands with extensive areas of both open water with unconsolidated bottom, and emergent wetland interspersed with aquatic beds. It is particularly important as a breeding and feeding habitat for waterfowl, and provides important roosting and feeding habitat for waterbirds and migratory waders. Buffalo Lake is the largest of several similar lakes in the general vicinity (Claridge et al., 1988). The site extends to the maximum high water mark of the drainage depression. It is formed in a shallow depression on a slightly elevated plain behind a low dune-swale formation which seasonally dams water from the local catchment of the elevated plain.

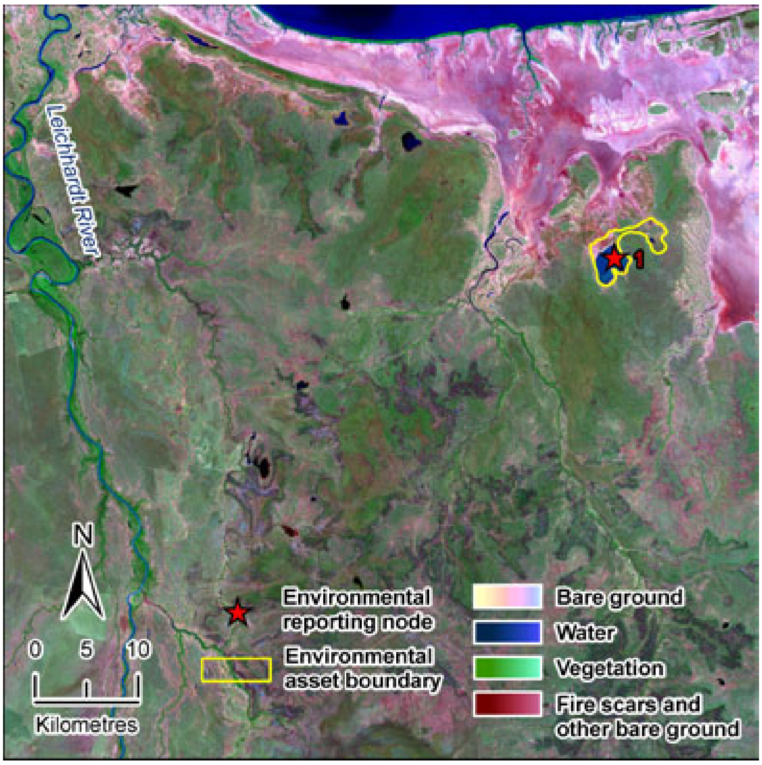



Figure FL-8. False colour satellite image of the Buffalo Lake Aggregation (derived from ACRES, 2000). Clouds may be visible in image

## Lake Julius

Lake Julius is a water storage formed by damming a valley of the Leichhardt River below the junction with Paroo Creek in 1976 (Figure FL-9). The lake provides mining and industrial water and town water supply. At maximum storage Lake Julius has an area of 1940 ha and is situated at an elevation of 224 m. The storage capacity of Lake Julius is 107,500 ML. The lake is permanent (Finlayson et al., 1984) and provides deep water habitat. Lacustrine wetlands dominate, with minor areas of palustrine forested wetland fringing the shoreline (Blackman et al., 1992). Lake Julius is an important dry season refuge for waterbirds and is a significant large permanent water body in a semi-arid area. Although artificial, it provides the equivalent of natural lake and lagoonal habitat. Lake Julius includes a minor Indigenous art site and is an important local recreational area. There is extensive cattle grazing in the land surrounding the lake.

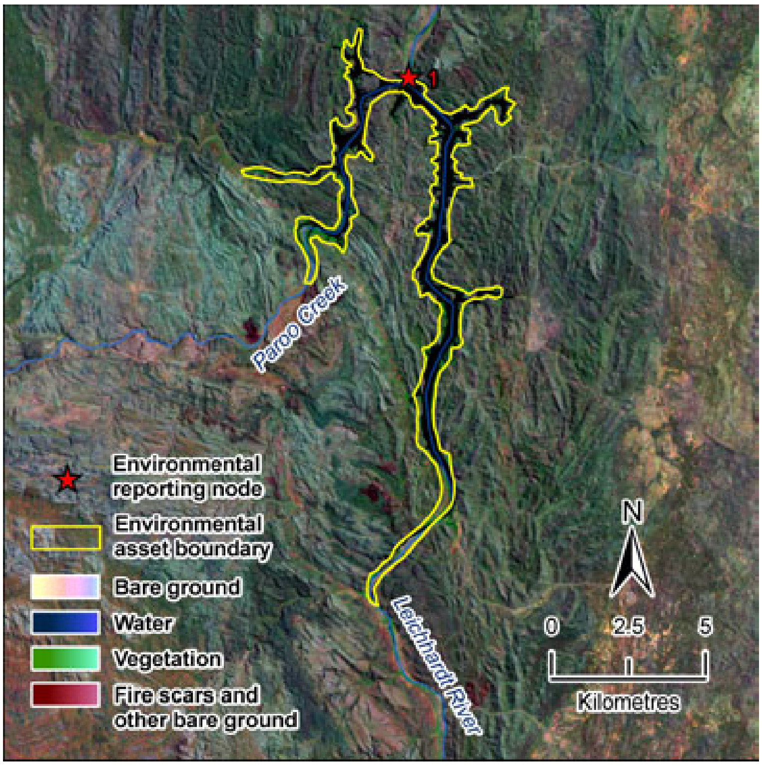



Figure FL-9. False colour satellite image of Lake Julius (derived from ACRES, 2000). Clouds may be visible in image

This site is part of or adjacent to a modified water body currently managed for the primary purpose of water supply infrastructure and that also serves as a wetland. Even though this is a modified or constructed wetland, the site does have biodiversity values that are consistent with the criteria for listing an important wetland on the Directory of Important Wetlands.

## Southern Gulf Aggregation

This huge coastal aggregation covers an area of 546,000 ha and ranges in elevation from zero to 10 m above sea level (Figure FL-10). This wetland area extends across three of the regions defined for this project: the Flinders-Leichhardt, South-West Gulf and South-East Gulf regions. Buffalo Lake also occurs within this aggregation. Only reporting nodes 2 and 3 (Figure FL-9) are relevant to the Flinders-Leichhardt region.

The Southern Gulf Aggregation is a complex continuous wetland aggregation (Blackman et al., 1992) that also encompasses several complex disjunct aggregations of closed depressions. Seaward to landward it comprises a continuum of extensive marine intertidal flats, beaches and foredunes, secondary dunes and swales, saline clay plains, seaward margins of saline clay plains, margins and levees of tidal channels, low elevated plains, and depressions within low elevated plains. The area is under the dominating influence of estuarine tides and massive freshwater flooding during wet season events.

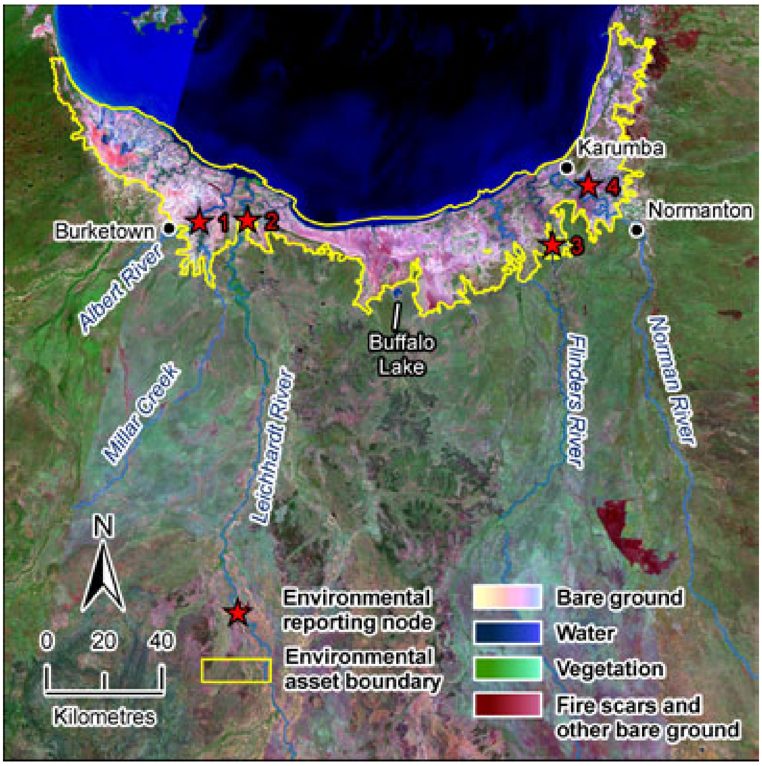



Figure FL-10. False colour satellite image of the Southern Gulf Aggregation (derived from ACRES, 2000). Clouds may be visible in image

Marine and estuarine tidal waters permanently inundate or regularly flood much of the area, with wet season flooding by freshwater from the streams and rivers of the inland catchment combined with local runoff from the plains of the Gulf Fall. The wetlands occurring along the inland margins of the area are brackish and all are seasonal. The aggregation has a major influence on nutrient flow into the Gulf of Carpentaria (Wolanski, 1993).The Southern Gulf Aggregation is the largest continuous estuarine wetland aggregation of its type in northern Australia. It is one of the three most important areas for shorebirds in Australia (Watkins, 1993).

## FL-2.2 Data availability

### FL-2.2.1 Climate

The rainfall-runoff modelling uses historical daily climate data (Scenario A) from the SILO database for the period 1 September 1930 to 31 August 2007 at 0.05 x 0.05 degree (~ 5 x 5 km) grid cells. Full details and characterisation of the SILO database are provided at the division level in Section 2.1 of Chapter 2. Scenario B and Scenario C climate data are rescaled versions of the Scenario A data; this is also discussed in Section 2.1 of Chapter 2.

### FL-2.2.2 Surface water

Streamflow gauging stations are, or have been, located at 44 sites within the Flinders-Leichhardt region, 28 of these in the Flinders catchment and 16 in the Leichhardt catchment. Ten of these gauging stations either are (i) flood warning stations, and measure stage height only; or (ii) have less than ten years of measured data. Of the remaining 34 stations, 21 recorded more than half of their total volume of flow during events that exceed the maximum gauged stage height. The majority of gauging stations in the Flinders-Leichhardt region are located in headwater catchments. Figure FL-11 shows the spatial distribution of gauges with good quality data (duration) for flows above maximum gauged stage height (MGSH). There are 15 gauging stations currently operating in the Flinders-Leichhardt region at density of one gauge for every 7700 $km^2$. For the 13 regions of northern Australia, the median number of gauging stations per region is 12 and the median density of gauging stations per region is one gauge for every 9700 $km^2$. By comparison, the mean density of current stream gauging stations across the Murray-Darling Basin is one gauge for every 1300 $km^2$.

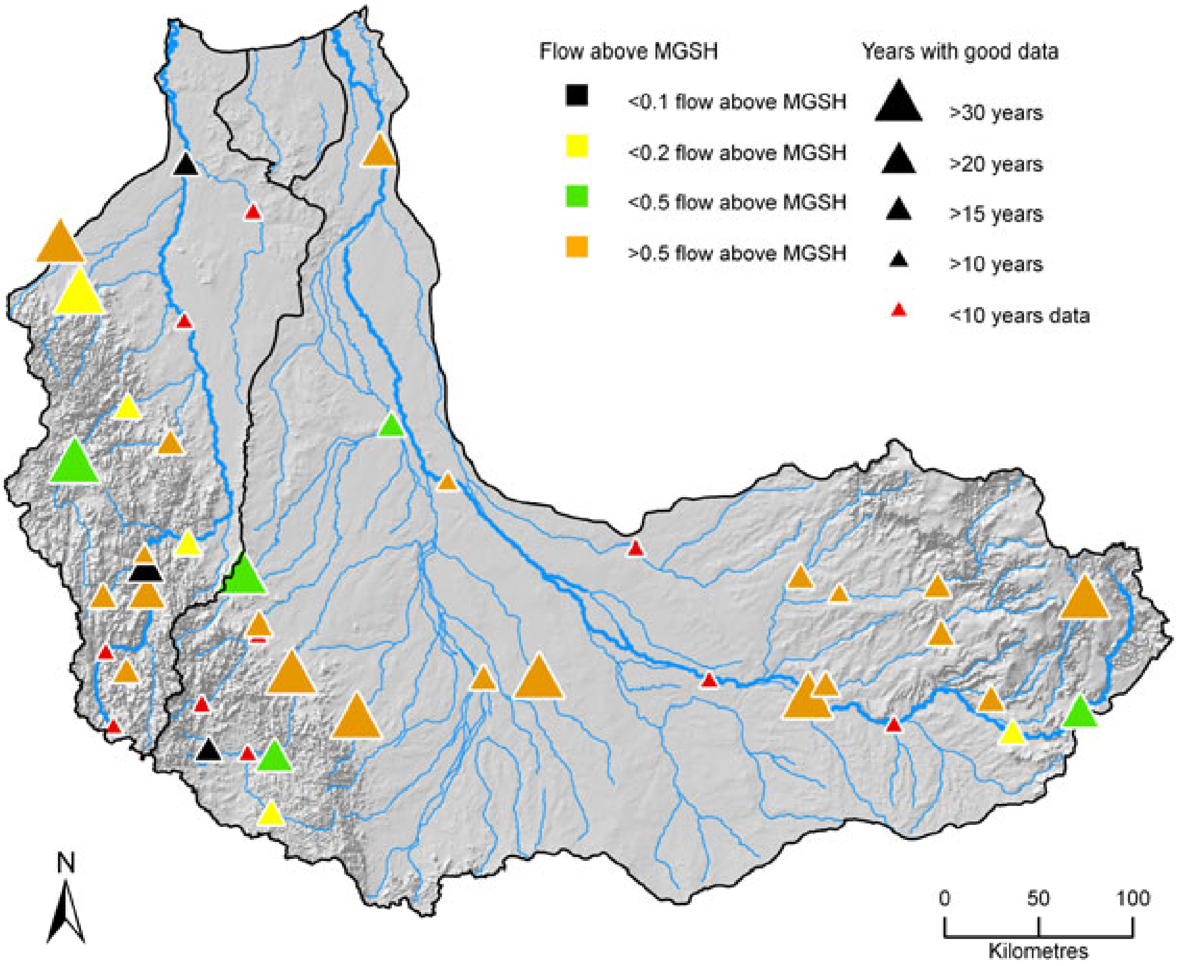



Figure FL-11. Location of streamflow gauging stations overlaid on a relative relief surface showing the proportion of gauges with flow above maximum gauged stage height across the Flinders-Leichhardt region

### FL-2.2.3 Groundwater

The Flinders-Leichhardt region contains a total 3347 registered groundwater bores – 1247 of these have surveyed elevations that could enable watertable surfaces to be constructed for the main aquifers. However, these bores are not necessarily monitored on a regular basis. According to Queensland Department of Environment and Resource Management (DERM) databases, there are only 42 water level monitoring bores in the region; two are historical and 40 are current (Figure FL-12). All of the 40 current monitoring bores are for the Great Artesian Basin (GAB) aquifer. However, it is noted that the Queensland Water Resources Commission (QWRC, 1987) also report a number of observation bores constructed in alluvial deposits in the Nelia and Hughenden – Richmond Sections and routine water levels from these bores were collected on a regular basis. This information was not available to the Northern Australia Sustainable Yields project. It is also noted that (Kellett et al., 2003) report some monitoring bores drilled into the intake beds for the Gilbert River Formation; the locations of these are not shown in Figure FL-12.

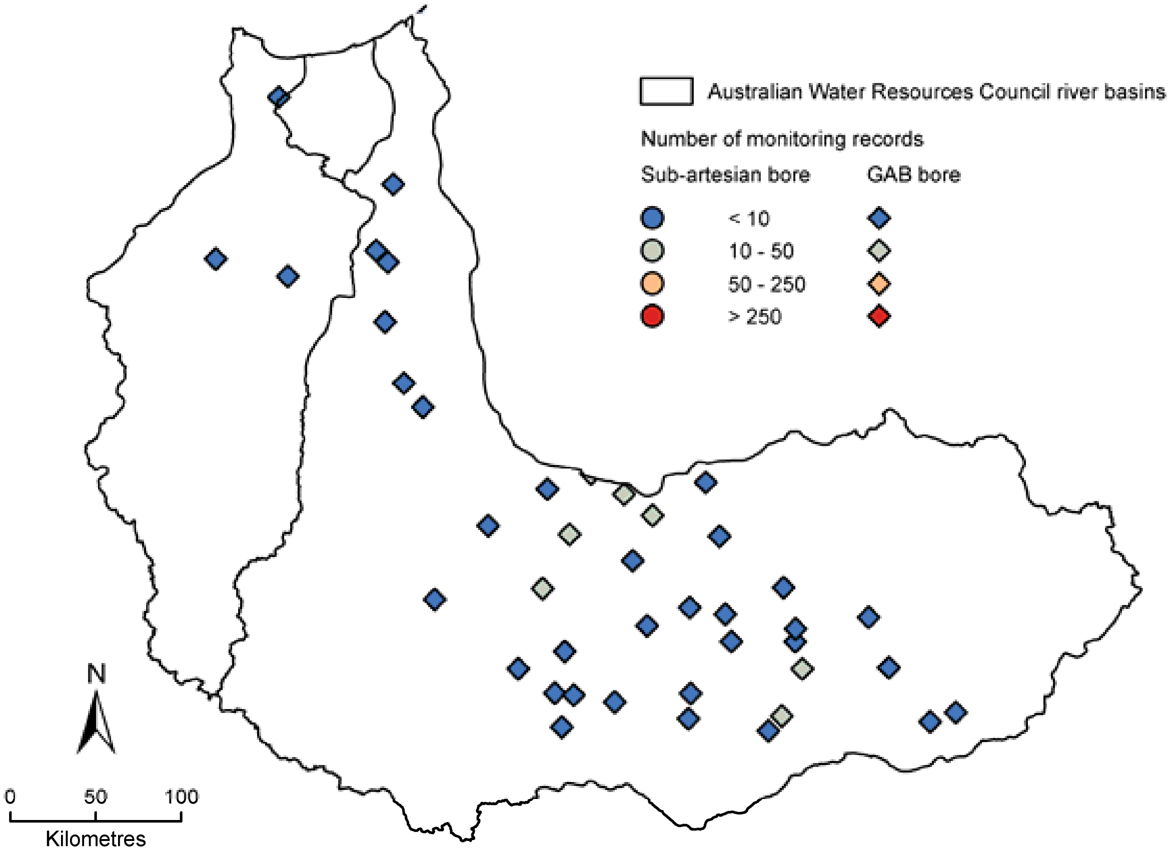



Figure FL-12. Location of groundwater monitoring bores and the number of their monitoring records in the Flinders-Leichhardt region

### FL-2.2.4 Data gaps

Time series groundwater level and salinity data are required for each of the main aquifer types in the Flinders-Leichhardt region to provide greater understanding of recharge processes and inter-aquifer leakage, particularly for the GAB aquifers.

# FL-2.3 Hydrogeology

## FL-2.3.1 Aquifer types

Three main aquifer types exist in the Flinders-Leichhardt region: (i) outcropping, fractured Proterozoic rocks; (ii) mostly confined Jurassic-Cretaceous GAB sediments, including the outcropping Gilbert River Formation; and (iii) Cainozoic sediments, mostly in the form of Quaternary alluvial sediments (Figure FL-2).

### Fractured rock aquifer

Extensively mineralised Proterozoic rocks outcrop in the south-west of the Flinders-Leichhardt region (Figure FL-2) and comprise granite, metamorphic rocks and little-altered sediments and lavas. These rocks form the Isa Highlands which occur as south-trending ridges, typically between 360 to 450 m above Australian Height Datum (AHD). Faults are generally silicified so that the only water reservoirs in the lavas and granite are joints or deeply weathered pockets. The sandstone is probably too highly silicified to provide reasonable yield aquifers and water is stored mainly in joints and along bedding planes. For these reasons the Proterozoic rocks are generally not considered a viable groundwater resource. Nevertheless, (McEniery, 1980) points out that prior to the construction of Lake Moondarra Dam, the Mount Isa township drew most of its water from fractured shale at rates of 5 to 10 L/sec with aquifers at depths of 60 to 80 m.

### Great Artesian Basin aquifers

The GAB comprises a multi-layered sequence of Triassic, Jurassic and Cretaceous age sandstones bounded by low permeability mudstones and siltstones. The Gilbert River Formation is the most widespread aquifer of the GAB in the Flinders-Leichhardt region and forms part of a continuous stratigraphic unit that stretches across the entire Carpentaria Basin (Smart et al., 1980). The Gilbert River Formation outcrops in several small areas in the far east of the Flinders-Leichhardt region (Figure FL-2), elsewhere the depth to this aquifer ranges from 175 m in the south-west near the foothills of the Isa Highlands, to 700 m towards the mouth of the gulf (Ingram et al., 1972). Thickness ranges from 45 to 70 m (Ingram et al., 1972; Smart, 1973; Grimes, 1973) and is largely determined by the topology of the underlying basement.

In areas where the Gilbert River Formation does not outcrop, the aquifer is confined and generally artesian in nature, meaning the groundwater is under hydrostatic pressure and rises above the ground surface in boreholes. Many once-artesian bores have ceased flowing over the last 50 years as a result of a decline in pressure head (GABCC, 1998).

The aquifers of the Gilbert River Formation often provide a well yield of around 10 L/sec (Ingram et al., 1972). However, it should be noted that maximum pumping yield from individual wells constructed in the Gilbert River Formation varies considerably across the GAB, mainly as a result of the variability in depth of available drawdown.

The Gilbert River Formation is typically overlain by the Lower Cretaceous Rolling Downs Group, which contains only minor disconnected lenticular aquifers of poor water quality, and is of variable thickness, ranging from approximately 250 to 700 m thick (Ingram et al., 1972; Smart, 1973; Grimes, 1973).

### Cainozoic aquifers

The Flinders-Leichhardt region is characterised by a significant floodplain comprising Quaternary clay, silt and sand of the Armraynald and Wondoola beds, which have a combined maximum thickness of approximately 45 m (Ingram et al., 1972; Smart, 1973; Grimes, 1973).

The Flinders River has deposited alluvium of depths ranging up to 25 m (Cochrane, 1967). This deposit consists predominantly of brown silts with gravel and sand which vary in volume from area to area. Recharge to the alluvial sands and gravels occur through the sandy beds of the Flinders River when it flows. (Cochrane, 1967) concluded that given the variation in alluvial thickness and groundwater quality, the river alluvium was not a viable resource. The Queensland Government groundwater database indicates that there are 37 bores screened in the alluvial aquifer, which is primarily unconfined. Water levels, which were measured predominantly at the time of drilling of these bores, range between 1 and 29 m below natural surface. The median water level recorded from these bores is 6 m below natural surface.

Tertiary age basalts of the Sturgeon province outcrop in the far east of the Flinders-Leichhardt region. There are numerous records of failed bores in this formation due to its limited saturated thickness. Nevertheless the aquifer may be locally important for providing baseflow in tributaries of the Flinders River.

### FL-2.3.2 Inter-aquifer connection and leakage

There may be inter-connection between the GAB aquifers and the overlying alluvial sediments where the confining beds are relatively thin, where pressures are high and particularly in marginal areas of the basin. Despite the low permeability of the aquitards and hence low percolation rates, this leakage probably accounts for considerable volumes of discharge (DNRM, 2005). The presence of spring groups in the centre of the Flinders-Leichhardt region (Figure FL-3) is indicative of leakage from the GAB aquifer to the overlying aquifers, although it should be noted that many of the springs shown on this map are no longer active – that is, they have ceased to flow.

Interconnection also exists between the GAB aquifers and the Flinders River, where the river is incised into the Gilbert River Formation in the recharge beds to the east of the region.

### FL-2.3.3 Recharge, discharge and groundwater storage

#### Great Artesian Basin aquifers

Recharge to the GAB aquifers is by infiltration of rainfall and leakage from streams into outcropping sandstone. In the Flinders-Leichhardt region, this primarily occurs along the elevated margins of the Basin on the western slopes of the Great Dividing Range, in areas referred to as ‘recharge beds’ or ‘intake beds’ (Figure FL-3).

Recharge occurs in three ways (Kellett et al., 2003): diffuse rainfall (with rates from 0.03 to 2.4 mm/year); preferred pathway flow (0.5 to 28.2 mm/year); and river/aquifer leakage (up to 30 mm/year). Preferred pathway flow, which involves the movement of water through conduits such as fissures, joints, remnant tree roots or highly permeable beds, is considered the dominant recharge process for the intake beds, though river leakage may dominate in at least one tributary (Porcupine Creek) of the Flinders River. The rate of recharge via preferred pathway flow depends on the frequency of episodic high magnitude rainfall events, which will be high in the Flinders-Leichhardt region as it is situated at the northern end of the intake beds.

Discharge from the GAB aquifers occurs in a number of ways, including: natural discharge from springs; upward vertical leakage through the confining beds; subsurface outflow into the Gulf of Carpentaria (although little is known about the volume or significance of this form of discharge); and artificial discharge, via artesian flow and pumped extraction from wells drilled into the aquifers.

Figure FL-13 shows time series water levels for three bores located in the Flinders-Leichhardt region; note readings are limited to a maximum of seven occasions over a 94-year period. These bores do not have stratigraphic information to indicate which formation they are screened in. They range in depths from 342 to 573 m and are recorded as being either ‘sub-artesian’ or ‘artesian ceased to flow’. The general trend seen for these hydrographs is a decline in water level. The decline in water level may be associated with a decline in hydrostatic pressure as a result of increased groundwater use. As long ago as 1891, users noted a decline in spring discharge rates, with an increase in the number of bores (DNRM, 2005). Given the deep drilled depths of these bores and the fact that they show a gradual decline in pressure, it is likely they are screened in the most developed aquifer of the Gilbert River Formation.

In recent years, an increase in artesian pressures has been observed due to the rehabilitation and piping of bores in the Flinders area.



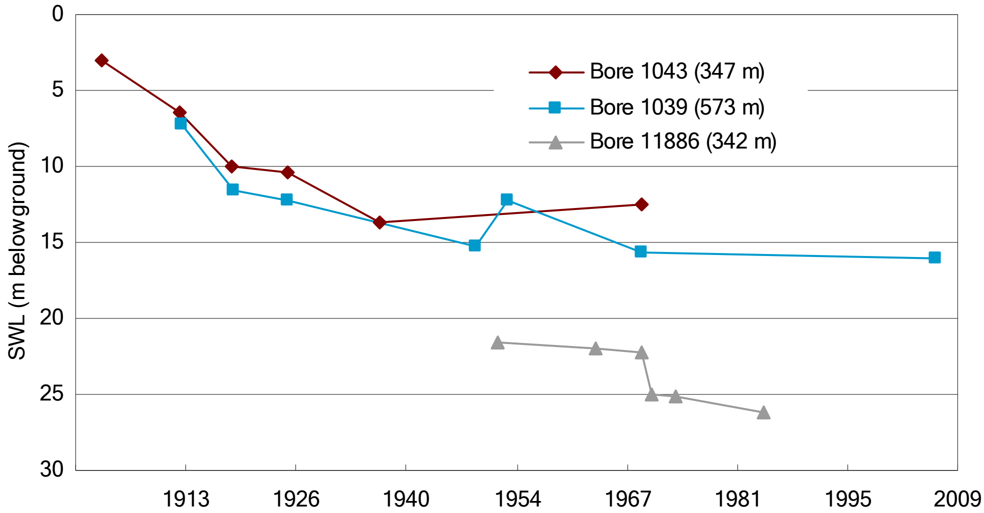



Figure FL-13. Observed groundwater levels in monitoring bores in aquifers of the Great Artesian Basin within the Flinders-Leichhardt region

## Cainozoic sediments

Recharge to the alluvial sands and gravels that border the Flinders and Leichhardt rivers predominantly occurs via lateral flow through the sandy river beds during the wet season when stage is highest (Cochrane, 1967; SKM, 1993). Recharge is likely to occur to a lesser degree, via vertical infiltration of rainfall and also on the extensive floodplain when the river floods. The alluvial aquifers also receive upward recharge from the GAB, where confining beds are relatively thin; this is supported by subsurface river valley flow during the dry season (May to October), as observed during an investigation into the Flinders River alluvium (Cochrane, 1967).

Discharge from the alluvium predominantly occurs in the form of evapotranspiration; however during the dry season direct discharge to the rivers also occurs. This will be discussed in detail in the following section.

### FL-2.3.4 Groundwater quality

The artesian aquifer in the Gilbert River Formation contains groundwater of variable quality, with salinity (as electrical conductivity) generally in the range of 1000 to 5000 µS/cm (DNRM, 2005). Regional groundwater quality information is not available for the shallow alluvial aquifers of the Flinders-Leichhardt region, although quality is expected to be variable.

Figure FL-14 shows groundwater salinity for approximately 1000 bores in the region, which have measurement dates ranging from 1965 to 2008. These bores screen various aquifers and have a median depth of 306 m, indicating that the map mainly reflects water quality in the GAB aquifers. A distinctive pattern is evident, with fresher groundwater (zero to 750 µS/cm) in the east of the region, and a progression towards more saline groundwater (751 to 5000 µS/cm) to the northwest. The trend may be due in part to a change in aquifers in which the bores are completed. For example, progressing towards the gulf, the Gilbert River Formation gets deeper and thus more bores are likely to be tapping the shallower more-saline aquifers in the Rolling Downs Group.

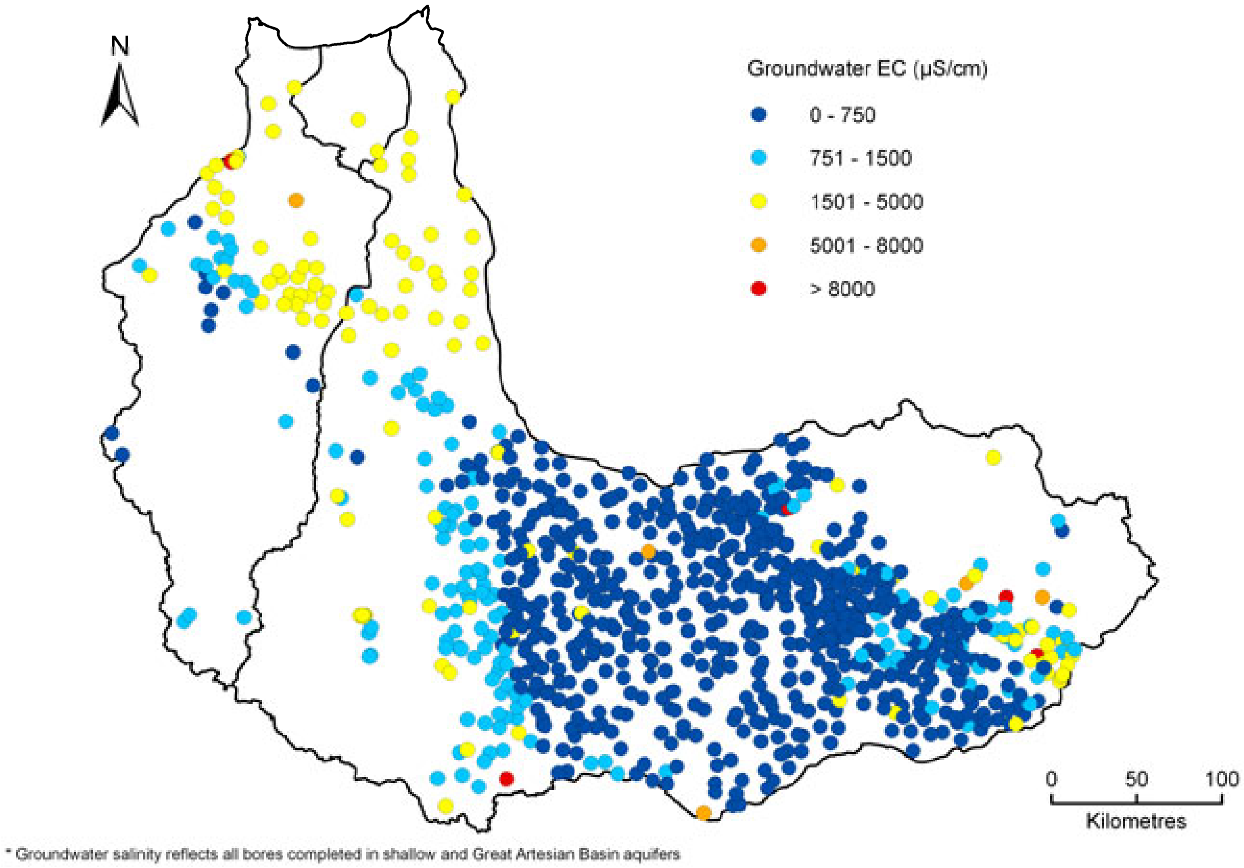



Figure FL-14. Groundwater salinity distribution for all bores drilled in the Flinders-Leichhardt region

# FL-2.4 Legislation, water plans and other arrangements

## FL-2.4.1 Legislated water use, entitlements and purpose

Water entitlements and use in the Flinders-Leichhardt region are governed by the *Water Resources (Gulf) Plan* (DNRW, 2007). Water entitlements from the GAB aquifers are also governed by the *Water Resource (Great Artesian Basin ) Plan 2006*.

Within the region, demand for additional water for proposed irrigated agriculture has occurred primarily in the Flinders River catchment. The water licence applications received by the Queensland Department of Environment and Resource Management for the Flinders River catchment largely reflect this demand.

Surface water utilisation for irrigation is highest in the Flinders River catchment. Industrial use, however, is highest in the Leichhardt River catchment and can be attributed to the Mount Isa mine developments. Stock and domestic (including town water supplies) use is also highest in the Leichhardt River catchment and is attributed to the regional centre of Mount Isa, with a population of approximately 21,000.

The main population centres in the Flinders-Leichhardt region are Mount Isa in the south of the Leichhardt River catchment and Cloncurry, Julia Creek, Richmond and Hughenden in the Flinders River catchment. The main commercial activities in the region are related to mining or grazing.

Figure FL-15 shows the locations of allocated and unallocated surface water within the region. In this figure green indicates current surface water allocation and red indicates unallocated surface water. Values at the bottom of the catchment include existing and proposed water entitlements at various extraction locations throughout the catchment.

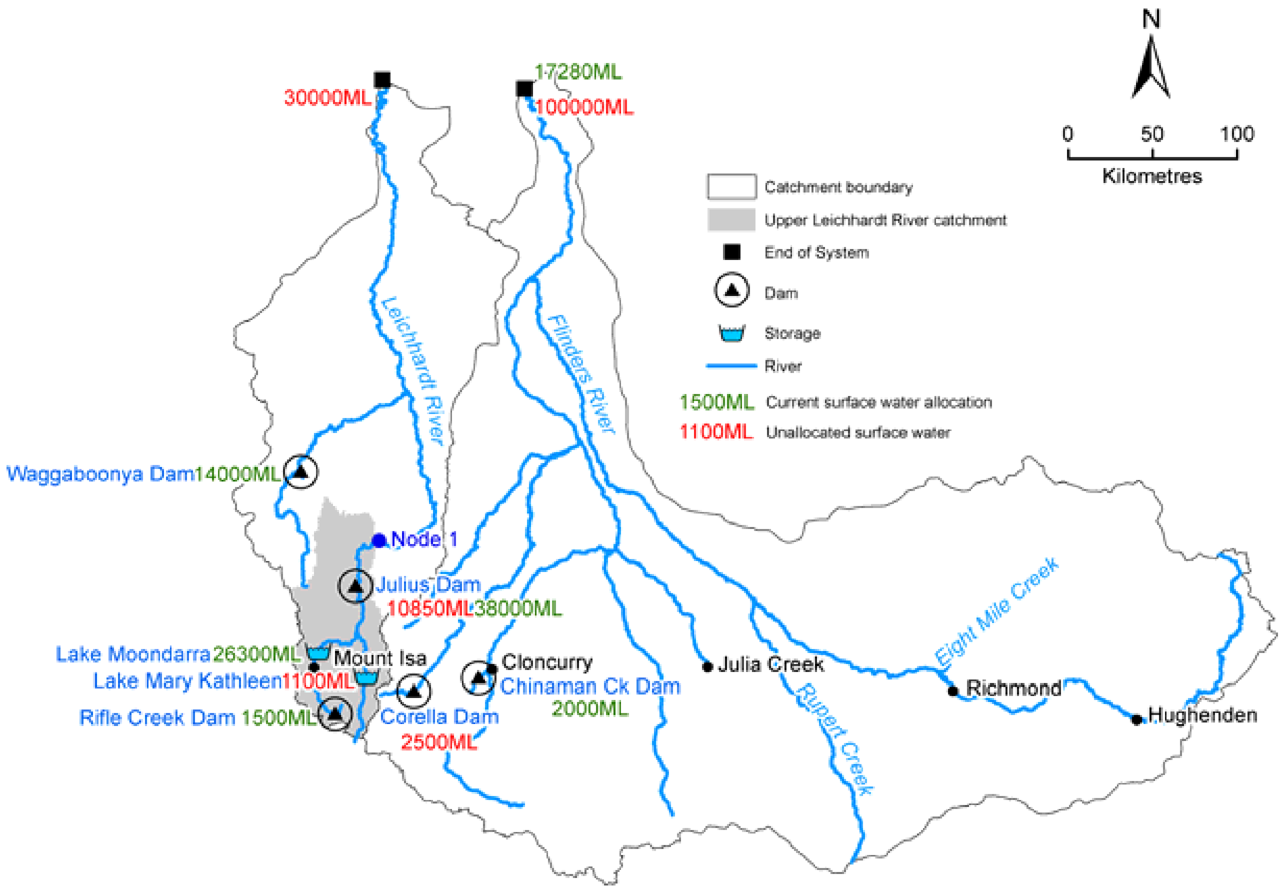



Figure FL-15. Current surface water allocation (green) and unallocated surface water (red) for (a) the Leichhardt and (b) the Flinders catchments (after *Water Resources (Gulf) Plan* (DNRW, 2007). Note: the unallocated water indicated for Lake Julius represents unused water allocated to SunWater; total allocation from Lake Julius is 48,850 ML.

The Morning Inlet catchment is declared a wild river area. The *Wild Rivers Act 2005* includes a process for the Minister for Environment and Resource Management to declare wild river areas. The intent of the *Morning Inlet Wild River Declaration 2007* is to preserve the natural values of wild rivers in the Morning Inlet wild river area. The declaration does this by regulating most future development activities and resource allocations within the wild river area. Water allocations for this wild river area are dealt with under the *Water Resource (Gulf) Plan 2007*. In the wild river area new development activities will be regulated through existing development assessment processes with wild river requirements applied through the wild river declarations or the wild rivers code. Developments and authorisations in place at the time the declarations were made are not affected.

There is currently 1000 ML/yr of unallocated strategic surface water allocation in the Morning Inlet catchment.

### FL-2.4.2 Groundwater use and entitlements

The current distribution of groundwater licences in the Flinders-Leichhardt region is shown in Figure FL-17. Groundwater entitlement volumes and estimated stock and domestic use volumes were reported as part of the GAB Water Resource Plan (DNRM, 2005). This information was collated in terms of the management areas defined for the GAB in Queensland and has been reconfigured by the Queensland Department of Environment and Resource Management to estimate volumes for the Northern Australia Sustainable Yield Project reporting regions.

Groundwater of the GAB is vital to the outback regions of Queensland, as it is often the only water supply available for towns and properties for their stock and domestic requirements. It also supplies water for industrial purposes such as mining, power generation, aquaculture, feedlots and piggeries. However, the predominant current use in the GAB is, by far, for stock and domestic purposes.

For the Flinders-Leichhardt region the estimated volume of stock and domestic use is approximately 60 GL/year and the volume of licensed entitlements is about 13 GL/year (Table FL-3). This table shows that over 90 percent of both stock and domestic use and groundwater entitlements are associated with the GAB aquifers, further indicating that the GAB comprises the predominant aquifers developed for groundwater extraction in the Flinders-Leichhardt region.

Table FL-3. Estimated stock and domestic groundwater use and groundwater entitlements in the Flinders-Leichhardt region

| Formation | Stock & domestic use | Entitlement |
|---|---|---|
| | GL/y | |
| Quaternary alluvium | 0.11 | 0.436 |
| Cainozoic sediments/basalt | 0.30 | 0.012 |
| Cretaceous sedimentary rocks | 0.04 | 0.000 |
| Jurassic – Early Cretaceous Great Artesian Basin aquifers | 58.19 | 12.265 |
| Palaeozoic rocks | 0.04 | 0.000 |
| Proterozoic rocks | 1.09 | 0.674 |
| **Total volume** | **59.77** | **13.387** |

The artesian nature of the GAB aquifers is an inherent characteristic that is taken advantage of by water users. It allows the reticulation of water around properties without the need for pumping.

The GAB Consultative Committee completed a *Strategic Management Plan* for the GAB in 2000 (GABCC, 2000). This was superseded by the *Water Resources (Great Artesian Basin) Plan 2006*, creating seven zones in the GAB for broad management purposes, four of which fall within the Flinders-Leichhardt region (Figure FL-16). The Gilbert River Formation is the primary artesian aquifer in these management areas, with development mainly for stock and domestic use due to the varying groundwater quality and bore yields.

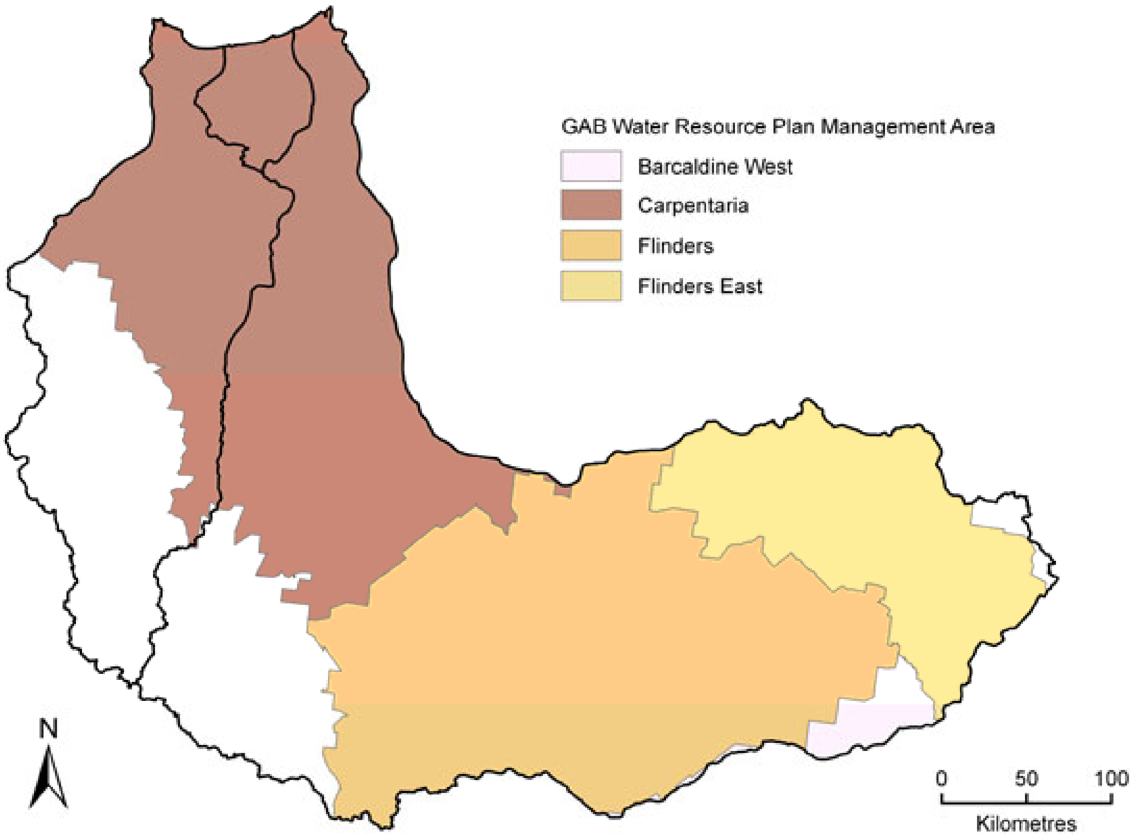



Figure FL-16. Groundwater management areas of the GAB in the Flinders-Leichhardt region

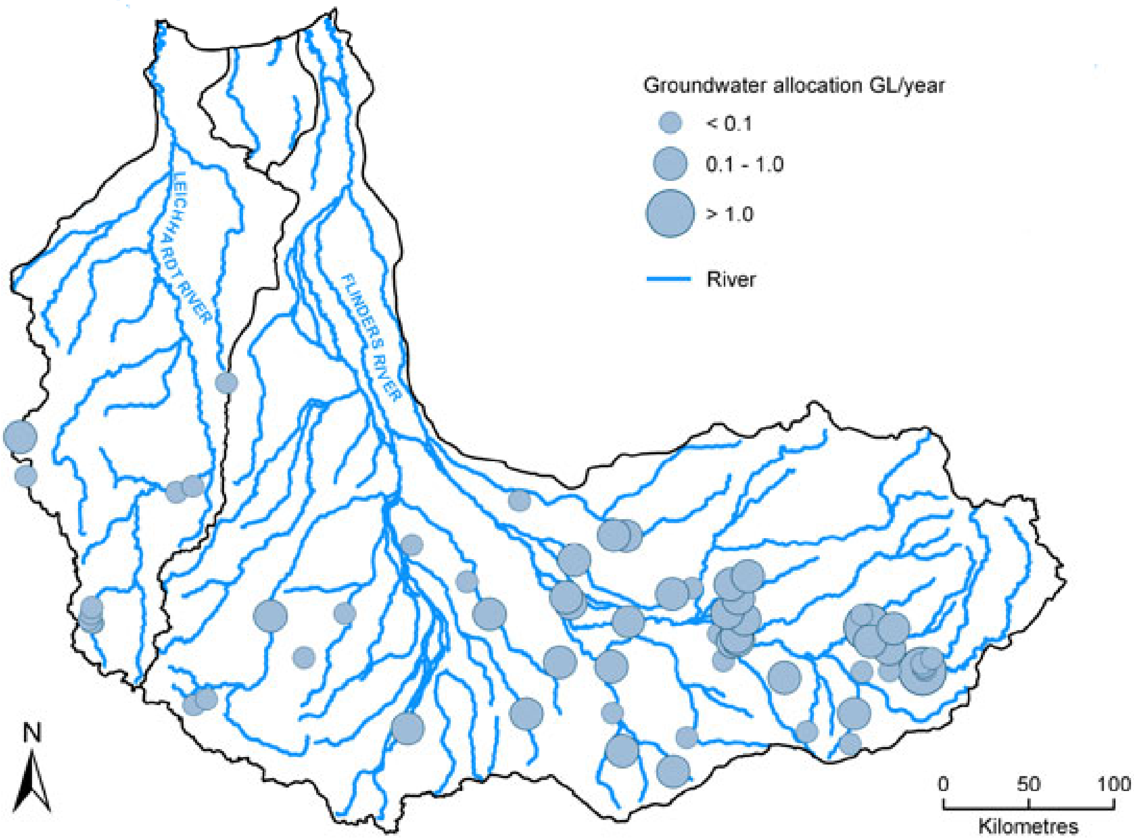



Figure FL-17. Location of existing groundwater allocations in the Flinders-Leichhardt region

### FL-2.4.3 Rivers and storages

Significant surface water storages on the Flinders and Leichhardt rivers and their tributaries are listed in Table FL-4. The largest storages provide water supplies for urban, mining and industrial use in the upper Leichhardt catchment, around Mount Isa.



Table FL-4. Instream storages on the Flinders and Leichhardt rivers (within the IQQM modelled area)

| Storage name | River | Capacity |
|---|---|---|
| | | ML |
| Flinders River | | |
| Corella Dam | Corella River | 15,800 |
| Chinaman Creek Dam | Chinaman Creek | 2,750 |
| Storage instream | Rupert Creek | 2,400 |
| Storage instream | Eight Mile Creek | 1,300 |
| Riverside bedsand irrigation | Flinders River | 400 |
| Flinders Shire Council Bedsands | Flinders River | 300 |
| Onstream storage | Armstrong Creek | 280 |
| Storage instream Hazelwood | Cecil Creek | 250 |
| storage instream | Woolgar River | 84 |
| Storage instream Lagaven | McKinlay River | 30 |
| **Total** | | **23,594** |
| Leichhardt River | | |
| Julius Dam | Leichhardt River | 107,500 |
| Lake Moondarra | Leichhardt River | 106,833 |
| Waggaboonya Dam | Greenstone Creek | 14,000 |
| Lake Mary Kathleen | East Leichhardt River | 12,200 |
| Rifle Creek Dam | Rifle Creek | 9,488 |
| - | Alexandra River | 3,000 |
| - | Leichhardt River | 500 |
| Star Gully storage | Star Gully | 20 |
| **Total** | | **253,541** |

### FL-2.4.4 Unallocated water

Unallocated water in the Flinders River catchment can be held as a general reserve (general unallocated water) or a strategic reserve (strategic unallocated water). General unallocated water may be granted for any purpose whilst strategic unallocated water may be granted for a state purpose or from Lake Corella. There is no definition of the location from which future extraction of unallocated water in the Flinders River catchment may come from other than from Lake Corella.

Unallocated water in the Leichhardt River catchment can be held as a general reserve (general unallocated water) or a strategic reserve (strategic unallocated water). General unallocated water may be granted for any purpose whilst strategic unallocated water may be granted for a state purpose or from water from Lake Mary Kathleen.

Unallocated water from Julius Dam, held by SunWater under an interim water allocation, could meet any future urban demands from Mount Isa city or mining interests in the region but is not currently being used. Julius Dam impounds the Leichhardt River at 390.9 km AMTD.

Additional rules apply to water in the Upper Leichhardt subcatchment.

The Lower Leichhardt subcatchment is the remaining area of the catchment downstream of Node 1 (Figure FL-15). There is no definition of the location from which future extraction of unallocated water in the Lower Leichhardt subcatchment may come from.

### FL-2.4.5 Social and cultural considerations

The *Gulf Draft Resource Operations Plan* provides for ‘the protection of water-related cultural values of Aboriginal and Torres Strait Islander communities’ (DNRW, 2008). Under the plan, the health and needs of natural values are addressed through provisions that are consistent with the general and ecological outcomes of the water resource plan. These outcomes aim to sustain natural characteristics such as variability of flows and water levels, which provide for, and support, native animal and plant communities; protect the natural attributes of the river systems to support the habitats of native plants and animals in watercourses, floodplains, wetlands, lakes and springs; and ensure connectivity of river systems to allow for the passage of fish species, which maintains natural populations as well as enabling fresh water to reach estuaries and the Gulf of Carpentaria (DNRW, 2008).

### FL-2.4.6 Changed diversion and extraction regimes

Within the project area, demand for additional water for proposed irrigated agriculture has occurred primarily in the Flinders catchment. The water licence applications received by the DERM for the Flinders catchment largely reflect this demand.

### FL-2.4.7 Changed land use

DERM has undertaken several soil investigations in the area, especially around Richmond. These investigations have shown that large areas, which potentially could be supplied with water, have significant development limitations associated with high levels of salinity or sodicity. Such limitations are likely to constrain the scope and scale of any future irrigation developments.

The Flinders and Richmond Shire Councils are continuing to investigate soil suitability in an effort to promote the expansion of irrigated agriculture. A recent soil investigation identified potential for irrigation in the Richmond area. However, additional work would be required to identify any long-term impacts irrigation could have on the landscape, streams or groundwater systems and whether innovative irrigation practices could be utilised to mitigate impacts and ensure that development is sustainable.

### FL-2.4.8 Environmental constraints and implications of future development

Legislative constraints have been applied to satisfy environmental flow requirements at Node 1 Leichhardt River at Miranda Creek (at 357.3 km AMTD):

#### Low flow objectives

The low flow objectives set for Node 1:

- the number of periods of no flow of more than 1 month but less than 6 months be not more than 150; and
- the number of periods of no flow of 6 months or more be not more than 80; and
- the number of days on which the daily flow equals or exceeds the median non-zero daily flow, expressed as a percentage of the number of days on which the daily flow for the pre-development flow pattern equals or exceeds the median non-zero daily flow, be at least 50 percent.

#### Medium to high flow objectives

The medium to high flow objectives set for Node 1:

- the mean annual flow, expressed as a percentage of the mean annual flow for the pre-development flow pattern, be at least 63 percent; and
- the median annual flow, expressed as a percentage of the median annual flow for the pre-development flow pattern, be at least 37 percent; and
- the 10 percent daily flow be equalled or exceeded on at least 5 percent of the number of days in the period; and
- the 1.5-year daily flow volume, expressed as a percentage of the 1.5-year daily flow volume for the pre-development flow pattern, be at least 37 percent; and
- the 5-year daily flow volume, expressed as a percentage of the 5-year daily flow volume for the pre-development flow pattern, be at least 70 percent; and
- the 20-year daily flow volume, expressed as a percentage of the 20-year daily flow volume for the pre-development flow pattern, be at least 72 percent.

Diverting flows may also have to adhere to licence conditions. For example, near the Cloncurry Gauging Station, diverting water is prohibited during a period when the daily flow in the Cloncurry River at the Cloncurry Gauging Station (327.6 km AMTD) is less then 432 ML/day.

Both the Flinders and Leichhardt rivers are managed with reference to modelling of flows, diversions and losses using the IQQM model. Flow objectives are set with reference to Node 1 (Figure FL-15) depending on the flow modelled for a given year.

Volumetric limits exist on all groundwater entitlements under the *Water Resource (Great Artesian Basin) Plan 2006*. Stock and domestic bores don't require a volumetric entitlement and can access water if they meet criteria in regard to distance from existing bores and springs to protect existing users and groundwater dependent ecosystems.

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# FL-3 Water balance results for the Flinders-Leichhardt region

This chapter describes modelling results and the assessment of the water resources undertaken by this project for the Flinders-Leichhardt region. Detailed, quantified assessments are made where possible, and relevant, and confidence is estimated. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2. This chapter is sub-divided into:

- climate
- recharge estimation
- conceptual groundwater models
- groundwater modelling results
- rainfall-runoff modelling results
- river system water balance
- changes to flow regimes at environmental assets.

## FL-3.1 Climate

### FL-3.1.1 Historical climate

The Flinders-Leichhardt region receives an average of 493 mm of rainfall over the September to August water year (Figure FL-18), most of which (473 mm) falls in the November to April wet season (Figure FL-19). Across the region there is a strong north–south gradient in annual rainfall (Figure FL-20), ranging from 812 mm in the north to 331 mm in the south. Rainfall has been gradually increasing over the historical (1930 to 2007) period. The highest yearly rainfall received was 1326 mm in 1974, and the lowest was 189 mm in 1952.

Areal potential evapotranspiration (APET) is very high across the region, averaging 1939 mm over a water year (Figure FL-18), with highest rates occurring in the wet season (Figure FL-19). APET generally remains higher than rainfall throughout the year resulting in year-round water-limited conditions.

 

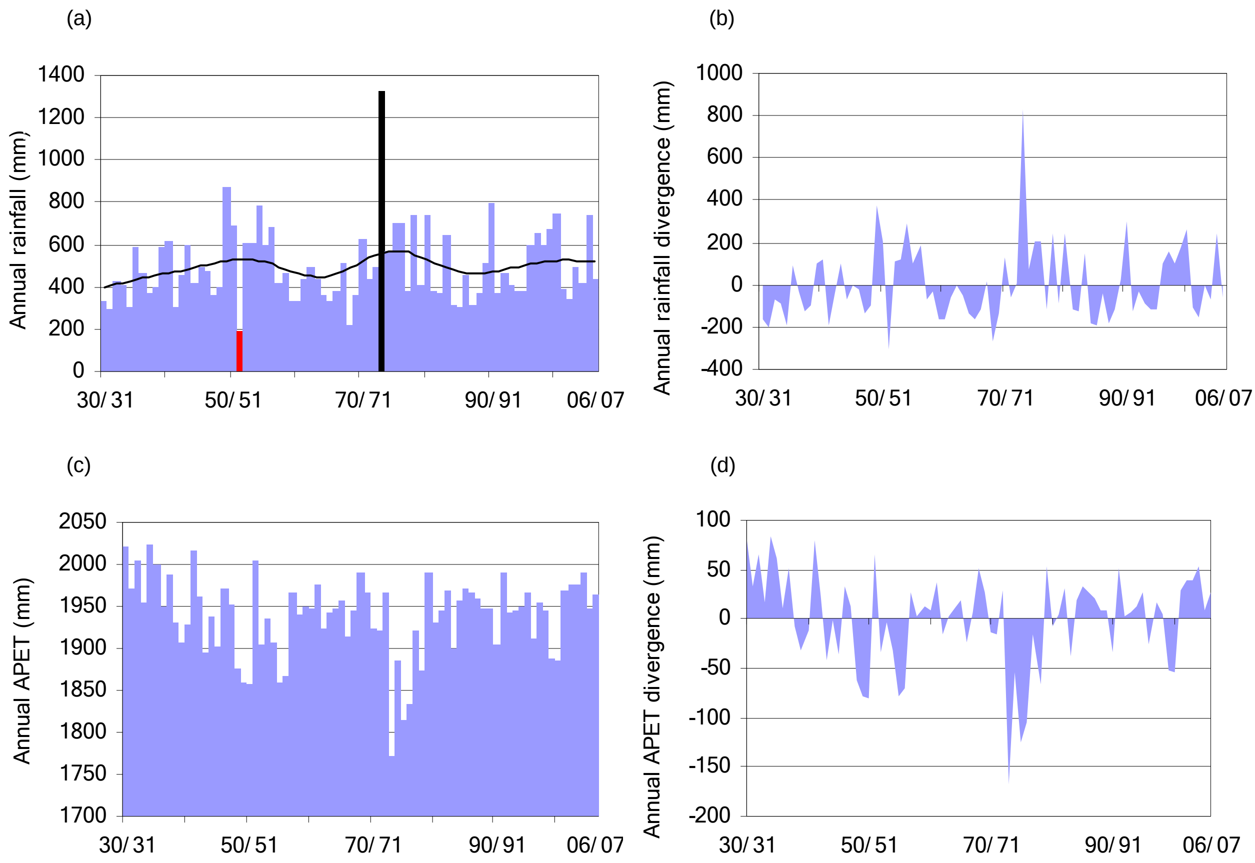


Figure FL-18. (a) Historical annual rainfall and (b) its divergence from the long-term mean; and (c) historical annual areal potential evapotranspiration and (d) its divergence from the long-term mean averaged over the Flinders-Leichhardt region. The low-frequency smoothed line in (a) indicates longer term variability

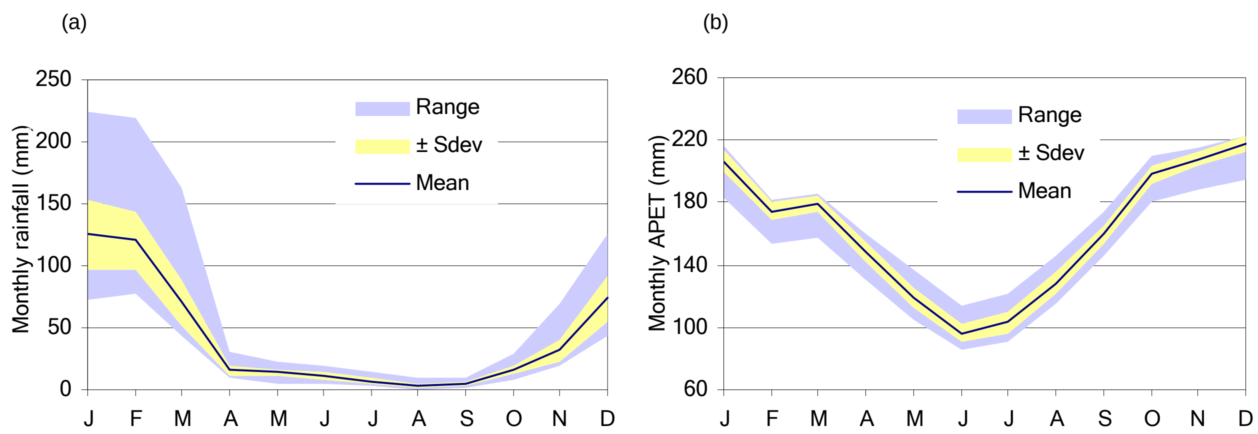


Figure FL-19. Historical mean monthly (a) rainfall and (b) areal potential evapotranspiration and their temporal variation (range and ± one standard deviation) averaged over the Flinders-Leichhardt region

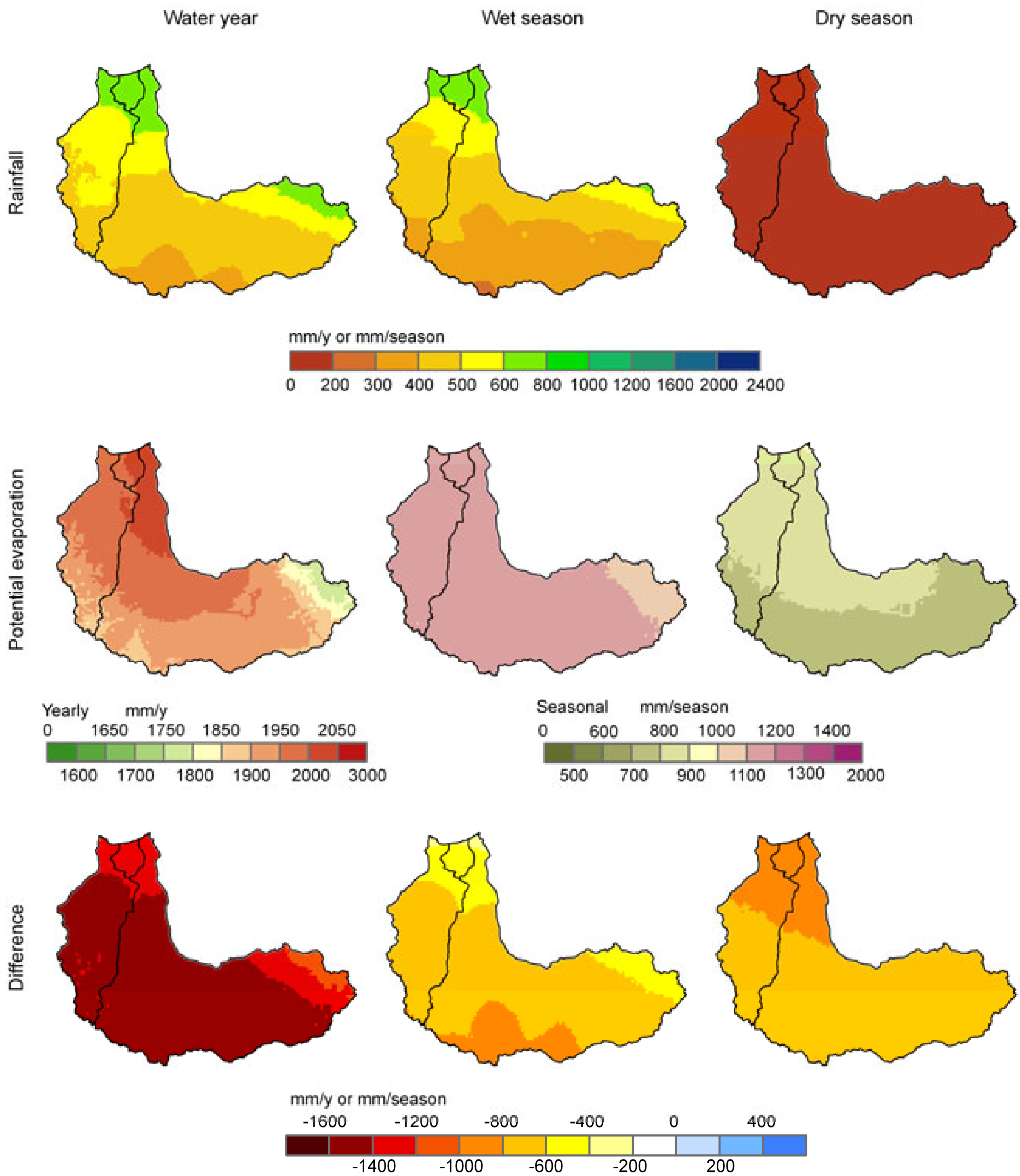


Figure FL-20. Spatial distribution of historical mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration (potential evaporation) and their difference (rainfall less areal potential evapotranspiration) across the Flinders-Leichhardt region

### FL-3.1.2 Recent climate

Figure FL-21 compares recent (1996 to 2007) to historical (in this case the 66-year period 1930 to 1996) mean annual rainfall for the Flinders-Leichhardt region. Across most of the region, rainfall has changed little between the historical and recent periods. Recent rainfall is between zero and 20 percent higher generally across the region; however, larger increases have occurred in the west of the region and only in these areas are the differences statistically significant.

 

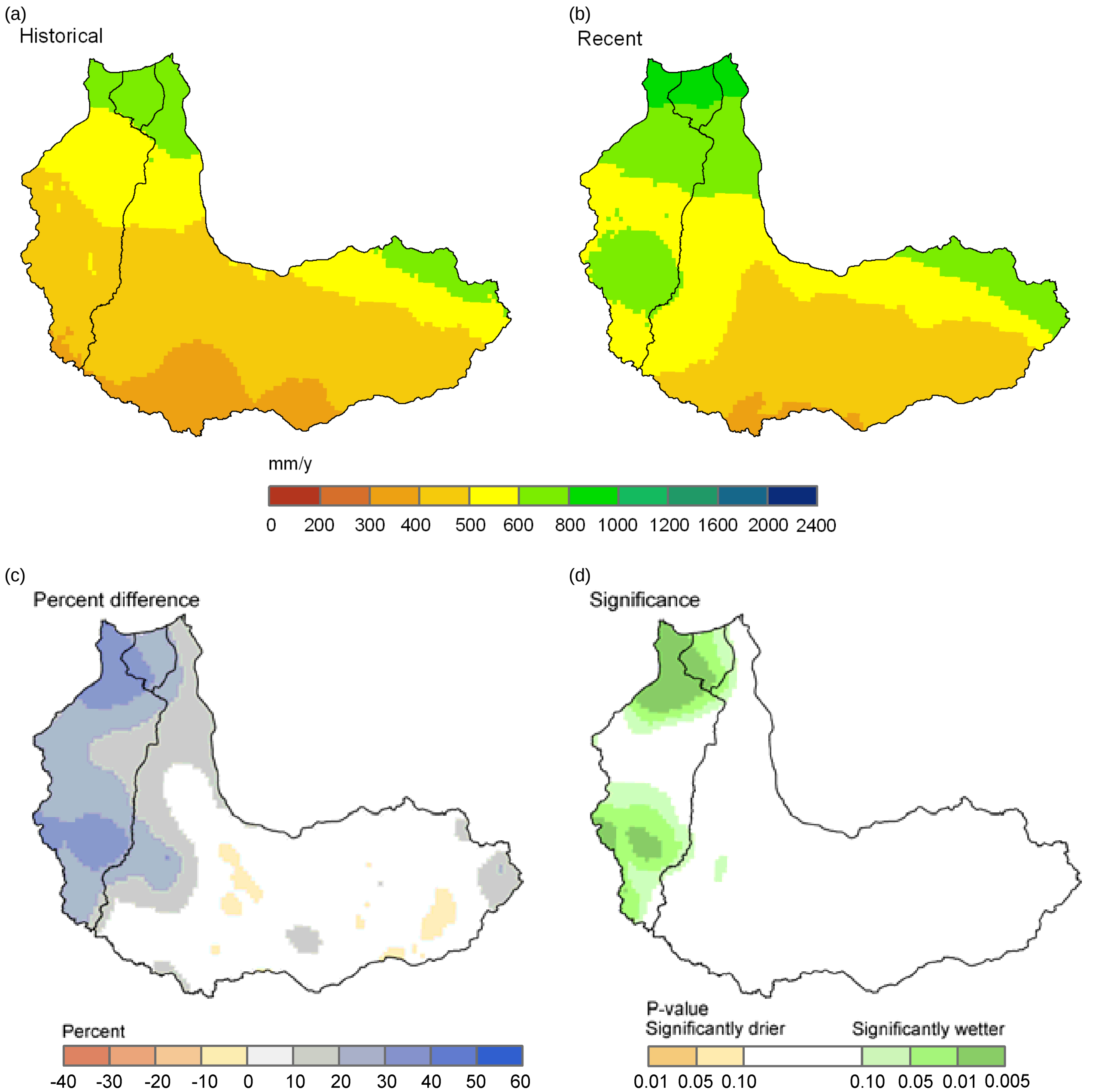


Figure FL-21. Spatial distribution of (a) historical and (b) recent mean annual rainfall; and (c) their relative percent difference and (d) the statistical significance of these differences across the Flinders-Leichhardt region. (Note that historical in this case is the 66-year period 1930 to 1996)

### FL-3.1.3 Future climate

Under Scenario C annual rainfall varies between 456 and 547 mm (Table FL-5) compared to the historical mean of 493 mm. Similarly APET ranges between 1993 and 2038 mm compared to the historical mean of 1939 mm.

A total of 45 variants of Scenario C were modelled (15 GCMs for each of the high, medium and low global warming scenarios). Subsequently, results from an extreme 'wet', median and extreme 'dry' variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet annual rainfall and APET increase by 11 percent and 3 percent, respectively. Under Scenario Cmid annual rainfall is the same as the historical mean and APET increases by 3 percent. Under Scenario Cdry annual rainfall decreases by 8 percent and APET increases by 5 percent.

Under Scenario Cmid long-term monthly averages of rainfall and APET do not differ much from historical values (Figure FL-22). The historical mean rainfall lies well within the predicted range in values from all 45 future climate variants. The seasonality of rainfall and APET are not expected to change substantially. The historical mean APET lies at the lower end of the range in values expected under Scenario C.

The spatial distributions of rainfall and APET under Scenario C are compared to the historical distribution in Figure FL-23 and Figure FL-24. Under Scenario C the strong north–south gradient in rainfall is retained, but with a southwards shift under Scenario Cwet and a northwards shift under Scenario Cdry. The spatial distribution of APET under Scenario C is similar to the highly regionalised historical distribution. The greatest changes to APET occur in the north of the region.

Table FL-5. Mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration in the Flinders-Leichhardt region under historical climate and Scenario C

| | Water year* | Wet season | Dry season |
|---|---|---|---|
| | mm/y | mm/season | |
| Rainfall | | | |
| Historical | 493 | 437 | 56 |
| Cwet | 547 | 481 | 59 |
| Cmid | 492 | 432 | 54 |
| Cdry | 456 | 398 | 51 |
| Areal potential evapotranspiration | | | |
| Historical | 1939 | 1134 | 805 |
| Cwet | 1993 | 1160 | 828 |
| Cmid | 1994 | 1159 | 830 |
| Cdry | 2038 | 1186 | 847 |

* Note that the sum of the wet season and dry season values does not always equal the water year values because the combined wet season and dry season period (November to October) is different to the water year period (September to August).

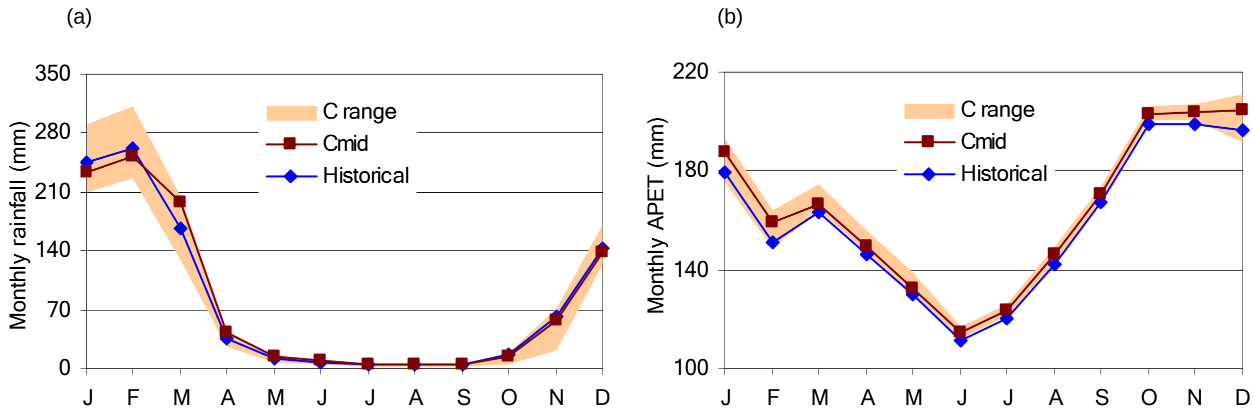


Figure FL-22. Mean monthly (a) rainfall and (b) areal potential evapotranspiration across the Flinders-Leichhardt region under historical climate and Scenario C (C range is the range in potential evapotranspiration pooled from all GCM outputs from all three emission scenarios – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

### FL-3.1.4 Confidence levels

Analysis of confidence of the climate data is presented in Section 2.1.4 of the division-level Chapter 2.

 

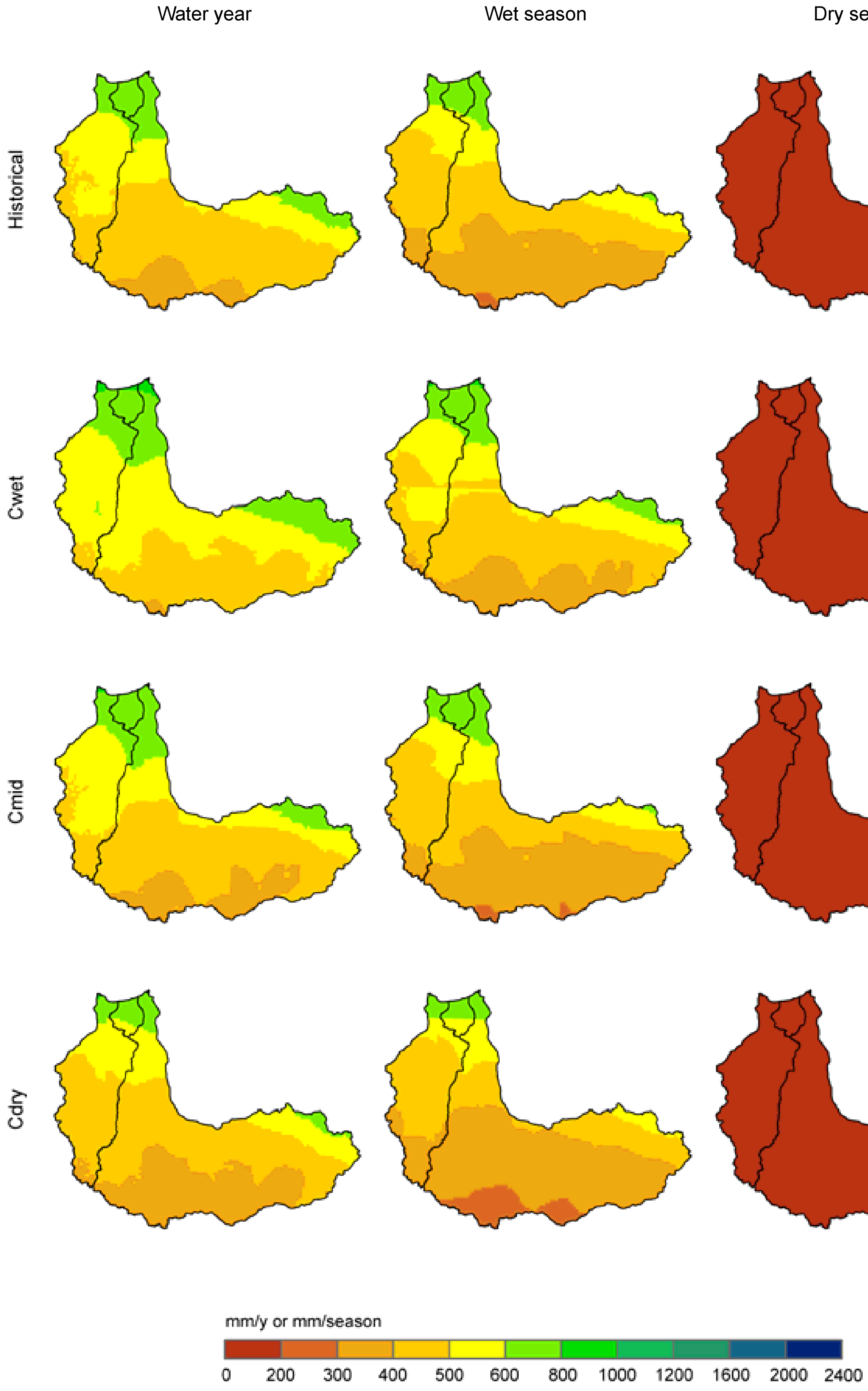


Figure FL-23. Spatial distribution of mean annual (water year), wet season and dry season rainfall across the Flinders-Leichhardt region under historical climate and Scenario C

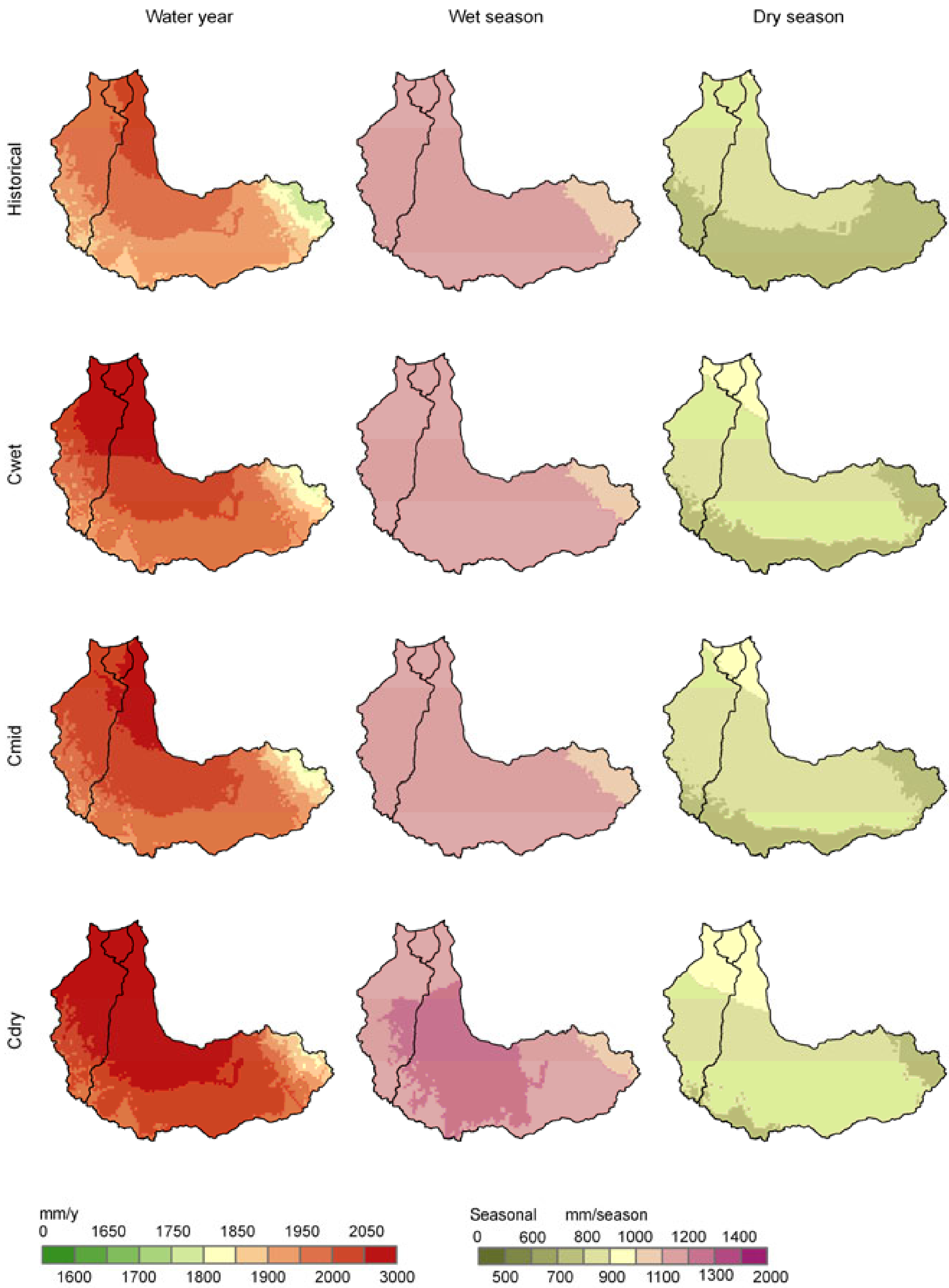


Figure FL-24. Spatial distribution of mean annual (water year), wet season and dry season areal potential evapotranspiration across the Flinders-Leichhardt region under historical climate and Scenario C

 

## FL-3.2 WAVES potential diffuse recharge estimations

The WAVES model (Zhang and Dawes, 1998) is used to estimate the change in groundwater recharge across the Flinders-Leichhardt region under a range of different historical and future climate scenarios. WAVES is a vertical recharge flux model that can model plant physiological feedbacks in response to increased $CO_2$, as well as modelling the water balance based on different soil, vegetation and climate regimes. This model has been chosen for its balance in complexity between plant physiology and soil physics. This model was also chosen to assess recharge for the Murray-Darling Basin Sustainable Yields project (Crosbie et al., 2008).

### FL-3.2.1 Under historical climate

The historical recharge in the Flinders-Leichhardt region is comparatively low (areal average 19 mm/year) compared to the other regions studied within the Northern Australia Sustainable Yields Project. Recharge is lowest on vertosol soils located near the river and highest in the far-east and west of the region where the soils are coarser in texture (Figure FL-25). The historical record was assessed to establish any difference between wet and dry periods of recharge. We used a 23-year period, which allows us to project recharge estimates to 2030, and hence provide a 2030 variant assuming similar conditions to the historical past (Scenario A). For the three variants of Scenario A the mean annual recharge does change for a 23-year period when compared to the 77-year long-term mean value. For the recharge that is exceeded in 10 percent of 23-year periods (Awet), recharge is (on average) 10 percent greater than the 77-year average: a recharge scaling factor (RSF) of 1.10. For the recharge that is exceeded in 50 percent of 23-year periods (Amid), recharge is on average 2 percent lower than the 77-year average (RSF=0.98). For the recharge that is exceeded in 90 percent of 23-year periods (Adry), recharge is on average 13 percent lower than the 77-year average (RSF=0.87) (Table FL-6).

Table FL-6. Recharge scaling factors in the Flinders-Leichhardt region for scenarios A, B and C

| Region | Awet | Amid | Adry | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| Flinders-Leichhardt | 1.10 | 0.98 | 0.87 | 1.04 | 1.32 | 1.02 | 0.88 |

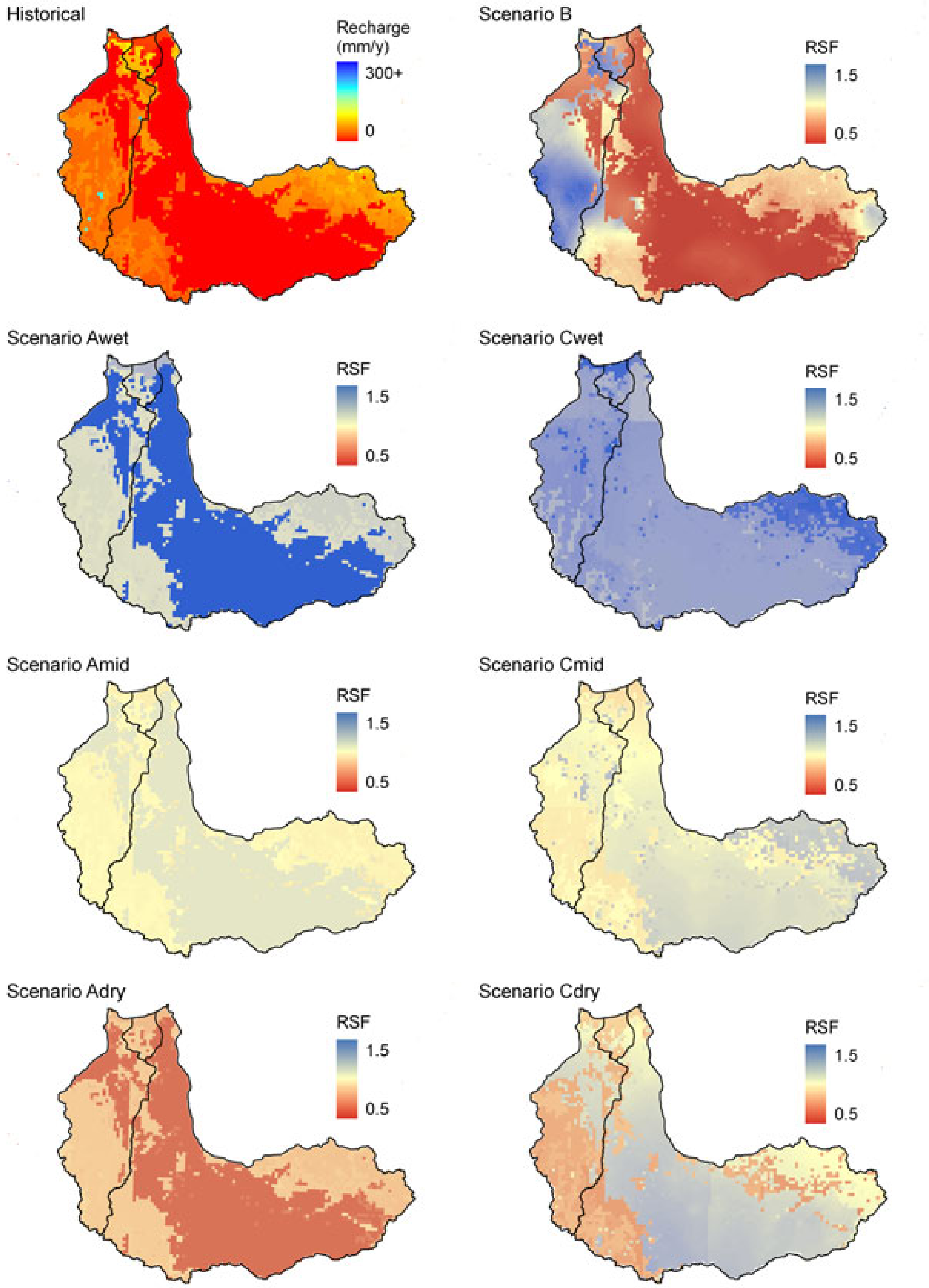


Figure FL-25. Spatial distribution of historical mean recharge rate; and recharge scaling factors in the Flinders-Leichhardt region under scenarios A, B and C

### FL-3.2.2 Under recent climate

The years 1996 to 2007 in the Flinders-Leichhardt region have, on average, seen an increase of 4 percent in recharge when compared to the average of the historical (1930 to 2007) period (Table FL-7). This increase is not spatially uniform

 

(Figure FL-25) with the centre of the region actually showing a decrease in recharge where vertosol soils exist. These areas, however, have very low intrinsic recharge (Figure FL-25).

### FL-3.2.3 Under future climate

Figure FL-26 shows the percentage change in modelled mean annual recharge averaged over the Flinders-Leichhardt region for Scenario C relative to Scenario A for the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The percentage change in the mean annual rainfall and recharge from the corresponding GCMs are also tabulated in Table FL-7. In some scenarios the recharge is projected to increase despite a decrease in rainfall. This is because total rainfall is not the only climate variable that has an influence over recharge, Daily rainfall intensity, temperature and $CO_2$ concentration are also important drivers (see Section 2.3.3 in the division-level Chapter 2), and specific situations can result in this counter-intuitive result. In particular, rainfall intensity is seen as a significant factor in this relationship.

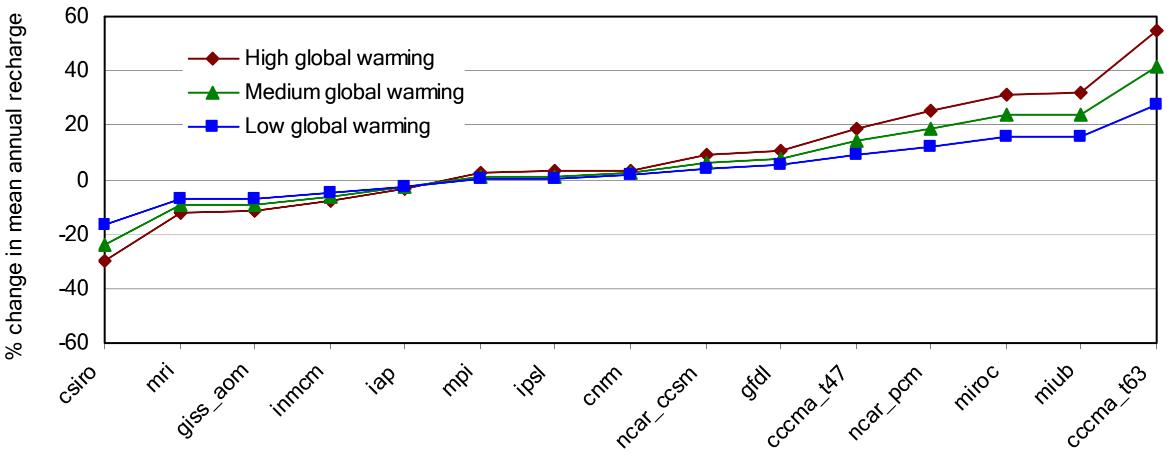


Figure FL-26. Percentage change in mean annual recharge under the 45 Scenario C simulations (15 GCMs and three global warming scenarios relative to Scenario A recharge

Table FL-7. Summary results under 45 Scenario C simulations (numbers show percentage change in mean annual rainfall and recharge under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Recharge | GCM | Rainfall | Recharge | GCM | Rainfall | Recharge |
| csiro | -22% | -30% | csiro | -17% | -24% | csiro | -12% | -17% |
| **mri** | **-8%** | **-12%** | mri | -6% | -9% | mri | -4% | -7% |
| giss_aom | -8% | -11% | giss_aom | -6% | -9% | giss_aom | -4% | -7% |
| inmcm | -3% | -8% | inmcm | -2% | -7% | inmcm | -2% | -5% |
| iap | -5% | -4% | iap | -4% | -3% | iap | -2% | -2% |
| mpi | -3% | 2% | mpi | -3% | 1% | mpi | -2% | 1% |
| ipsl | 1% | 3% | ipsl | 1% | 1% | ipsl | 0% | 0% |
| cnrm | -4% | 3% | **cnrm** | **-3%** | **2%** | cnrm | -2% | 2% |
| ncar_ccsm | 1% | 9% | ncar_ccsm | 1% | 6% | ncar_ccsm | 1% | 4% |
| gfdl | -1% | 10% | gfdl | 0% | 8% | gfdl | 0% | 6% |
| cccma_t47 | 3% | 19% | cccma_t47 | 2% | 14% | cccma_t47 | 2% | 9% |
| ncar_pcm | 8% | 25% | ncar_pcm | 6% | 19% | ncar_pcm | 4% | 12% |
| miroc | 11% | 32% | miroc | 8% | 24% | miroc | 6% | 16% |
| **miub** | **8%** | **32%** | miub | 7% | 24% | miub | 5% | 16% |
| cccma_t63 | 12% | 55% | cccma_t63 | 9% | 41% | cccma_t63 | 6% | 28% |

Under an extreme wet future climate (Scenario Cwet) the Flinders-Leichhardt region is calculated, on average, to have an increase in recharge of 32 percent (Table FL-7), with the greatest increase in the east of the region. Under the modelled median estimate of future climate (Scenario Cmid) the region is calculated to have, on average, an increase in recharge of 2 percent, again with the greatest increase in the east of the region. Under an extreme dry future climate (Scenario Cdry) the region is calculated to have an overall decrease in recharge of 12 percent, but a slight increase in recharge across the vertosol soils in the centre of the region.

### FL-3.2.4 Confidence levels

The estimation of potential diffuse recharge from WAVES, as done here, is only indicative of the actual recharge and has not been validated with field measurements. A steady state groundwater chloride mass balance was conducted as an independent measure of recharge (Crosbie et al., 2009). The results in the Flinders-Leichhardt region show that the historical estimate of potential diffuse recharge using WAVES (19 mm/year) is within the range of estimates made using the chloride mass balance (1 to 93 mm/year). The WAVES estimate is very similar to the best estimate using the chloride mass balance (15 mm/year).

## FL-3.3 Conceptual groundwater models

### FL-3.3.1 Great Artesian Basin aquifers

The Great Artesian Basin (GAB) is a multi-layered, mostly confined aquifer system, with aquifers occurring in sandstones and confining beds consisting of mudstone and siltstone. The confining beds retard flow but do not prevent flow of water to or from adjacent aquifers. The upper confining beds of the Rolling Downs Group (see Figure FL-2 for location) range in thickness from being absent (where they abut the Mount Isa Block and where they are eroded off the top of the main aquifers in the east of the area), to around 700 m across the Flinders-Leichhardt region.

The Gilbert River Formation (see Figure FL-2 for location) is the dominant GAB aquifer in the Flinders-Leichhardt region, as it is the shallowest artesian aquifer and contains good quality groundwater. This formation occurs at various depths across the region from outcropping in the east where tributaries of the Flinders River intersect Gilbert River Formation sediments, to within 175 m of ground surface at the foothills of the Mount Isa Block in the west, and up to around 700 m below ground surface towards the centre of the region.

Recharge to the GAB aquifers mainly occurs via the infiltration of rainfall into outcropping areas of sandstone along the elevated eastern margins of the basin (commonly referred to as ‘recharge beds’ or ‘intake beds’) and by vertical leakage through unconsolidated sediments overlying the aquifers.

Groundwater movement is from the recharge areas in the east of the region to the major spring areas and to the Gulf of Carpentaria, however, the significance of this form of discharge to the Gulf is not well known.

### FL-3.3.2 Other aquifers

Overlying the GAB sediments is a duricrust (a hard layer of indurated sediments) that forms an aquitard up to 10 m thick and present in outcrop, particularly on the Donors Plateau and the Canobie Depression. Extensive floodplain deposits of the Flinders and Leichhardt Rivers dominate the surface geology of this region and have an approximate combined thickness of 45 m. The young valley fill deposits associated with the Flinders and Leichhardt rivers have a maximum thickness of approximately 25 m.

The valley fill alluvium relies on wet season high-stage river flows for recharge, either in the form of lateral inflow through incised beds, or vertical infiltration beneath the floodplain when the river floods (Cochrane, 1967; SKM, 1993). To a lesser degree these aquifers are recharged via vertical infiltration of rainfall. The alluvial aquifers distal from the main river channels rely more heavily on rainfall recharge, because they receive negligible river recharge. The alluvial aquifers are also considered to receive upward recharge from the underlying GAB aquifers, particularly along the eastern margin of the region, where confining beds are thin and hydraulic pressure is high.

 

Upper reaches of the Flinders River and its tributaries receive baseflow contributions from the GAB aquifers. In these parts of the Flinders River catchment, surface water flows are likely to extend into the dry season (May to October) as they are being fed by groundwater discharge.

### FL-3.3.3 Baseflow index analysis

The results of the baseflow analysis for suitable gauges in the Flinders-Leichhardt region are provided in Table FL-1. The annual baseflow index (BFI) values range from 0.04 to 0.17 (n=13). Figure FL-2 shows the surface geology of the Flinders-Leichhardt region and the average volume of dry season baseflow to rivers. This indicates that the volume of dry season baseflow is small in this region and is less than 1 GL/year for the majority of rivers. The most significant recorded groundwater contribution occurs in the lower reaches of the Flinders River at stream gauge 915003A, where dry season baseflow ranges from 1 to 5 GL/year.

## FL-3.4 Groundwater modelling results

### FL-3.4.1 Historical groundwater balance

In order to determine the relative importance of the various hydrogeological processes occurring in the Flinders-Leichhardt region, a groundwater balance is calculated for each of the dominant aquifer systems; namely the Quaternary alluvial aquifers and the Gilbert River Formation of the GAB (Table FL-8). The alluvial aquifers include the Quaternary clay, silt and sand of the Armraynald and Wonoola Beds and the river valley alluvium. A detailed breakdown of each component of the water balance for each aquifer in both wet and dry seasons is provided in Table FL-8. The total sums of all inputs and outputs are then summarised in Table FL-9. Detailed methods of this water balance are presented in Harrington et al. (2009).

Table FL-8. Groundwater inputs and outputs for the aquifers in the Flinders-Leichhardt region

| | Rainfall recharge | | River recharge / groundwater discharge | | Evapo transpiration (actual) | | Vertical leakage | | Throughflow | | Discharge to springs | | Groundwater extraction | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm* | GL* | mm* | GL* | mm* | GL* | mm* | GL* | mm* | GL* | mm* | GL* | mm* | GL* |
| Alluvial aquifers | | | | | | | | | | | | | | |
| Wet season | 19.0 | 1793.5 | 3.1 | 290.4 | -15.0 | -1415.9 | 0.0 | 2.5 | -0.0 | -1.1 | NA | NA | -0.0 | -0.1 |
| Dry season | 0.0 | 0.0 | -2.5 | -232.3 | -5.0 | -472.0 | 0.0 | 2.5 | -0.0 | -0.6 | NA | NA | -0.0 | -0.4 |
| Gilbert River Formation (GAB) | | | | | | | | | | | | | | |
| Wet season | 25.0 | 375.0 | 0.0 | 43.3 | -18.0 | -270.0 | -0.0 | -3.1 | -0.0 | -3.7 | -0.0 | -2.3 | -0.2 | -17.6 |
| Dry season | 0.0 | 0.0 | -0.0 | -43.3 | -5.0 | -75.0 | -0.0 | -3.1 | -0.0 | -2.9 | -0.0 | -2.3 | -0.5 | -52.8 |

* Values are totals for the entire wet or dry season, i.e. mm/6 months, GL/6 months.
NA = not available.

Table FL-9. Summary of groundwater inputs and outputs for the aquifers in the Flinders-Leichhardt region

| | Inputs | Outputs | Difference |
|---|---|---|---|
| | GL/y | | percent |
| Alluvial aquifers | | | |
| Wet season | 2086.4 | 1417.1 | |
| Dry season | 2.5 | 705.3 | |
| **Total** | 2088.9 | 2122.4 | **-2%** |
| Gilbert River Formation (GAB) | | | |
| Wet season | 418.3 | 296.7 | |
| Dry season | 0 | 179.4 | |
| **Total** | 418.3 | 476.1 | -14% |

Table FL-8 and Table FL-9 demonstrate that for both the Flinders-Leichhardt Alluvium and Gilbert River Formation, the dominant groundwater processes in the Flinders-Leichhardt region are diffuse recharge via rainfall; discharge via evapotranspiration; and river discharge and recharge.

It should be noted that this assessment is a Tier 4 water balance, based on very limited datasets and no field testing. Accordingly, the results should only be used for conceptualisation of the groundwater systems, and not for water allocation planning.

### FL-3.4.2 Surface–groundwater interaction

The total volume of allocations issued on existing groundwater licences in the Flinders-Leichhardt region amounts to about 13.4 GL/year (Table FL-3). More than 90 percent of this volume is associated with allocations from the sandstone aquifers of the GAB, while the remaining volume is distributed across other aquifer types in the region.

In this section, the impact of groundwater extractions on surface water yields is considered; the ‘impact’ is to stream depletion whereby pumped groundwater eventually is sourced from a nearby river. Figure FL-27 shows the locations of the existing groundwater licences and their proximity to the river network. The distance between a groundwater pump and a nearby river greatly affects the time before river water is drawn into the aquifer towards the pump.

#### Groundwater development in the alluvium

The total volume of existing groundwater allocations from the Quaternary alluvium of the Flinders-Leichhardt region is 0.436 GL/year (Table FL-3). The locations for all of these allocations are in close vicinity of rivers. Thus, the impacts of groundwater extraction of on river flows would have already been realised.

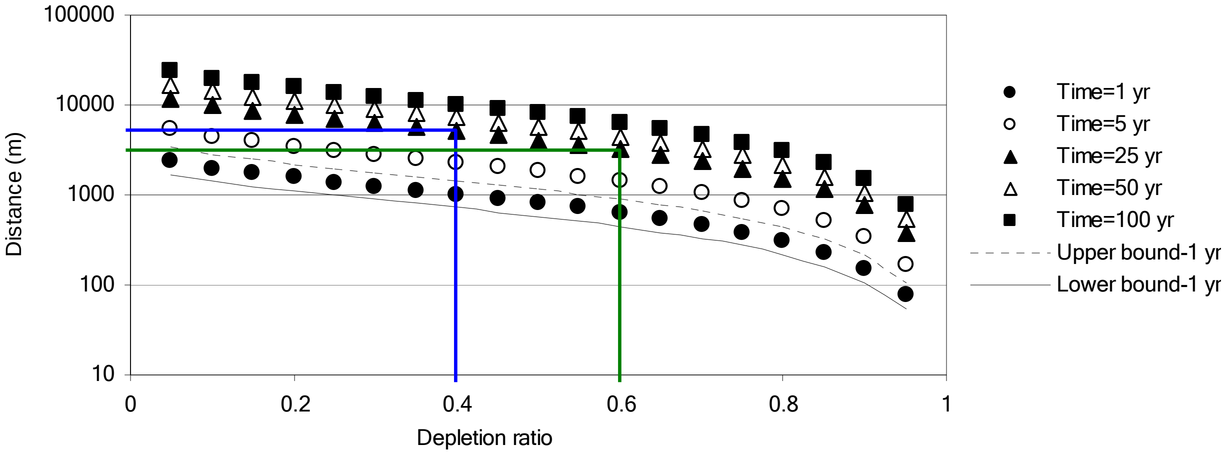


Figure FL-27. Impact of hypothetical scenarios in an unconfined aquifer on stream depletion



 

The impacts of current groundwater development on river flows in the Flinders-Leichhardt region is marginal. If however the level of groundwater development for the alluvial aquifers increases then the impacts will likely increase. Figure FL-27 shows results of stream depletion calculations for hypothetical scenarios in the alluvium to provide some insight into the potential future impacts of further development. This analysis assumed an aquifer transmissivity of 400 $m^2$/day and specific yield of 0.2.

Figure FL-27 can be used as a management tool in two different ways:

- locating bores to minimise stream depletion. For example, if a proponent wanted to pump groundwater at 0.01 GL/day and was not allowed to deplete the river by more than 0.004 GL/day (i.e. depletion ratio = 0.4) on any occasion during the next 25 years, the pumping bores would need to be located no closer than 5 km from the river (see blue lines in Figure FL-27).
- determining maximum groundwater pumping rates at specified distances from the stream. For example, if a proponent wanted to pump groundwater from a bore located 3 km from a river and was not permitted to deplete the river by more than 0.004 GL /day on any occasion during the next 25 years, the corresponding depletion ratio would be 0.6 (see green lines in Figure FL-27) and the maximum pumping rate becomes 0.004/0.6 = 0.007 GL/day.

There is great uncertainty in estimating representative aquifer parameters for this analysis. One can define upper and lower limits for this uncertainty and hence estimate corresponding upper and lower bounds for impacts. The example shown in Figure FL-27 represents the likely impacts (after 1 year) for a 100 percent uncertainty in aquifer transmissivity.

Any new groundwater developments in the alluvial aquifer should ideally be located as far as possible from rivers to minimise the short-term (seasonal) impacts of pumping, which can potentially reduce streamflow during the dry season. Locating developments away from the river causes the impacts to be delayed, depleting the aquifer rather than the river. However groundwater developments tapping alluvium near to key recharge sources such as rivers are often more reliable - the real key is the overall quantity of water captured from the river and the timing of this. For example, major wet season flows are likely to provide the majority of recharge to an alluvial aquifer system in this area and for the rest of the time the impact of groundwater pumping on streamflow may be relatively insignificant.

### Groundwater development outside the alluvium

The total volume of existing groundwater allocations for deeper Cainozoic sediments, Tertiary basalts and GAB aquifers in the Flinders-Leichhardt region amounts to about 12.3 GL/year. Using the distances of the nearest rivers from these existing groundwater developments, the impact of groundwater pumping (at rates equivalent to the full allocation) on surface flow in each river is estimated. The results of this exercise are shown in Table FL-10 and are based on several basic assumptions about the type of interaction between the deep (largely confined) aquifers and the nearby rivers. It should be noted however that many of the groundwater allocations are from deep, mostly confined aquifers where there is likely to be no direct interaction with rivers.

Table FL-10. Impact of groundwater development in deep aquifers on stream depletion in the Flinders-Leichhardt region

| River | Allocation | Level of short-term impact ** |
|---|---|---|
| | GL/y | |
| Flinders River* | 5.12 | 1 |
| Express Creek* | 0.98 | 7 |
| Julia Creek* | 0.787 | 2 |
| Rupert Creek* | 0.49 | 8 |
| Cloncurry River* | 0.428 | 4 |
| Alexander Creek* | 0.37 | 9 |
| Mailman Creek* | 0.36 | 5 |
| Giddery Creek | 0.33 | 3 |
| O'Connell Creek* | 0.242 | 11 |
| Leichhardt River* | 0.1716 | 6 |
| Warianna Creek* | 0.165 | 12 |
| McKinlay River | 0.15 | 10 |
| Betts Gorge Creek | 0.12 | 13 |
| Eastern Creek | 0.12 | 14 |
| Gunpowder Creek* | 0.112 | 31 |
| Corella Creek | 0.11 | 18 |
| Middle Branch Creek | 0.1 | 15 |
| Middle Creek | 0.1 | 17 |
| Hamilton Creek | 0.1 | 22 |
| Stawell River | 0.06 | 21 |
| Walker Creek | 0.05 | 25 |
| Saxby River | 0.048 | 24 |
| Stewart Creek | 0.04 | 19 |
| Rocky Creek | 0.04 | 23 |
| Malbon River | 0.04 | 26 |
| Galah Creek | 0.032 | 16 |
| Sloane/Western Creek | 0.024 | 20 |
| Williams River* | 0.019 | 28 |
| Alick Creek | 0.006 | 27 |
| Gilliat River | 0.002 | 29 |
| Alexandra River | 0.002 | 30 |

* Have multiple licences

** 1 is highest impact; 31 is lowest impact.

A comparative analysis of short-term (up to 10 years) and long-term (up to 100 years) impacts of groundwater development in confined aquifers on stream depletion (Table FL-10) revealed the Flinders River has the highest theoretical impact from existing developments in the region, both in the short and long term. This is primarily due to the high allocation volumes located close to the river. Again, it should be noted that many assumptions were made in regard to river-groundwater connections for this analysis and, in reality, the risk is minimal in most cases. Express and Rupert creeks are two examples where the long-term impact becomes higher than the short-term impact – this is due to the allocations being located at a large distance from the river (relative to others). This theoretical analysis identifies priority areas for future groundwater management.

 

## FL-3.5 Rainfall-runoff modelling results

In this section the term runoff is the sum of overland flow, interflow and baseflow. It is equivalent to streamflow expressed as a mm depth equivalent. All plots show data averaged over the modelled subcatchments of the Flinders-Leichhardt region. For this reason rainfall reported in this section may vary slightly from that reported elsewhere due to differences between the catchment boundaries (shown in Figure FL-1) and the DEM-derived catchment boundaries used here. In this section, where annual data are reported years are represented by numbers 1 through 77. Consistently throughout this report, annual data are based on the water year (1 September to 31 August) and the dry season is defined as 1 May to 31 October. Unless stated otherwise scenarios Cwet, Cmid and Cdry are selected on the basis of the ranked mean annual runoff. For more details on methods refer to Section 2.2 of the division-level Chapter 2.

### FL-3.5.1 Regional synopsis

The rainfall-runoff modelling estimates runoff in 0.05 degree grid cells in 52 subcatchments (Figure FL-28). Optimised parameter values from ten calibration catchments are used. Six of these calibration catchments are in the Flinders catchment, and two are in the Leichhardt catchment. The remaining calibration catchments are in the South-East Gulf region to the north of the headwaters of the Flinders catchment, one of which is shown in Figure FL-28. The calibration catchments are predominantly located in the headwater areas.

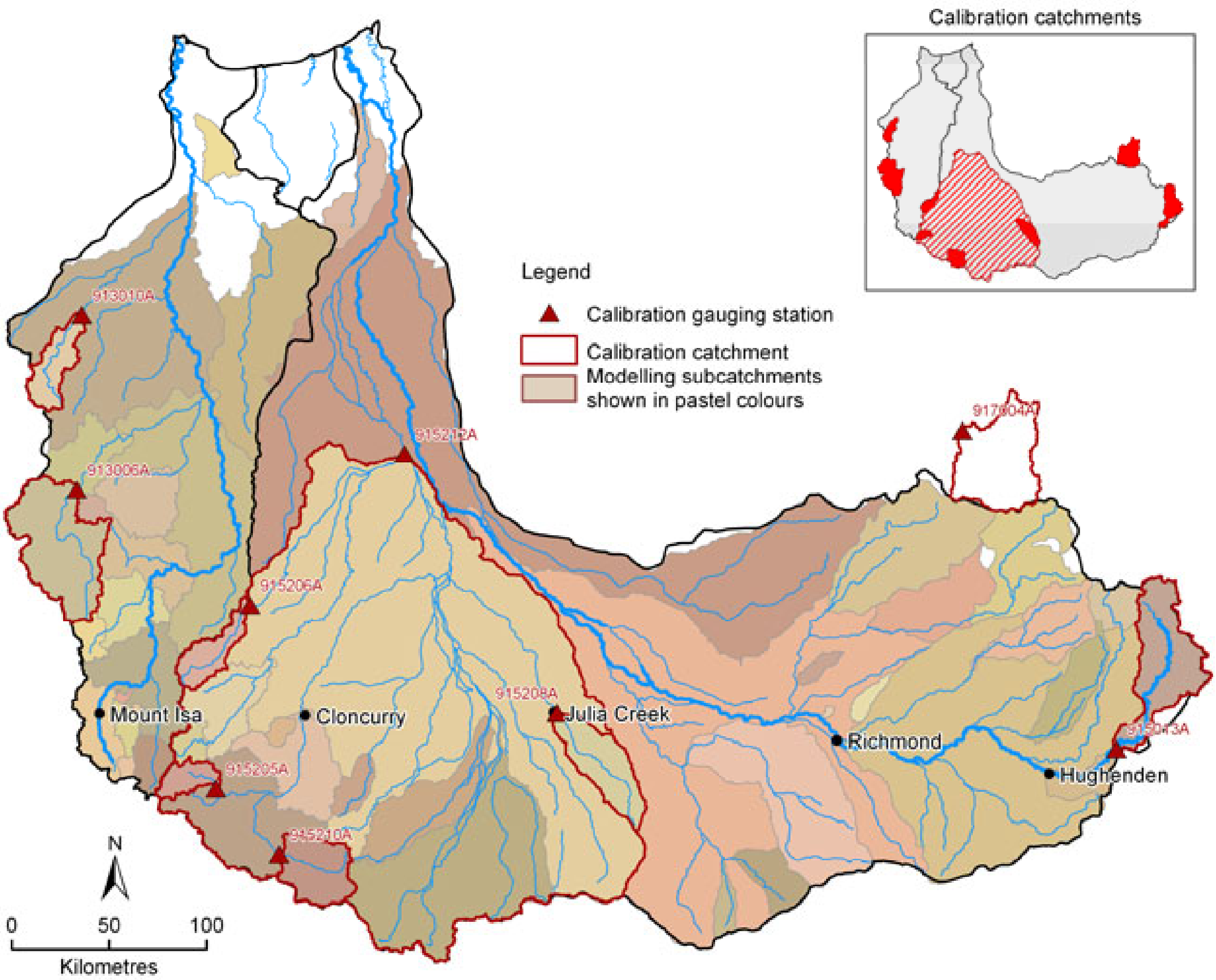


Figure FL-28. Map of the modelling subcatchments, calibration catchments and calibration gauging stations used for the Flinders-Leichhardt region with inset highlighting (in red) the extent of the calibration catchments

### FL-3.5.2 Model calibration

Figure FL-29 compares the modelled and observed monthly runoff and the modelled and observed daily flow exceedance curves for the ten calibration catchments. Nash-Sutcliffe efficiency (NSE) values provide a quantitative measure of how well simulated values match observed values. NSE is described in more detail in Section 2.2.3 of the division-level Chapter 2. On the monthly plots NSE is the monthly Nash-Sutcliffe efficiency value and NSE (dry season) is the dry season monthly Nash-Sutcliffe efficiency value. On the daily flow exceedance plots, NSE is the daily flow exceedance curve Nash-Sutcliffe efficiency value and NSE (50 to 100 percent) is the lower half of the daily flow exceedance curve Nash-Sutcliffe efficiency value.

The results indicate that the ensemble calibration of the rainfall-runoff models Sacramento and IhacresClassic does well at reproducing the observed monthly runoff series (monthly NSE values generally greater than 0.75) and the daily flow exceedance curve (NSE values generally greater than 0.85). The volumetric constraint used in the model calibration also ensures that the total modelled runoff is within 5 percent of the total observed runoff.

The calibration method places more importance on the simulation of high runoff, and therefore rainfall-runoff modelling of the medium and high runoff is considerably better than the modelling of low runoff. This is demonstrated by the relatively low NSE values for the monthly dry season and lower half of the daily flow exceedance curve. It should be noted, however, that while the relative difference between the observed and simulated low flow values may be large (which is what gives rise to the low monthy dry season NSE values for example), the absolute difference between the observed and simulated low flow values is generally small because both values are small. Nevertheless, an optimisation to reduce overall error variance can result in some underestimation of high runoff and overestimation of low runoff. This is evident in some of the scatter plots comparing the modelled and observed monthly runoff and many of the daily flow exceedance curves. For the majority of calibration catchments the disagreement between the modelled and observed daily runoff curves is discernable for runoff that is exceeded less than 1 percent of the time. This is accentuated in the plots because of the linear scale on the y-axis and normal probability scale on the x-axis. In any case, the volumetric constraint used in the model calibration ensures that the total modelled runoff is always within 5 percent of the total observed runoff. As indicated by the relatively low NSE values for the lower half of the daily flow exceedance curve there may be considerable disagreement between observed and modelled low flow values (i.e. cease-to-flow).

Overall the monthly NSE values are considered sufficient for the general purposes of estimating long-term mean annual runoff. The runoff estimates for the Flinders-Leichhardt region are reasonable in the headwater catchments because there are many calibration catchments from which to estimate the model parameter values. There are, however, few gauges in the lower reaches. To model these low lying areas parameter values had to be adopted from the nearest headwater catchments.

 

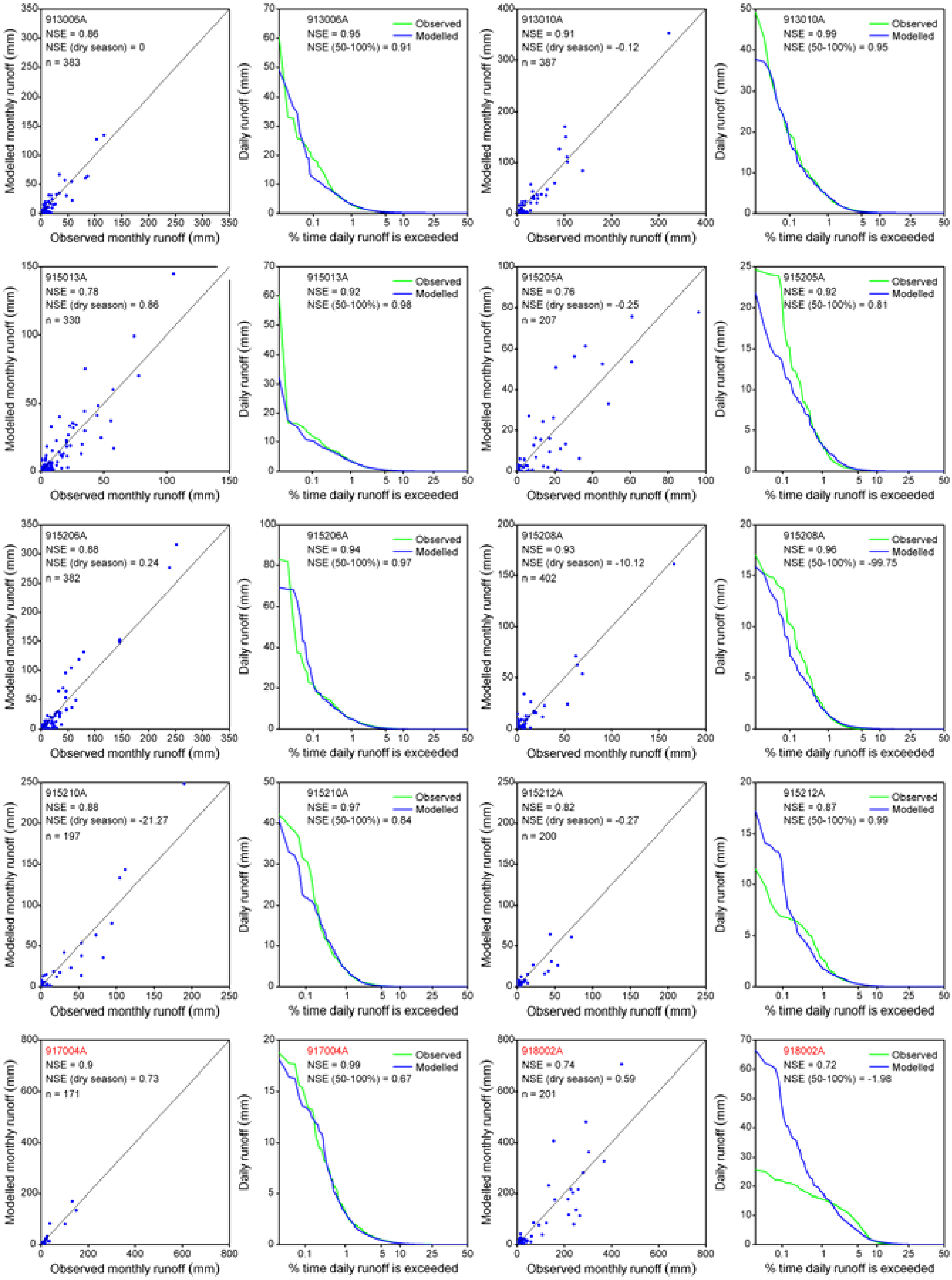


Figure FL-29. Modelled and observed monthly runoff and daily flow exceedance curve for each calibration catchment in the Flinders-Leichhardt region. (Red text denotes catchments located outside the region; blue text denotes catchments used to predict streamflow only)

### FL-3.5.3 Under historical climate

Figure FL-30 shows the spatial distribution of mean annual rainfall and runoff under Scenario A (averaged over 1930 to 2007) across the Flinders-Leichhardt region. Figure FL-31 shows the mean annual rainfall and runoff averaged over the region.

The mean annual rainfall and runoff averaged over the Flinders-Leichhardt region are 495 mm and 44 mm respectively. The mean wet season and dry season runoff averaged over the Flinders-Leichhardt region are 43 mm and 1 mm respectively.

In this project, all runoff grids are presented as long-term mean annual values. However the distributions of monthly and annual runoff data in northern Australia can be highly skewed, consequently the median and additional percentile values spatially averaged over the region are also reported. The 10th percentile, median and 90th percentile annual runoff values across the Flinders-Leichhardt region are 89, 22 and 3 mm respectively. The median wet season and dry season runoff averaged over the Flinders-Leichhardt region are 22 mm and zero mm respectively.

The mean annual rainfall varies from about 700 mm in the north to less than 300 mm in the south. The mean annual runoff varies from over 100 mm in the north to less than 10 mm in the south (Figure FL-30) and subcatchment runoff coefficients vary from 4 to 16 percent of rainfall. The majority of rainfall and runoff occurs during the wet season months December to April (Figure FL-32). Rainfall and runoff can vary considerably from year to year with long periods over several years or decades that are considerably wetter or drier than others (Figure FL-31). The coefficients of variation of annual rainfall and runoff averaged over the Flinders-Leichhardt region are 0.36 and 1.51 respectively.

(a) (b)

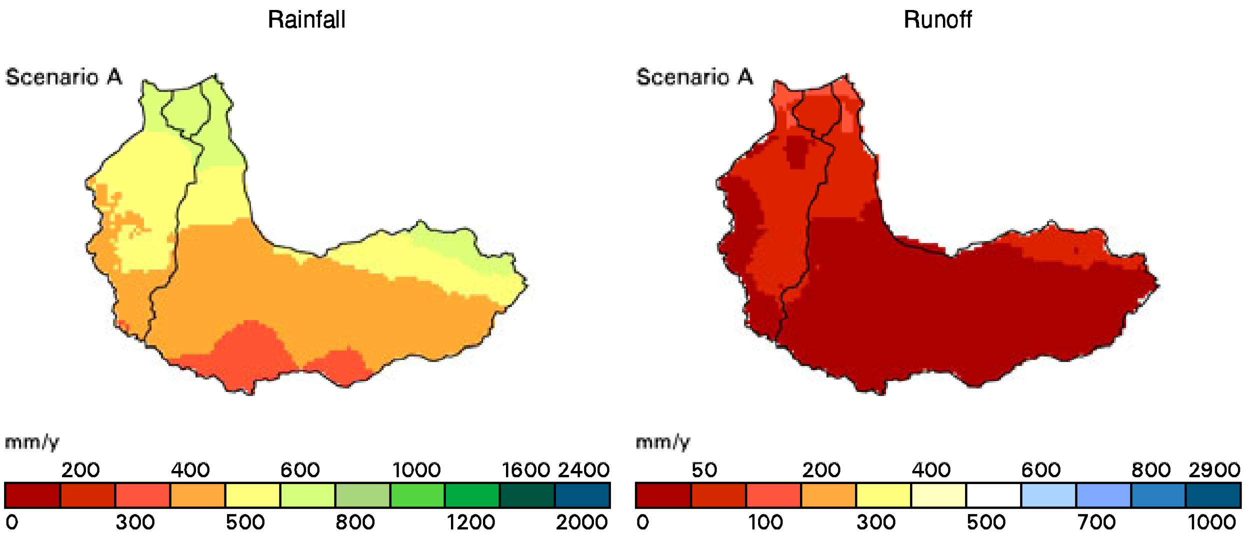


Figure FL-30. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the Flinders-Leichhardt region under Scenario A

The Flinders-Leichhardt is one of 13 regions which cover the three divisions studied in this project. Mean annual rainfall and runoff, as well as coefficients of variation, have been calculated for all of these 13 regions, and it is useful to compare the Flinders-Leichhardt results to results across all 13 regions. Across all 13 regions in this project 10th percentile, median and 90th percentile values are 1371, 936 and 595 mm respectively for mean annual rainfall and 374, 153 and 78 mm respectively for mean annual runoff. The mean annual rainfall (495 mm) and runoff (44 mm) averaged over the Flinders-Leichhardt region are the lowest of the 13 regions. Across all 13 regions in this project the 10th percentile, median and 90th percentile values are 0.34, 0.26 and 0.19 respectively for the coefficient of variation of annual rainfall and 1.39, 0.69 and 0.48 for the coefficient of variation of runoff. The coefficients of variation of annual rainfall (0.36) and runoff (1.51) averaged over the Flinders-Leichhardt region are the highest of the 13 reporting regions.

 

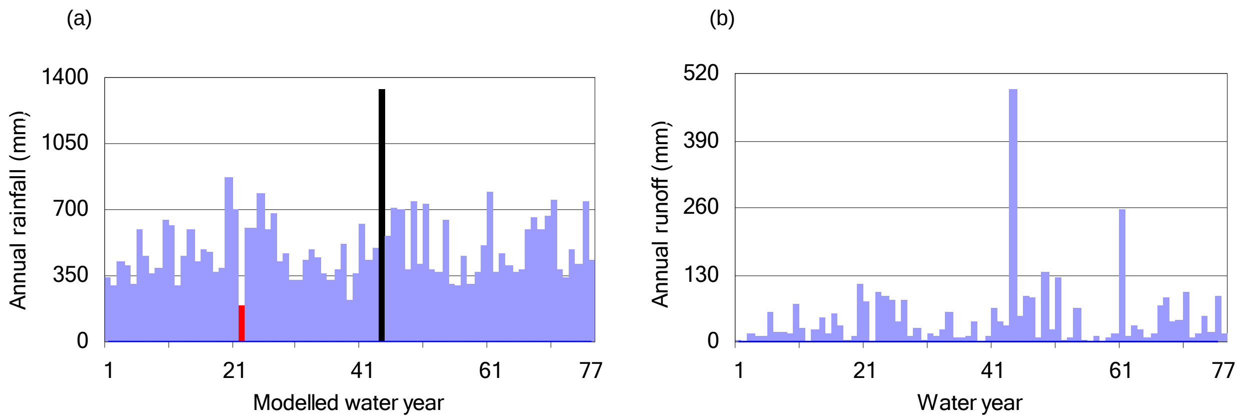


Figure FL-31. Annual (a) rainfall and (b) modelled runoff in the Flinders-Leichhardt region under Scenario A

The second largest annual runoff occurred in Year 61 and was twice that of the third largest runoff event (Figure FL-31). However the annual rainfall in Year 61 was comparable to the annual rainfall in at least ten years over the 77-year sequence. This illustrates that runoff in northern Australia can be largely dependent upon the timing and intensity of events.

Figure FL-32 (a and b) shows the minimum and maximum monthly rainfall and runoff and the range of values between the 25$^{th}$ and 75$^{th}$ percentile monthly rainfall and runoff. Figure FL-32 (c and d) shows the mean and median monthly flows and the range of values between the 25$^{th}$ and 75$^{th}$ percentile monthly rainfall and runoff. The large difference in the mean and median wet season monthly runoff values indicates that the distribution of monthly runoff in the Flinders-Leichhardt region is highly skewed.

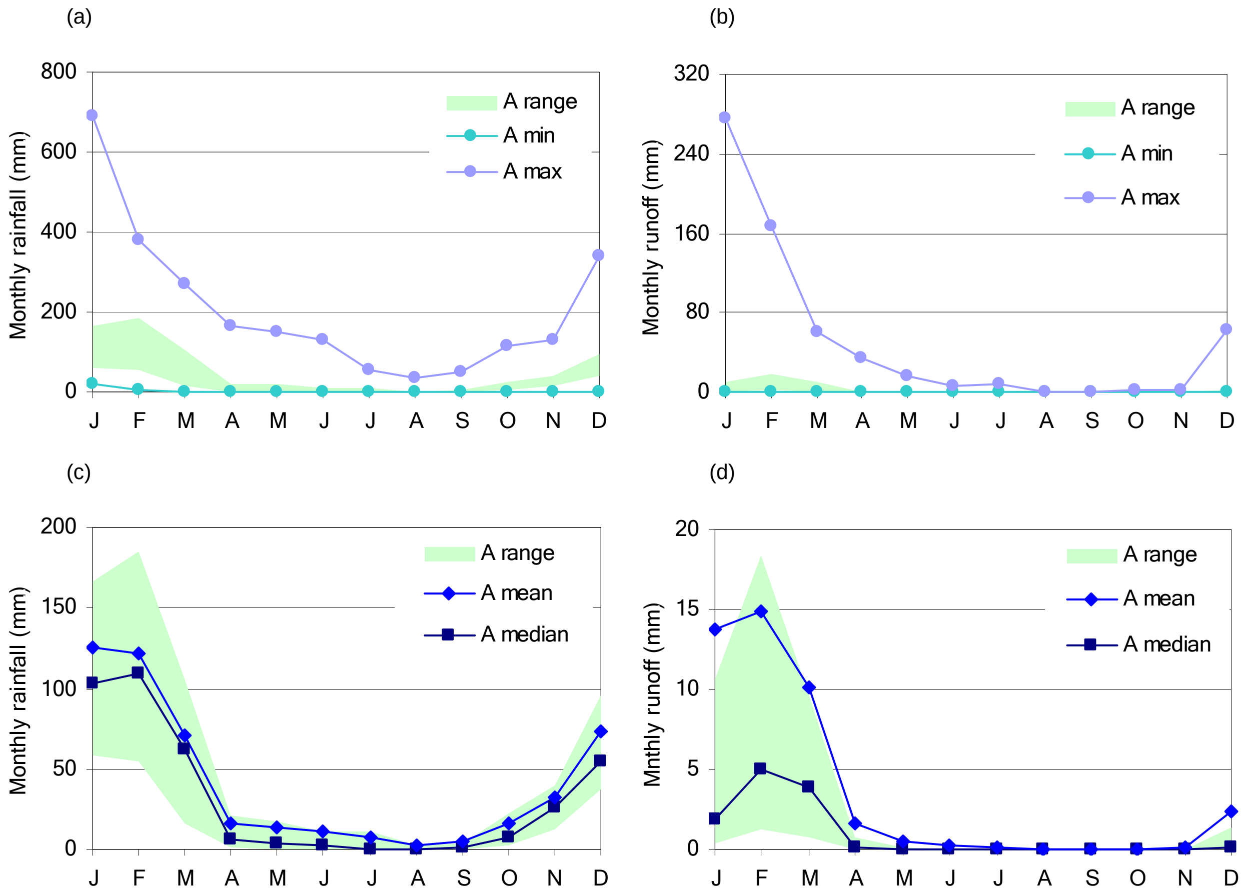


Figure FL-32. Minimum, maximum and A range monthly (a) rainfall and (b) modelled runoff; and mean, median and A range monthly (c) rainfall and (d) modelled runoff in the Flinders-Leichhardt region under Scenario A. (A range is the 25$^{th}$ to 75$^{th}$ percentile monthly rainfall or runoff)

### FL-3.5.4 Under recent climate

The mean annual rainfall and runoff under Scenario B (1996 to 2007) are 12 percent and 9 percent higher respectively than the historical (1930 to 2007) mean values. The spatial distribution of rainfall and runoff across the Flinders-Leichhardt region under Scenario B is shown in Figure FL-33.

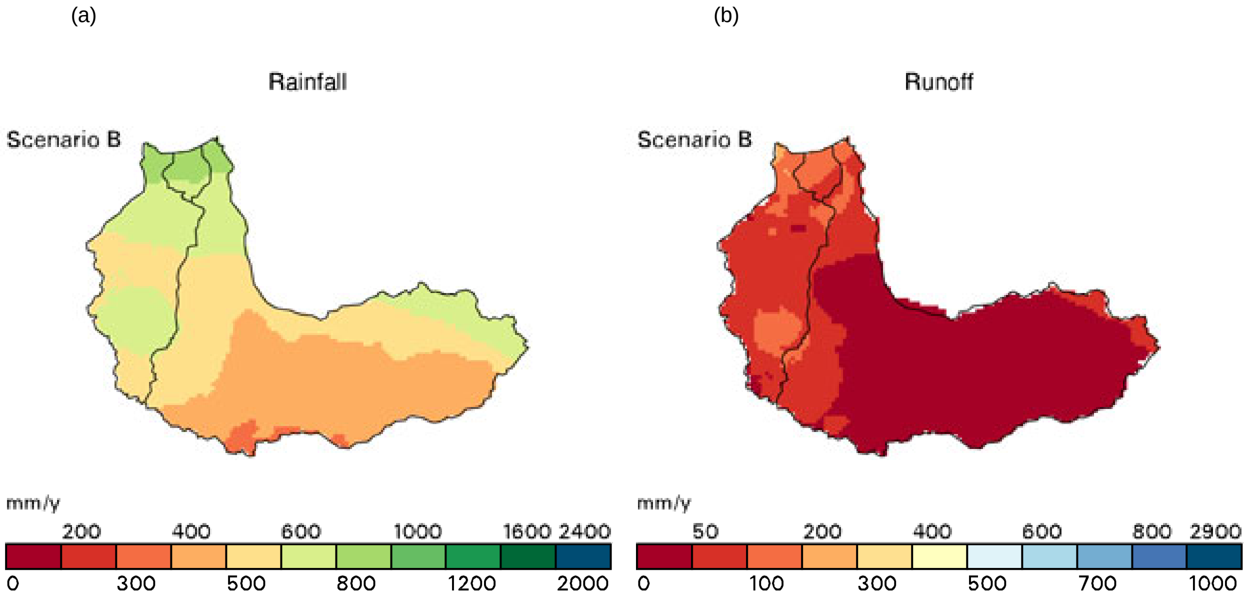


Figure FL-33. Spatial distribution of mean annual (a) rainfall and (b) runoff across the Flinders-Leichhardt region under Scenario B

### FL-3.5.5 Under future climate

Figure FL-34 shows the percentage change in the mean annual runoff averaged over the Flinders-Leichhardt region under Scenario C relative to Scenario A for the 45 scenarios (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). The percentage change in the mean annual runoff and rainfall from the corresponding GCMs are also tabulated in Table FL-11.

The figure and table indicate that the potential impact of climate change on runoff can be very significant. Although there is considerable uncertainty in the estimates, the results indicate that runoff in ~2030 in the Flinders-Leichhardt region is as likely to increase as decrease. Rainfall-runoff modelling with climate change projections from half of the GCMs shows a reduction in mean annual runoff, while rainfall-runoff modelling with climate change projections from the other half of the GCMs shows an increase in mean annual runoff. The wide range of mean annual runoff values shown in Figure FL-34 and Table FL-7 is primarily due to the wide range of future projections of rainfall by the 15 GCMs.

Because of the large variation between GCM simulations and the method used to obtain the climate change scenarios, the biggest increase and biggest decrease in runoff come from the high global warming scenario. For the high global warming scenario, rainfall-runoff modelling with climate change projections from five of the GCMs indicates a decrease in mean annual runoff greater than 10 percent while rainfall-runoff modelling with climate change projections from five of the GCMs indicates an increase in mean annual runoff greater than 10 percent.

In subsequent reporting here and in other sections, only results from an extreme 'wet', 'mid' and extreme 'dry' variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet, results from the second highest increase in mean annual runoff from the high global warming scenario are used. Under Scenario Cdry, results from the second highest reduction in mean annual runoff from the high global warming scenario are used. Under Scenario Cmid, the median mean annual runoff results from the medium global warming scenario are used. These are shown in bold in Table FL-11.

 

Under scenarios Cwet, Cmid and Cdry, mean annual runoff increases by 28 percent relative to Scenario A and decreases by 0.2 and 23 percent respectively. By comparison, the range based on the low global warming scenario is a 15 to -13 percent change in mean annual runoff. Figure FL-35 shows the mean annual runoff across the Flinders-Leichhardt region under scenarios A and C. The linear discontinuities evident in Figure FL-35 are due to GCM grid cell boundaries.

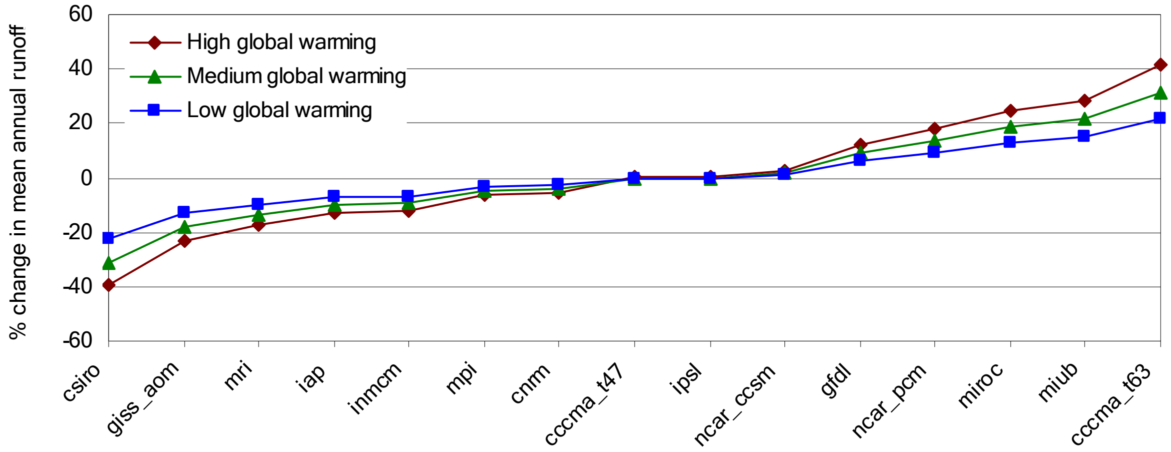


Figure FL-34. Percentage change in mean annual runoff under the 45 Scenario C simulations (15 global climate models and three global warming scenarios) relative to Scenario A

Table FL-11. Summary results under the 45 Scenario C simulations for the modelling subcatchments in the Flinders-Leichhardt region (numbers show percentage change in mean annual rainfall and runoff under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Runoff | GCM | Rainfall | Runoff | GCM | Rainfall | Runoff |
| csiro | -22% | -39% | csiro | -17% | -31% | csiro | -12% | -23% |
| **giss_aom** | **-8%** | **-23%** | giss_aom | -6% | -18% | giss_aom | -4% | -13% |
| mri | -8% | -17% | mri | -6% | -13% | mri | -4% | -10% |
| iap | -5% | -13% | iap | -4% | -10% | iap | -3% | -7% |
| inmcm | -3% | -12% | inmcm | -2% | -10% | inmcm | -2% | -7% |
| mpi | -3% | -6% | mpi | -3% | -5% | mpi | -2% | -3% |
| cnrm | -4% | -5% | cnrm | -3% | -4% | cnrm | -2% | -3% |
| cccma_t47 | 3% | 0% | **cccma_t47** | **2%** | **0%** | ipsl | 0% | 0% |
| ipsl | 1% | 1% | ipsl | 0% | 0% | cccma_t47 | 1% | 0% |
| ncar_ccsm | 1% | 3% | ncar_ccsm | 1% | 2% | ncar_ccsm | 1% | 1% |
| gfdl | -1% | 12% | gfdl | -1% | 9% | gfdl | 0% | 6% |
| ncar_pcm | 7% | 18% | ncar_pcm | 6% | 14% | ncar_pcm | 4% | 9% |
| miroc | 11% | 25% | miroc | 8% | 19% | miroc | 6% | 13% |
| **miub** | **8%** | **28%** | miub | 6% | 22% | miub | 4% | 15% |
| cccma_t63 | 12% | 42% | cccma_t63 | 9% | 31% | cccma_t63 | 6% | 21% |

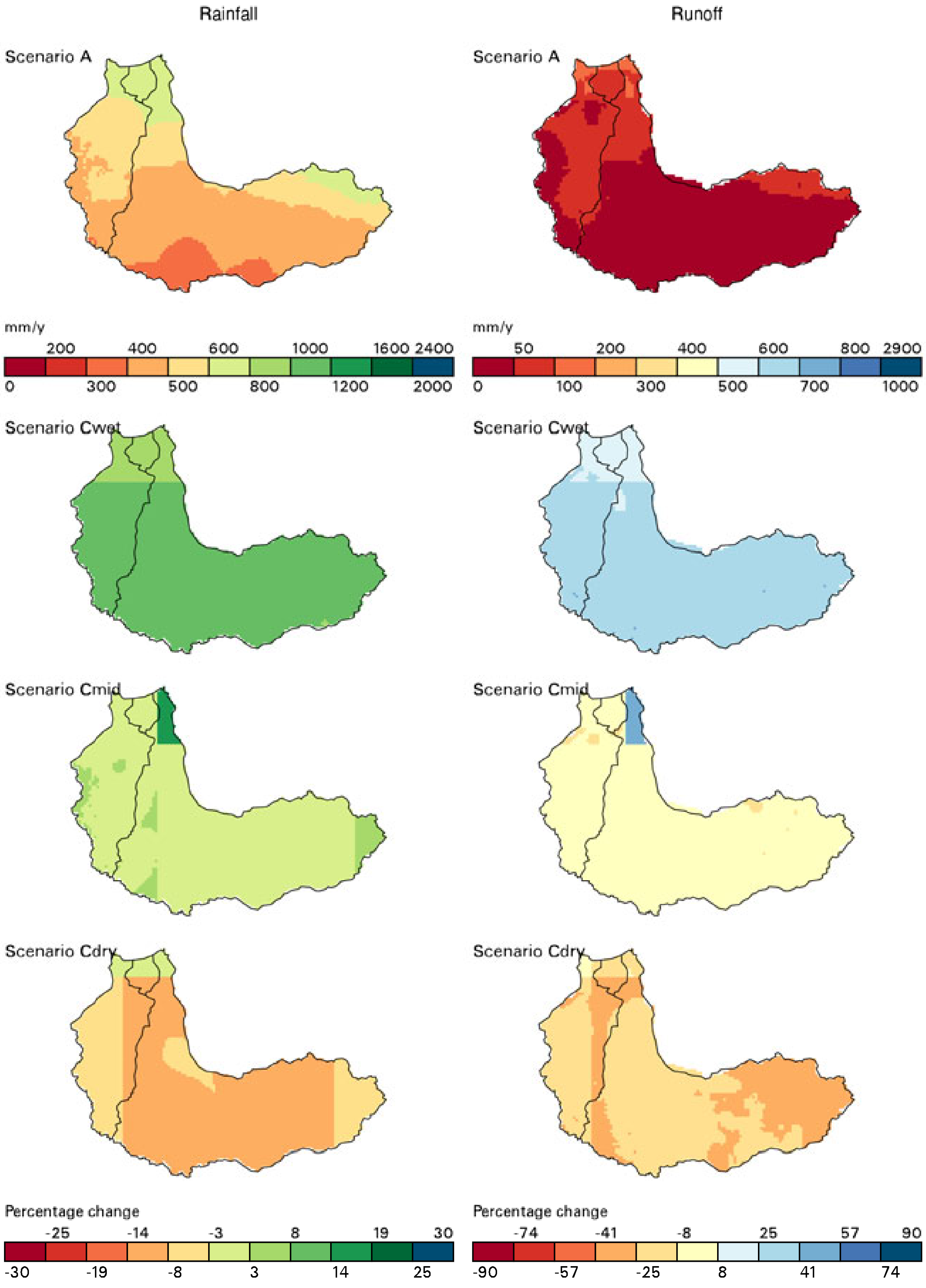


Figure FL-35. Spatial distribution of mean annual rainfall and runoff across the Flinders-Leichhardt region under Scenario A and under Scenario C relative to Scenario A

 

### FL-3.5.6 Summary results for all scenarios

Table FL-12 shows the mean annual rainfall, runoff and actual evapotranspiration under Scenario A averaged over the Flinders-Leichhardt region, and the percentage changes in the rainfall, runoff and actual evapotranspiration under scenarios B and C relative to Scenario A. The Cwet, Cmid and Cdry results are based on the mean annual runoff, and the rainfall changes shown in Table FL-12 are the changes in the mean annual value of the rainfall series used to obtain the runoff under scenarios Cwet, Cmid and Cdry. The changes in mean annual rainfall do not necessarily translate directly to the changes in mean annual runoff because of changes in seasonal and daily rainfall distributions and the relationship between rainfall and runoff is non-linear. The latter factor usually results in small changes in rainfall to be amplified in runoff (Table FL-11).

Figure FL-36 shows the mean monthly rainfall and runoff under scenarios A and C averaged over the 77 years for the region. Figure FL-37 shows the daily rainfall and flow exceedance curves under scenarios A and C averaged over the region. In Figure FL-36 Cwet, Cmid and Cdry are selected on a month-by-month basis, while in Figure FL-37 Cwet, Cmid and Cdry are selected for every day of the daily flow exceedance curve.

Table FL-12. Water balance over the entire Flinders-Leichhardt region under Scenario A and under scenarios B and C relative to Scenario A

| Scenario | Rainfall | Runoff | Evapotranspiration |
|---|---|---|---|
| | | mm | |
| A | 495 | 44 | 451 |
| | | percent change from Scenario A | |
| B | 12% | 9% | 12% |
| Cwet | 8% | 28% | 6% |
| Cmid | 2% | 0% | 2% |
| Cdry | -8% | -23% | -6% |

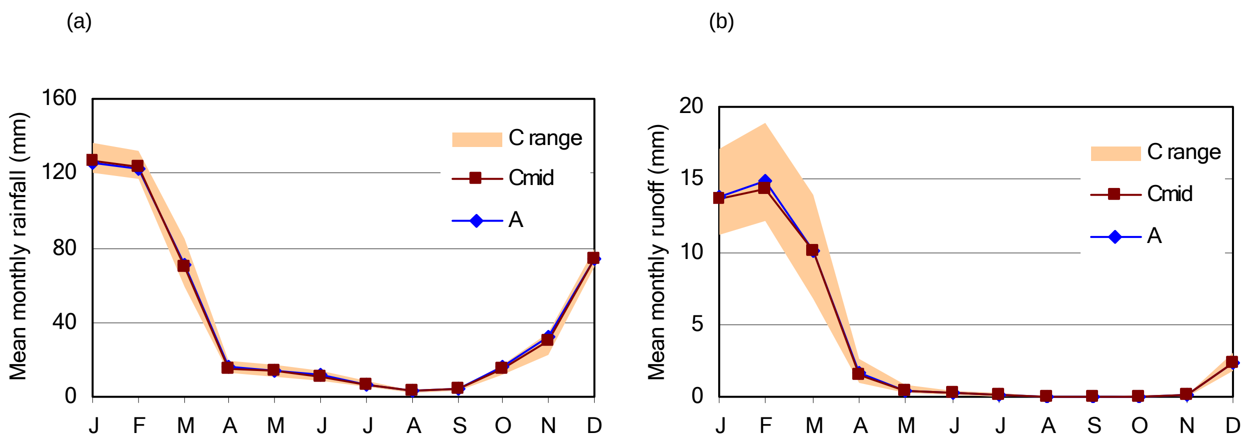


Figure FL-36. Mean monthly (a) rainfall and (b) modelled runoff in the Flinders-Leichhardt region under scenarios A and C. (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

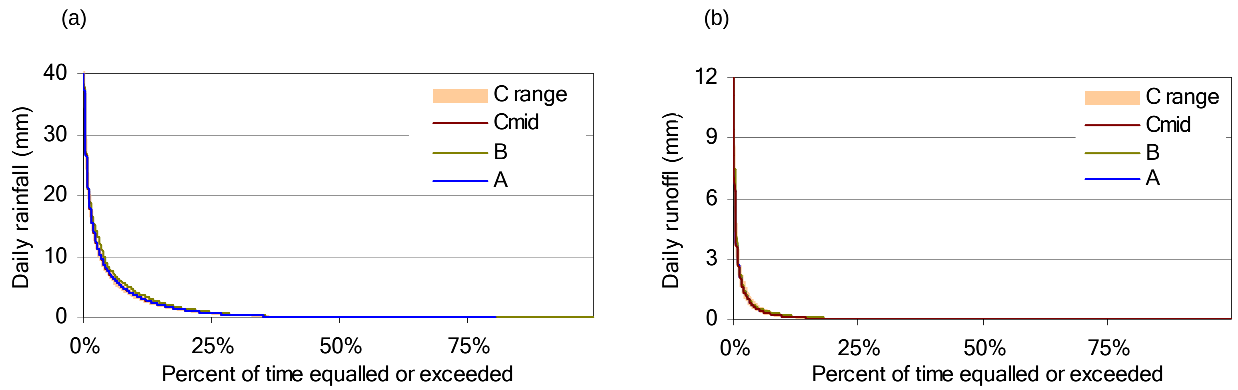


Figure FL-37. Daily flow exceedance curves for (a) rainfall and (b) modelled runoff in the Flinders-Leichhardt region under scenarios A, B and C (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

## FL-3.5.7 Confidence levels

There is a reasonable level of confidence associated with mid to high level runoff events for the headwater catchments in Flinders-Leichhardt region. This is because this is where the majority of streamflow gauging stations used in this project are located. As shown in Figure FL-29 the ensemble calibration at these stations does reasonably well at reproducing the observed monthly runoff series. In the Flinders catchment a large proportion of the area is commanded by station 915212A. Despite this station's large catchment area (about 40,000 $km^2$) the rainfall-runoff model ensemble is able to reproduce runoff at this gauge reasonably well (NSE for monthly flows of 0.82). However a consequence of calibrating to gauges with large catchment areas is that the areas mapped as high runoff tend to give under-predictions and the areas mapped as low runoff tend to give over-predictions. Dry season NSE values tend to be poor (Figure FL-29). There are no calibration catchments in the lower reaches of the Flinders-Leichhardt region. Diagrams in Petheram et al. (2009a) illustrate which calibrated rainfall-runoff model parameter sets are used to model streamflow in the ungauged subcatchments in the Flinders-Leichhardt region.

The rainfall-runoff model verification analysis with data from 123 catchments from across all of northern Australia indicates that the mean annual runoff for ungauged catchments are under estimated or over estimated, when using optimised parameter values from a nearby catchment, by less than 20 percent in 40 percent of catchments and by less than 50 percent in 80 percent of the catchments. In the Flinders-Leichhardt region transposing parameter sets from calibration catchments to ungauged subcatchments appears to result in reasonable mid to high flow predictions in ungauged areas. While there is a high level of confidence that the runoff during the dry season is very low (i.e. less than several mm), the ability of the rainfall-runoff models to accurately simulate low dry season flows in ungauged catchments is poor. This is because groundwater recharge and lateral groundwater flow processes are represented relatively simply in the rainfall-runoff models. Further lumped rainfall-runoff models cannot explicitly account for subsurface heterogeneity, which can strongly influence the spatial location of groundwater discharge. Consequently the level of confidence for dry season flow map shown in Figure FL-38 provides a relative indication of how well dry season metrics, such as cease-to-flow, are simulated.

Figure FL-38 illustrates the level of confidence in modelling the mid to high (i.e. peak flows) and dry season runoff events (respectively) for the subcatchments of the Flinders-Leichhardt region. It should be noted that these maps of level of confidence are not statistical confidence levels and are intended to only convey a broad reliability of prediction. The level of confidence in streamflow predictions will vary slightly from the level of confidence in runoff predictions shown below and as discussed in Section 2.2.6 of the division-level Chapter 2.

Although there is uncertainty associated with annual runoff volumes for individual ungauged catchments in the Flinders-Leichhardt region, they are not all biased to one direction. The non-systematic errors therefore tend to cancel one another to some extent, and across the entire Flinders-Leichhardt region the long-term average monthly and annual results are reasonable. As shown in Figure FL-38, in many areas of the Flinders-Leichhardt region localised studies will require more detailed analysis than undertaken and reported here and would most likely require the site to be visited and additional field measurements made.



 

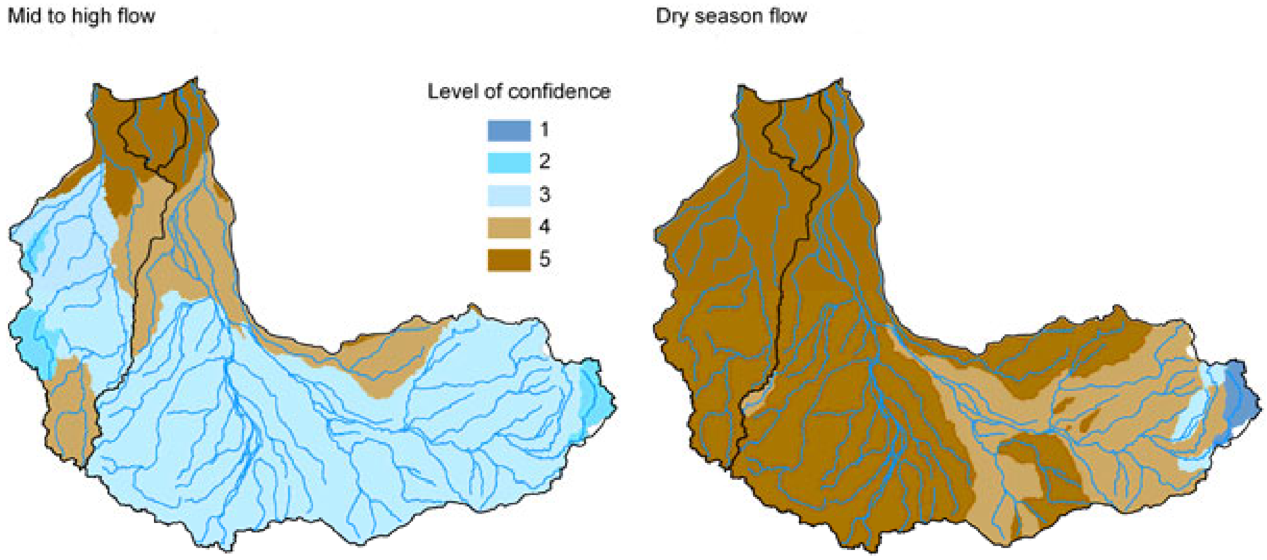


Figure FL-38. Level of confidence in the modelling of runoff for (a) mid- to high flow events and (b) monthly dry season flow events for the modelling subcatchments of the Flinders-Leichhardt region. 1 is the highest level of confidence and 5 is the lowest

## FL-3.6 River system water balance

General information about river modelling methods is presented at the division-level in Chapter 2. In that chapter, scenarios are defined in Section 2.1 and river modelling methods which apply to all regions are described in Section 2.2. The following section summarises this generic river modelling approach as applied to the Flinders-Leichhardt region. The river modelling results for the Flinders and Leichhardt River models are reported using a range of metrics, which were consistently applied across all regions. The use of a common set of metrics across the entire project area enables comparisons between regions.

In this section where annual data are reported, years are represented by numbers 1 to 77. Consistently throughout the report, annual data are based on the water year (1 September to 31 August) and the dry season is defined as 1 May to 31 October. Scenarios Cwet, Cmid and Cdry are selected on the basis of the ranked mean annual rainfall for the modelled subcatchments in Section FL-3.5. River system models can be used to assess the implications of the changes in inflows on the reliability of water supply to users. They may also be used to support water management planning by assessing the trade-offs between supplies to various competing categories of users. These models describe infrastructure, water demands, and water management and sharing rules. Given the time constraints of the project, and the need to link the assessments to state water planning processes, it is necessary to use the river system models currently used by state agencies.

The Flinders and Leichhardt regions are modelled using the IQQM program (version 6.42.2). The river basin boundaries and the subdivision of the river basin into subcatchments for modelling purposes are shown in Figure FL-28. The models were set up by the Department of Environment and Resource Management to support the Queensland Water Resource Planning Process. Results from this model for the period from January 1890 to June 2003 were used to establish the water sharing rules in the draft *Gulf Resource Operations Plan* (DNRW, 2008). The level of development represented by the model is based on the full use of existing entitlements. It should be noted that the results presented in DERM reports (Water Assessment Group, 2006a and 2006b) may differ from numbers published in this report due to the different modelling period and different initial conditions.

As part of the Northern Australia Sustainable Yields Project, input data for the model were extended so that they covered the period 1 January 1890 to 30 June 2008. The results for this project are reported for 77-year sequences. In this project the river system modelling for the Flinders and Leichhardt regions consist of ten scenarios:

- Scenario A – historical climate sequence and full use of existing entitlements
  This scenario assumes a full use of existing entitlements. Full use of existing entitlements refers to the total entitlements within a plan area including existing water authorisations and unallocated reserves. This refers to the water accounted for in the draft Gulf Resource Operations Plan, but the licences are interim or not allocated as yet. The period of analysis commences on 1 September 2007 and streamflow metrics are produced by modelling the 77-year historical climate sequence between 1 September 2007 and 31 August 2084. This scenario is used as a baseline for comparison with all other scenarios.
- Scenario AN – historical climate sequence and without-development
  Current levels of development such as public storages and demand nodes are removed from the model to represent without-development conditions. Inflows were not modified for groundwater extraction, major land use change or farm dam development because the impact of these factors on catchment yield are currently considered to be negligible. This scenario uses the historical flow and climate inputs used for Scenario A.
- Scenario BN – recent climate and without-development
  Current levels of development such as public storages and demand nodes are removed from the model to represent without-development conditions. Inflows were not modified for groundwater extraction, major land use change or farm dam development because the impact of these factors on catchment yield are currently considered to be negligible. This scenario incorporates the effects of current land use and uses seven consecutive climate sequences between 1 September 1996 and 31 August 2007 to generate a 77-year climate sequence representative of the ‘recent climate’ (see Section 2.1.2 in the division-level Chapter 2 for more detail).
- Scenario CN – future climate and without-development
  Current levels of development such as public storages and demand nodes are removed from the model to represent without-development conditions. Inflows were not modified for groundwater extraction, major land use change or farm dam development because the impact of these factors on catchment yield are currently considered to be negligible. Scenarios CNwet, CNmid and CNdry represent a range of future climate conditions that are derived by adjusting the historical climate and flow inputs used in Scenario A.
- Scenario B – recent climate and full use of existing entitlements
  This scenario incorporates the effects of current land use and uses seven consecutive climate sequences between 1 September 1996 and 31 August 2007 to generate a 77-year climate sequence representative of the ‘recent climate’ (see Section 2.1.2 in the division-level Chapter 2 for more detail).
- Scenario C – future climate and full use of existing entitlements
  Scenarios Cwet, Cmid and Cdry represent a range of future climate conditions that are derived by adjusting the historical climate and flow inputs used in Scenario A. The level of development for Scenario C assumes the full use of existing entitlements, i.e. the same as for Scenario A.

The changes in inflows between scenarios reported in this chapter differ from the changes in runoff reported in Section FL-3.5. These differences are due to difference in the methods by which the GCMs were ranked and difference in areas that are considered to contribute runoff to the surface water model. In Section FL-3.5 the entire region is considered while a subset of this area is considered here. The scenarios presented in this project may not eventuate but they encompass consequences that might arise if no management changes were made. Consequently results from this assessment are designed to highlight pressure points in the system, both now and in the future. This assessment does not elaborate on what management actions might be taken to address any of these pressure points. Where management changes to mitigate the effects of climate change have recently been implemented, the impacts of the changes predicted in this section may be an overestimate.

 

# River system water balance – Flinders system

## FL-3.6.1 Flinders system model configuration

### Flinders model description

The Flinders region is described by the Flinders IQQM system model (Figure FL-39) (Water Assessment Group, 2006a). The model extends from the headwaters of the Flinders catchment, in the east upstream of Hughenden on the Flinders River and in the west upstream of Cloncurry on Cloncurry River, to the mouth of the Flinders River on the Gulf of Carpentaria west of Karumba. The Cloncurry River joins the Flinders River just upstream of the outlet to the ocean. The Walkers Bend gauge (915003a) is the most downstream flow monitoring station in the system. The tributaries of the Flinders system include Porcupine Creek, Betts Creek, Dutton River, Mountain Creek, Stawell River and Woolgar River which contribute to the Flinders River flows and Malbon River, Williams River, Gilliat River, Julia Creek, Corella River and Dugald River which contribute to the Cloncurry River flows.

The system is represented in the model by 55 river sections and 170 nodes. Twelve of these nodes are water demand nodes which are used for simulating water-harvesting rules in the lower section of the basin. There are two main storages represented in the model, Corella Dam and Chinaman Creek Dam, and ten smaller instream storages. There are no passing flow requirements for the major storages. Details of the major storages in the Flinders catchment are provided in Table FL-13. The degree of regulation metric presented in Table FL-13 is the sum of the net evaporation and controlled releases from the dam divided by the total inflows. Controlled releases exclude spillage. Storages with radial gates and without spillways are not reported in this table. The degree of regulation of Corella Dam for the full use of existing entitlements is 0.41.

The level of development represented by the model is based on the full use of existing entitlements. A consequence of this is that the model does not simulate current levels of development. Water use is modelled by 49 nodes that are categorised into different uses in Table FL-14. In Table FL-14 and the sections that follow, unsupplemented water is defined as surface water that is not sourced from a water storage that is able to regulate or control supply to users. Diversions are modelled from:

- 7 nodes for mining, industrial or town water supply purposes
- 27 nodes representing high flow (water harvesting) diversions (5 of these nodes are not direct users because they divert water to other tributaries)
- 15 nodes representing unregulated diversions.

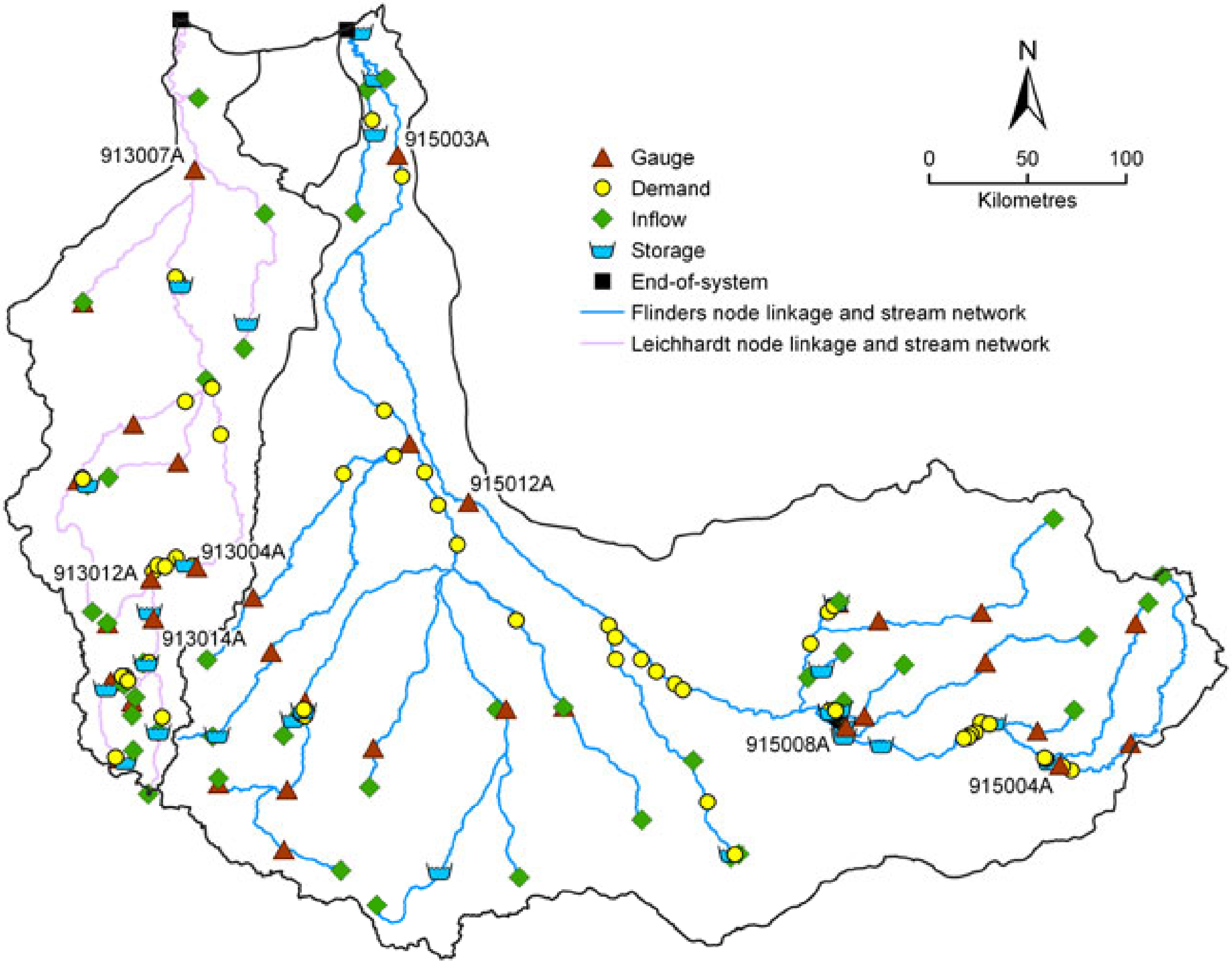


Figure FL-39. Schematic of the approximate location of gauging stations, main demand nodes and storages for the Flinders river system model (green lines) and Leichhardt river system model (pink lines)

Table FL-13. Storages in the Flinders river system model

| Major storages | Active storage | Average annual Inflow | Average annual release | Average annual net evaporation | Degree of regulation |
|---|---|---|---|---|---|
| | GL | GL/y | | | |
| Corella Dam | 15.8 | 18.5 | 2.5 | 5.1 | 0.41 |
| Chinaman Creek Dam | 2.8 | 13.5 | 2.0 | 0.2 | 0.16 |
| Other | 3.8 | 243.6 | 2.8 | 1.0 | 0.02 |
| **Total** | **22.4** | **275.7** | **7.3** | **6.2** | **0.05** |

In Table FL-14 and the sections that follow, ‘volumetric limit’ is defined as being the maximum volume of water that can be extracted from a river system within this region under the draft *Gulf Resource Operations Plan*. Unsupplemented water is defined as surface water that is not sourced from a water storage that is able to regulate or control supply to users.

Table FL-14. Modelled water use configuration in the Flinders river system model

| Water users | Number of nodes | Volumetric limit | Model notes |
|---|---|---|---|
| | | GL/y | |
| Town Water Supply | | | |
| High Security | 2 | 3.5 | Fixed demand |
| Unsupplemented | 1 | 0.2 | Fixed demand |
| Agriculture | | | |
| General Security | 5 | 20.2 | No On Farm Storage |
| Unsupplemented | 27 | 105.8 | On Farm Storage |
| Other Demands | | | |
| High Security | 2 | 2.5 | Fixed demand |
| Unsupplemented | 7 | 1.5 | Fixed demand |
| **Total** | **44** | **133.696** | |

## Flinders model setup

The original Flinders River model and associated IQQM V6.42.2 executable code were obtained from the Queensland Department of Environment and Resource Management. The time series rainfall, evaporation and flow inputs to this model for the historical climate time series were set to cover the reporting period 1 September 1930 to 31 August 2007. The model was run for the reporting period and validated against the original model run results for the same period.

For the scenarios that assume the full use of existing entitlements, the initial state of storages can influence the results obtained so the same initial storage levels need to be used for all scenarios. In this project all scenarios are reported for a common 77-year sequence commencing on 1 September 2007. However the demand simulated by an IQQM model for month *n* is dependent upon the simulation results for month *n-1*. For this reason the initial conditions (i.e. storage levels) are set to the levels simulated on the 1 August 2007 for all scenarios. The models are then run for 77 years and one month.

A without-development version of the Flinders model was created by removing all instream storages, all irrigators and fixed demands.

Table FL-15. Flinders river system model setup information

| Model setup information | | Version | Start date | End date |
|---|---|---|---|---|
| Flinders | IQQM | 6.42.2 | 01/01/1890 | 20/08/2008 |
| Connection | | | | |
| | | | | |
| Baseline models | | | | |
| Warm up period | | | 1/08/2007 | 31/08/2007 |
| Flinders | IQQM | 6.42.2 | 1/09/2007 | 31/08/2084 |
| Connection | | | | |
| | | | | |
| Modifications | | | | |
| Data | Data extended by DERM | | | |
| Inflows | | | | |
| Initial storage volumes | set to level at 01/08/2007 | | | |
| Corella | 7.69 GL | | | |
| Chinaman Creek Dam | 2.55 GL | | | |
| | | | | |
| Other storages | set to level at 01/08/2007 | | | |

### FL-3.6.2 Flinders system river water balance

The mass balance table (Table FL-16) shows volumetric components under Scenario A as GL/year, with all other scenarios presented as a percentage change from Scenario A. Mass balance includes the change in storage that is averaged over the 77-year period and is shown as GL/year.

The directly gauged inflows represent the inflows into the model that are based on data from a river gauge. The indirectly gauged inflows include inflows that are derived to achieve a mass balance between mainstream gauges. Diversions are listed based on the different water products in the region. End-of-system flows are shown for the Flinders River at modelled end-of-system.

Mass balance tables for the river reaches in the model are provided in Petheram et al. (2009b). The mass balance of each of these river reaches and the overall mass balance were checked by taking the difference between total inflows, outflows of the system and change in storage volumes. In all cases the mass balance error was zero. Unattributed fluxes in Table FL-16 are the modelled river losses. River losses are estimated from loss relationships that are determined during calibration of the IQQM model such that flow is conserved between upstream and downstream gauging stations.

Results in Table FL-16 show that under scenarios Cwet and Cdry inflows in the Flinders catchment increase by 32 percent and decrease by 25 percent respectively. End-of-system flows increase by 33 percent and decrease by 26 percent under scenarios Cwet and Cdry respectively. However, the impact of climate change on diversions is small (<8 percent) as demands in the region are much smaller than the total inflows. Results for consumptive use are discussed further in Section FL-3.6.5.

### FL-3.6.3 Flinders system inflows

#### Inflows

There are several ways that the total inflows into the river system can be calculated. The obvious way would be to sum all of the inflows in the model. This is 2940 GL/year for the Flinders IQQM (Table FL-16). The table also shows that a large proportion of the inflow is indirectly gauged and therefore estimated as part of model calibration. The approach used to calibrate these inflows varies considerably between reaches and model implementations. In some cases inflows are inflated and subsequently compensated for by loss relationships. In other cases the losses are inherent in the inflows. Totalling inflows does not provide a consistent assessment of total river system inflows across different models because of the different approaches to calibration.

An alternative to simply totalling modelled inflows is to locate the point of maximum average annual flow in the river system under without-development conditions. The gauge with maximum average annual flow is a common reference across all models irrespective of how mass balance is calibrated. This is because all river models are calibrated to achieve mass balance at mainstream gauges. The without-development scenarios remove the influences of upstream extractions and regulation and gives a reasonable indication of total inflows. For the IQQM catchments in northern Australia, where there have been minimal modifications to subcatchment inflows due to farm dams, commercial forestry plantations and groundwater use, Scenario AN can be considered to be broadly representative of pre-European settlement conditions.

A comparison between scenarios for reaches along the Flinders River is presented in Figure FL-40. This shows that the maximum average annual mainstream gauged flow occurs at the last gauge 915003a (Flinders River at Walkers Bend) with a value of 2023 GL/year under Scenario AN. This is typical of the Gulf catchments as the rivers are continually gaining to the region's outlet.

 

Table FL-16. Finders river system model mean annual water balance under Scenario A and under scenarios B and C relative to Scenario A

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | | | | |
| Storage volume | | | | | |
| Change over period | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | GL/y | percent change from Scenario A | | | |
| Inflows | | | | | |
| Subcatchments | | | | | |
| Gauged | 535.8 | 2% | 33% | 0% | -27% |
| Ungauged | 2404.2 | -8% | 31% | 3% | -24% |
| **Sub-total** | **2940.0** | **-6%** | **32%** | **2%** | **-25%** |
| Diversions | | | | | |
| Agriculture | | | | | |
| General Security | 13.1 | 0% | 3% | -3% | -6% |
| Unsupplemented | 86.7 | -2% | 4% | -2% | -8% |
| Town Water Supply | | | | | |
| High Security | 3.3 | -1% | 0% | 0% | -1% |
| Unsupplemented | 0.0 | 0% | 5% | -5% | -5% |
| Other Uses | | | | | |
| High Security | 2.5 | 0% | 0% | 0% | 0% |
| Unsupplemented | 1.4 | 1% | 2% | -2% | -4% |
| **Sub-total** | **107.0** | **-1%** | **4%** | **-2%** | **-7%** |
| Outflows | | | | | |
| End-of-system flow | 1981.9 | -6% | 33% | 3% | -26% |
| **Sub-total** | **1981.9** | **-6%** | **33%** | **3%** | **-26%** |
| Net evaporation | | | | | |
| Storages | 10.0 | 1% | 4% | 3% | -1% |
| **Sub-total** | **10.0** | **1%** | **4%** | **3%** | **-1%** |
| Unattributed fluxes | | | | | |
| | **841.0** | **-6%** | **33%** | **2%** | **-26%** |

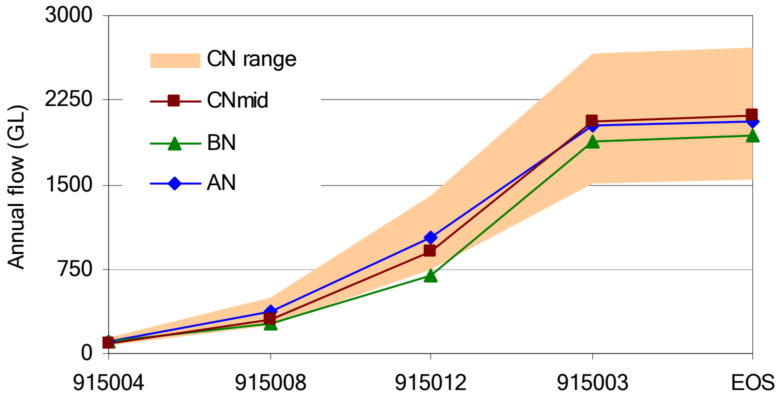


Figure FL-40. Transect of total mean annual river flow in the Flinders system under scenarios AN, BN and CN

## Water availability

In the Murray-Darling Basin Sustainable Yields Project, water availability was defined as the volume of water under the without-development scenario which occurs at the point of maximum mean annual flow along a river system. This generally occurred where a river system turned from a gaining reach to a losing reach. The major rivers in the Gulf of Carpentaria Drainage Division are, however, gaining systems. This means that their highest mean annual flow occurs at their end-of-system. However end-of-system flow volumes are often uncertain due to considerable ungauged flow contribution to these points. For this reason water availability is defined in this project as the volume of water under the without-development scenario which occurs at the gauged point of maximum mean annual flow along a river system. In the river systems of the Gulf of Carpentaria this point occurs at the most downstream gauge. When computing water availability for this project, ecological, social, cultural and economic values are not considered.

It must also be noted, however, that not all of the water at the most downstream gauge is accessible for consumptive use. In the Gulf of Carpentaria the majority of suitable locations for large carry over storages are in the headwater catchments and not at or near the last gauge in the system. Further during large out of bank flows (flood flows) water harvesting operations, which are usually located in the lower reaches, are constrained by the rapid rise and fall in river height (Petheram et al. 2008) and insufficient on-farm storage capacity.

A time series of total annual surface water availability under Scenario AN is shown in Figure FL-41. The lowest annual water availability is 16 GL in Year 39 while the greatest annual water availability is 16,806 GL in Year 44. Figure FL-42 shows the difference in annual total surface water availability under Scenario CN relative to Scenario AN.

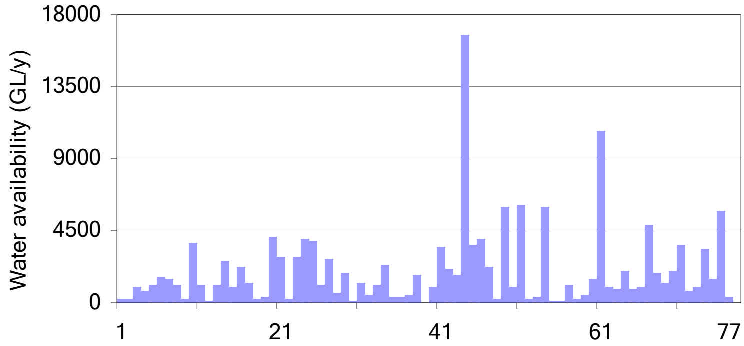


Figure FL-41. Annual water availability at streamflow gauging station 915003 under Scenario AN

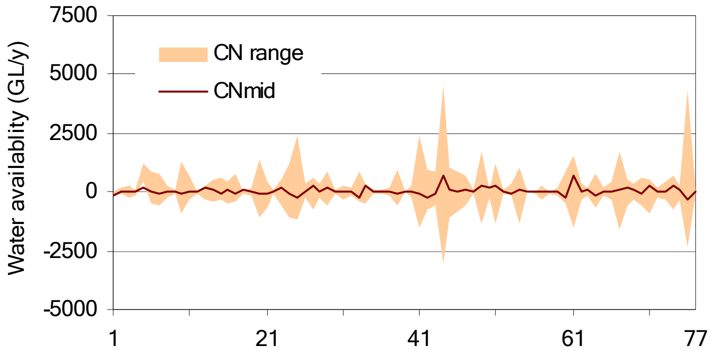


Figure FL-42. Change in total annual surface water availability at streamflow gauging station 915003 under Scenario CN relative to Scenario AN

## FL-3.6.4 Flinders system storage behaviour

The modelled behaviour of major storages indicates how reliable the storage is during extended periods of low or no inflows. Table FL-17 provides indicators that show under each scenario the lowest recorded storage volume and the corresponding date for Corella Dam and Chinaman Creek Dam. The minimum storage date refers to the first occurrence of the minimum storage volume. The average and maximum years between spills is also provided. A spill commences when the storage exceeds full supply volume and ends when the storage falls below 90 percent of full supply volume. The end condition is applied to remove the periods when the dam is close to full and oscillates between spilling and just below full which would otherwise distort the analysis. The period between spills is the length of time from when one spill ends (i.e. storage falls below 90 percent of the full supply volume) until the next spill commences (i.e. when the storage exceeds the fully supply volume).

 

Corella Dam completely empties under Scenario Cdry. The storage behaviour under Scenario Cmid is similar to that under Scenario A based on the average and maximum years between spills for Corella Dam. Despite the initial storages levels for Corella Dam being relatively high, under all scenarios the minimum storage volume occurred within the first few years of simulation. This is because the first few years of simulation are very dry and demands are relatively large. Hence it is likely that the minimum storage volume would have occurred in the first few years of simulation regardless of the initial storage volume. Under all scenarios Chinaman Creek Dam completely empties.

The minimum storage for Chinaman Creek Dam, which provides town water supply for Cloncurry, occurred in Year 31 for all scenarios. The minimum storage volume occurred after numerous spills had taken place. Hence the initial storage conditions for Chinaman Creek Dam do not influence the minimum storage date.

Table FL-17. Details of dam behaviour in the Flinders system under scenarios A, B and C

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| Corella Dam | | | | | |
| Minimum storage volume (GL) | 1 | 1 | 2 | 1 | 0 |
| Minimum storage date | 26 June, year 5 | 26 June , year 5 | 15 May, year 2 | 15 May, year 2 | 5 June, year 5 |
| Average years between spills | 1.4 | 1.2 | 1.1 | 1.3 | 1.8 |
| Maximum years between spills | 5.9 | 5.4 | 4.9 | 5.9 | 6.9 |
| Chinaman Creek Dam | | | | | |
| Minimum storage volume (GL) | 0 | 0 | 0 | 0 | 0 |
| Minimum storage date | 21 Oct, year 31 | 16 Oct, year 31 | 21 Nov, year 310 | 19 Oct, year 31 | 4 Oct, year 31 |
| Average years between spills | 0.6 | 0.6 | 0.5 | 0.6 | 0.6 |
| Maximum years between spills | 1.9 | 1.4 | 1.5 | 2.0 | 2.0 |

The time series of storage behaviour for these two storages for the maximum period between spills under each of the scenarios is shown in Figure FL-43.

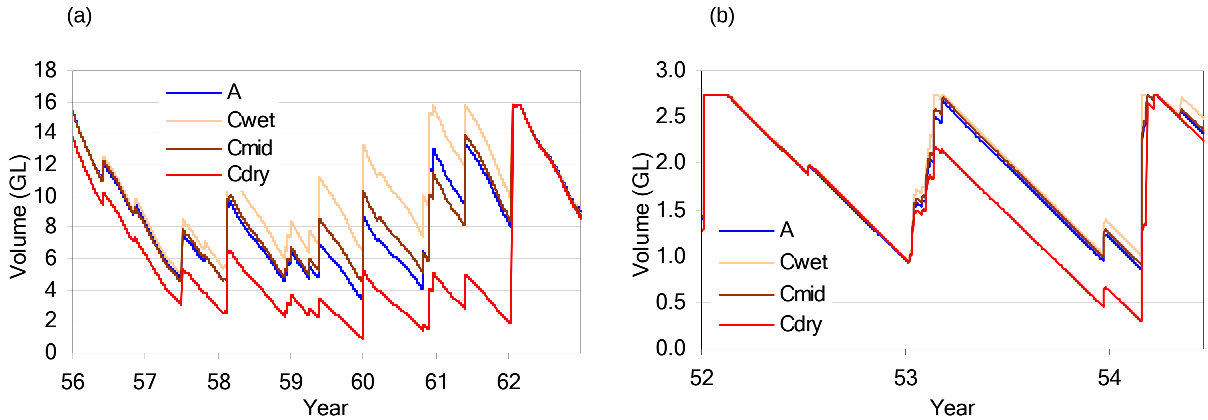


Figure FL-43. Storage behaviour over the maximum days between spills for (a) Corella Dam and (b) Chinaman Creek Dam under scenarios A and C

### FL-3.6.5 Flinders system consumptive water use

#### Diversions

Table FL-18 shows the total average annual diversions for each subcatchment ((Figure FL-28) under Scenario A and the percentage change under scenarios B and C relative to Scenario A. The majority of these diversions (95.7 GL/year or 89 percent of total diversions under Scenario A) are from water harvesting of high river flows. Demand in the Flinders appears to be modelled independent of climate. Hence, diversions slightly decrease under Scenario Cdry because there is less water accessible.

Table FL-18. Total mean annual diversions in each subcatchment in the Flinders system under Scenario A and under scenarios B and C relative to Scenario A

| Reach | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | percent change from Scenario A | | | |
| 915004 | 8.5 | 0% | 4% | -6% | -11% |
| 915008 | 11.4 | 1% | 5% | -5% | -11% |
| 915012 | 57.0 | -4% | 4% | -2% | -7% |
| 915203 | 5.5 | 1% | 2% | 0% | -2% |
| 915212 | 21.8 | 2% | 4% | 1% | -6% |
| 915209 | 2.5 | 0% | 0% | 0% | 0% |
| 915003 | 0.4 | -1% | 9% | -1% | -9% |
| 915999 | 0.0 | 0% | 0% | 0% | -1% |
| **Total** | **107.0** | **-1%** | **4%** | **-2%** | **-7%** |

Figure FL-44 shows total average annual diversions under scenarios A, B and C for subcatchment reaches. Two reaches contain 74 percent of all diversions – Flinders River between gauges 915008 and 915012 and on the Cloncurry River between gauges 915203 and 915212.

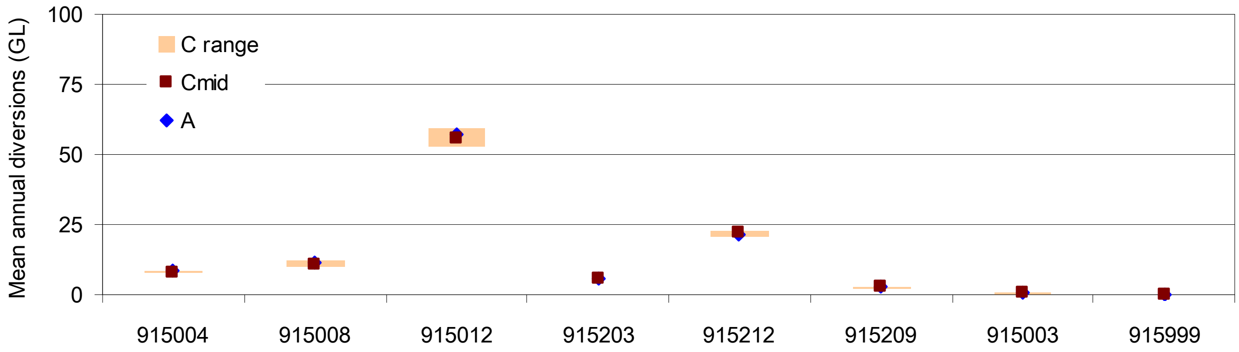


Figure FL-44. Total mean annual diversions for each subcatchment in the Flinders system under scenarios A and C

 

Figure FL-45 shows the annual time series of total diversions under Scenario A and the difference between diversions under scenarios C and A. The maximum and minimum diversions under Scenario A are 137.3 GL in Year 14 and 18.9 GL in Year 39 respectively.

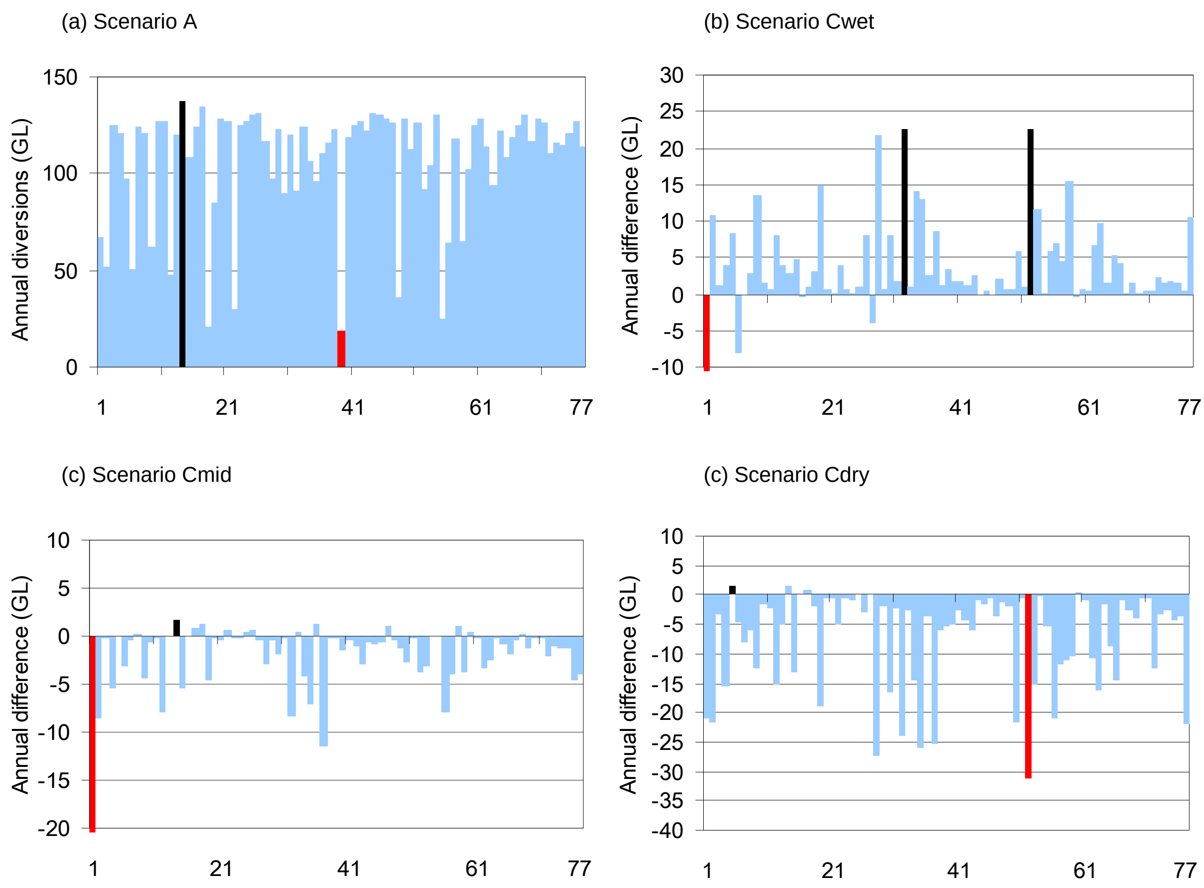


Figure FL-45. Total annual diversions in the Flinders system under (a) Scenario A; and difference from Scenario A under (b) Scenario Cwet, (c) Scenario Cmid and (d) Scenario Cdry

## Level of use

The level of use metric used in this project is indicated by the ratio of total use to surface water availability. Total use comprises subcatchment and streamflow use. Subcatchment use (e.g. commercial forestry, farm dams) is considered negligible in the Flinders catchment. Streamflow use includes total net diversions, which are defined as the net water diverted for the full range of water products. Net diversion is the sum of the diversions minus the return flows. It should be noted, however, there are no return flows in the Flinders IQQM. Net diversions are used to reflect the change in mass balance of the system.

Level of use is presented in two ways for this region. The first approach is the same as presented in the Murray-Darling Basin Sustainable Yields Project: the ratio of total use to total surface water availability (Table FL-19). The second approach is to present a transect of level of use at each main river gauge with use being the cumulative use up to the gauge including use on effluents and tributaries compared with the average annual river gauge. This approach shows the spatial variation of use along the main transect (Figure FL-46).

The level of use for the Flinders catchment is low at 5 percent of the total available surface water resource under Scenario A. The location of maximum level of use is for the first reported reach at stream gauge 915004. At this location under Scenario A level of use is also relatively low at 8 percent. In Table FL-19 the total use is lowest under Scenario Cdry for the reasons outlined in the above section on diversions.

Current utilisation of licences is estimated by considering the unallocated water reserves from the *Gulf (draft) Resource Operations Plan* (DNRW, 2008) and the modelled volumetric limits. For the Flinders catchment, the long-term volumetric limit is 107 GL/year and the unallocated reserves are reported to be 102.5 GL/year. Based on these values it is estimated that current usage is about 5 GL/year. Allowable usage or total average diversions from IQQM are for the historical period (1930 to 2007) and therefore may differ to the volumes used to develop the Resource Operations Plan.

Table FL-19. Relative level of surface water use in the Flinders system under scenarios A, B and C

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GLy | | | | |
| Total surface water availability | 2023 | 1916 | 2661 | 2044 | 1521 |
| Streamflow use | | | | | |
| Total net diversions | 107 | 106 | 111 | 105 | 100 |
| **Total use** | **107** | **106** | **111** | **105** | **100** |
| | percent | | | | |
| Relative level of use | 5% | 6% | 4% | 5% | 7% |

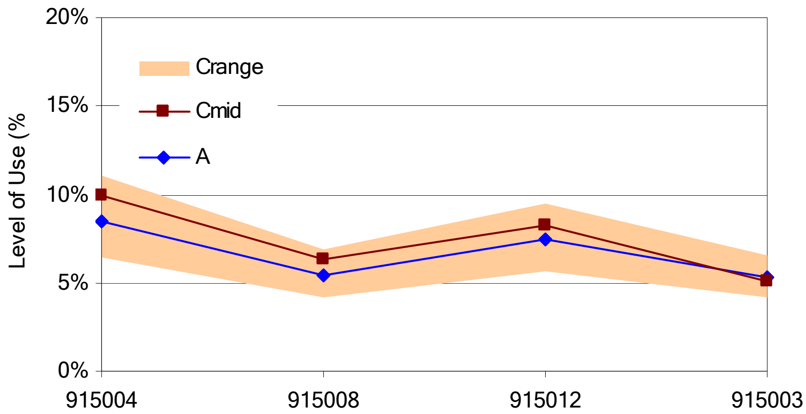


Figure FL-46. Transect of relative level of surface water use in the Flinders system under scenarios A and C

## Use during dry periods

Table FL-20 shows the average annual use for surface water diversions, as well as the annual diversions for the lowest 1-, 3- and 5-year periods under Scenario A and the percentage change from Scenario A under each other scenario. These figures indicate the relative impact on surface water use during dry periods is greatest for a 1-year period.

Table FL-20. Indicators of surface water diversions in the Flinders system during dry periods under Scenario A and under scenarios B and C relative to Scenario A

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | percent change from Scenario A | | | |
| Lowest 1-year period | 19 | 20% | 17% | -1% | -29% |
| Lowest 3-year period | 69 | 4% | 8% | -6% | -18% |
| Lowest 5-year period | 75 | 1% | 9% | -4% | -16% |
| Average | 107 | -1% | 4% | -2% | -7% |

## Reliability

The average reliability of water products can be indicated by the ratio of total diversions to the volumetric limit. For the Flinders region, volumetric limits for town water supply, mining and other uses are taken to be the licence volume or nominated reference demand; agricultural limits is the maximum area planted by an application rate or a specified licence capacity. Table FL-21 shows the average reliability under Scenario A and the percent change under scenarios B and C relative to Scenario A. Results indicate that reliability is best for high security use. For other water products reliability is good with less than 10 percent change in diversions for each product.



 

Table FL-21. Average reliability of water products in the Flinders system under Scenario A and under scenarios B and C relative to Scenario A

| Licensed private usage | A | | | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| | Volumetric limit | Mean annual diversions | Fraction diverted per 1ML allocated | | | | |
| | GL/y | | | percent change from Scenario A | | | |
| Town Water Supply | | | | | | | |
| High Security | 3.5 | 3.3 | 0.95 | -1% | 0% | 0% | -1% |
| Unsupplemented | 0.2 | 0.0 | 0.25 | 0% | 5% | -5% | -5% |
| Agriculture | | | | | | | |
| General Security | 20.2 | 13.1 | 0.65 | 0% | 3% | -3% | -6% |
| Unsupplemented | 105.8 | 86.7 | 0.82 | -2% | 4% | -2% | -8% |
| Other demands | | | | | | | |
| High Security | 2.5 | 2.5 | 1.00 | 0% | 0% | 0% | 0% |
| Unsupplemented | 1.5 | 1.4 | 0.89 | 1% | 2% | -2% | -4% |

There is a difference in most systems between the water that is available for use, as modelled in the Flinders IQQM, and the water that is actually diverted for use. These differences may be due to a range of factors, such as: unallocated water reserves, underutilisation of licences and water being provided from other sources such as rainfall. The difference between available and diverted water will vary considerably across water products and time.

## FL-3.6.6 Flinders system river flow behaviour

There are many ways of considering the flow characteristics in river systems. For this report three different indicators are provided: daily flow exceedance, seasonal plot and daily event frequency. These are considered at the end-of-system. Figure FL-47(a) shows the flow exceedance curves at the end-of-system.

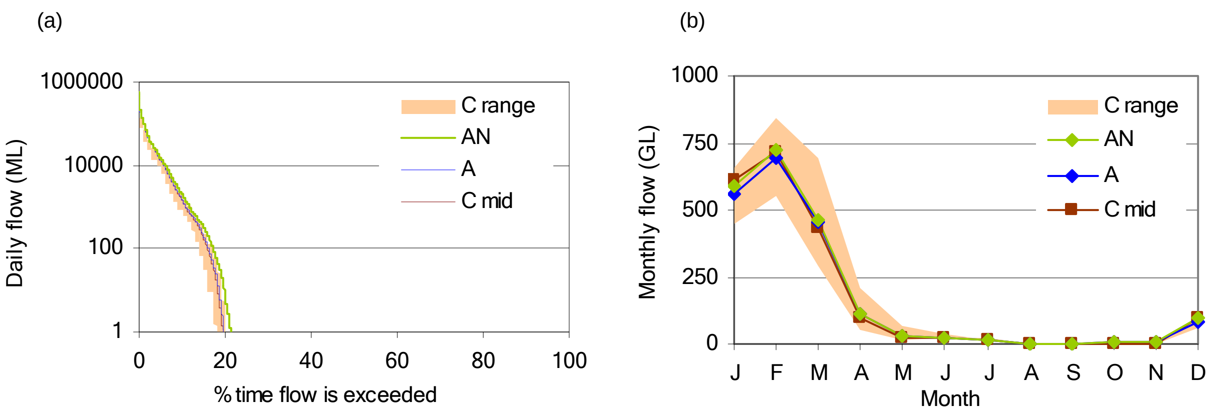


Figure FL-47. (a) Daily flow exceedance curves and (b) mean monthly flow for the Flinders end-of-system under scenarios AN, A and C

Figure FL-47(b) gives the mean monthly flow under scenarios AN, A and C at the end-of-system. This figure shows a strong seasonality at the end-of-system gauges reflecting the wet and dry seasons. It also shows minimal change in end-of-system flows compared to without-development conditions under all scenarios.

The percentage of time that flow is greater than 1 ML/day under these scenarios is presented in Table FL-22. Under climate scenarios there is not a large impact to low flows at the end-of-system.

Table FL-22. Percentage of time modelled flow at the Flinders end-of-system is greater than 1 ML/day under scenarios AN, A, B and C

| Catchment | AN | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|
| Flinders | 31% | 28% | 29% | 30% | 28% | 26% |

## FL-3.6.7 Flinders system share of water resource

### Non-diverted water shares

There are several ways of considering the relative level of impact on non-diverted water. Table FL-23 presents two indicators for relative impact on non-diverted water:

- the mean annual non-diverted water as a proportion of the available water
- mean annual non-diverted water under each scenario compared with average annual non-diverted water under Scenario A.

Most water in the Flinders is not diverted (95 percent) therefore the change in non-diverted water predominantly reflects changes due to climate.

Table FL-23. Relative level of non-diverted water in the Flinders system under scenarios A, B and C

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| Flinders | | | | | |
| Non-diverted water as a percentage of total available water | 95% | 94% | 96% | 95% | 93% |
| Non-diverted share relative to Scenario A non-diverted share | 100% | 93% | 134% | 102% | 74% |

### Combined water shares

Figure FL-48 combines the results from water availability, level of development and non-diverted water. The size of the bars indicates total water availability and the subdivision of the bars indicates the diverted and non-diverted fractions. It should be noted, however, that water availability is based on the mean annual volume of water at the last gauge in the system. For the reasons discussed in Section 0 it is unlikely that this volume of water is accessible for consumptive use.

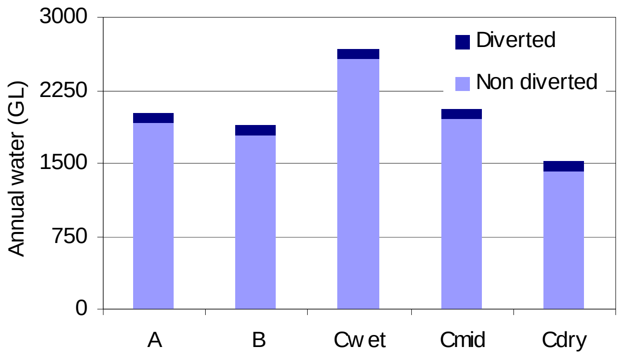


Figure FL-48. Comparison of diverted and non-diverted shares of water under scenarios A, B and C

# River system water balance – Leichhardt system

## FL-3.6.8 Leichhardt system river model configuration

### Leichhardt model description

The Leichhardt region is described by the Leichhardt IQQM systems model (Figure FL-39) (Water Assessment Group, 2006b). The model extends from the headwaters of the river basin and includes Rifle Creek south of Mount Isa, to the mouth of the Leichhardt River on the Gulf of Carpentaria north-east of Burketown. The Floraville gauge (913007) is the most downstream flow monitoring station in the system. The tributaries of the Leichhardt system include Alexandra River, Paroo Creek, Gunpowder Creek, Mistake Creek, Gorge Creek, Rifle Creek, Fiery Creek and Doughboy Creek.

The system is represented in the model by 42 river sections and 122 nodes. Thirty-one of these nodes are water accounting nodes which are used for simulating water-harvesting rules in the lower section of the basin. There are five large storages as noted in Table FL-24 and four smaller instream storages in the model. There are no passing flow requirements for the major storages. Details of the major storages in the Leichhardt catchment are provided in Table FL-24. The degree of regulation metric in Table FL-24 is the sum of the net evaporation and controlled released from the dam divided by the total inflows. Controlled releases exclude spillage. Storages with radial gates and without spillways are not reported in this table. The degree of regulation of Rifle Creek Dam and Lake Moondarra are 0.68 and 0.71 respectively. The remaining three major storages in the Leichhardt catchment have a degree of regulation ranging from 0.3 to 0.38.

The level of development represented by the model is based on the full use of existing entitlements. Water use nodes in the model are categorised into different uses in Table FL-25. In Table FL-25 and the sections that follow, unsupplemented water is defined as surface water that is not sourced from a water storage that is able to regulate or control supply to users. Diversions are modelled from:

- 13 nodes representing high security supply
- 3 nodes representing irrigation supply from private storages
- 7 nodes representing high flow (water harvesting) diversions (2 divert water into tributaries, therefore not included in Table FL-25)
- 2 nodes representing unregulated diversions.

Table FL-24. Major storages in the Leichhardt river system model

| Major storages | Active storage | Average annual inflow | Average annual release | Average annual net evaporation | Degree of regulation |
|---|---|---|---|---|---|
| | GL | GL/y | | | |
| Julius | 100.1 | 222.9 | 48.0 | 19.6 | 0.30 |
| Lake Moondarra | 103.2 | 61.3 | 22.5 | 20.8 | 0.71 |
| Waggaboonya | 14.0 | 18.2 | 2.2 | 3.2 | 0.30 |
| Lake Mary Kathleen | 12.2 | 34.3 | 1.0 | 12.2 | 0.38 |
| Rifle Creek | 9.5 | 5.4 | 1.5 | 2.2 | 0.68 |
| **Total** | **238.98** | **342.10** | **75.18** | **57.99** | **0.39** |

In Table FL-25 and the sections that follow, 'volumetric limit' is defined as being the maximum volume of water that can be extracted from a river system within this region under the draft *Gulf Resource Operations Plan*. Unsupplemented water is defined as surface water that is not sourced from a water storage that is able to regulate or control supply to users.

Table FL-25. Modelled water use configuration in the Leichhardt river system model

| Water users | Number of nodes | Volumetric limit | Model notes |
|---|---|---|---|
| | | GL/y | |
| Agriculture | | | |
| General Security | 4 | 15.7 | Fixed Demand |
| Unsupplemented | 5 | 26.0 | |
| Mining | | | |
| High Security | 5 | 31.5 | Fixed Demand |
| Unsupplemented | 2 | 4.0 | Fixed Demand |
| Town Water Supply | | | |
| High Security | 3 | 34.4 | Fixed Demand |
| Other Demands | | | |
| High Security | 4 | 14.3 | Fixed Demand |
| **Total** | **23** | **111.6** | |

## Leichhardt model setup

The original Leichhardt river model and associated IQQM V6.42.2 executable code were obtained from DNRW. The time series rainfall, evaporation and flow inputs to this model for the historical climate time series were set to cover the reporting period 1 September 2007 to 31 August 2084. The model was run for the reporting period and validated against the original model run results for the same period.

The initial state of storages can influence the results obtained so the same initial storage levels was used for all scenarios. In this project all scenarios are reported for a common 77-year sequence commencing on 1 September 2007. However the demand simulated by an IQQM model for month *n* is dependent upon the simulation results for month *n-1*. For this reason the initial conditions (i.e. storage levels) are set to the levels simulated on the 1 August 2007 for all scenarios. The models are then run for 77 years and one month.

A without-development version of the Leichhardt model was created by inactivating all instream storages, all demand and diversion nodes.

Table FL-26. Leichhardt river system model setup information

| Model setup information | | Version | Start date | End date |
|---|---|---|---|---|
| Leichhardt | IQQM | 6.42.2 | 01/01/1890 | 30/06/2008 |
| Connection | | | | |
| Baseline models | | | | |
| Warm up period | | | 1/08/2007 | 31/08/2007 |
| Leichhardt | IQQM | 6.42.2 | 1/09/2007 | 31/08/2084 |
| Connection | | | | |
| Modifications | | | | |
| Data | Data extended by DERM | | | |
| Inflows | | | | |
| Initial storage volumes | | | | |
| Julius | 79.8 GL | Modelled level for 1 August 2007 | | |
| Lake Moondarra | 43.6 GL | | | |
| Waggaboonya | 8.8 GL | | | |
| Lake Mary Kathleen | 4.4 GL | | | |
| Rifle Creek | 5.7 GL | | | |

 

## FL-3.6.9 Leichhardt system river water balance

The mass balance table (Table FL-27) shows volumetric components under Scenario A as GL/year, with all other scenarios presented as a percentage change from Scenario A. Mass balance includes the change in storage that is averaged over the 77-year period and is shown as GL/year.

The directly gauged inflows represent the inflows into the model that are based on data from a river gauge. The indirectly gauged inflows include inflows that are derived to achieve a mass balance between mainstream gauges. Diversions are listed based on the different water products in the region. End-of-system flows are shown for the Leichhardt River at modelled end-of-system which includes inflows from Alexandra River and Lagoon Creek that join below gauge 913007.

Mass balance tables for the reaches in the model are reported in Petheram et al. (2009b). The mass balance of each of these river reaches and the overall mass balance were checked by taking the difference between total inflows and outflows of the system. In all cases the mass balance error was zero. Unattributed fluxes in Table FL-27 are the modelled river losses. River losses are estimated from loss relationships that are determined during calibration of the IQQM model such that flow is conserved between upstream and downstream gauging stations.

Results in Table FL-27 show that under scenarios Cwet and Cdry inflows in the Leichhardt catchment increase by 27 percent and decrease by 23 percent respectively. End-of-system flows increase by 29 percent and decrease by 25 percent under scenarios Cwet and Cdry respectively. However the impact of climate change on diversions is small (<5 percent) as demands in the region are low compared to the total inflows. These results are discussed further in Section FL-3.6.12.

There is a larger increase in inflows under Scenario B for the Leichhardt (52 percent) than the Flinders (6 percent).l This difference can be explained by the spatial distribution of the increase in rainfall under Scenario B (Figure FL-21).

## FL-3.6.10 Leichhardt system inflows

### Inflows

There are several ways that the total inflows into the river system can be calculated. The obvious way would be to sum all of the inflows in the model. This is 2041 GL/year for the Leichhardt IQQM (Table FL-16). The table also shows that a large proportion of the inflow is indirectly gauged and therefore estimated as part of model calibration. The approach used to calibrate these inflows varies considerably between reaches and model implementations. In some cases inflows are inflated and subsequently compensated for by loss relationships. In other cases the losses are inherent in the inflows. Totalling inflows does not provide a consistent assessment of total river system inflows across different models because of the different approaches to calibration.

An alternative to simply totalling modelled inflows is to locate the point of maximum average annual flow in the river system under without-development conditions. The gauge with maximum average annual flow is a common reference across all models irrespective of how mass balance is calibrated. This is because all river models are calibrated to achieve mass balance at mainstream gauges. The without-development scenarios remove the influences of upstream extractions and regulation and gives a reasonable indication of total inflows. For the IQQM catchments in northern Australia, where there have been minimal modifications to subcatchment inflows due to farm dams, commercial forestry plantations and groundwater use, Scenario AN can be considered to be broadly representative of pre-European settlement conditions.

A comparison between scenarios for reaches along the Leichhardt River is presented in Figure FL-49. This shows that the maximum average annual mainstream gauged flow occurs at the last gauge 913007 (Leichhardt River at Floraville) with a value of 1368 GL/year under Scenario AN. This is typical of the Gulf catchments as the rivers are continually gaining to the region’s outlet.

Table FL-27. Leichhardt river system model mean annual water balance under Scenario A and under scenarios B and C relative to Scenario A

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | | | | |
| Storage volume | | | | | |
| Change over period | 0.0 | 0.7 | 0.5 | 0.3 | -0.5 |
| | GL/y | percent change from Scenario A | | | |
| Inflows | | | | | |
| Subcatchments | | | | | |
| Gauged | 233.0 | 70% | 35% | 19% | -22% |
| Ungauged | 1807.7 | 50% | 25% | 19% | -24% |
| **Sub-total** | **2040.7** | **52%** | **27%** | **19%** | **-23%** |
| Diversions | | | | | |
| Agriculture | | | | | |
| General Security | 7.8 | -2% | 0% | 0% | -1% |
| Unsupplemented | 23.6 | 5% | 2% | 2% | -4% |
| Mining | | | | | |
| High Security | 29.4 | 5% | 4% | 2% | -6% |
| Unsupplemented | 3.8 | 4% | 3% | 1% | -4% |
| Town Water Supply | | | | | |
| High Security | 32.3 | 5% | 3% | 2% | -5% |
| Other Uses | | | | | |
| High Security | 13.9 | 2% | 1% | 1% | -2% |
| **Sub-total** | **110.8** | **4%** | **3%** | **2%** | **-4%** |
| Outflows | | | | | |
| End-of-system flow | 1784.6 | 57% | 29% | 21% | -25% |
| **Sub-total** | **1784.6** | **57%** | **29%** | **21%** | **-25%** |
| Net evaporation | | | | | |
| Major storages | 71.6 | 18% | 14% | 9% | -10% |
| Other Storages | 1.2 | 5% | 0% | -1% | -4% |
| **Sub-total** | **72.8** | **17%** | **13%** | **9%** | **-10%** |
| Unattributed fluxes | | | | | |
| | **72.4** | **38%** | **18%** | **10%** | **-16%** |

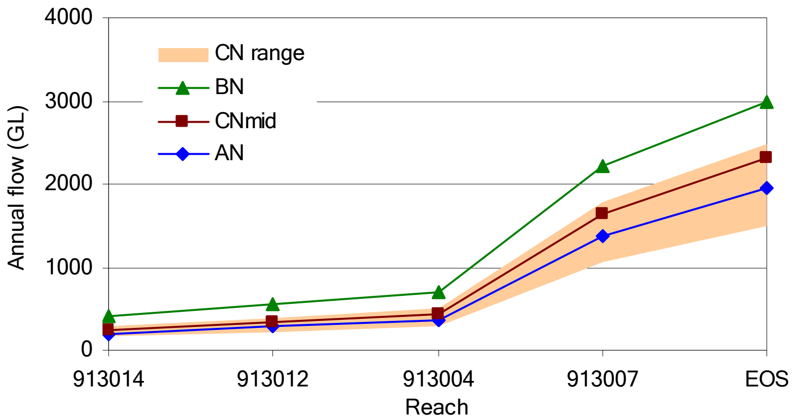


Figure FL-49. Transect of total mean annual river flow in the Leichhardt system under scenarios AN, BN and CN

## Water availability

In the Murray-Darling Basin Sustainable Yields Project, water availability was defined as the volume of water under the without-development scenario which occurs at the point of maximum mean annual flow along a river system. This generally occurred where a river system turned from a gaining reach to a losing reach. The major rivers in the Gulf of Carpentaria Drainage Division are, however, gaining systems. This means that their highest mean annual flow occurs at their end-of-system. However end-of-system flow volumes are uncertain due to considerable ungauged flow contribution to these points. For this reason water availability is defined in this project as the volume of water under the without-development scenario which occurs at the gauged point of maximum mean annual flow along a river system. In the river systems of the Gulf of Carpentaria this point occurs at the most downstream gauge. When computing water availability for this project ecological, social, cultural and economic values are not considered.

It must also be noted, however, that not all of the water at the most downstream gauge is accessible for consumptive use. In the Gulf of Carpentaria the majority of suitable locations for large carry over storages are in the headwater catchments and not at or near the last gauge in the system. Further during large out of bank flows (flood flows) water harvesting operations, which are usually located in the lower reaches, are constrained by the rapid rise and fall in river height (Petheram et al. 2008) and insufficient on-farm storage capacity.

A time series of total annual surface water availability under Scenario AN is shown in Figure FL-50. The lowest annual water availability is 59 GL in Year 72 while the greatest annual water availability is 11,707 GL in Year 44. Figure FL-51 shows the difference in annual total surface water availability under Scenario CN relative to Scenario AN.

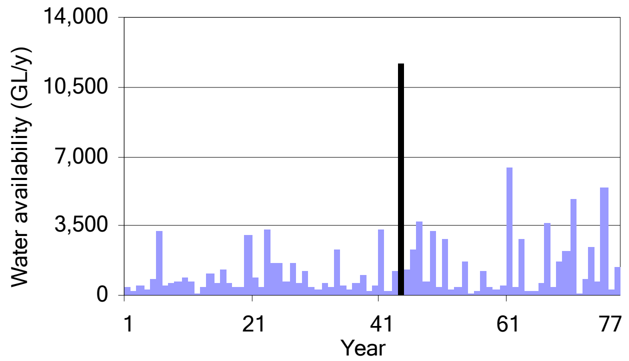


Figure FL-50. Annual water availability at streamflow gauging station 913007 under Scenario AN

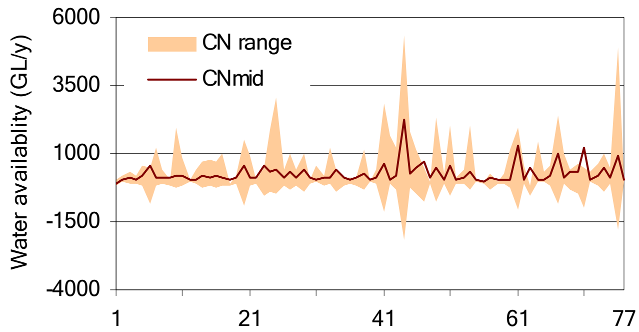


Figure FL-51. Change in total annual surface water availability at streamflow gauging station 913007 under Scenario CN relative to Scenario AN

### FL-3.6.11 Leichhardt system storage behaviour

The modelled behaviour of major storages indicates how reliable the storage is during extended periods of low or no inflows. Table FL-28 provides indicators that show for each of the scenarios the lowest recorded storage volume and the corresponding date for Rifle Creek Dam, Lake Moondarra, Julius Dam, Lake Mary Kathleen and Waggaboonya Dam. The minimum storage date refers to the first occurrence of the minimum storage volume. The minimum storage volume for Rifle Creek Dam and Waggaboonya Dam are reached several times over the period. Lake Mary Kathleen reaches minimum level (zero GL) many times under all scenarios. A spill commences when the storage exceeds full supply volume and ends when the storage is below 90 percent of full supply volume. The end condition is applied to remove the periods when the dam is close to full and oscillates between spilling and just below full which would otherwise distort the analysis. The period between spills is the length of time from when one spill ends (i.e. storage falls below 90 percent of the full supply volume) until the next spill commences (i.e. when the storage exceeds the fully supply volume).

Table FL-28. Details of dam behaviour in the Leichhardt system under scenarios A, B and C

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| Rifle Creek Dam | | | | | |
| Minimum storage volume (GL) | 0.0 | 1.1 | 0.3 | 0.0 | 0.0 |
| Number of times storages is at minimum | 3 | | | 1 | 6 |
| Minimum storage date | 5 June, year 5 | 27 June, year 5 | 27 June, year 5 | 27 June, year 5 | 10 Dec, year 40 |
| Average years between spills | 4.1 | 3.6 | 2.3 | 3.0 | 6.0 |
| Maximum years between spills | 19.5 | 5.9 | 8.8 | 11.9 | 20.8 |
| Lake Moondarra | | | | | |
| Minimum storage volume (GL) | 1 | 3 | 2 | 1 | 1 |
| Minimum storage date | 3 Feb, year 41 | 7 Nov, year 4 | 3 Feb, year 41 | 3 Feb, year 41 | 3 Feb, year 41 |
| Average years between spills | 4.4 | 3.9 | 2.7 | 3.7 | 6.5 |
| Maximum years between spills | 19.5 | 6.7 | 11.8 | 19.5 | 20.8 |
| Julius Dam | | | | | |
| Minimum storage volume (GL) | 4 | 5 | 4 | 4 | 3 |
| Minimum storage date | 31 Dec, year 74 | 31 Dec, year 74 | 31 Dec, year 74 | 31 Dec, year 74 | 31 Dec, year 74 |
| Average years between spills | 0.9 | 0.8 | 0.7 | 0.7 | 1.2 |
| Maximum years between spills | 4.5 | 2.9 | 2.7 | 2.8 | 5.4 |
| Lake Mary Kathleen | | | | | |
| Minimum storage volume (GL) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Number of times storages is at minimum | 35 | 21 | 30 | 35 | 55 |
| Minimum storage date | 3 Feb, year 42 | 10 Jan, year 73 | 3 Feb, year 41 | 3 Feb, year 41 | 3 Feb, year 41 |
| Average years between spills | 1.1 | 1.0 | 0.8 | 0.9 | 1.5 |
| Maximum years between spills | 4.8 | 4.6 | 3.0 | 3.0 | 7.0 |
| Waggaboonya Dam | | | | | |
| Minimum storage volume (GL) | 0 | 1 | 1 | 0 | 0 |
| Number of times storages is at minimum | 2 | - | - | 2 | 6 |
| Minimum storage date | 19 Oct, year 14 | 7 Dec, year 4 | 2 Jan, year 67 | 18 Dec, year 14 | 12 Oct, year 13 |
| Average years between spills | 2.3 | 2.2 | 1.8 | 2.2 | 2.8 |
| Maximum years between spills | 9.6 | 6.8 | 7.5 | 7.6 | 9.6 |

The time series of storage behaviour for these five major storages for the maximum period between spills under each of the scenarios is shown in Figure FL-52.

 

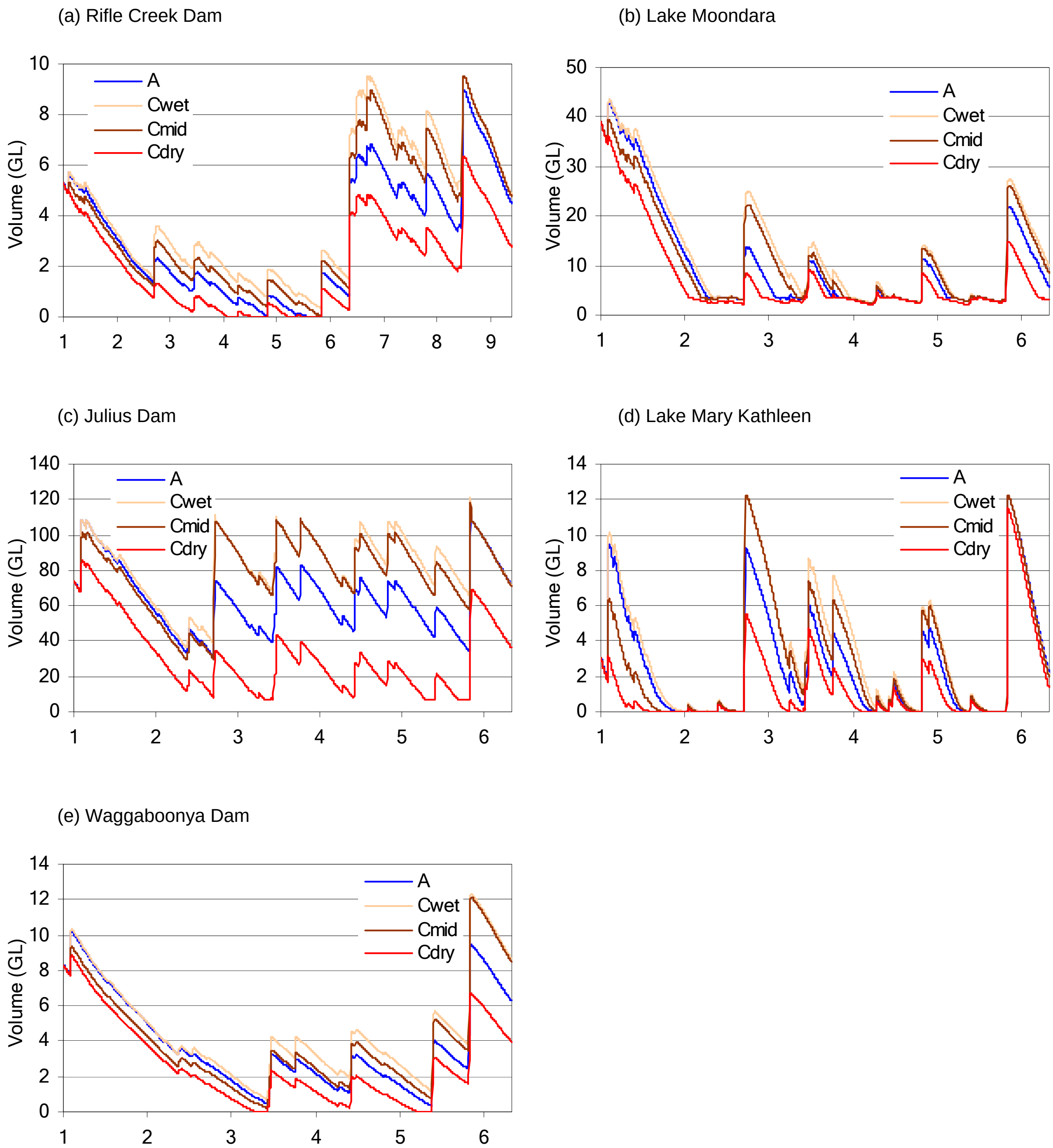


Figure FL-52. Storage behaviour over the maximum days between spills for (a) Rifle Creek Dam, (b) Lake Moondarra, (c) Julius Dam, (d) Lake Mary Kathleen and (e) Waggaboonya Dam under scenarios A and C

## FL-3.6.12 Leichhardt system consumptive water use

### Diversions

Table FL-29 shows the total average annual diversions for each subcatchment (Figure FL-28) under Scenario A and the percentage change under scenarios B and C relative to Scenario A. Water harvesting of high river flows accounts for 26 percent of total diversions (28.4 GL/year).

Table FL-29. Total mean annual diversions in each subcatchment in the Leichhardt system under Scenario A and under scenarios B and C relative to Scenario A

| Reach | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | percent change from Scenario A | | | |
| 9130141 | 25.1 | 13% | 9% | 6% | -12% |
| 9130121 | 48.0 | 0% | 0% | 0% | -1% |
| 9130041 | 2.3 | 4% | 3% | 1% | -5% |
| 9130031 | 4.0 | 2% | 1% | 1% | -3% |
| 9130071 | 24.0 | 4% | 2% | 2% | -4% |
| 9139991 | 7.4 | 1% | 0% | 1% | -4% |
| **Total** | **110.8** | **4%** | **3%** | **2%** | **-4%** |

Figure FL-53 shows total mean annual diversions under scenarios A, B and C for subcatchment reaches.

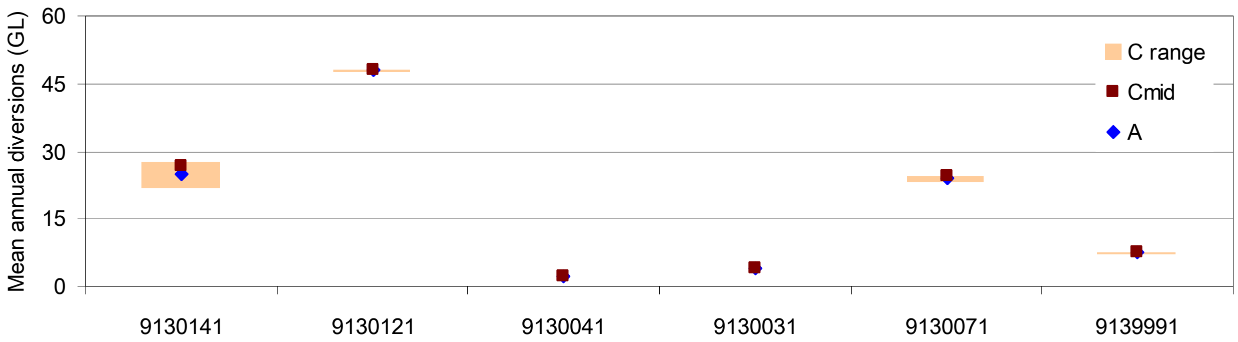


Figure FL-53. Total mean annual diversions for each subcatchment in the Leichhardt system under scenarios A and C

Figure FL-54 shows the annual time series of total diversions under Scenario A and the difference from Scenario A under Scenario C. The maximum and minimum diversions under Scenario A are 128.8 GL in Year 48 and 75.9 GL in Year 74 respectively.

 

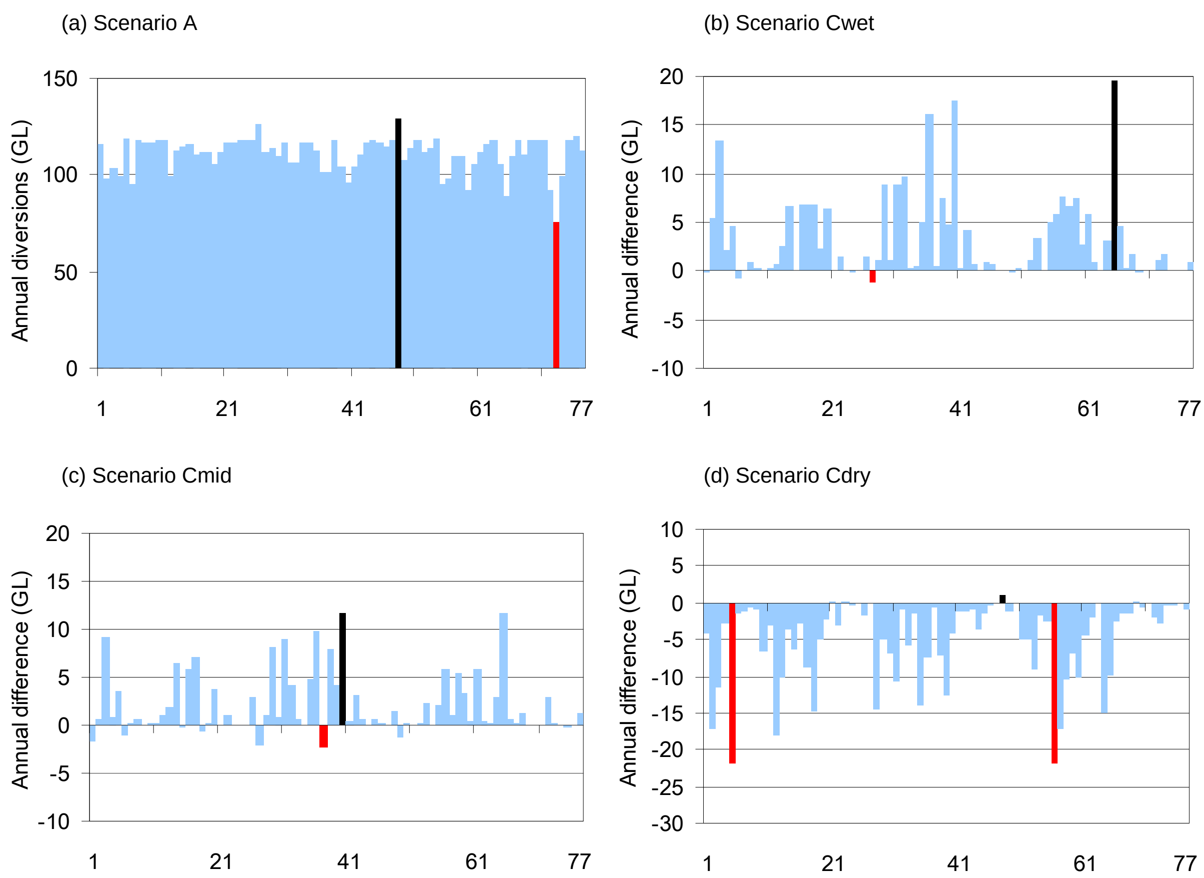


Figure FL-54. Total diversions in the Leichhardt system under (a) Scenario A; and difference from Scenario A under (b) Scenario Cwet, (d) Scenario Cmid and (f) Scenario Cdry

## Level of use

The level of use metric used in this project is indicated by the ratio of total use to surface water availability. Total use comprises subcatchment (e.g. commercial forestry, farm dams) and streamflow use. There is negligible subcatchment use in the Leichhardt catchment. Streamflow use includes total net diversions, which are defined as the net water diverted for the full range of water products. Net diversion is the sum of the diversions minus the return flows. It should be noted, however, there are no return flows in the Flinders IQQM. Net diversions are used to reflect the change in mass balance of the system.

Level of use is presented in two ways for this region. The first approach is the same as presented in the Murray-Darling Basin Sustainable Yields Project: the ratio of total use to total surface water availability. The second is to present a transect of level of use at each main river gauge with use being the cumulative use up to the gauge including use on effluents and tributaries compared with the average annual flow. This approach shows the spatial variation of use (Figure FL-55).

The level of use for the Leichhardt region is low at 8 percent of the total available surface water resource under Scenario A. The location of maximum level of use is for the first reported reach at stream gauge 913012. At this location under Scenario A level of use is moderate at 26 percent. In total, use is lowest under Scenario Cdry for the reasons outlined in the above section on diversions.

Current utilisation of licences is estimated by considering the unallocated water reserves from the *Gulf (draft) Resource Operations Plan* (DNRW, 2008) and the modelled volumetric limits. For the Leichhardt catchment, the long-term volumetric limit is 111 GL/year and the unallocated reserves are reported to be 31.1 GL/year. Based on these values it is estimated that current usage is about 80 GL/year. Allowable usage or total average diversions from IQQM are for the historical period (1930 to 2007) and therefore may differ to the volumes used to develop the *Gulf Draft Resource Operations Plan*.

Table FL-30. Relative level of surface water use in the Leichhardt system under scenarios A, B and C

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | | | GL/y | | |
| Total surface water availability | 1368 | 2216 | 1773 | 1634 | 1050 |
| Streamflow use | | | | | |
| Total net diversions | 111 | 115 | 114 | 113 | 106 |
| **Total use** | **111** | **115** | **114** | **113** | **106** |
| | | | percent | | |
| Relative level of use | 8% | 5% | 6% | 7% | 10% |

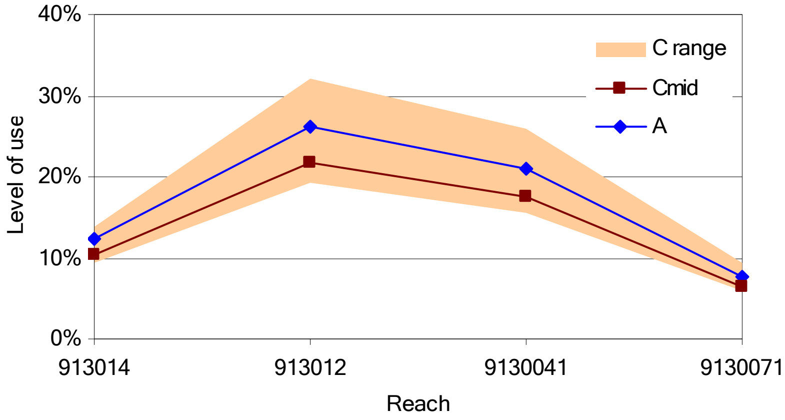


Figure FL-55. Transect of relative level of surface water use in the Leichhardt system under scenarios A and C

## Use during dry periods

Table FL-31 shows the average annual use for surface water diversions, as well as the annual diversions for the lowest 1-, 3- and 5-year periods under Scenario A and the percentage change from Scenario A under each other scenario. These figures indicate the relative impact on surface water use during dry periods is greatest over a 5-year period.

Table FL-31. Indicators of diversions in the Leichhardt system during dry periods under scenarios A, B and C

| Annual diversion | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | percent change from Scenario A | | | |
| Lowest 1-year period | 76 | 16% | 2% | 0% | -4% |
| Lowest 3-year period | 89 | 6% | 1% | 1% | -3% |
| Lowest 5-year period | 101 | 3% | 1% | 1% | -12% |
| Average | 111 | 4% | 3% | 2% | -4% |

## Reliability

The average reliability of water products can be indicated by the ratio of total diversions to the volumetric limit or equivalent benchmark. For the Leichhardt region, volumetric limits for town water supply, mining and other users are taken to be licence volume or nominated reference demand; unsupplemented agricultural usage is the maximum area planted by an application rate or a specified capacity. Table FL-32 shows the average reliability under Scenario A and the percent change under scenarios B and C relative to Scenario A. Results indicate that reliability is good for all water products with less than 6 percent change in diversions for each product.

 

Table FL-32. Average reliability of water products in the Leichhardt system under scenarios A, B and C

| Licensed private usage | Volumetric limit | A Mean annual diversions | A Fraction diverted per 1ML allocated | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| | GL/y | | | percent change from Scenario A | | | |
| Mining | | | | | | | |
| High Security | 31.5 | 29.4 | 0.94 | 5% | 4% | 2% | -6% |
| Unsupplemented | 4.0 | 3.8 | 0.94 | 4% | 3% | 1% | -4% |
| Agriculture | | | | | | | |
| General Security | 15.7 | 7.8 | 0.50 | -2% | 0% | 0% | -1% |
| Unsupplemented | 26.0 | 23.6 | 0.91 | 5% | 2% | 2% | -4% |
| Town Water Supply | | | | | | | |
| High Security | 34.4 | 32.3 | 0.94 | 5% | 3% | 2% | -5% |
| Other Demands | | | | | | | |
| High Security | 14.3 | 13.9 | 0.97 | 2% | 1% | 1% | -2% |

There is a difference in most systems between the water that is available for use, as modelled in the Leichhardt IQQM as full entitlements are modelled, and the water that is actually diverted for use. These differences may be due to a range of factors including unallocated water reserves, underutilisation of licences and water being provided from other sources such as rainfall. The difference between available and diverted water will vary considerably across water products and time.

## FL-3.6.13 Leichhardt system river flow behaviour

There are many ways of considering the flow characteristics in river systems. For this report three different indicators are provided: daily flow exceedance, seasonal plot and daily event frequency. These are considered at the end-of-system. Figure FL-56 shows the flow exceedance curves at the end-of-system.

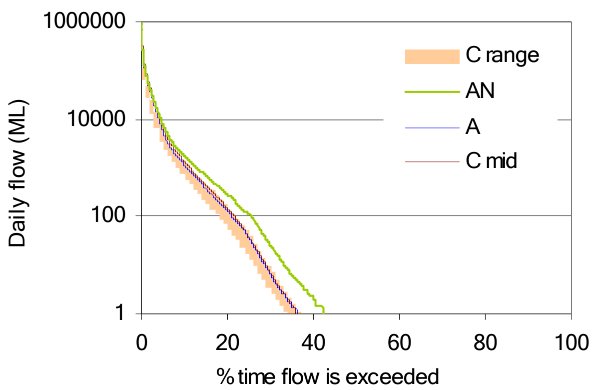


Figure FL-56. Daily flow exceedance curves for the Leichhardt end-of-system under scenarios AN, A and C

Figure FL-57 gives the mean monthly flow under scenarios AN, A, B and C at the end-of-system. This figure shows a strong seasonality at the end-of-system gauges reflecting the wet and dry seasons. This figure also shows there is a minimal change in the seasonality of end-of-system flows under all scenarios relative to Scenario AN. Mean monthly flow under Scenario Cmid falls outside of the C range for the months January and February. This is because the GCMs were ranked by rainfall not runoff and because the GCMs were ranked on the basis of annual data not monthly data.

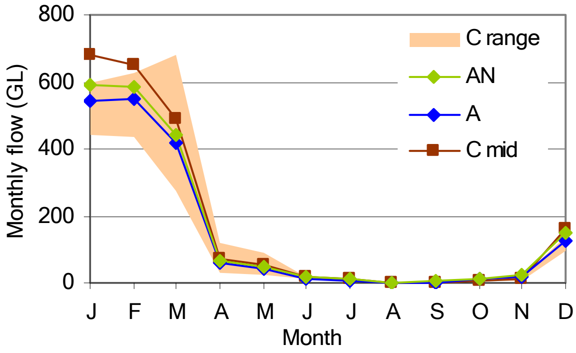


Figure FL-57. Mean monthly flow at the Leichhardt end-of-system under scenarios AN, A and C

The percentage of time that flow is greater than 1 ML/day under these scenarios is presented in Table FL-33. Under climate scenarios there is not a large impact to low flows at the end-at-system.

Table FL-33. Percentage of time modelled flow at the Leichhardt end-of-system is greater than 1 ML/day under scenarios AN, A, B and C

| Catchment | AN | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|
| Leichhardt | 61% | 52% | 51% | 53% | 52% | 50% |

## FL-3.6.14 Leichhardt system share of water resource

### Non-diverted water shares

There are several ways of considering the relative level of impact on non-diverted water. Table FL-34 presents two indicators for relative impact on non-diverted water:

- the average annual non-diverted water as a proportion of the available water
- average annual non-diverted water under each scenario compared with average annual non-diverted water under Scenario A.

Most water in the Leichhardt is not diverted (92 percent) therefore the change in non-diverted water predominantly reflects changes due to climate.

Table FL-34. Relative level of non-diverted water in the Leichhardt system under scenarios A, B and C

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| Non-diverted water as a percentage of total available water | 92% | 95% | 94% | 93% | 90% |
| Non-diverted share relative to Scenario A non-diverted share | 100% | 167% | 132% | 121% | 75% |

 

## Combined water shares

Figure FL-58 combines the results from water availability, level of development and non-diverted water. The size of the bars indicates total water availability and the subdivision of the bars indicates the diverted and non-diverted fractions.

It should be noted, however, that water availability is based on the mean annual volume of water at the last gauge in the system. For the reasons discussed in Section 0 it is unlikely that this volume of water is accessible for consumptive use.

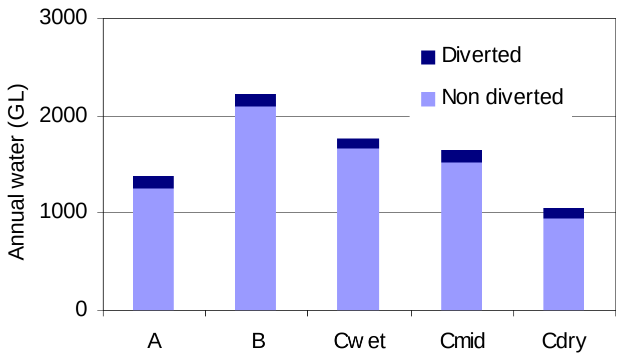


Figure FL-58. Comparison of diverted and non-diverted shares of mean annual water in the Leichhardt system under scenarios A, B and C

FL-3 Water balance results for the Flinders-Leichhardt region

# FL-3.7 Changes to flow regimes at environmental assets

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Three environmental assets have been shortlisted in the Flinders-Leichhardt region: Buffalo Lake Aggregation, Lake Julius and Southern Gulf Aggregation. The locations of these assets are shown in Figure FL-1 and these assets are characterised in Chapter FL-2.

This section presents the assessment of these shortlisted assets and reports metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis. Confidence in results for low flows and high flows was calculated separately on a scale of 1 to 5, with 1 indicating results with the highest confidence (as described in Section 2.2.6 of the division-level Chapter 2). Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are 1, 2 or 3. If confidence levels in the low flows or high flows are ranked 4 or 5, results are not reported and are labelled NR (not reported).

Some of the assets in this region have multiple nodes at which streamflow modelling results are available. When reporting hydrological regime metrics for such assets a single node was selected. The selected node was that with the highest streamflow confidence level and the largest proportion of streamflow to the asset. Results for all nodes are presented in McJannet et al. (2009).

In the absence of site-specific metrics for the Flinders-Leichhardt region a set of standard metrics related to high and low flows have been utilised. However the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and ecology.

## FL-3.7.1 Standard metrics

Table FL-35. Standard metrics for changes to flow regime at environmental assets in the Flinders-Leichhardt region

| Standard metrics | Units | AN | B | Cwet | Cmid | Cdry | Dwet | Dmid | Ddry |
|---|---|---|---|---|---|---|---|---|---|
| | | | change from Scenario A | | | | | | |
| Lake Julius - Node 1 (confidence level: low flow = <3, high flow = <3) | | | | | | | | | |
| Annual flow (mean) | GL | 279 | +72% | +16% | +0% | -40% | nm | nm | nm |
| Wet season flow (mean)* | GL | 251 | +87% | +19% | +3% | -36% | nm | nm | nm |
| Dry season flow (mean)** | GL | 28.0 | -58% | -7% | -22% | -68% | nm | nm | nm |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | 0 | | | | | nm | nm | nm |
| Number of days below low flow threshold (mean) | d/y | 188 | +57.1 | +56 | +58.1 | +65.4 | nm | nm | nm |
| Number of days of zero flow (mean) | d/y | 188 | +57.1 | +56 | +58.1 | +65.4 | nm | nm | nm |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | 2.1 | | | | | nm | nm | nm |
| Number of days above high flow threshold (mean) | d/y | 18.3 | +5.9 | +0.9 | -0.8 | -5.4 | nm | nm | nm |
| Southern Gulf Aggregation - Node 2 (confidence level: low flow = <3, high flow = <3) | | | | | | | | | |
| Annual flow (mean) | GL | 1949 | +44% | +18% | +10% | -32% | nm | nm | nm |
| Wet season flow (mean)* | GL | 1855 | +50% | +17% | +11% | -31% | nm | nm | nm |
| Dry season flow (mean)** | GL | 94.0 | -72% | +37% | -7% | -50% | nm | nm | nm |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | 0 | | | | | nm | nm | nm |
| Number of days below low flow threshold (mean) | d/y | 118 | -4.9 | +6.3 | -11.6 | -3.1 | nm | nm | nm |
| Number of days of zero flow (mean) | d/y | 118 | -4.9 | +6.3 | -11.6 | -3.1 | nm | nm | nm |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | 17.2 | | | | | nm | nm | nm |
| Number of days above high flow threshold (mean) | d/y | 18.3 | +2.6 | +0.3 | +0.1 | -4.4 | nm | nm | nm |

* Wet season covers the six months from November to April.

** Dry season covers the six months from May to October.

nm – not modelled

 

Note that the results for the above asset nodes come from an IQQM model therefore Scenario AN results represent predevelopment conditions. Scenario B represents the last 11 years of climate with full allocation of existing water entitlements and Scenario C represents climate change scenarios with full allocation of existing water entitlements (see Section FL-3.6 for details).

### Buffalo Lake Aggregation

The surface water flow confidence level for this asset is considered unreliable (4 or 5) for both high flows and lows which is too unreliable to allow environmental flow metrics to be calculated for this asset.

### Lake Julius

The surface water flow confidence level for the selected reporting node for Lake Julius (see location on Figure FL-9) is considered to be at least moderately reliable (<3) for wet season and dry season flows (Table FL-35). Under Scenario AN annual flow into this asset is dominated by wet season flows (90 percent) which increase greatly (87 percent) under Scenario B. On the other hand, compared to Scenario AN, dry season flows are less than half (-58 percent) under Scenario B. Annual and wet season flows do not change much under Scenario Cmid compared to Scenario AN, but there are moderate increases under Scenario Cwet (7 to 19 percent) and large decreases under Scenario Cdry (36 to 68 percent). No separate Scenario D modeling was undertaken.

The low flow threshold for this asset node is zero, which occur 52 percent of the year on average under Scenario AN (Table FL-35). The number of days when flow is less than the low flow threshold increases dramatically under all three scenarios Cdry, Cmid and Cwet. Under Scenario B high flows have been more frequent than under Scenario AN. Under scenarios Cmid or Cwet high flow threshold exceedance do not change much from Scenario AN. However, there is a moderate decrease in high flow days under Scenario Cdry.

### Southern Gulf Aggregation

The surface water flow confidence level for the selected reporting node for the Southern Gulf Aggregation (see location on Figure FL-10) is considered to be at least moderately reliable (<3) for both wet season and dry season flows (Table FL-35). Under Scenario AN annual flow into this asset is dominated by wet season flows (95 percent) which are a lot higher (50 percent) under Scenario B. On the other hand, dry season flows are less than half (-72 percent) under Scenario B when compared to Scenario AN. Annual and wet season flows increase moderately under Scenario Cmid when compared to Scenario AN, and there are even higher increases under Scenario Cwet (17 to 37 percent) and large decreases under Scenario Cdry (31 to 50 percent). No separate Scenario D modeling was undertaken.

Under Scenario AN the low flow threshold for this asset node is zero, which occurs 32 percent of the year on average (Table FL-35). The number of days when flow is less than the low flow threshold decreases moderately under scenarios Cmid and Cdry when compared to Scenario AN and there is a small increase in low flow days under Scenario Cwet. Under Scenario B flows have been more frequent than under Scenario AN. Under scenarios Cmid and Cwet high flow threshold exceedance does not change much from Scenario AN. However there is a moderate decrease in high flow days under Scenario Cdry.

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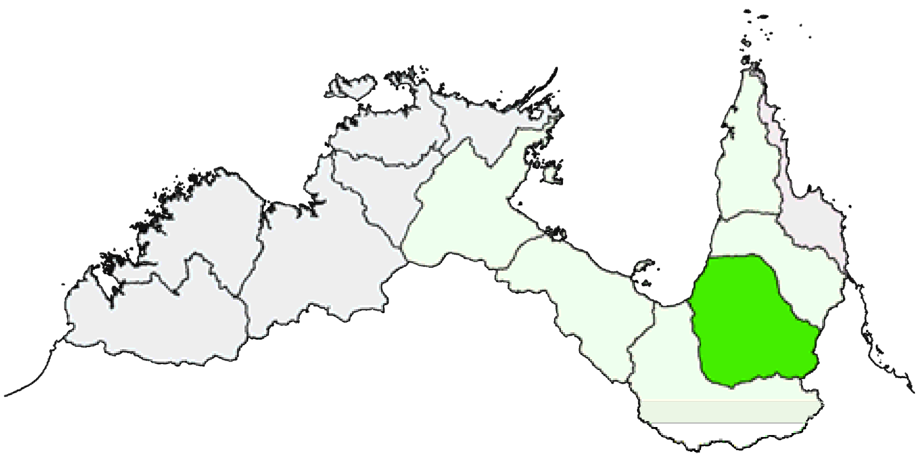
# Water in the South-East Gulf region



# SE-1 Water availability and demand in the South-East Gulf region

The first part of this report (the Preamble, Chapter 1 and Chapter 2) reports at the division level, including division-wide descriptions of climate and geology and methods which apply to all regions. Subsequent chapters report at the region level. In particular, Chapters SE-1, SE-2 and SE-3 focus on the South-East Gulf region (Figure SE-1).

This chapter summarises the water resources of the South-East Gulf region, using information from Chapter SE-2 and Chapter SE-3, and directly addresses the Terms of Reference, specifically terms 3, 4 and 5 as listed in the Preamble. Essentially, this chapter provides a synoptic view of the region and covers:

- regional observations
- water resource assessment
- seasonality of water resources
- surface–groundwater interaction
- changes to flow regime at environmental assets
- water storage options
- data and knowledge gaps.

For further details on the context of the region (physical and climate descriptions, hydrogeology and legislation) see Chapter SE-2. Region-specific methods and results are provided in Chapter SE-3. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2.

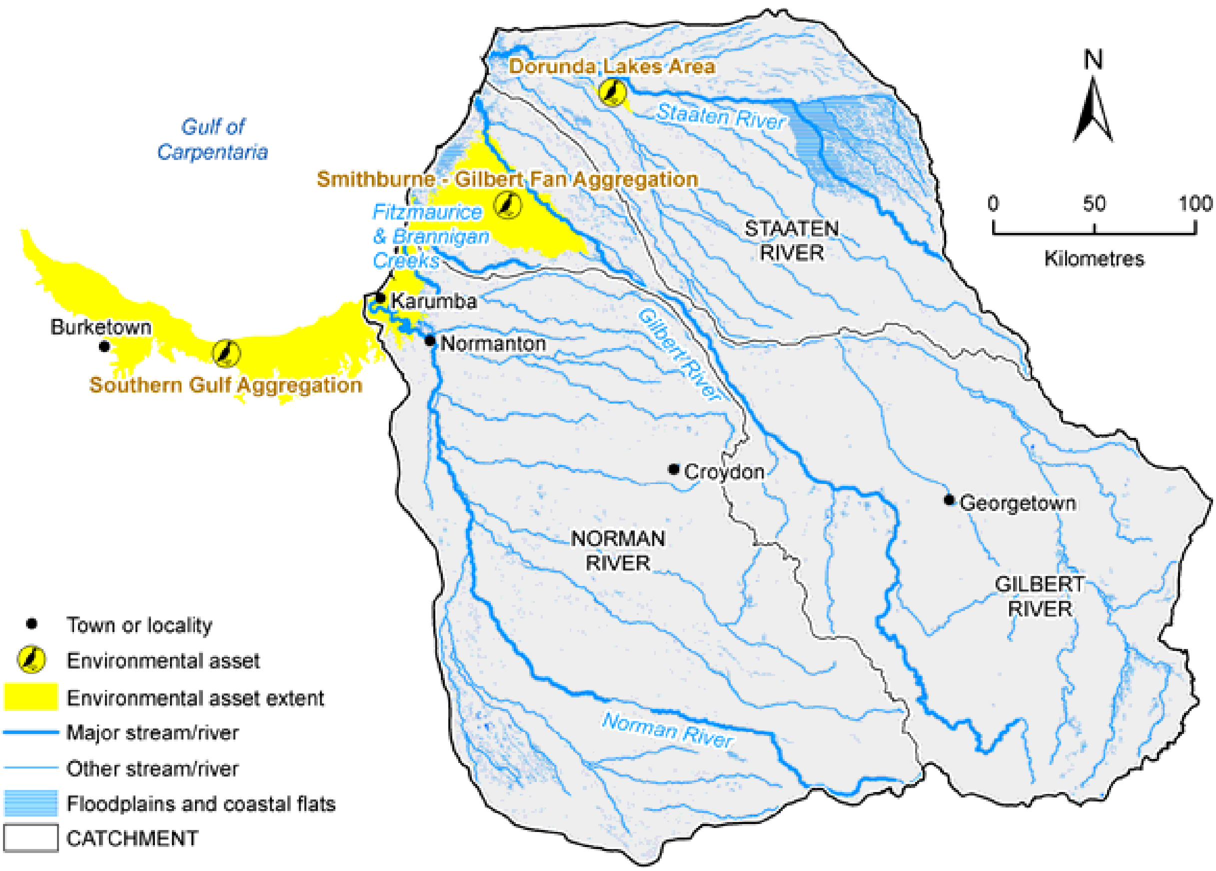



Figure SE-1. Major rivers, towns and location of environmental assets selected for assessment of changes to hydrological regime in the South-East Gulf region

## SE-1.1 Regional summary

These regional observations summarise key modelling results and other relevant water resource information about the South-East Gulf region.

The South-East Gulf region has a high inter-annual variability in rainfall and hence runoff and recharge. Coefficients of variation are the highest of the regions across northern Australia and reflect multiple years over significantly below average and above average rainfall.

The mean annual rainfall for the region is 750 mm. Mean annual areal potential evapotranspiration (APET) is 1980 mm. The mean annual runoff averaged over the modelled area of the South-East Gulf region is 113 mm, 15 percent of rainfall. Compared to other regions, average rainfall is low and APET is high. Under the historical climate the mean annual streamflow over the South-East Gulf region is estimated to be 14,430 GL.

There is a strong seasonality in rainfall patterns, with 95 percent of rainfall falling between November and May, and a very high dry season potential evapotranspiration. The region has a relatively high rainfall intensity, and hence rapid runoff and short lag between rainfall and runoff with a slightly increasing amount and intensity of rainfall from 1930 to 2007.

There is a strong north–south rainfall gradient and between 10 and 30 percent of precipitation flows as runoff.

The region is water-limited; in other words there is more energy available to remove water than there is water available to be removed.

The South-East Gulf region has a recent (1996 to 2007) climate record that is statistically significantly similar to the historical (1930 to 2007) record. Modelling suggests that future (~2030) conditions will also be similar to historical conditions; hence, future runoff and recharge are likely similar to historical levels.

Deep aquifers contain the largest storage of water. The Gilbert River Formation of the Great Artesian Basin is the main groundwater resource in the region. This is predominantly a confined aquifer, but is found in rock outcrop to the south and east where it provides baseflow to the Norman River and is likely responsible for extending the duration of flow into the dry season. The Gilbert River Formation and Eulo Queen Group aquifers also provide groundwater discharge to the Gilbert River, Yappar River, Clara River and Boorabin Creek, allowing surface water flows in many rivers to be maintained well into the dry season.

The Great Artesian Basin springs discharging in the region provide an important source of water. The shallow alluvial aquifers are characterised by variable thickness and groundwater quality and are therefore a relatively undeveloped groundwater resource.

There are few opportunities for surface water storage and most are in the southern, drier headwater areas, where potential evapotranspiration is highest within the region. Lower reaches are flood determined and dominated. Generally the region has low relief.

None of the environmental assets in this region have any site-specific ecology related flow metrics by which to gauge the potential impacts of future climate change and development scenarios. Streamflow estimates in this region are not of a sufficient confidence level to even assess changes to flow regime at these assets.

Only the Gilbert River basin has a river systems model. Current average surface water availability in the Gilbert system is 3724 GL/year and on average about 29 GL/year (or less than 1 percent) of this water is used. This is a very low level of development.

The region is generally data poor.

The South-East Gulf region is a relatively isolated area with little development. There is minor demand for water in this region largely owing to the small population.

# SE-1.2 Water resource assessment

Term of Reference 3a

## SE-1.2.1 Under historical climate and current development

Term of Reference 3a (i)

Mean annual rainfall in the South-East Gulf region is 750 mm, with a standard deviation of 129 mm. Maximum recorded rainfall fell in 1974 with 2126 mm; the lowest was in 1952 with 329 mm. Mean annual areal potential evapotranspiration (APET) is 1980 mm, with a relatively small variation (standard deviation of 74 mm). Highest APET occurred in 1931 (2075 mm); lowest in 1974 (1804 mm). The mean annual modelled runoff averaged over the modelled area of the South-East Gulf region is 110 mm, 15 percent of rainfall. Rainfall and runoff generation both decline with distance from the coast but otherwise show little spatial variation.

Rainfall is very seasonal, with 95 percent falling during the wet season (November to April), and runoff is highest in February and March.

Rainfall values are low in comparison to other regions. Rainfall and runoff vary little across the region, in keeping with the subdued topography. Rainfall is very seasonal and runoff is highest in February and March.

Current average surface water availability is 3724 GL/year and on average about 29 GL/year (or less than 1 percent) of this water is allocated under full use of existing entitlements. This is a low level of development.

Licensed groundwater extraction is currently a very low 0.193 GL/year in the South-East Gulf region. All groundwater extraction from Great Artesian Basin (GAB) aquifers is licensed, including that used for stock and domestic purposes – although these purposes have no volumetric entitlement. Groundwater use for stock and domestic purposes in the region is estimated to be more than 11 GL/year, most of which comes from the GAB aquifers. Natural groundwater discharge from the GAB aquifers plays an important role in providing dry season flows in many of the streams in the region, as reflected in the dry season baseflow volumes estimated for the Einasleigh, Gilbert and Norman rivers and Elizabeth Creek (Table SE-1). It has been suggested that dry season baseflow is also important in the Clara and Yappar rivers, as well as Boorabin Creek (AGE, 2005).

Table SE-1. Estimated groundwater contribution (baseflow) to streamflow, modelled diffuse recharge and groundwater extraction for the for the South-East Gulf region under historical climate

| Station | River | Station name | Annual BFI * | Dry season BFI * | Dry season baseflow ** |
|---|---|---|---|---|---|
| | | | | | GL |
| 916001A | Norman | Rocky Waterhole | 0.18 | 0.16 | 0.5 |
| 917001D | Gilbert | Rockfields | 0.09 | 0.14 | 0.6 |
| 917002A | Robertson | Robin Hood | 0.07 | 0.23 | 0.2 |
| 917008A | Little | Inorunie | 0.13 | 0.31 | 0.1 |
| 917104A | Etheridge | Roseglen | 0.10 | 0.16 | 0.2 |
| 917105A | Copperfield | Narrawa No 2 | 0.11 | 0.28 | 1.5 |
| 917106A | Einasleigh | Einasleigh | 0.11 | 0.26 | 3.1 |
| 917107A | Elizabeth Ck | Mount Surprise | 0.26 | 0.76 | 3.4 |
| 917108A | McKinnons Ck | Possum Pad | 0.05 | 0.06 | 0.1 |
| 917115A | Copperfield | Spanner Waterhole | 0.14 | 0.40 | 1.0 |
| 917116A | Copperfield | Kidston Dam Headwater | 0.12 | 0.16 | 0.1 |
| 917118A | Copperfield | Kidston Dam Tailwater | 0.11 | 0.19 | 0.6 |
| | | Historical recharge ** | Estimated groundwater extraction | | |
| | | GL/y | | | |
| Entire South-East Gulf region | | 8310 | | | 12 |

* BFI (baseflow index) and baseflow volume derived from gauged data.

** Aggregated recharge using Zhang and Dawes (1998).

Under a continued historical climate, mean annual groundwater recharge to the unconfined aquifers of the South-East Gulf region is likely to be similar to the historical (1930 to 2007) average. When coupled with current rates of groundwater extraction from the shallow aquifers, this means the groundwater balance of these systems is unlikely to change by 2030. Furthermore, because the GAB is such a large, regional groundwater flow system that is recharged in a relatively small area of intake beds, subtle changes in the recharge rates are unlikely to be reflected in the groundwater levels of this system by 2030.

### SE-1.2.2 Under recent climate and current development

Term of Reference 3a (ii)

The mean annual rainfall under the recent (1930 to 2007) climate, averaged over the entire region, has increased by 7 percent relative to the historical average, but within the region varies from -10 to +30 percent. Only the slight increase recorded in the Staaten River basin is statistically significantly different from the historical average. Runoff over the last 11 years is lower by 13 percent relative to the historical (1930 to 2007) mean values.

Under a continued recent climate, mean annual groundwater recharge to unconfined aquifers in the South-East Gulf region may be slightly lower than the historical average rate. The fact that recharge is predicted to be lower when rainfall is higher than the historical value reflects the importance of climate variables other than total rainfall (e.g., rainfall intensity and temperature) in determining recharge (see division approaches section 2.3.3). Nevertheless, because groundwater extraction from these systems is currently very low, it is unlikely there would be measurable change in groundwater resource condition by 2030.

### SE-1.2.3 Under future climate and current development

Term of Reference 3a (iii)

Future climate is expected to be similar to historical climate. Under the median future climate, annual rainfall is 750 mm; under the wet extreme future climate, annual rainfall is 855 mm; and under the dry extreme future climate, annual rainfall is 698 mm. Corresponding areal potential evapotranspiration (APET) under these scenarios is 2026, 2035 and 2065 mm, respectively, or 2.3 to 4.3 percent higher than historical results.

Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the South-East Gulf region is slightly more likely to decrease than increase. Rainfall-runoff modelling with climate change projections from three-fifths of the GCMs shows a reduction in mean annual runoff, while rainfall-runoff modelling with climate change projections from two-fifths of the GCMs shows an increase in mean annual runoff. The median estimate is for a -1 percent change to the mean annual runoff by 2030. The extreme estimates, which come from the high global warming scenario, range from a 46 percent increase to a 23 percent decrease in mean annual runoff. By comparison, the range from the low global warming scenario is a 24 percent increase to a 13 percent reduction in mean annual runoff.

Under the median future climate there would be a 7 percent increase in water availability and no change to diversions for all water products.

The climate extremes for 2030 indicate:

- under the wet extreme future climate, water availability increases 23 percent and no change to total diversions
- under the dry extreme future climate, water availability decreases 15 percent and total diversions decrease 3 percent.

Under the future climate, modelled mean annual groundwater recharge to the unconfined aquifers of the South-East Gulf region is likely to be higher than the historical average. This finding is counter-intuitive and reflects the fact that annual recharge is dependent on factors other than just annual rainfall (e.g., rainfall intensity). Without an appropriate groundwater model for the region, it is not possible to predict the magnitude of any resource condition change that might occur as a result of this increased recharge.

### SE-1.2.4 Under future climate and future development

Term of Reference 3a (iv)

Most water in the Gilbert River basin (99 percent) and all in the Staaten and Norman river basins is not diverted, therefore future development scenarios for surface water are similar to the scenario under current development.

There is currently no existing numerical groundwater flow model for the South-East Gulf region that incorporates all of the main aquifer types, including the alluvial aquifers, Tertiary sediments and GAB aquifer. Without such a model, it was not possible to predict the impacts of future climate or potential future development on these groundwater resources.



## SE-1.3 Changes to flow regime at environmental assets

Term of Reference 3b

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Three environmental assets were shortlisted for the South-East Gulf region: Dorunda Lakes Area, the Smithburne–Gilbert Fan Aggregation and the Southern Gulf Aggregation. These assets are characterised in Chapter SE-2.

In deciding whether it is feasible to report hydrological regime metrics for these shortlisted assets, it is important to consider the confidence levels in modelled streamflow (as described in Section 2.2.6 of the division-level Chapter 2). Confidence in results for low flows and high flows was calculated separately. Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are sufficiently high. If confidence in the low flow or high flow is too low, metrics are not reported, and hence an important gap in our knowledge is identified.

Unfortunately there is insufficient confidence in the modelled streamflow to report hydrological regime metrics for any of the environmental assets in the region.

## SE-1.4 Seasonality of water resources

Term of Reference 4

The rivers have a marked seasonal flow regime of high water levels and extensive flooding during the wet season (November to April) and decreased water flow and river stage towards the end of the dry season.

Approximately 95 percent of rainfall and 99 percent of runoff occurred during the wet season months under the historical and recent climate. Very similar seasonal percentages of rainfall and runoff are projected to occur at 2030.

## SE-1.5 Surface–groundwater interaction

Term of Reference 4

The Norman River originates in the Gregory Range to the southeast and terminates at Alligator Point on the coast of the Gulf of Carpentaria. The smaller Carron, Clara and Yappar rivers all flow into the Norman. There is considerable interconnection between streams which results in widespread and severe flooding in times of high flow. Groundwater discharge from the Gilbert River Formation provides significant baseflow in a number of these streams, including the Norman, Yappar and Clara rivers.

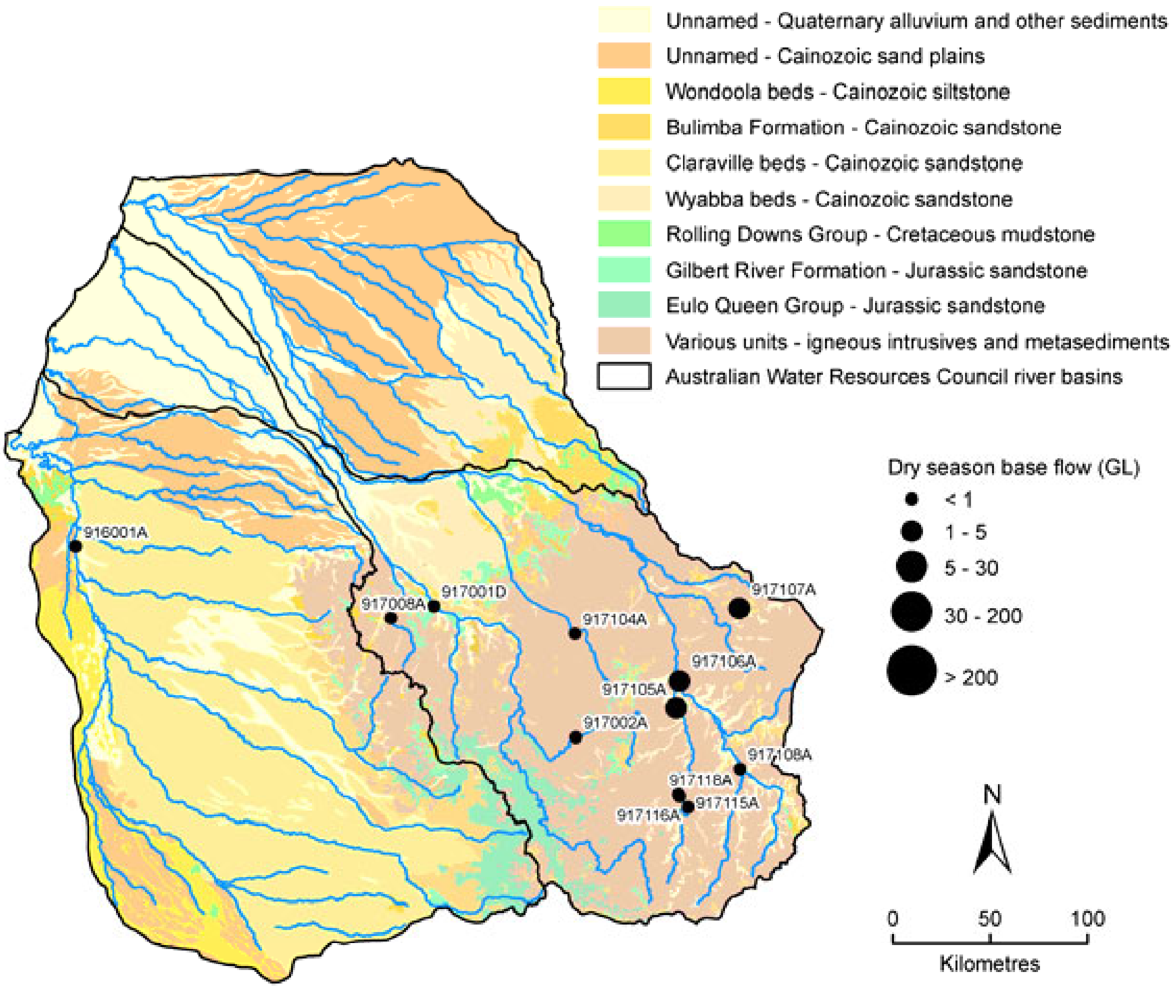



Figure SE-2. Surface geology and modelled mean dry season baseflow of the South-East Gulf region

The Einasleigh River joins the Gilbert River in the north of the Gilbert River basin, before flowing to the Gulf of Carpentaria. Groundwater discharge from the Gilbert River Formation provides baseflows to the upper reaches of the Gilbert River (DNRM, 2005) and its tributaries (Table SE-1 and Figure SE-2).

Spring discharge occurs in the outcrop areas of the Gilbert River Formation and Eulo Queen Group due to rejected recharge, where topography is relatively steep and incised compared with the remainder of the South-East Gulf region. Where rivers intersect these aquifers, they receive baseflow for much of the dry season. The Gilbert River Formation and Eulo Queen Group aquifers support significant surface water features in the outcrop areas such as Cobbold and Porcupine Gorge National Parks (DNRM, 2005). Throughflow from these aquifers to the west and south-west support mound springs and associated environments of the Flinders Spring Group. Figure SE-3 shows the river reaches potentially receiving baseflow as well as the location of GAB springs.

During the wet season, surface water infiltrates from the river to the surficial aquifers, either laterally via the incised sediments, or vertically via diffuse recharge when overbank flooding occurs.

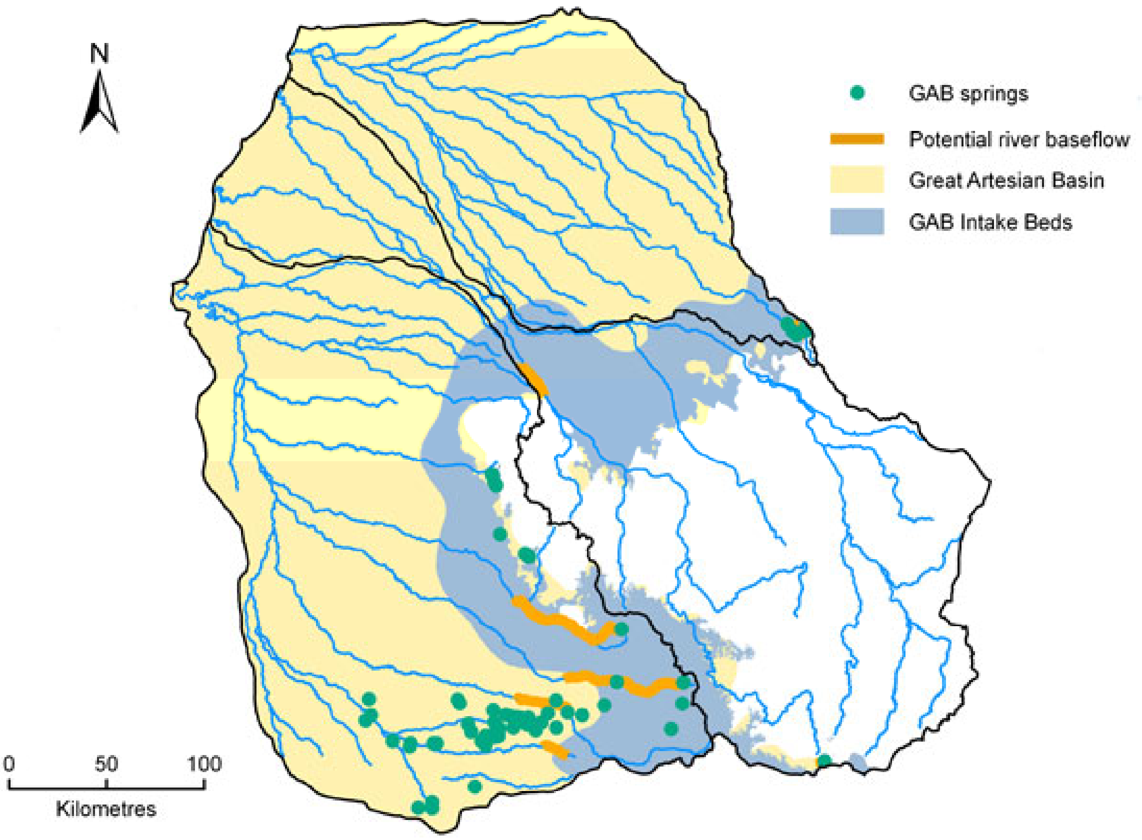



Figure SE-3. Locations of spring groups and potential river baseflow in the South-East Gulf region

## SE-1.6 Water storage options

Term of Reference 5

### SE-1.6.1 Surface water storages

There are few major storages in the region. The Kidston Dam on the Copperfield River in the far south-east of the Gilbert River basin is the largest with an active storage of 18.5 GL. The Norman River has a few small local storages. Storage options are restricted to small regions in the headwater areas of the region. The Staaten rivers basin is a declared wild river area. In stream dams and weirs cannot be constructed in wild rivers or their major tributaries.

### SE-1.6.2 Groundwater storages

The main aquifer in the South-East Gulf region is the Gilbert River Formation of the GAB. Extraction from this resource for stock and domestic purposes is, by far, the greatest use of water in the region. Where the aquifer outcrops and is unconfined, recharge during the wet season fills any available storage before ‘rejecting’ excess recharge back into the rivers. Managed aquifer recharge (MAR) therefore has limited applicability in these areas. Further towards the north-west, the aquifer in the Gilbert River Formation becomes confined and ultimately artesian – a condition not favourable for MAR.

## SE-1.7 Data gaps

Term of Reference 1e

There are 19 weather stations in the region that have better than 80 percent record completeness, and 11 that pass 90 percent, making the South-East Gulf region the second most data-rich region of northern Australia, at least for rainfall.

Floodplain gauging is lacking, hence only end-of-system flow is modelled. Flood extent and volume measurements would increase the accuracy of the river system models.

Confidence levels in the modelled streamflow were too low to allow flow metrics to be calculated at environmental assets and there is uncertainty as to the contribution of groundwater to certain rivers. This would suggest that more river gauging and groundwater monitoring is required.

Time series groundwater level and salinity data are required for each of the main aquifer types in the South-East Gulf region to provide greater understanding of recharge processes and inter-aquifer leakage, particularly for the GAB aquifers.

## SE-1.8 Knowledge gaps

Term of Reference 1e

Dry season flows are poorly understood in this region – therefore the ability to predict the potential impacts of the various scenarios on low or zero flows at environmental assets is very limited. Improved monitoring of low streamflow conditions is needed along with the development of hydrological models that combine surface and groundwater regimes. Further monitoring of groundwater levels is also required so that the potential impacts of climate change and development scenarios on groundwater dependant ecosystems can be better understood.

Flooding is an important factor that sustains many environmental assets and this occurs when the stream breaks out of it's banks (a level known as bankfull stage or discharge). However, bank full discharge is not known for many streams, nor is the dependence of area flooded on increasing stream depth, so it is difficult to predict when assets are inundated. Further information about bank full stage and discharge are needed for most environmental assets.

None of the environmental assets in this region have any site-specific metrics by which to gauge the potential impacts of future climate change and development scenarios. In the absence of site-specific metrics a set of standard metrics related to high and low flows have been utilised; however, the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and specific ecological entities (for example, macrophyte populations, fish passage, faunal and floral habitats, etc.).

Many environmental assets depend not simply on duration above or below certain flow levels, but on triggers (e.g. for reproduction or migration) set by the rate of change of flow. In addition, some environmental assets depend on the frequency and duration of events that occur less than annually (i.e. once every 5, 10 or 20 years or more). Further analysis is therefore required to look at how the timing, duration and rate of rise and fall in flow at critical times of the season will vary under the various scenarios.

Diffuse upward leakage of water out of the GAB aquifers and into overlying Tertiary sediments is yet to be quantified. Further research is required to estimate these discharge fluxes so that a detailed groundwater balance can be developed for the aquifers to guide future management in the region.

## SE-1.9 References

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# SE-2 Contextual information for the South-East Gulf region

This chapter summarises the background information for the region, outlining existing knowledge of water resources and prior and current investigations relevant to the water resources of the region. This chapter also outlines the current and potential future legislation, water plans and other water resource management arrangements. This chapter is arranged into four sections:

- physical and climate descriptions
- data availability
- hydrogeology
- legislation, water plans and other arrangements.

# SE-2.1 Overview of the region

## SE-2.1.1 Geography and geology

The South-East Gulf region is located in the Gulf of Carpentaria Drainage Division and covers 122,530 km$^2$. It comprises the Australian Water Resource Council (AWRC) river basins of the Staaten (25,897 km$^2$), Gilbert (46,354 km$^2$) and Norman (50,279 km$^2$). These rivers rise in the Great Dividing Range south and east of Georgetown, flowing in a generally north-west direction to the coast, where the rivers spread out into extensive floodplains and deltas running north of Karumba.

The Norman river rises in the Gregory Range (Great Dividing Range) 200 km south-east of Croydon and flows in a north-westerly direction. It is joined by its major tributaries, the Clara and Yappar Rivers, near the river height and rainfall station of Yappar River. The river flows through the major town of Normanton, before finally entering the Gulf of Carpentaria through the major fishing port of Karumba. The only other town in the catchment is the old historic gold mining town of Croydon. Floods normally develop in the headwaters of the Norman, Clara and Yappar rivers; however, general heavy rainfall situations can develop from cyclonic influences causing widespread flooding, particularly in the lower delta country around Normanton and Karumba. There is considerable interconnection between streams in this catchment, hence high flow leads to severe flooding.

The Gilbert River flows in a north-westerly direction from the Great Dividing Range, 150 km south-east of Georgetown, and is joined by its major tributary, the Einasleigh River, downstream of Strathmore, before finally entering the Gulf of Carpentaria in a river delta 100 km wide. The other main tributary, the Etheridge River, joins the Einasleigh River downstream of Georgetown, which is the only town in this vast catchment. Smaller settlements can be found at Forsayth, Mt Surprise and Einasleigh. Floods develop almost annually in the headwaters of the Gilbert and Einasleigh rivers; however general heavy rainfall situations can develop from cyclonic influences resulting in widespread flooding, particularly in the lower reaches below Strathmore.

The Staaten river basin contains the catchments of the Staaten River and Vanrook Creek, and ten major tributaries. The river systems in the area are in near natural condition due to very low levels of development in their catchments. These river systems have extensive floodplains which are inundated in most wet seasons, further restricting the suitability of these areas for development. Also there are no towns, mining or heavy industry in the area; and large areas of land are within national parks within the wild river area.

Figure SE-4 shows the surface geology of the region, with major towns and relief shading.

 

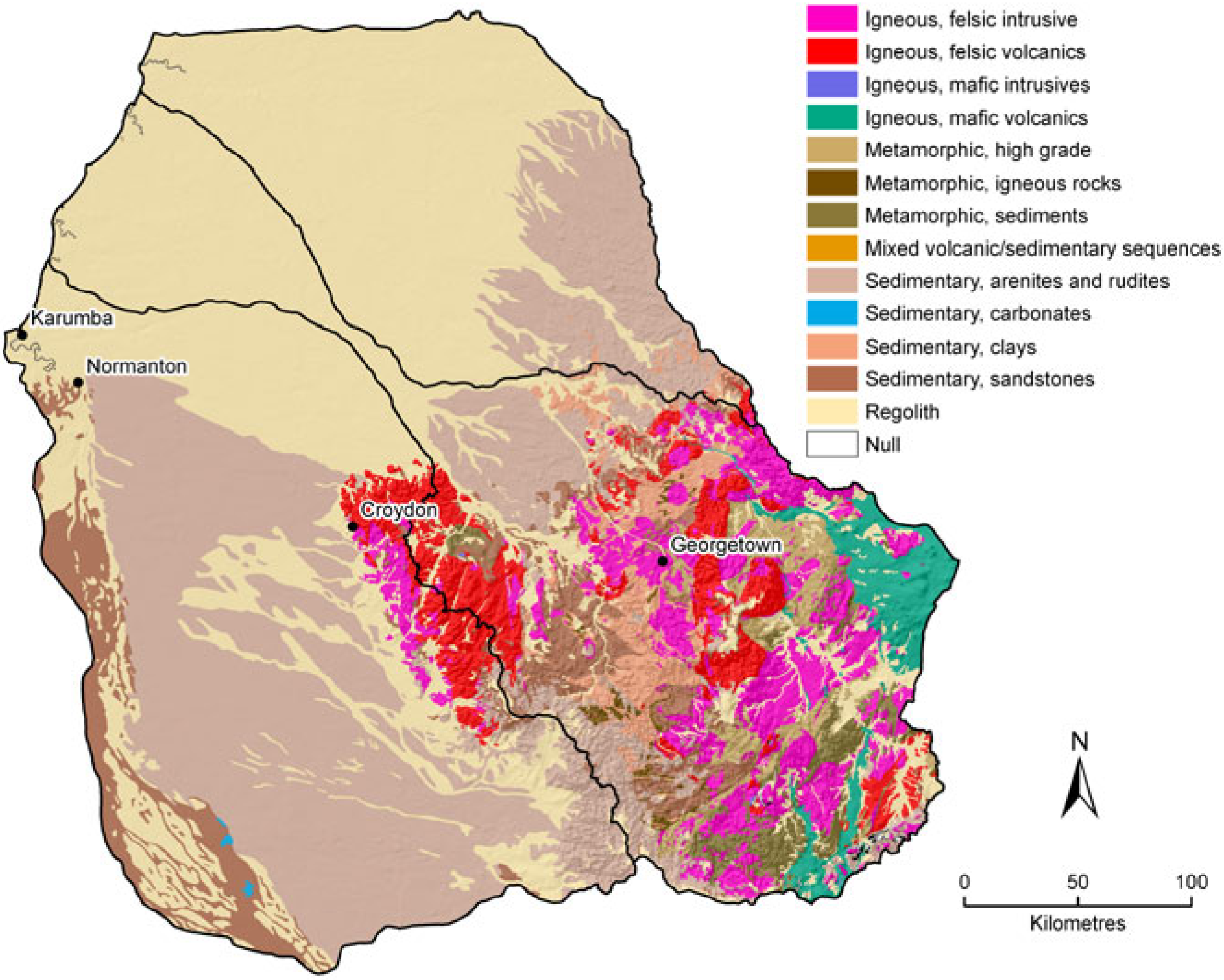


Figure SE-4. Surface geology of the South-East Gulf region overlaid on a relative relief surface



### SE-2.1.2 Climate, vegetation and land use

The South-East Gulf region receives an average of 750 mm of rainfall over a water year (September to August), most of which (710 mm) falls in the November to April wet season (Figure SE-5). Across the region there is a strong north–south gradient in annual rainfall, ranging from 1078 mm in the north to 490 mm in the south. Over the historical (1930 to 2007) period, yearly rainfall has remained reasonably constant.

Areal potential evapotranspiration (APET) is very high across the region, averaging 1980 mm over a water year, and varies moderately across the seasons. APET generally remains higher than rainfall for most of the year resulting in near-year-round water-limited conditions. The exceptions to this are the months January to March, when more rain falls than can potentially be evaporated.

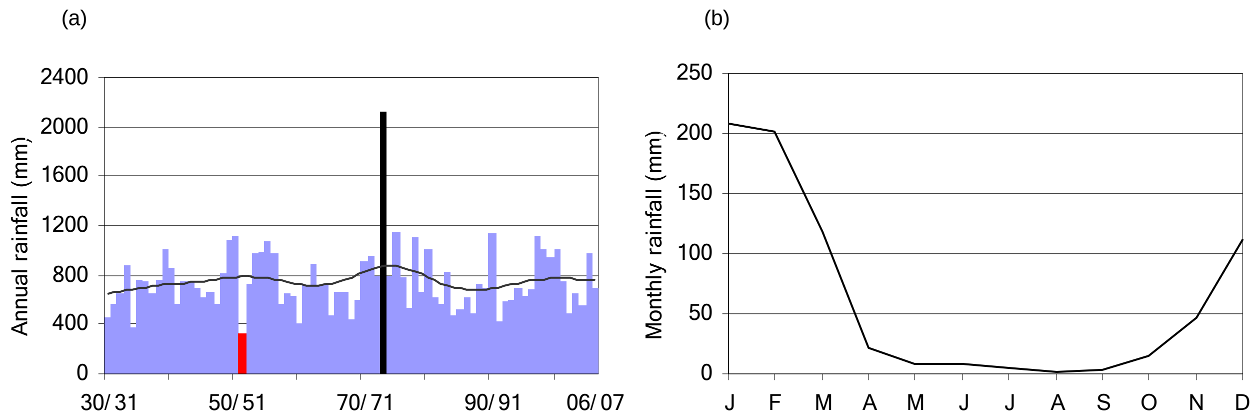


Figure SE-5. Annual and mean monthly rainfall for the South-East Gulf region. The low-frequency smoothed line in (a) indicates longer term variability

There is great variation in vegetation in the South-East Gulf region, ranging from dense eucalypt woodland in the vicinity of surface drainage features, to open grassland (Figure SE-6). The dominant vegetation of the region is medium density scrub with some parcels of swamp land. Highlands are dominated by eucalypt woodlands and flat country by melaleuca forest. The coastal region is characterised by saline coastal flats. There are substantial areas of flood prone land near major watercourses where consequently the vegetation increases in density.

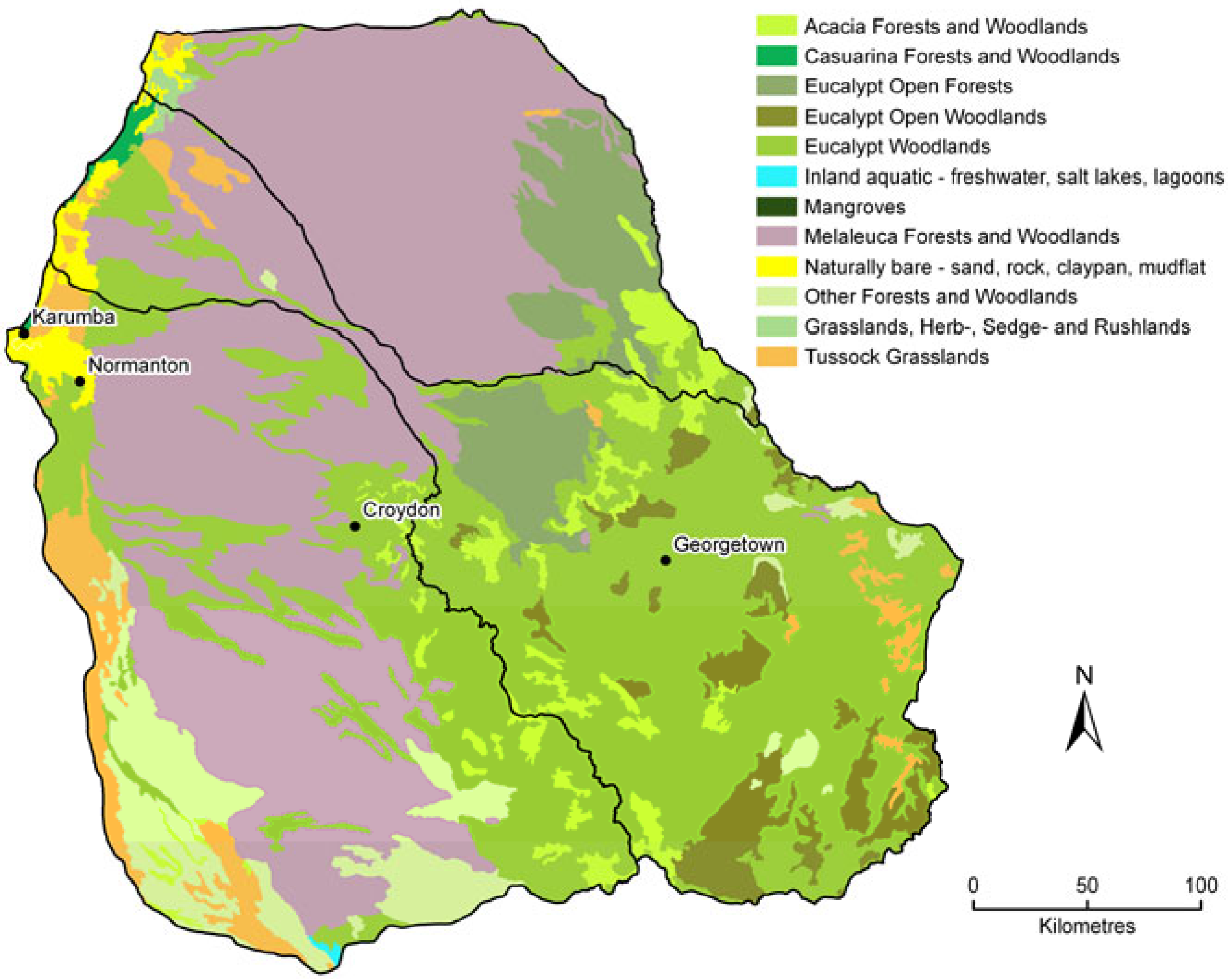


Figure SE-6. Map of current vegetation types across the South-East Gulf region (source DEWR, 2005)

 

The vast majority of the region remains uncleared and is considered an isolated area with little or no development. Pastoralism is the major industry (Figure SE-7).

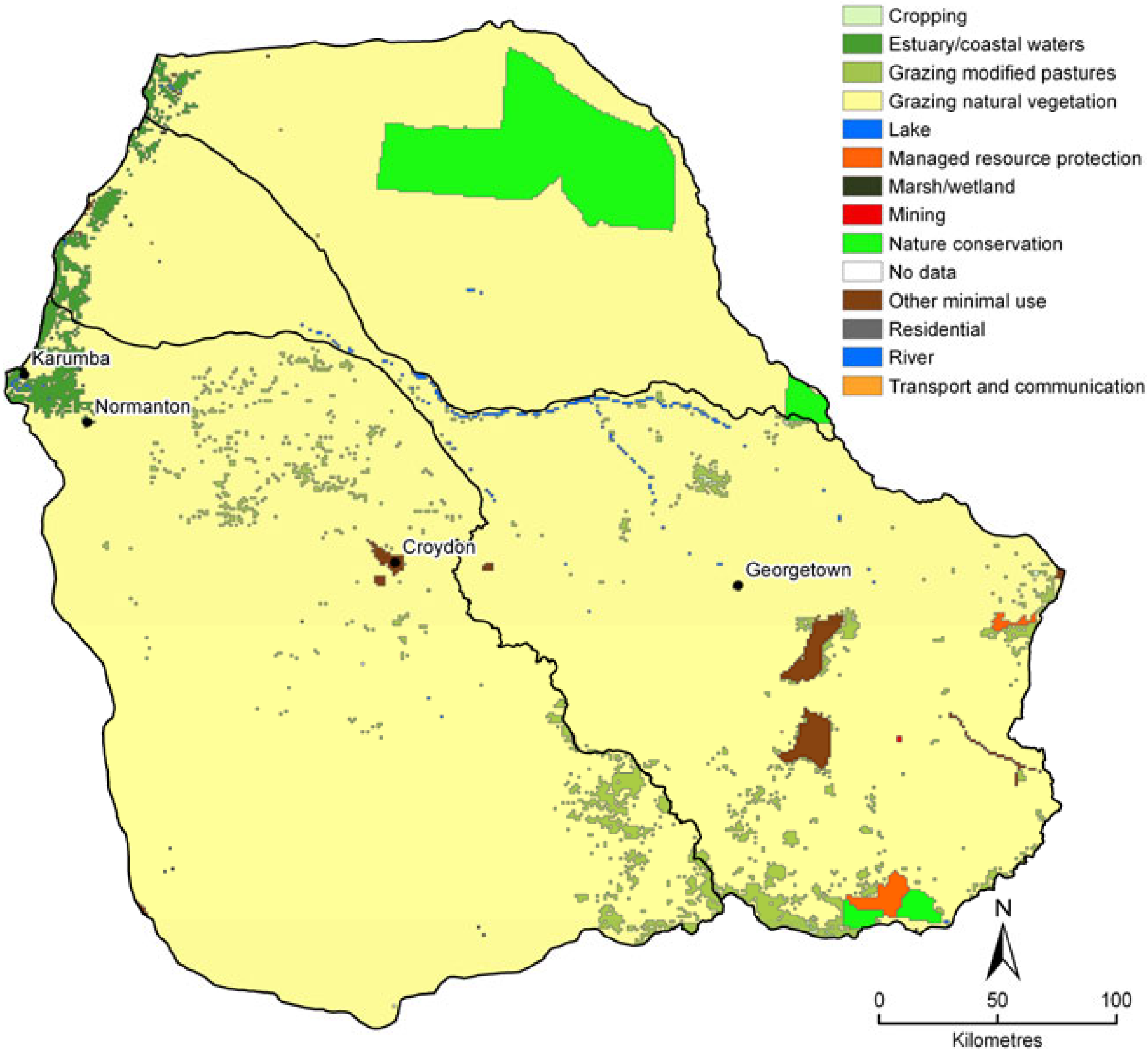


Figure SE-7. Map of dominant land uses of the South-East Gulf region (after BRS, 2002)

## SE-2.1.3 Regional environmental asset description

Environmental assets were chosen from wetlands which are listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001). From this directory, environmental assets were shortlisted for assessing changes to the hydrological regime under the climate and development scenarios. The selection of this shortlist was undertaken in consultation with state governments and the Australian Government through direct discussions and through internal reviews (see Section 1.3 in the division-level Chapter 1 for further detail).

All nationally, or internationally, important wetlands listed for the South-East Gulf region in the Directory of Important Wetlands in Australia (Environment Australia, 2001) are detailed in Table SE-2, with asterisks identifying the three shortlisted assets: Dorunda Lakes Area, Smithburne–Gilbert Fan Aggregation, and Southern Gulf Aggregation. The location of these shortlisted wetlands is shown in Figure SE-1. There are no wetlands classified as Ramsar sites in this region. Wetlands may be nationally or regionally significant depending on more locally specific criteria. All wetlands are important for a variety of ecological reasons or because they bear historical significance or have high cultural value, particularly to Indigenous people.

The following section characterises these shortlisted wetlands and is based largely on the description of these assets as outlined by Environment Australia (2001). Chapter ID-3 presents the assessment of those shortlisted assets, and reports hydrological regime metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis.

Table SE-2. List of Wetlands of National Significance located within the South-East Gulf region

| Site code | Name | Area | Ramsar site |
|---|---|---|---|
| | | ha | |
| QLD104 * | Dorunda Lakes Area | 6,810 | No |
| QLD107 | Macaroni Swamp | 258 | No |
| QLD112 * | Smithburne–Gilbert Fan Aggregation | 251,000 | No |
| QLD113 | Southeast Karumba Plain Aggregation | 336,000 | No |
| QLD114 * | Southern Gulf Aggregation | 546,000 | No |
| QLD094 | Undara Lava Tubes | 1,250 | No |

* Asterisk against the site code identifies those assets which are shortlisted for assessment of changes to flow regime

## Dorunda Lakes Area

The Dorunda Lakes Area (Figure SE-8) is a particularly good example of a complex of permanent, semi permanent and seasonal wetland types with a localised occurrence within the Gulf Plains province of the Gulf Plains bioregion. It is an important refuge for wetland bird species. The Dorunda Lake site is a large semi abandoned riverine channel complex with associated oxbows and swamps. The catchment is a series of unnamed mostly unidirectional streams which drain part of an immense undulating alluvial plain with shallow, widely spaced valleys and a uniform pattern associated with the Mitchell, Staaten and Gilbert rivers. The site has an area of 6,810 ha and an elevation ranging between 10 and 20 m above sea level (Environment Australia, 2001).

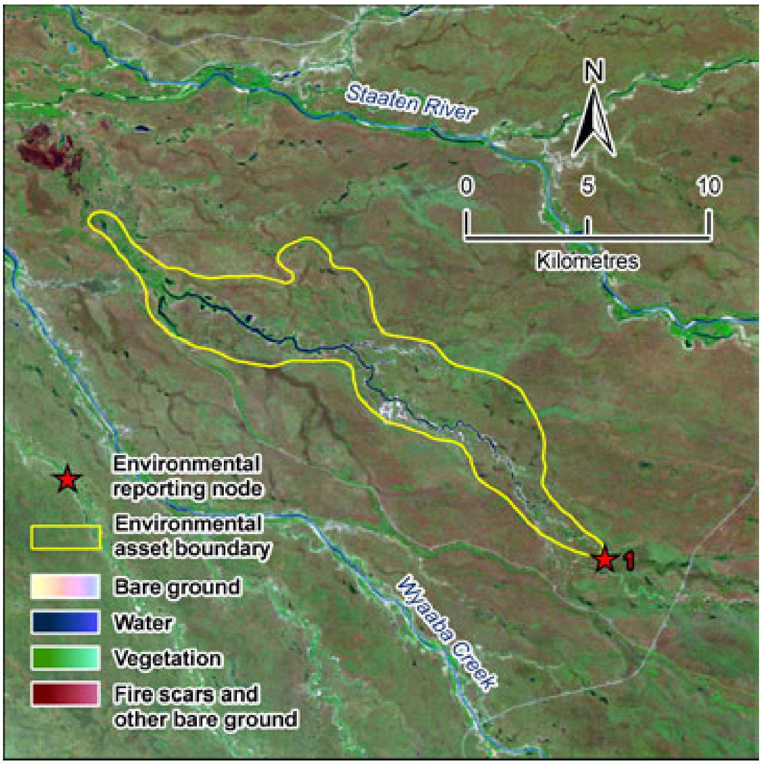


Figure SE-8. False colour satellite image of the Dorunda Lakes Area (derived from ACRES, 2000). Clouds may be visible in image



 

The site's emergent vegetation communities line the large deep riverine pools and aquatic beds occur in the limnetic and littoral areas of the ox-bows and swamps. Upland areas are mostly woodland. The estuarine and freshwater crocodile are found in the area. This is one of the most pristine inland wetland sites in the Gulf Plains (Environment Australia, 2001).

### Smithburne–Gilbert Fan Aggregation

The Smithburne–Gilbert Fan Aggregation (Figure SE-9) contains the best examples of alluvial plain wetlands characteristic of the southern portions of the Smithburne–Gilbert Fans Province of the Gulf Plains bioregion. The site encompasses portions of a stable alluvial plain incised by a complex system of active, mostly seasonal stream channels, frequently flooded depressions and older shallower channels, and partially flooded plains and level terraces. The broad alluvial plain also provides additional local catchment for the many wetlands of the aggregation. The site has an area of 251,000 ha and an elevation ranging between 10 m and 45 m above sea level (Environment Australia, 2001).

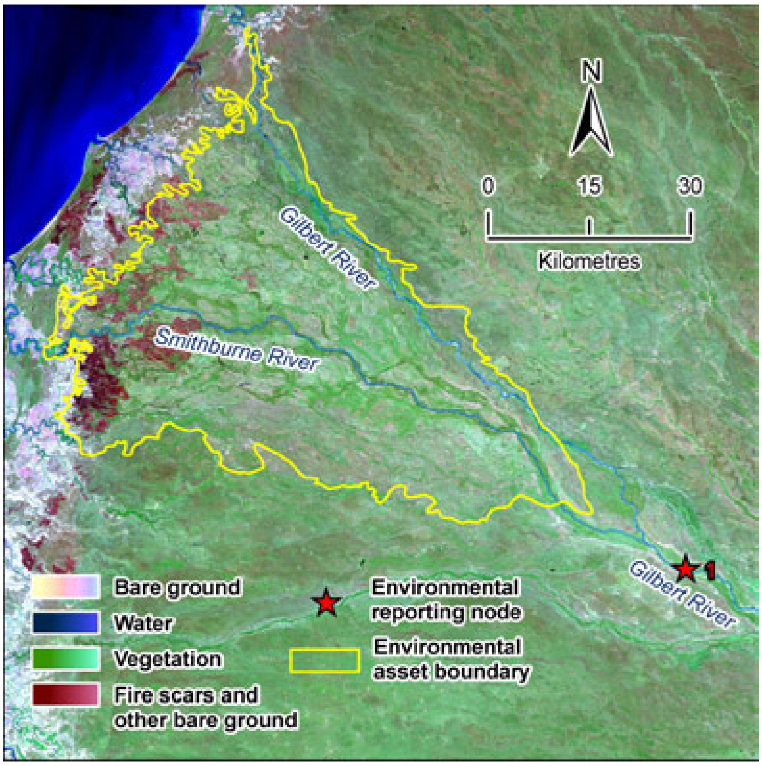


Figure SE-9. False colour satellite image of the Smithburne–Gilbert Fan Aggregation (derived from ACRES, 2000). Clouds may be visible in image

The Smithburne–Gilbert Fan Aggregation contains the greatest concentration of coastal floodplain lagoonal wetlands in the western Cape York Peninsula (Environment Australia, 2001). These provide important dry season (May to October) habitat for many birds. A breeding rookery on the Smithburne River is one of the largest in the western Cape York Peninsula.

## Southern Gulf Aggregation

This huge coastal aggregation covers an area of 546,000 ha and ranges in elevation from zero to 10 m above sea level (Figure SE-10). This wetland area extends across three of the regions defined for this project: the Flinders-Leichhardt, South-West Gulf and South-East Gulf regions. In the South-East Gulf region we are considering reporting node 4. The Southern Gulf Aggregation is a complex continuous wetland aggregation (Blackman et al., 1992) that also encompasses several complex disjunct aggregations of closed depressions. Seaward to landward it comprises a continuum of extensive marine intertidal flats, beaches and foredunes, secondary dunes and swales, saline clay plains, seaward margins of saline clay plains, margins and levees of tidal channels, low elevated plains, and depressions within low elevated plains. The area is under the dominating influence of estuarine tides and massive freshwater flooding during wet season events.

Marine and estuarine tidal waters permanently inundate or regularly flood much of the area. This wet season flooding consists of freshwater from the streams and rivers of the inland catchment combined with local runoff from the plains of the Gulf Fall. The wetlands occurring along the inland margins of the area are brackish and all are seasonal. The aggregation has a major influence on nutrient flow into the Gulf of Carpentaria (Wolanski, 1993).The Southern Gulf Aggregation is the largest continuous estuarine wetland aggregation of its type in northern Australia. It is one of the three most important areas for shorebirds in Australia (Watkins, 1993).

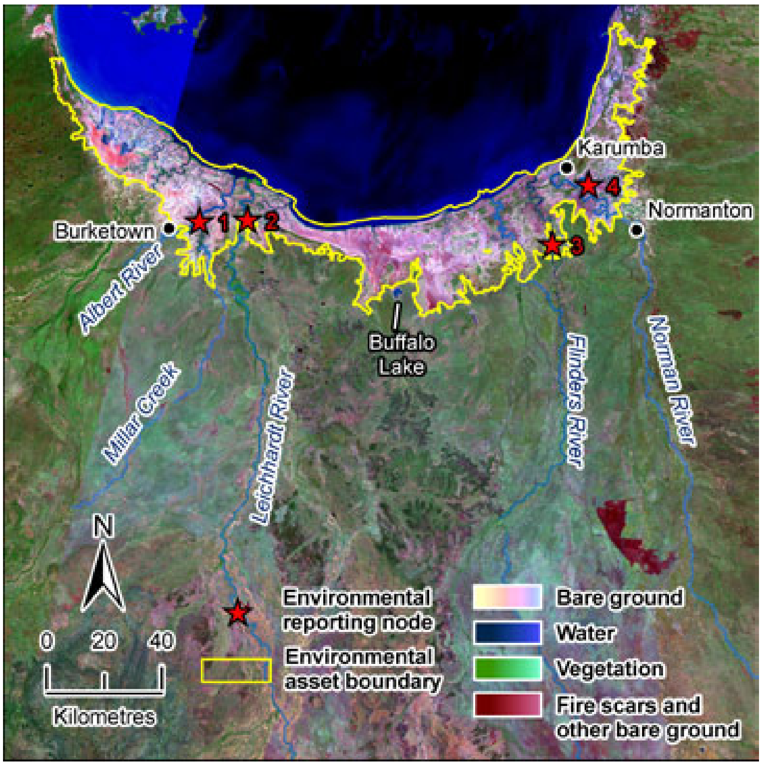


Figure SE-10. False colour satellite image of the Southern Gulf Aggregation (derived from (ACRES, 2000). Clouds may be visible in image

 

# SE-2.2 Data availability

## SE-2.2.1 Climate

The rainfall-runoff modelling uses historical daily climate data (Scenario A) from the SILO database for the period 1 September 1930 to 31 August 2007 at 0.05 x 0.05 degree (~ 5 x 5 km) grid cells. Full details and characterisation of the SILO database are provided at the division level in Section 2.1 of Chapter 2. Scenario B and Scenario C climate data are rescaled versions of the Scenario A data; this is also discussed in Section 2.1 of Chapter 2.

## SE-2.2.2 Surface water

Streamflow gauging stations are or have been located at 41 locations within the South-East Gulf region. Fourteen of these gauging stations either: (i) are flood warning stations and measure stage height only; or (ii) have less than ten years of measured data. Of the remaining 27 stations, 18 recorded more than half of their total volume of flow during events that exceed the maximum gauged stage height (MGSH). Figure SE-11 shows the spatial distribution of good quality data (duration) and the percentage of flow above maximum gauged stage height (MGSH) (this assessment was only undertaken on stations with ten years or more data). The location of streamflow gauging stations in the South-East Gulf is biased to locations in the upper Gilbert catchment, although with the redirection of Commonwealth funding for surface water assessment in 1988 approximately 70 percent of the streamflow gauging stations in the Gilbert were closed (seven remain open). The closure of the gauging stations in the lower Gilbert catchment (i.e. Miranda Downs on the Gilbert River, 917009, and Minnie Dip on the Einasleigh River,G917111A) means that a large part of the catchment is now ungauged.

Locating suitable gauging stations and undertaking high flow gaugings in the Norman, Staaten and lower reaches of the Gilbert (the Great Southern Aggregation) is problematic due to extensive flooding that takes place and distributary inflows from neighbouring catchments.

There are ten gauging stations currently operating in the South-East Gulf region at density of one gauge for every 12,200 $km^2$. For the 13 regions the median number of current gauging stations per region is 12 and the median density of current gauging stations per region is one gauge for every 9,700 $km^2$. The South-East Gulf region has a low density of current gauging stations relative to the other 12 regions in northern Australia. The density of current gauging stations in the South-East Gulf region is considerably lower than the MDB average. The mean density of current stream gauging stations across the entire MDB is one gauge for every 1,300 $km^2$.

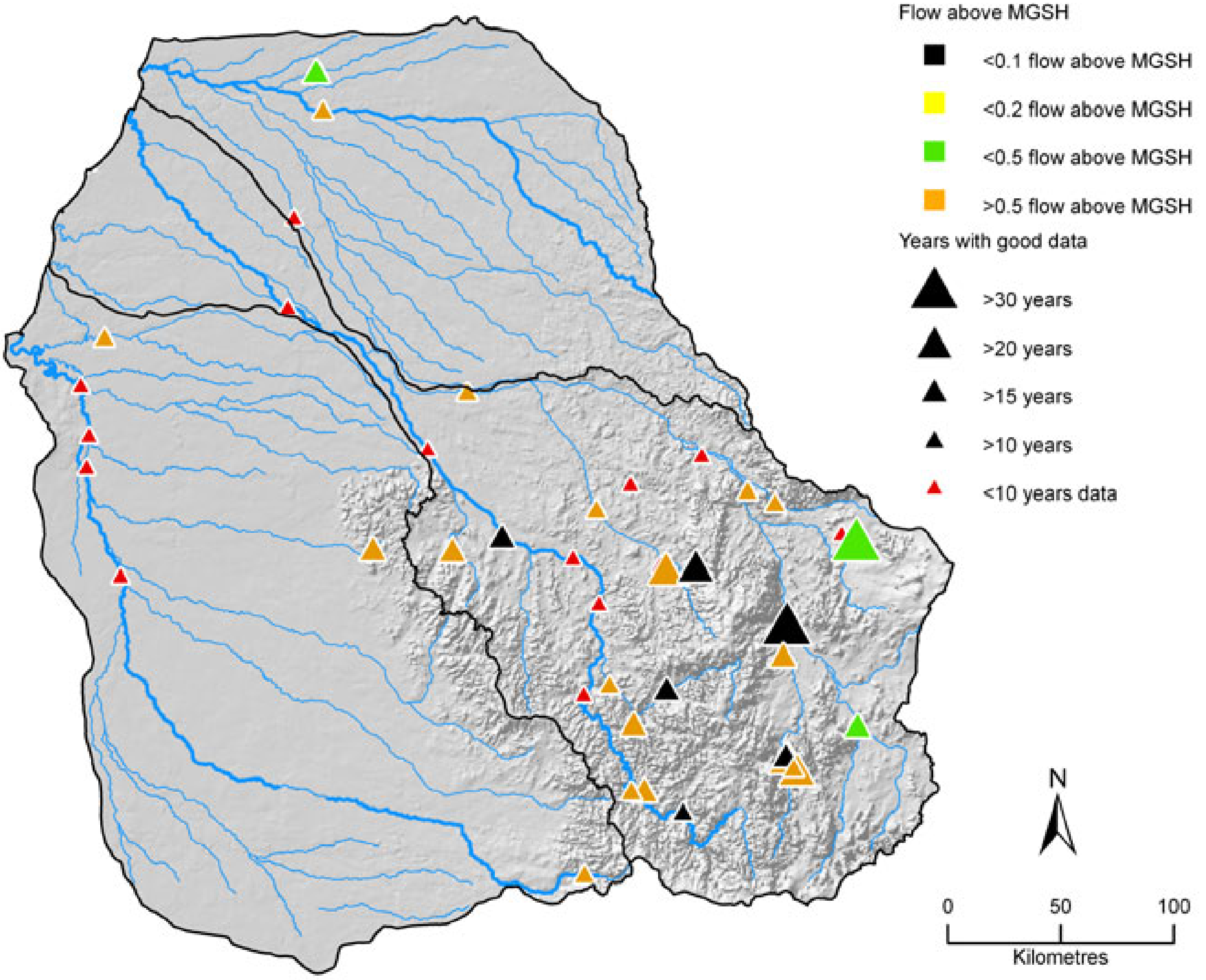


Figure SE-11. Location of streamflow gauging stations overlaid on a relative relief surface showing the proportion of gauges with flow above maximum gauged stage height across the South-East Gulf region

 

## SE-2.2.3 Groundwater

The South-East Gulf region contains a total 811 registered groundwater bores. 375 of these bores have surveyed elevations that could enable a water table surface (or piezometric surface in the case of confined aquifers) to be constructed for the main aquifers. However these bores are not necessarily monitored on a regular basis. According to the Queensland Government databases, there are 27 water level monitoring bores in the region and all are current (Figure SE-12). Of the 27 current monitoring bores, 13 are for the Great Artesian Basin (GAB) aquifer and 14 are for sub-artesian aquifers.

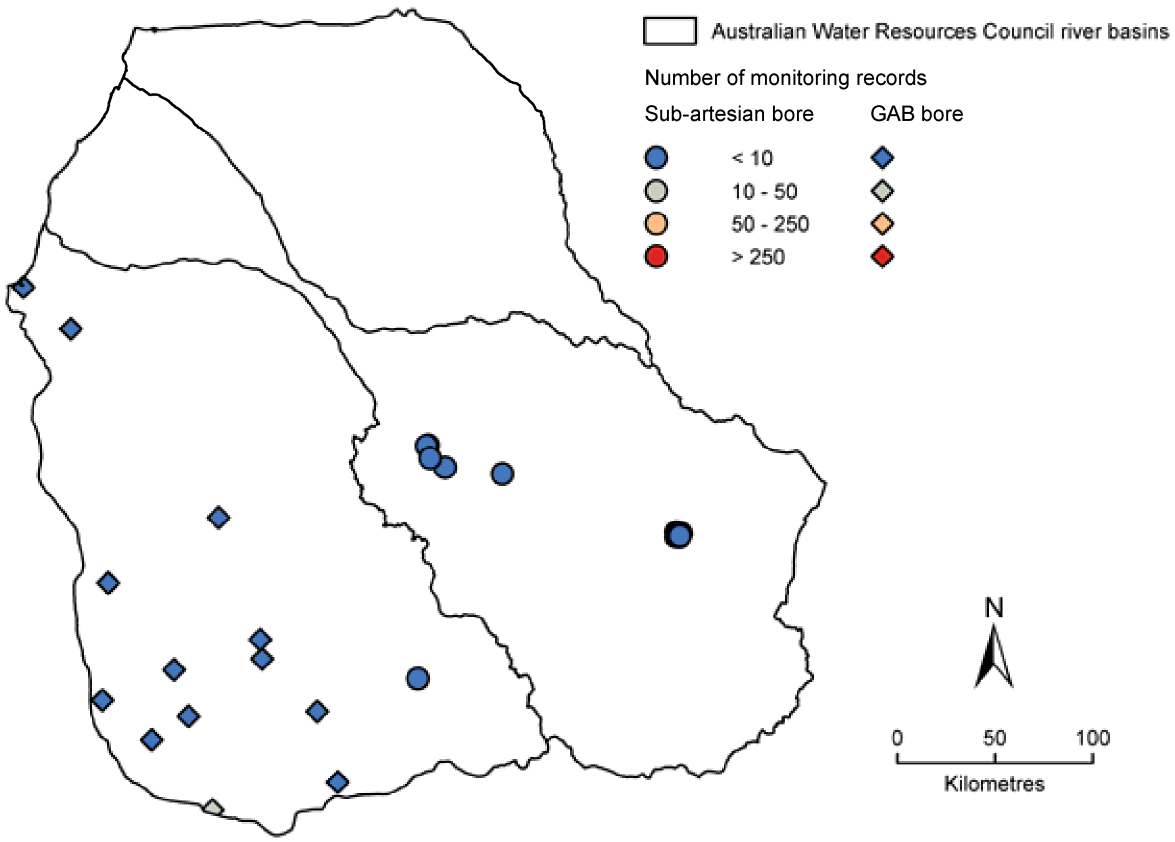


Figure SE-12. Current groundwater monitoring bores in the South-East Gulf region

## SE-2.2.4 Data gaps

Additional time series groundwater level and salinity data are required for each of the main aquifer types in the South-East Gulf region to provide greater understanding of recharge processes and inter-aquifer leakage, particularly for the GAB aquifers.

# SE-2.3 Hydrogeology

This section describes the key sources of groundwater in the South-East Gulf region.

## SE-2.3.1 Aquifer types

The South-East Gulf region comprises four main types of aquifers: (i) fractured rock basement, (ii) sandstones within the Carpentaria Basin of the GAB, (iii) Tertiary sediments, and (iv) Quaternary alluvium and beach ridge deposits (Figure SE-2).

### Basement aquifers

Palaeozoic and Precambrian intrusive, volcanic, metamorphic and sedimentary rocks form the basement fractured rock aquifer in this region. Basement outcrop occurs extensively to the east of the region (Smart, 1973). There is no potential for large-scale groundwater development of this aquifer due to low bore yields.

### Great Artesian Basin aquifers

The GAB comprises a multi-layered confined aquifer system, with aquifers occurring in Triassic, Jurassic and Cretaceous age continental quartzose sandstones, predominantly confined by low permeability mudstones and siltstones.

The Jurassic Eulo Queen Group sandstone rests conformably on the basement and is limited in extent across the South-East Gulf region. Development of this unit is not significant because water quality and bore yields are variable.

The Gilbert River Formation (which has numerous equivalents including the Wrotham Park Sandstone (Warner, 1967) is the most widespread aquifer in the South-East Gulf region. It rests either on basement or the Eulo Queen Group and forms part of a continuous unit throughout the Carpentaria Basin (Smart et al., 1980). The Gilbert River Formation is often the shallowest major artesian aquifer in the GAB in Queensland and is variable in thickness, which is primarily controlled by basement structure. Aquifer thickness ranges from approximately zero to 100 m in this region (Bultitude & Rees, 1996; Needham and Doutch, 1973; Simpson, 1973; Doutch, 1977; Smart and Bain, 1977) and comprises fine to coarse-grained quartzose sandstone with pebble conglomerate and siltstone. Sediment deposition occurs in lakes, rivers and shallow marine environments. To the west of the region, the Gilbert River Formation is confined and provides artesian groundwater supplies. To the east, where the aquifer is near the surface, groundwater bores are sub-artesian with yields less than 5 L/second.

The Rolling Downs Group is a predominantly argillaceous confining unit and ranges in thickness from approximately 500 to 900 m in the area of the Gilbert and Staaten rivers (Warner, 1967). It comprises mudstone sequences (Wallumbilla Formation and Allaru Mudstone) separated by the calcareous Toolebuc Formation, which is in turn overlain by sandstone and siltstone of the Normanton Formation.

### Cainozoic Aquifers

An unconformity exists between the GAB units and the Tertiary Bulimba Formation, with a thick lateritic profile developed on the early Tertiary erosion surface. In some bores the recorded thickness of this weathered material is in the order of 90 m, which indicates a significant hiatus prior to the start of deposition of the Bulimba Formation (Warner, 1967).

The Bulimba Formation comprises fluvial sediments derived mainly from weathering of the Gilbert River Formation outcrop in the eastern part of the region. Aquifers are typically constrained to paleochannels meandering through a matrix of clayey, less transmissive sediments and hence they are not continuous and not always in hydraulic connection with each other.

The Bulimba Formation is essentially present west of the basement margin, either in outcrop or in sub-crop beneath the Wyaaba Beds or Quaternary alluvium. Stratigraphic logs obtained during the 1971 BMR drilling program in the Carpentaria Basin, indicate there are three lithological units within the Bulimba Formation (Grimes, 1972):

- an upper hard, lateritic claystone (between 20 and 50 m thick)

 

- a clayey quartzose sand unit which contains the aquifer sands (between 50 and 80 m thick, thickening to the west)
- a lower claystone, similar to the uppermost unit, at least 35 m thick.

The Upper Tertiary Wyaaba Beds were deposited as outwash alluvium and consist of fluvial and marine quartzose clays, sandstone and clayey siltstone, with some calcareous sediments and limestone. The Wyaaba Beds unconformably overly the Bulimba Formation and range in thickness from 0 m to 120 m (Needham and Doutch, 1973; (Simpson, 1973). The marine facies of the Wyaaba Beds are characterised by muddy, coralline limestone and form the main aquifers in this formation. The limestone aquifers of the Wyaaba Beds are found near the base of the formation and are up to 50 m thick (DNRMW, 2006). The Wyaaba Beds limestone aquifer is limited to the present day coastline and only supplies artesian water 50 km inland from the coast (Horn et al., 1995). The Wyaaba Beds are not considered a significant groundwater resource outside of the area where the limestone occurs.

Quaternary cover is extensive in this region, however it can be thin or absent in places. The thickness of the Quaternary Cover is typically less than ten metres thick (Smart and Bain, 1977; Simpson, 1973).The Quaternary alluvial sediments consist of clean medium to coarse grained sand deposited in river channels, fine sand deposited on levee banks and extensive silt and clay flood plain deposits. McEniery (1980) described the unconsolidated sediments of alluvial, deltaic and lacustrine deposits in Northern Queensland; however no data exists for the Norman, Gilbert or Staaten River Basins (which comprise this region). McEniery (1980) hypothesised that groundwater supplies are likely to be poor in both yield and quality.

Warner (1967) identified three primary sources of shallow groundwater in the area, including:

- the channels of larger streams such as the Gilbert or Staaten rivers, which consist of clean, medium to coarse grained sands
- near abandoned stream channels, where the characteristically sandy ridges often act as areas of preferential recharge. Hence, although the watertable often resides below the Quaternary deposits, the sandy ridges act as an intake area for the underlying Wyaaba Beds
- coastal areas where fossil dunes contain lenses of fresh groundwater that may provide stock or domestic supplies.

### SE-2.3.2 Inter-aquifer connection and leakage

The conceptual model of interconnection between GAB aquifers and overlying Cainozoic sediments is of regional upward leakage from the deep GAB aquifers to the shallow overlying aquifers. Although limited groundwater data suggests there is an upward hydraulic gradient, this does not necessary mean there is measurable leakage.

There are 23 water level readings from bores screened in the Gilbert River Formation and they range from 63 m above ground surface (mAGS) to 39 m below ground surface (mBGS).

There are six bores screened in the Cainozoic aquifers with water level readings. These range from 0.5 mBGS to 24 mBGS, with a median water level reading of 5.5 mBGS. This indicates an upward vertical gradient from the Gilbert River Formation aquifer to the overlying Cainozoic aquifers.

It should be noted that these water level readings are temporally variable, with records ranging from 1962 to 2005 and hence these assumptions have an inherent level of uncertainty.

### SE-2.3.3 Recharge, discharge and groundwater storage

#### Basement aquifers

Recharge to the fractured rock aquifers is principally in the east of the region where they outcrop, and occurs via both vertical infiltration of rainfall and leakage from streams. Discharge occurs as evapotranspiration where the watertable is shallow in the recharge areas to the east, as a completely unknown volume of submarine discharge to the Gulf and via a small component of discharge to springs.

## Great Artesian Basin aquifers

Recharge to the GAB aquifers primarily occurs where the sandstone outcrops, along the western slopes of the Great Dividing Range, in areas referred to as 'recharge beds' or 'intake beds' (Figure SE-2 and Figure SE-13).

Kellett et al. (2003) investigated recharge to the Queensland GAB intake beds from Goondiwindi in the south to approximately 150 km north of Torrens Creek, immediately south of the South-East Gulf region. This investigation identified three primary recharge mechanisms: diffuse rainfall recharge, preferred pathway flow and localised recharge beneath rivers, creeks and alluvial groundwater systems overlying the intake beds. The range of recharge rates associated with the three recharge processes are:

- diffuse rainfall 0.03 to 2.4 mm/year
- preferred pathway flow 0.5 to 28.2 mm/year
- river/aquifer leakage up to 30 mm/year.

Preferred pathway flow involves the movement of water through conduits such as fissures, joints, remnant tree roots or highly permeable beds and is considered the dominant recharge process for the intake beds. The rate of recharge via preferred pathway flow depends on the frequency of episodic high magnitude rainfall events.

Discharge from the GAB occurs in a number of ways:

- As natural discharge from springs. Springs are quite common in the recharge areas along the eastern margins of the GAB and are mainly associated with 'overflow' or the 'rejection' of recharge into aquifers, or with the interaction between the local topography and aquifers. Flowing springs are also typically associated with faults along which the groundwater flows upwards, with the abutment of aquifers against low hydraulic conductivity bedrock and with pressurised water breaking through thin confining beds near the discharge margin of the basin. Some springs immediately west of the outcrop of the Gilbert River Formation are derived from Gilbert River Formation groundwater penetrating the thin mudstone of the Rolling Downs Group. Small springs occur along the margins of the Gregory Range, although these springs are not all sourced from the GAB aquifers; some are fed from the alluvium and a few from fractured basement rocks.
- As vertical leakage from aquifers upwards through the confining beds towards the regional watertable. This occurs throughout the basin and despite the slow percolation rates, may constitute a significant volume of water.
- As subsurface outflow from the GAB into the Gulf of Carpentaria. Although little is known about the volume or significance of this form of discharge, it is likely to be complex as seismic sections indicate pinching out of GAB sediments in the Gulf.
- As artificial discharge via artesian flow and pumped extraction from bores drilled into aquifers.

## Cainozoic aquifers

The Bulimba Formation is recharged via the vertical infiltration of rainfall in outcrop areas and via upward leakage from underlying GAB aquifers.

The Wyaaba limestone aquifer is completely confined and has no known onshore outcrop. The primary recharge mechanism is thought to be via lateral groundwater flow from east to west (DNRW, 2006).

Discharge from these aquifers is likely to occur in the form of evapotranspiration where watertables are close to the surface and as subsurface flow to the Gulf.

Recharge to the alluvial aquifers occurs primarily via the direct infiltration of rainfall (and floodwaters) and lateral flow through sandy river beds during high stage flow events in the wet season. There is also likely to be upward vertical leakage from the GAB aquifers where confining layers are thin and hydraulic pressures high, although the magnitude of such vertical leakage to the alluvium is unknown.

Alluvial deposits also receive recharge through the beach ridges and conversely, leakage of the beach ridge aquifers is likely to occur through the alluvial sediments (Horn et al., 1995).

Discharge from the alluvium predominantly occurs in the form of evapotranspiration; however during the dry season discharge to the rivers also occurs in the form of baseflow.

 

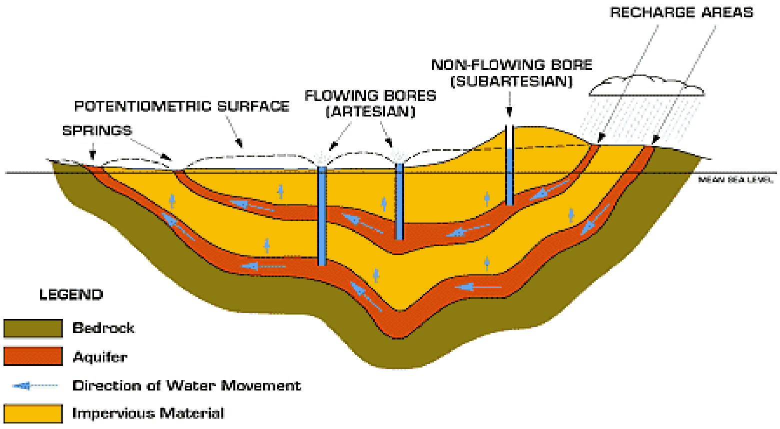


Figure SE-13. Operation of an artesian basin (from (GABCC, 2008)

## SE-2.3.4 Groundwater quality

In the South-East Gulf region, good quality groundwater is available from the shallow aquifers, albeit most bores exhibit very low yields.

Between 1962 and 1973 the Queensland Governement recorded groundwater quality information for eight bores constructed in Quaternary alluvium and beach dune deposits (depths from 3 to 43 m). Groundwater salinity ranged from 118 mg/L total dissolved solids (TDS) to 20,100 mg/L TDS, with a mean value from all records of 1102 mg/L TDS.

Groundwater quality of the Wyaaba Beds and Bulimba Formation aquifers are extremely variable, with low salinity groundwater found in the vicinity of streams and higher salinities proximal to the coast. Between 1966 and 1993 the DNRW recorded groundwater quality information for 33 bores constructed in either the Wyaaba Beds or Bulimba Formation (depths from 5 to 229 m). Groundwater salinity ranged from 114 mg/L TDS to 67,000 mg/L TDS, with a mean value from all records of 1454 mg/L TDS.

The groundwater salinity of the Gilbert River Formation aquifers is typically low. However deeper parts of this aquifer typically contain groundwater with high fluoride concentration, thereby precluding its use for stock or human consumption. Between 1987 to 2005 the DNRW recorded groundwater quality information for eight bores in this region (depths from 146 to 343 m). Groundwater salinity ranged from 50 mg/L TDS to 536 mg/L TDS, with a mean value from all records of 290 mg/L TDS.

Figure SE-14 shows groundwater salinity for approximately 225 bores in the region, measured between 1962 and 2007. The salinity values are electrical conductivity (EC) measured in µS/cm (NB. 1 µS/cm ~ 0.6 mg/L TDS). Approximately 40 percent of the bores mapped have a recorded total depth and this ranges from 3 to 381 m; hence the salinity map represents groundwater from different aquifers. Nevertheless, a distinctive pattern is evident in the map with fresher groundwater (EC values of 0 to 750 µS/cm) prominent in the south of the region in the vicinity of the GAB recharge areas (intake beds) and much higher groundwater salinity in the direction of regional groundwater flow to the north west (EC values in excess of 8000 µS/cm). These EC patterns may reflect the pattern of drilling depths, thus spatially biasing the sampling to specific aquifers. For example, progressing towards the gulf the Gilbert River Formation is deeper and thus more expensive to tap, so there is a tendency to drill shallow bores that tap more saline aquifers such as the Rolling Downs Group.

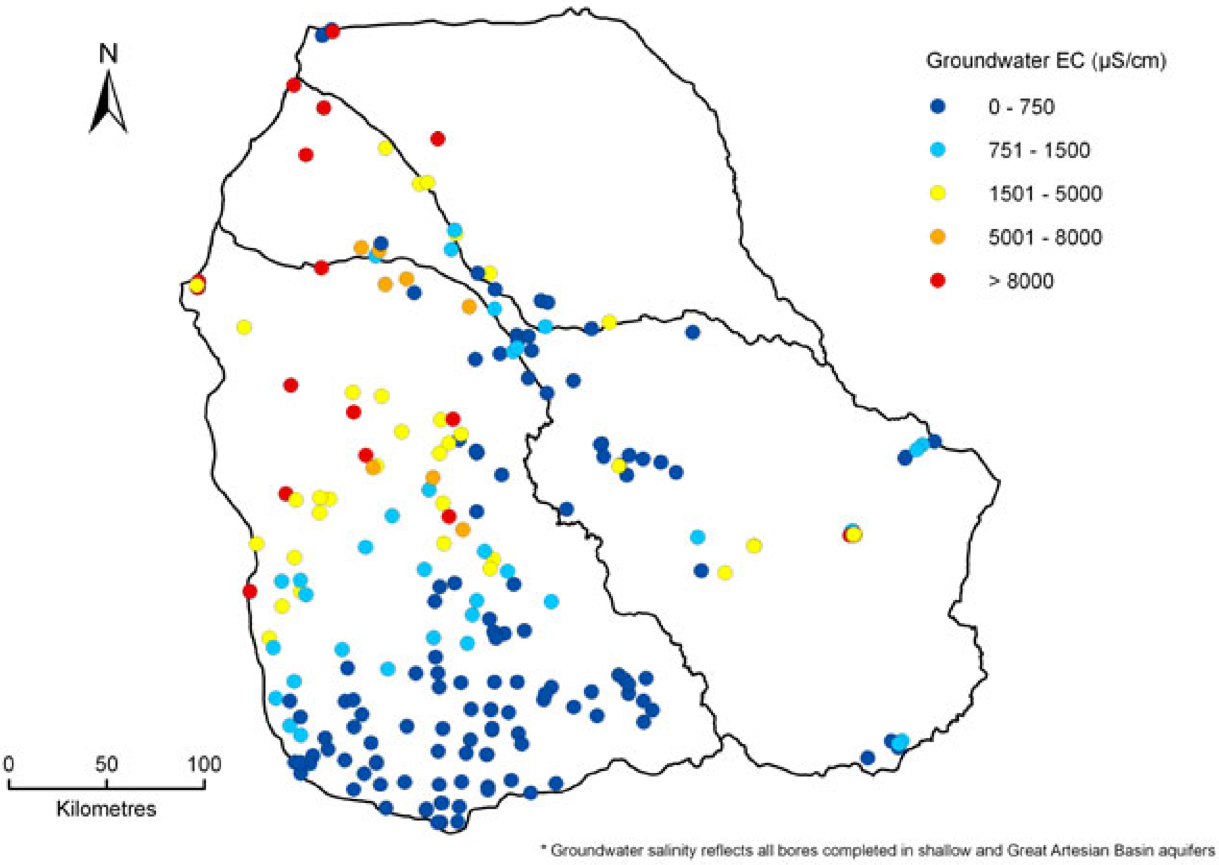


Figure SE-14. Groundwater salinity distribution for all bores drilled in the South-East Gulf region

 

# SE-2.4 Legislation, water plans and other arrangements

## SE-2.4.1 Legislated water use, entitlements and purpose

Water entitlements and use in the South-East Gulf region are governed by the *Water Resources (Gulf) Plan* (DNRW, 2007). Current surface water allocations are shown in Table SE-3. A Resource Operations Plan is currently under review and consultation.

Table SE-3. Current surface water allocations for the South-East Gulf region

| Allocation type | Location | Total volume |
|---|---|---|
| | | ML/y |
| Norman River Basin | | |
| Irrigation | - | 0 |
| Town water supply and industrial | Not specified | 2,100 |
| Non-riparian stock and domestic | - | 0 |
| Gilbert River Basin | | |
| Irrigation | Not specified | 9,115 |
| Town water supply and industrial | Not specified | 20 |
| Non-riparian stock and domestic | Not specified | 4,880 |
| Staatan River Basin | | |
| - | - | 0 |
| **Total volume** | | **16,115** |

The Staaten River basin is a declared wild river area. The *Wild Rivers Act 2005* includes a process for the Minister for Environment and Resource Management to declare wild river areas. The intent of the *Staaten Wild River Declaration 2007* is to preserve the natural values of wild rivers in the Staaten wild river area. It does this by regulating most future development activities and resource allocations within the Staaten wild river area. Water allocations for the Staaten wild river area are dealt with under the *Water Resource (Gulf) Plan 2007*. In the wild river area new development activities will be regulated through existing development assessment process with wild river requirements applied through the wild river declaration or the wild rivers code. Developments and authorisations in place at the time the declaration was made are not affected.

## SE-2.4.2 Groundwater use and entitlements

There is minor demand for groundwater across the South-East Gulf region due to its isolation and low population (ANRA, 2008a). Most stock and domestic supplies are obtained from permanent waterholes in creek and river courses, with only a small number of supplies (i.e. approximately 80 licences recorded by the DNRW) obtained from groundwater bores (Warner, 1967).

Groundwater entitlement volumes and estimated stock and domestic use volumes were reported as part of the *GAB Water Resource Plan* (DNRM, 2005). This information was collated in terms of the Management Areas defined for the GAB in Queensland (Figure SE-15) and has been reconfigured by the DNRW to estimate volumes for the Northern Australia Sustainable Yield project reporting regions.

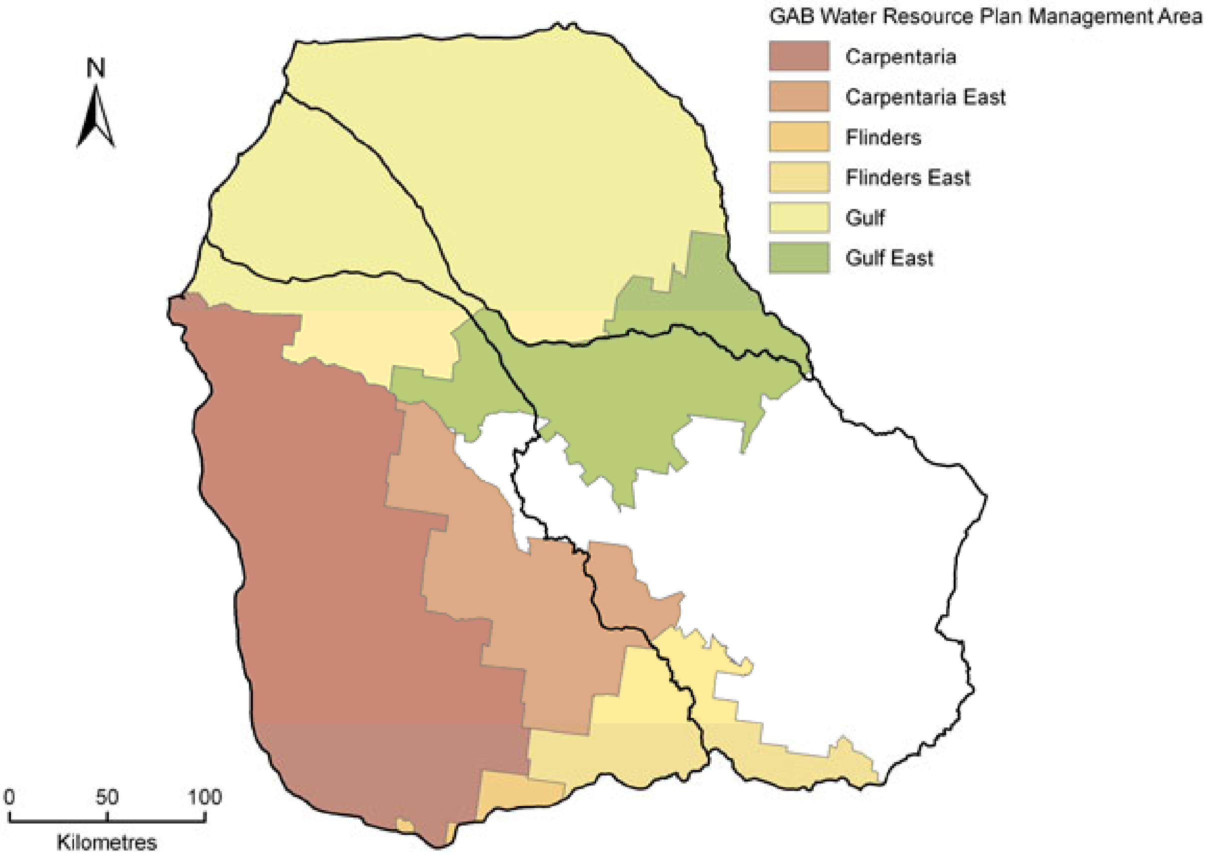


Figure SE-15. Groundwater management areas of the Great Artesian Basin in the South-East Gulf region

Groundwater of the GAB is vital to the outback regions of Queensland, as it is often the only water supply available for towns and properties for their stock and domestic requirements. It also supplies water for industrial purposes such as mining, power generation, aquaculture, feedlots and piggeries. However, the predominant current use in the GAB is by far, for stock and domestic purposes.

For the South-East Gulf region the estimated volume of stock and domestic use is approximately 11 GL/year and the volume of licensed entitlements is less than 1 GL/year (Table SE-4). This table shows that approximately 95 percent of stock and domestic use is extracted from the GAB aquifers, whilst the volume of licensed entitlements is smaller and predominantly associated with the Cainozoic sediments in the Karumba Basin.

Table SE-4. Estimated stock and domestic groundwater use and sum of groundwater entitlements for the South-East Gulf region

| Formation | Stock and domestic use | Entitlement |
|---|---|---|
| | GL/y | |
| Quaternary alluvium | 0.05 | 0.000 |
| Cainozoic sediments/basalt (including Karumba Basin) | 0.35 | 0.500 |
| Jurassic/cretaceous sedimentary rocks | 0.02 | 0.000 |
| Jurassic – Early Cretaceous Great Artesian Basin aquifers | 10.50 | 0.193 |
| Palaeozoic rocks | 0.05 | 0.000 |
| Proterozoic rocks | 0.160 | 0.000 |
| **Total volume** | **11.122** | **0.693** |

The Eulo Queen Group is developed only for stock and domestic purposes. Supplies from the Gilbert River Formation are also limited, due to low yields and a high fluoride concentration (DNRM, 2005). The Normanton Town bore however, is supplied from the Gilbert River Formation artesian aquifer, yielding 13 L/second (Simpson, 1973).

 

Very little extraction occurs from the Rolling Downs Group because of generally low yields and aquifers occurring only in isolated lenses of the Wallumbilla Formation. Although there has been an increase in the number of bores extracting groundwater from the Gilbert River and Wallumbilla formations over recent years, the density of bores is likely to be limited due to the prohibitive depth of the aquifer.

A limited number of bores utilise the Bulimba Formation or the Wyaaba Beds aquifers for groundwater use. Supplies are typically small, owing to poor permeability and in some cases the water from the Wyaaba Beds is saline and the fluoride content high (Smart and Bain, 1977).

### SE-2.4.3 Rivers and storages

There are few major storages in the region. The Kidston Dam on the Copperfield River in the far south-east of the Gilbert River basin is the largest with an active storage of 18.5 GL. The Staaten has no major storages and the Norman River has two small local storages (Table SE-5).

Table SE-5. Instream storages in the Norman and Gilbert rivers (within the IQQM modelled area)

| Storage name | River | Capacity |
|---|---|---|
| | | ML |
| Norman river basin | | |
| Belmore Creek Dam | Belmore Creek | 2,500 |
| Glenore Weir | Norman River | 1,850 |
| **Total** | | **4,350** |
| Gilbert river basin | | |
| Kidston Dam | Copperfield River | 18,500 |
| Mt Hogan water supply dam | Bernecker Creek | 700 |
| **Total** | | **19,200** |

### SE-2.4.4 Unallocated water

Unallocated water in the river basins of the South-East Gulf region can be held as a general reserve (general unallocated water) or a strategic reserve (strategic unallocated water). There is currently no definition of the location from which future extraction of unallocated surface water may come.

Table SE-6. Current unallocated surface water allocations in the South-East Gulf region

| Allocation type | Location | Total volume |
|---|---|---|
| | | ML/y |
| Norman River Basin | | |
| General allocation | Undefined | 3,000 |
| Strategic allocation (State purpose) | Undefined | 2,000 |
| Unlicensed extraction (overland flow) | - | Insignificant |
| Gilbert River Basin | | |
| General allocation | Undefined | 15,000 |
| Strategic allocation (State purpose) | Undefined | 5,000 |
| Unlicensed extraction (overland flow) | - | Insignificant |
| Staatan River Basin | | |
| General allocation | Undefined | 1,000 |
| Strategic allocation (State purpose) | Undefined | 1,000 |
| Unlicensed extraction (overland flow) | - | Insignificant |
| **Total volume** | | **27,000** |

## SE-2.4.5 Social and cultural considerations

The *Gulf (draft) Resource Operations Plan* provides for ‘the protection of water-related cultural values of Aboriginal and Torres Strait Islander communities’ (DNRW, 2008). Under the plan, the health and needs of natural values are addressed through provisions that are consistent with the general and ecological outcomes of the water resource plan. These outcomes aim to sustain natural characteristics such as variability of flows and water levels, which provide for, and support, native animal and plant communities; protect the natural attributes of the river systems to support the habitats of native plants and animals in watercourses, floodplains, wetlands, lakes and springs, and ensure connectivity of river systems to allow for the passage of fish species, which maintains natural populations as well as enabling fresh water to reach estuaries and the Gulf of Carpentaria (DNRW, 2008).

## SE-2.4.6 Changed diversion and extraction regimes

There is little demand for water in this region due to its isolation and low population.

## SE-2.4.7 Changed land use

The region is in an isolated area with little or no development.

## SE-2.4.8 Environmental and legislative constraints and implications of future development

The wetlands of the South-East region are amongst the most pristine and important wetlands of Australia (Environment Australia, 2001), with particular importance for shorebird breeding sites.

The *Gulf (draft) Resource Operations Plan* defines proposed conditions and requirements relating to existing and any future water licences to ensure that arrangements for the taking of water are consistent with local conditions. This includes defined pass flow requirements to ensure that downstream requirements will be met.

Environmental needs are met by provisions that will ensure total water use from existing and future entitlements does not amount to more than 0.35 percent of the overall mean annual discharge or the median annual discharge to the Gulf of Carpentaria, as stipulated under the *Water Resource (Gulf) Plan 2007*.

Within the Gilbert River Basin, specific ecological outcomes are to be achieved between AMTD 317 km and AMTD 263 km, such that:

- aquatic habitats for native plants and animals, particularly during dry seasons, are maintained
- riparian vegetation is supported
- there is contribution to the flow of the Gilbert River.

The *Staaten Wild River Declaration 2007* prohibits activities with greatest potential for negative impacts on the natural values of the wild river (such as dams and weirs, intensive animal husbandry, intensive agriculture and stream re-alignment). Prohibitions generally apply in the high preservation area, but can also apply in other management areas.

Prohibitions are generally applied through the legislation that regulates that particular type of activity. For example, instream weirs and dams are not permitted in high preservation area through provisions in the *Water Act 2000*.

 

## SE-2.5 References

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# SE-3 Water balance results for the South-East Gulf region

This chapter describes modelling results and the assessment of the water resources undertaken by this project for the South-East Gulf region. Detailed, quantified assessments are made where possible, and relevant, and confidence is estimated. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2. This chapter is sub-divided into:

- climate
- recharge estimation
- conceptual groundwater models
- groundwater modelling results
- rainfall-runoff modelling results
- river system water balance
- changes to flow regimes at environmental assets.



## SE-3.1 Climate

### SE-3.1.1 Historical climate

The South-East Gulf region receives an average of 750 mm of rainfall over the September to August water year (Figure SE-16), most of which (710 mm) falls in the November to April wet season (Figure SE-17). Across the region there is a strong north–south gradient in annual rainfall (Figure SE-18), ranging from 1078 mm in the north to 490 mm in the south. Over the historical (1930 to 2007) period, yearly rainfall has remained reasonably constant. The highest regionally averaged yearly rainfall received was 2126 mm which fell in 1974, and the lowest was 329 mm in 1952.

Areal potential evapotranspiration (APET) under the historical climate is very high across the region, averaging 1980 mm over a water year (Figure SE-16), and varies moderately across the seasons (Figure SE-17). APET generally remains higher than rainfall for most of the year resulting in near-year-round water-limited conditions. The exceptions to this are the months January to March, when more rain falls than can potentially be evaporated.

 

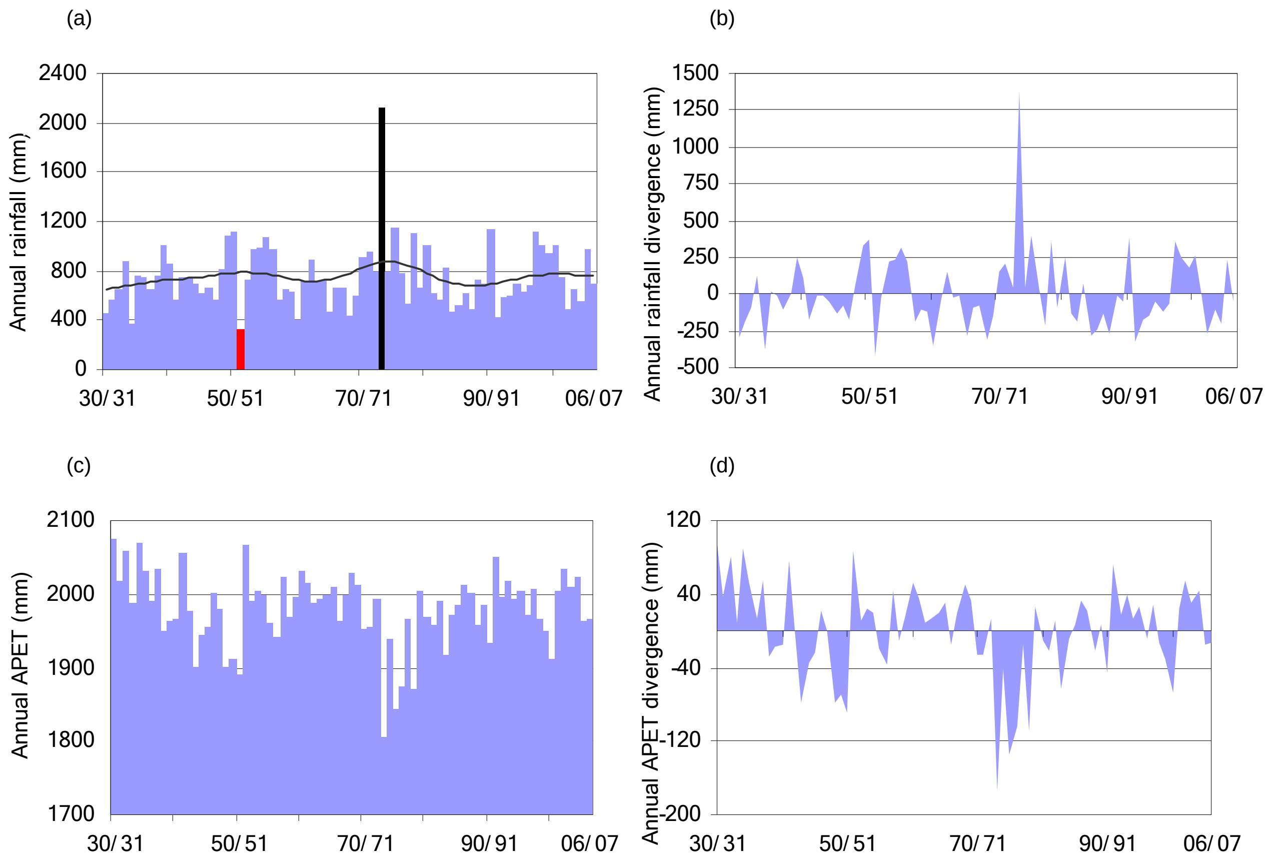


Figure SE-16. (a) Historical annual rainfall and (b) its divergence from the long-term mean; and (c) historical annual areal potential evapotranspiration and (d) its divergence from the long-term mean averaged over the South-East Gulf region. The low-frequency smoothed line in (a) indicates longer term variability

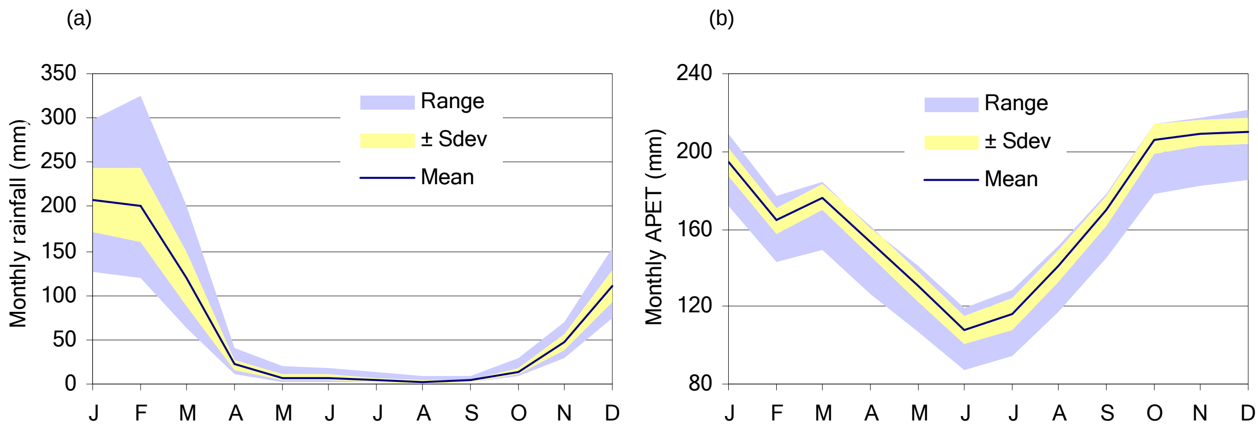


Figure SE-17. Historical mean monthly (a) rainfall and (b) areal potential evapotranspiration and their temporal variation (range and ± one standard deviation) averaged over the South-East Gulf region

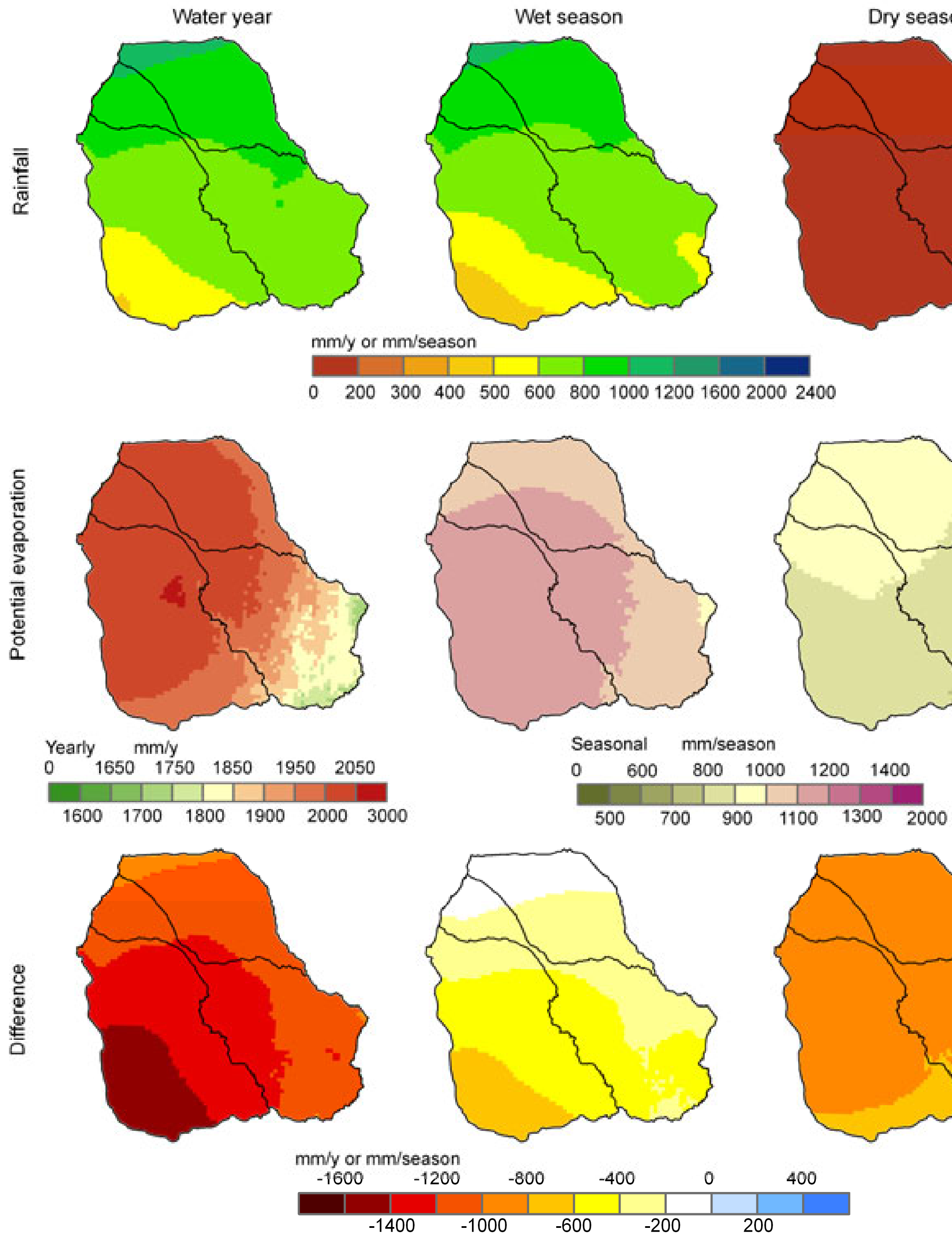


Figure SE-18. Spatial distribution of historical mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration (potential evaporation) and their difference (rainfall less areal potential evapotranspiration) across the South-East Gulf region

## SE-3.1.2 Recent climate

Figure SE-19 compares recent (1996 to 2007) to the preceding 66-year period (1930 to 1996) mean annual rainfall for the South-East Gulf region. Across the whole region, recent rainfall is usually between zero and 20 percent higher than historical rainfall – a difference which is not statistically significant for the majority of the region.

 

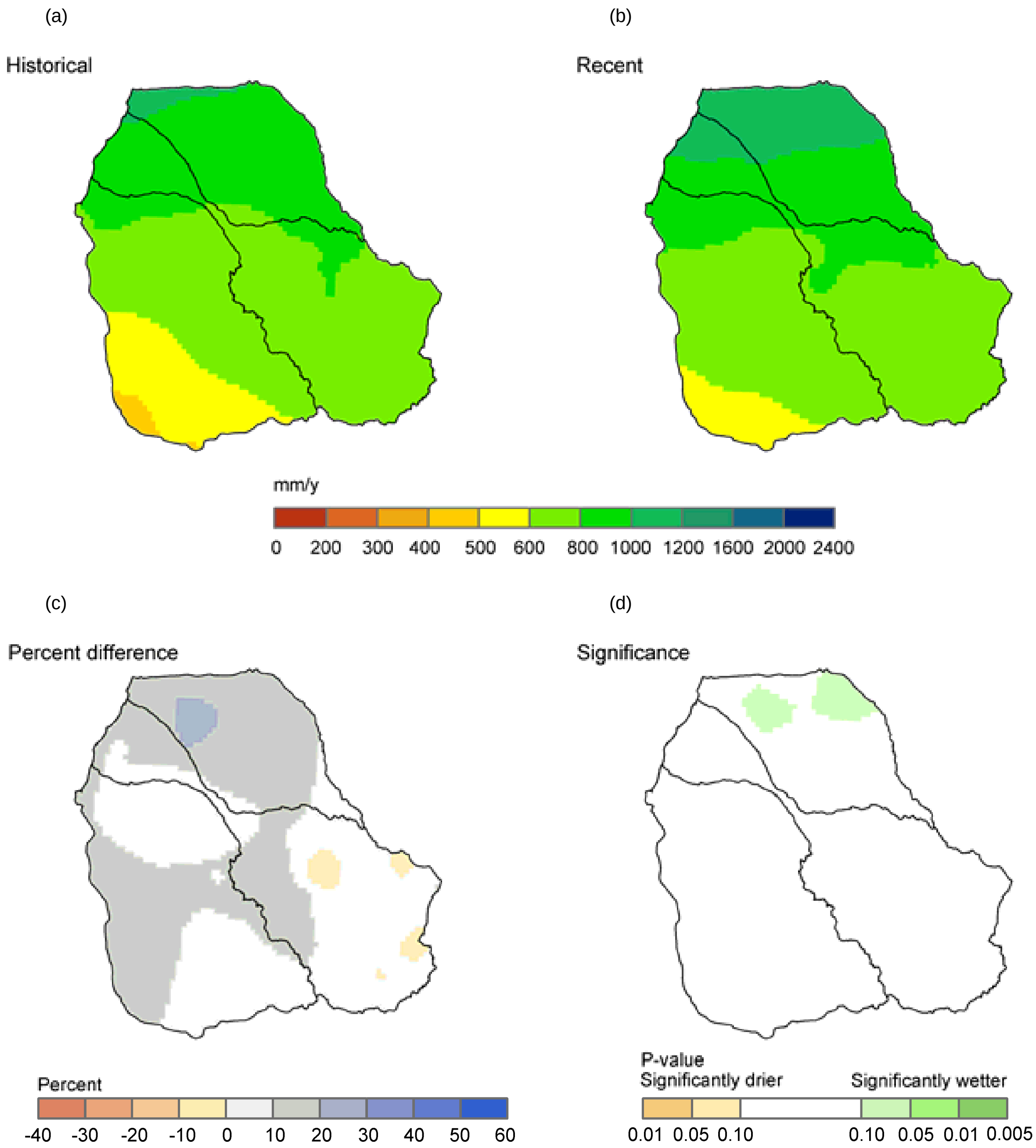


Figure SE-19. Spatial distribution of (a) historical and (b) recent mean annual rainfall; and (c) their relative percent difference and (d) the statistical significance of these differences across the South-East Gulf region. (Note that historical in this case is the 66-year period 1930 to 1996)

### SE-3.1.3 Future climate

Under Scenario C annual rainfall varies between 698 mm and 855 mm (Table SE-7) compared to the historical mean of 750 mm. Similarly, APET ranges between 2026 and 2065 mm compared to the historical mean of 1980 mm.

A total of 45 variants of Scenario C were modelled (15 GCMs for each of the high, medium and low global warming scenarios). Subsequently, results from an extreme 'wet', median and extreme 'dry' variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet annual rainfall and APET increase by 14 percent and 3 percent, respectively. Under Scenario Cmid annual rainfall is the same as the historical mean and APET increases by 2 percent. Under Scenario Cdry annual rainfall decreases by 7 percent and APET increases by 4 percent.

Under Scenario Cmid long-term monthly averages of rainfall do not differ much from historical values (Figure SE-20). Rainfall under Scenario Cmid lies well within the range in values from all 45 future climate variants. APET is consistently slightly higher than historical values throughout the year under Scenario Cmid. The seasonality of both rainfall and APET is not expected to change substantially. Under Scenario Cmid APET lies at the lower end of the range in values derived from all 45 Scenario C variants, primarily in the wet season.

The spatial distributions of rainfall and APET under Scenario C are compared to the historical distribution in Figure SE-21 and Figure SE-22. Under Scenario C the strong north–south gradient in rainfall is retained, but with a southwards shift under Scenario Cwet and a northwards shift under Scenario Cdry. The spatial distribution of APET under Scenario C is similar to the historical distribution.

Table SE-7. Mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration averaged over the South-East Gulf region under historical climate and Scenario C

| | Water year | Wet season | Dry season |
|---|---|---|---|
| | mm/y | mm/season | |
| Rainfall | | | |
| Historical | 750 | 710 | 40 |
| Cwet | 855 | 803 | 42 |
| Cmid | 750 | 702 | 39 |
| Cdry | 698 | 657 | 32 |
| Areal potential evapotranspiration | | | |
| Historical | 1980 | 1109 | 871 |
| Cwet | 2035 | 1132 | 899 |
| Cmid | 2026 | 1128 | 894 |
| Cdry | 2065 | 1153 | 908 |

* Note that the sum of the wet season and dry season values does not always equal the water year values because the combined wet season and dry season period (November to October) is different to the water year period (September to August).

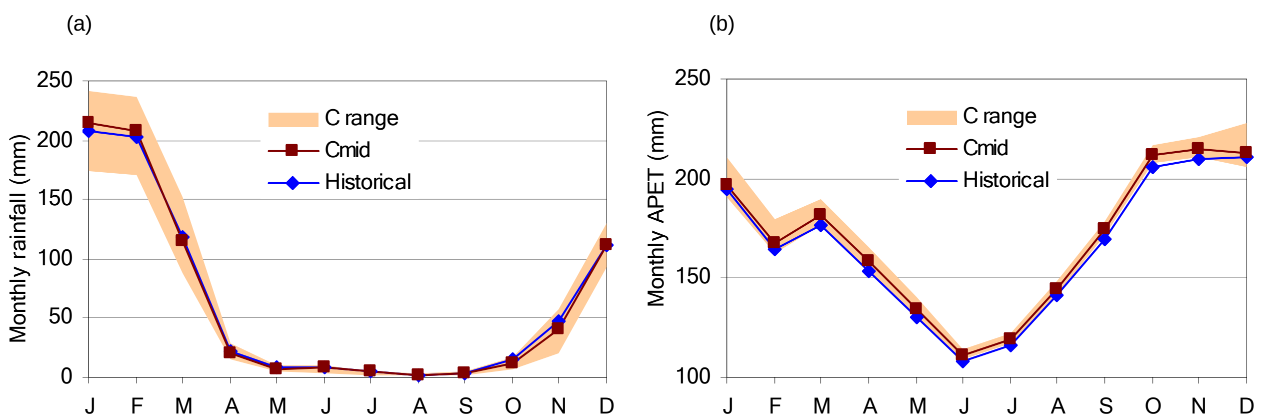


Figure SE-20. Mean monthly (a) rainfall and (b) areal potential evapotranspiration averaged over the South-East Gulf region under historical climate and Scenario C. (C range is the range under the 45 Scenario C simulations – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

## SE-3.1.4 Confidence levels

Analysis of confidence of the climate data is presented in Section 2.1.4 in the division-level Chapter 2.

 

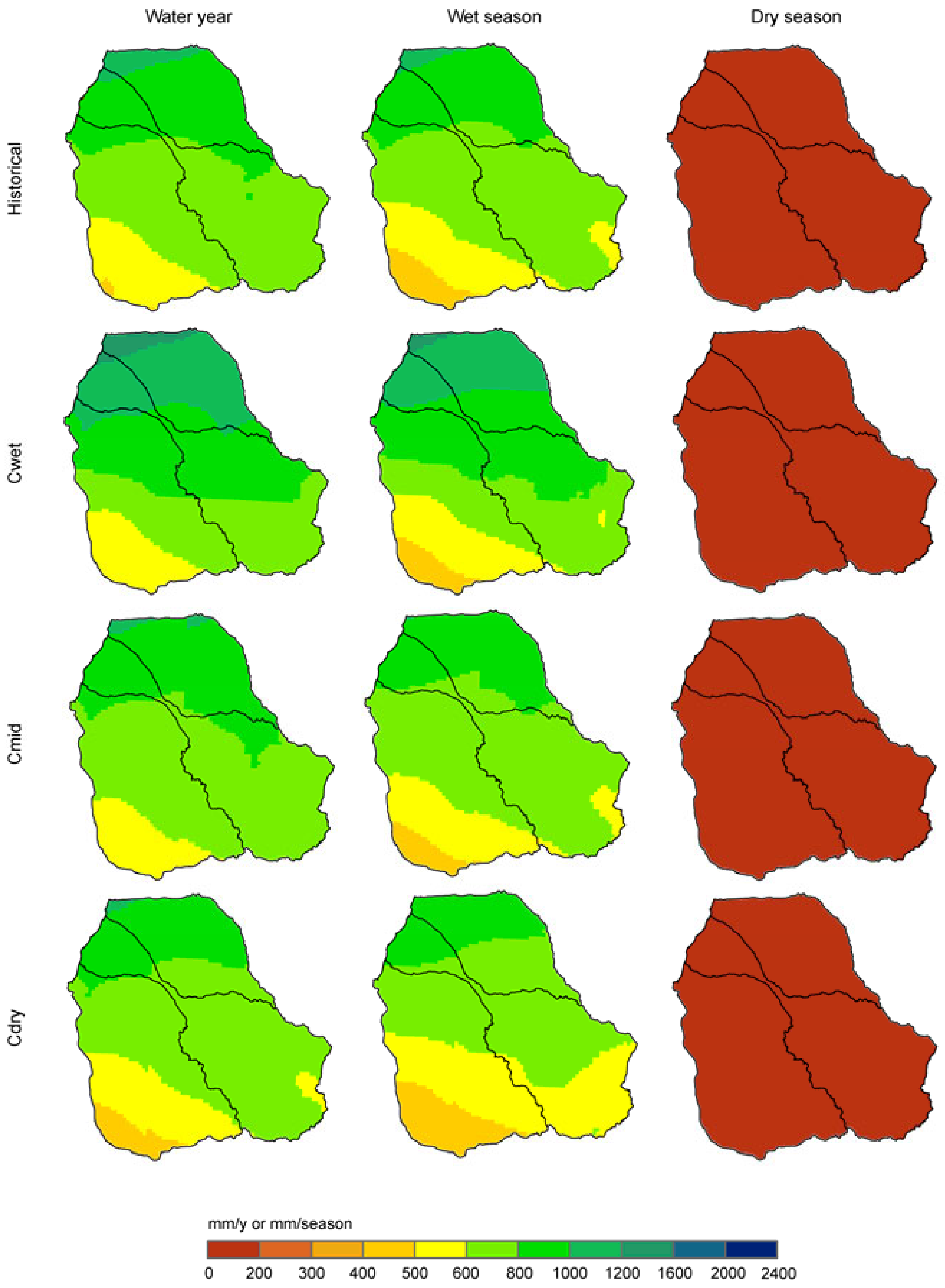


Figure SE-21. Spatial distribution of mean annual (water year), wet season and dry season rainfall across the South-East Gulf region under historical climate and Scenario C

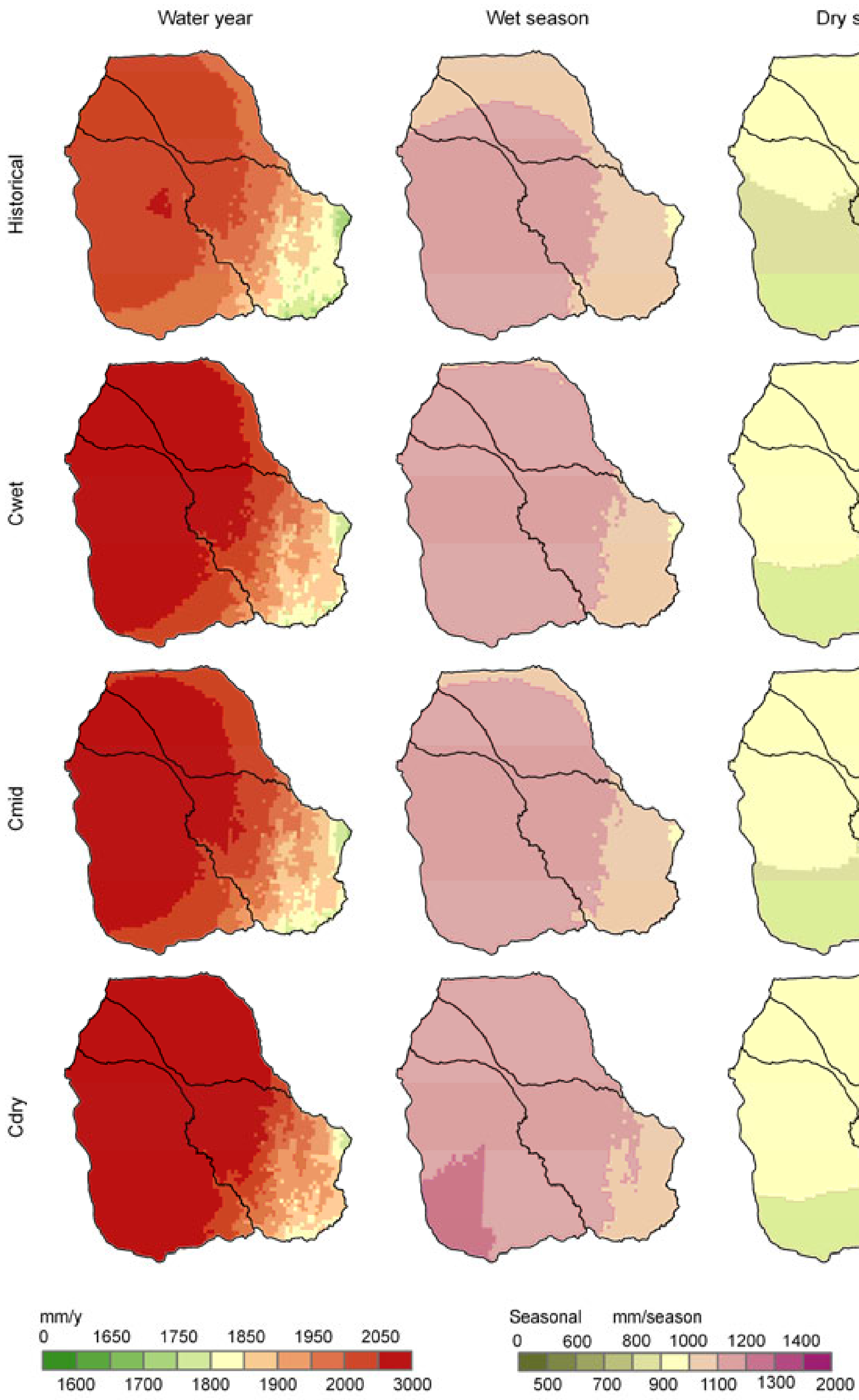


Figure SE-22. Spatial distribution of annual (water year), wet season and dry season areal potential evapotranspiration across the South-East Gulf region under historical climate and Scenario C

# SE-3.2 WAVES potential diffuse recharge estimations

The WAVES model (Zhang and Dawes, 1998) was used to estimate the change in groundwater recharge across the South-East Gulf region under a range of different climate scenarios. WAVES is a vertical recharge flux model that can model plant physiological feedbacks in response to increased $CO_2$, as well as modelling the water balance of different soil, vegetation and climate regimes. It was chosen for its balance in complexity between plant physiology and soil physics. It was also used to assess recharge for the Murray-Darling Basin Sustainable Yields Project (Crosbie et al., 2008).

## SE-3.2.1 Under historical climate

The calculated historical recharge for the South-East Gulf region shows that recharge is comparatively low when compared to the other regions. We assessed the historical record to establish any difference between wet and dry periods of recharge. We used a 23-year period, which allows us to project recharge estimates to 2030 – in other words, estimate recharge in 2030 assuming future climate is similar to historical climate (Scenario A). Under a wet historical climate (Awet) the South-East Gulf region is calculated to have a 12 percent increase in recharge. Under the median estimate of historical climate (Amid) the South-East Gulf region is calculated to have a 3 percent decrease in recharge. Under a dry historical climate (Adry) the South-East Gulf region is calculated to have a 14 percent decrease in recharge.

Table SE-8. Recharge scaling factors for scenarios A, B and C

| Region | Awet | Amid | Adry | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| South-East Gulf | 1.12 | 0.97 | 0.86 | 0.94 | 1.49 | 1.10 | 0.98 |

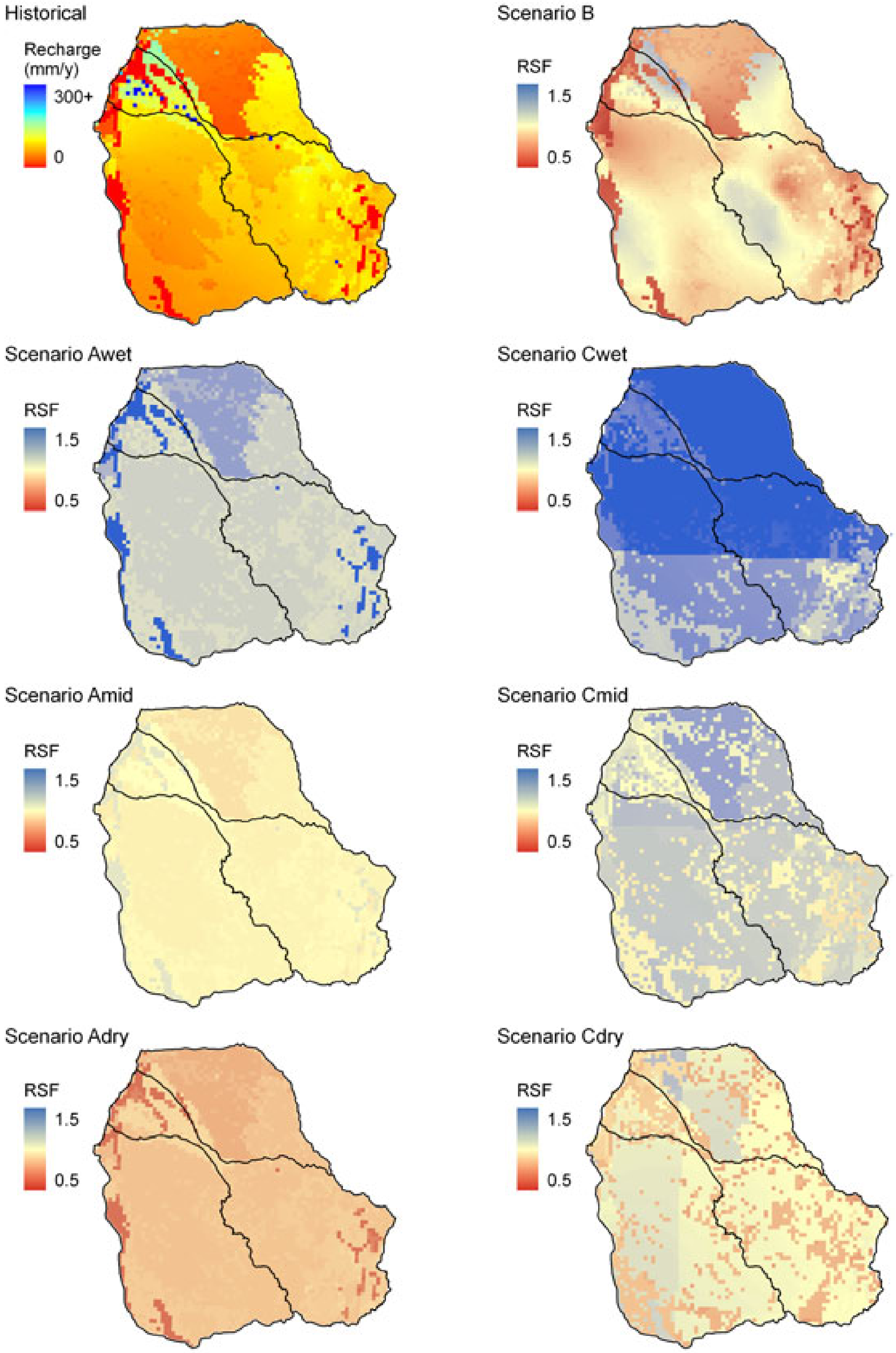


Figure SE-23. Spatial distribution of historical mean recharge rate; and recharge scaling factors for scenarios A, B and C across the South-East Gulf region

### SE-3.2.2 Under recent climate

The years 1996 to 2007 in the South-East Gulf region have been drier than the historical (1930 to 2007) average and consequently the calculated recharge has, on average, decreased by 6 percent compared to the historical average

 

(Table SE-8). This decrease has not been uniform with some areas showing an increase in recharge and others a decrease in recharge (Figure SE-23).

### SE-3.2.3 Under future climate

Figure SE-24 shows the percentage change in modelled mean annual recharge averaged over the South-East Gulf region for Scenario C relative to Scenario A for the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The percentage change in the mean annual rainfall and recharge from the corresponding GCMs are also tabulated in Table SE-9. In some scenarios the recharge is projected to increase despite a decrease in rainfall. This is because total rainfall is not the only climate variable that has an influence over recharge, Daily rainfall intensity, temperature and $CO_2$ concentration are also important drivers (see Section 2.3.3 in the division-level Chapter 2), and specific situations can result in this counter-intuitive result. In particular, rainfall intensity is seen as a significant factor in this relationship.

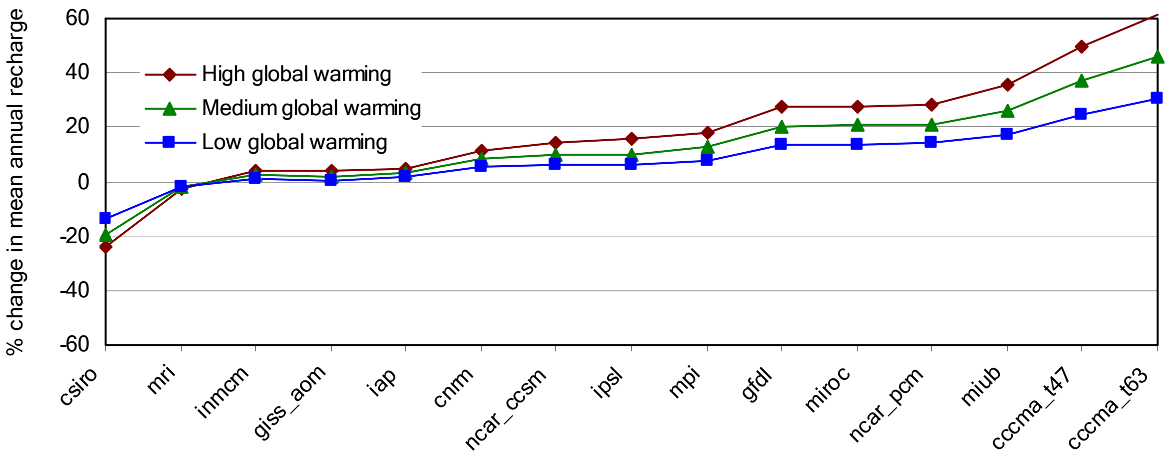


Figure SE-24. Percentage change in mean annual recharge under the 45 Scenario C simulations (15 global climate models and three global warming scenarios relative to Scenario A recharge

Table SE-9. Summary results under the 45 Scenario C simulations (numbers show percentage change in mean annual rainfall and recharge under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Recharge | GCM | Rainfall | Recharge | GCM | Rainfall | Recharge |
| csiro | -22% | -24% | csiro | -17% | -19% | csiro | -12% | -14% |
| **mri** | **-7%** | **-2%** | mri | -5% | -2% | mri | -4% | -2% |
| inmcm | -2% | 4% | inmcm | -1% | 2% | inmcm | -1% | 1% |
| giss_aom | -5% | 4% | giss_aom | -4% | 2% | giss_aom | -2% | 1% |
| iap | -3% | 5% | iap | -2% | 4% | iap | -1% | 2% |
| cnrm | -2% | 12% | cnrm | -2% | 8% | cnrm | -1% | 6% |
| ncar_ccsm | 2% | 15% | ncar_ccsm | 1% | 10% | ncar_ccsm | 1% | 6% |
| ipsl | 1% | 16% | **ipsl** | **1%** | **10%** | ipsl | 0% | 6% |
| mpi | -1% | 18% | mpi | -1% | 13% | mpi | -1% | 8% |
| gfdl | 0% | 28% | gfdl | 0% | 20% | gfdl | 0% | 14% |
| miroc | 4% | 28% | miroc | 3% | 21% | miroc | 2% | 13% |
| ncar_pcm | 7% | 28% | ncar_pcm | 5% | 21% | ncar_pcm | 4% | 14% |
| miub | 6% | 35% | miub | 4% | 26% | miub | 3% | 17% |
| **cccma_t47** | **14%** | **49%** | cccma_t47 | 11% | 37% | cccma_t47 | 8% | 25% |
| cccma_t63 | 14% | 62% | cccma_t63 | 11% | 46% | cccma_t63 | 8% | 31% |

Under the wet extreme future climate (Scenario Cwet) the South-East Gulf region is calculated to have a 49 percent increase in recharge with the greatest increases in the north. Under the median future climate (Scenario Cmid) the South-East Gulf region is calculated to have a 10 percent increase in recharge. Under the dry extreme future climate (Scenario Cdry) the South-East Gulf region is calculated to have a 2 percent decrease in recharge.

### SE-3.2.4 Confidence levels

The estimation of recharge from WAVES is only indicative of the actual recharge and has not been validated with field measurements. A steady state groundwater chloride mass balance (CMB) has been conducted as an independent measure of recharge (Crosbie et al., 2009). The results in the South-East Gulf region show that the historical estimate of recharge using WAVES (68 mm/year) is greater than the best estimate using the CMB (57 mm/year) but it is within the confidence limits of the CMB (9 to 235 mm/year). It is noted that Kellett et al. (2003) report recharge rates of 10 to 15 mm/year around Torrens Creek to the south.



## SE-3.3 Conceptual groundwater models

The basement fractured rock aquifer outcrops extensively to the east of the region and provides a poor source of groundwater largely owing to variable yields. Recharge to the fractured rock aquifer is principally via both vertical infiltration of rainfall and leakage from streams. Discharge occurs via several mechanisms, including: (i) evapotranspiration where the watertable is shallow in the recharge areas to the east; (ii) a small component of discharge to springs; and (iii) a small amount of baseflow (see Section SE-3.3.1). Groundwater may also discharge directly into the gulf, however there is no information to support this hypothesis.

The Gilbert River Formation is the most widespread aquifer in the South-East Gulf region. To the west of the region it is confined by the overlying Rolling Downs Group and provides artesian groundwater supplies, while to the east, where the aquifer is near the surface, groundwater bores are sub-artesian and low yielding. Recharge to the GAB aquifers primarily occurs where the sandstone outcrops, along the western slopes of the Great Dividing Range. Discharge from the GAB aquifers occurs as upward vertical leakage towards the regional watertable, subsurface outflow from the GAB into the Gulf, as discharge to springs and a minor component of groundwater extraction. The township of Normanton relies on artesian groundwater supply from the Gilbert River Formation, although because of elevated fluoride concentrations the groundwater must be blended with a surface water supply from Glenore weir.

Spring discharge occurs in the outcrop areas of the Gilbert River Formation and Eulo Queen Group due to rejected recharge, where topography is steep and incised. Where rivers intersect these aquifers, they receive baseflow for much of the dry season (May to October). Groundwater discharge from the Gilbert River Formation supports flow in the Norman River, Yappar River and Clara River, as well as Boorabin Creek. During the wet season (November to April), water infiltrates from the river to the aquifers, either laterally via the incised sediments, or vertically via diffuse floodout recharge when overbank flooding occurs.

The Bulimba Formation is present west of the basement margin, either in outcrop or sub-crop beneath the Wyaaba Beds or Quaternary alluvium. Aquifers are typically constrained to old stream channels and hence are not always in hydraulic connection with each other. Recharge occurs where the Bulimba Formation is found in outcrop and also from upward vertical leakage from underlying GAB aquifers. Discharge occurs as subsurface outflow and as baseflow to creeks, which helps maintain flow into the dry season.

The Upper Tertiary Wyaaba Beds unconformably overly the Bulimba Formation. The marine facies of the Wyaaba Beds form the main aquifers in this formation and is limited to 50 km inland from the present day coastline. It is completely confined and the primary recharge mechanism is considered to be via lateral groundwater inflow from the east. Discharge occurs as subsurface flow to the Gulf and via a small volume of groundwater extraction.

Quaternary cover is extensive in this region, but can be thin or absent in places. Groundwater supplies are considered poor in both yield and quality. Recharge to the alluvial aquifers is predominantly via the direct infiltration of rainfall. River valley alluvium also receives recharge via lateral flow through the sandy river beds during the wet season high river flows. Vertical infiltration occurs on the extensive floodplain when the river floods and upward vertical leakage from the GAB aquifers occurs where confining layers are thin and hydraulic pressures high. Discharge from the alluvium predominantly occurs in the form of evapotranspiration; however during the dry season discharge to the rivers also occurs in the form of baseflow.

### SE-3.3.1 Baseflow index analysis

The results of the baseflow analysis for suitable gauges in the South-East Gulf region are provided in Table SE-1. The annual baseflow index (BFI) values range from 0.05 to 0.26 (n=12, median = 0.11). Figure SE-02 shows the surface geology of the South-East Gulf region and the average volume of dry season baseflow to rivers. This figure indicates that dry season baseflow is small at the gauges analysed, with a maximum volume of 5 GL. However, the majority of the river gauges analysed (i.e. 10 out of the 12) are located outside the GAB and incise the older fractured rock aquifers. Therefore baseflow could be more significant in other parts of the region where GAB aquifers are encountered.

## SE-3.4 Groundwater modelling results

The limited data for the region precluded the development of quantitative groundwater models.

## SE-3.5 Rainfall-runoff modelling results

In this section the term runoff is the sum of overland flow, interflow and baseflow. It is equivalent to streamflow expressed as a mm depth equivalent. All plots show data averaged over the modelled subcatchments of the South-East Gulf region. For this reason rainfall reported in this section may vary slightly from that reported elsewhere due to differences between the catchment boundaries (shown in Figure SE-1) and the DEM-derived catchment boundaries used here. In this section, where annual data are reported years are represented by numbers 1 through 77. Consistently throughout this report, annual data are based on the water year (1 September to 31 August) and the dry season is defined as 1 May to 31 October. Unless stated otherwise scenarios Cwet, Cmid and Cdry are selected on the basis of the ranked mean annual runoff. For more details on methods refer to Section 2.2 of the division-level Chapter 2.

### SE-3.5.1 Regional synopsis

The rainfall-runoff modelling estimates runoff in 0.05 degree grid cells in 48 subcatchments (Figure SE-25). Optimised parameter values from ten calibration catchments are used. Seven of these calibration catchments are in the Gilbert catchment, one is on the Norman and one is in the Staaten. The remaining calibration catchment is in the Mitchell region to the north. The calibration catchments in the Gilbert are located in the mid to upper reaches.

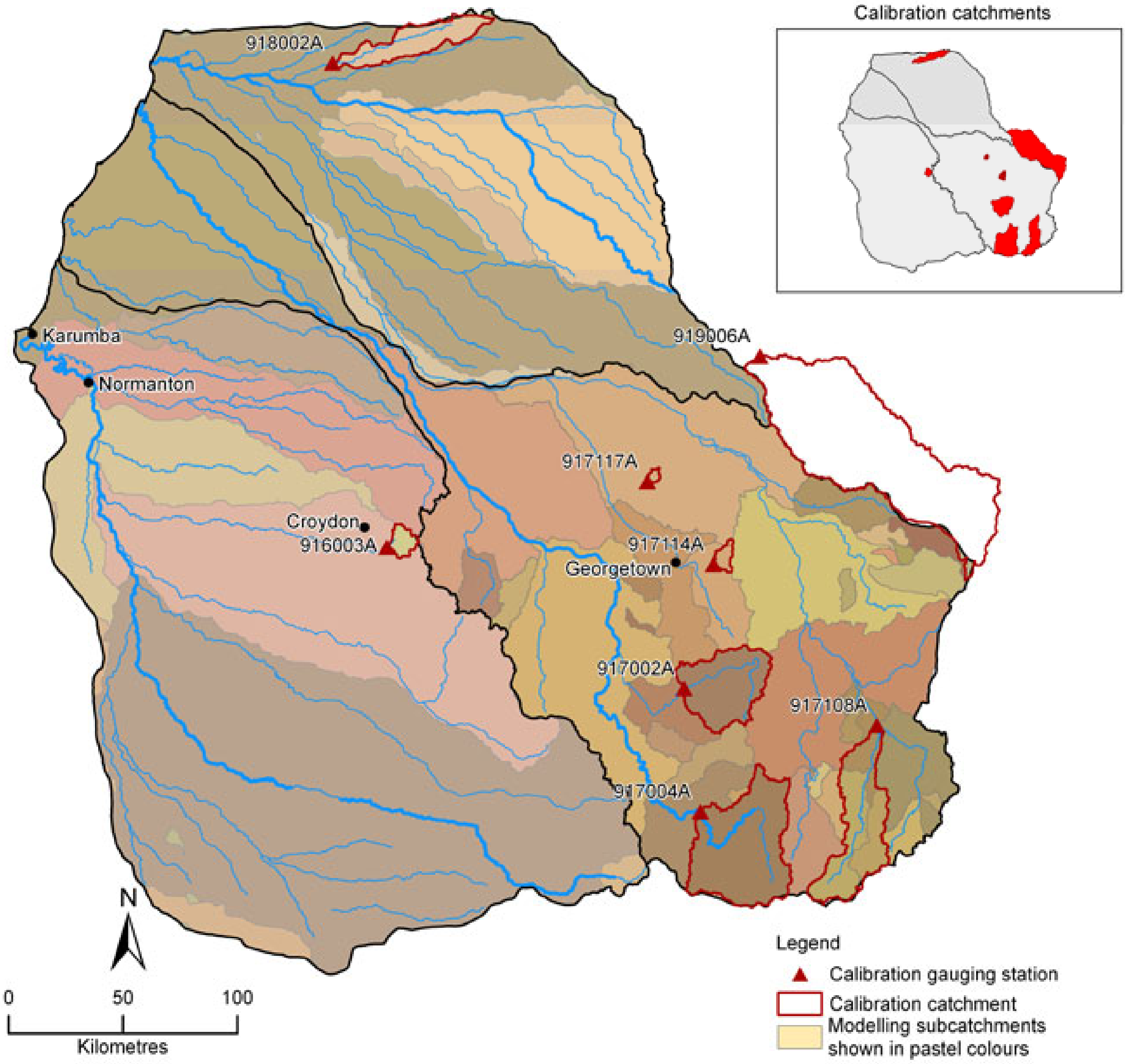


Figure SE-25. Map of the modelling subcatchments, calibration catchments and calibration gauging stations used for the South-East Gulf region with inset highlighting (in red) the extent of the calibration catchments

### SE-3.5.2 Model calibration

Figure SE-26 compares the modelled and observed monthly runoff and the modelled and observed daily flow exceedance curves for the eight calibration catchments. Nash-Sutcliffe efficiency (NSE) values provide a quantitative measure of how well simulated values match observed values. NSE values are described in more detail in Section 2.2.3 of the division-level Chapter 2. On the monthly plots NSE is the monthly Nash-Sutcliffe efficiency value and NSE (dry season) is the dry season monthly Nash-Sutcliffe efficiency value. On the daily flow exceedance plots, NSE is the daily flow exceedance curve Nash-Sutcliffe efficiency value and NSE (50 to 100 percent) is the lower half of the daily flow exeedance curve Nash-Sutcliffe efficiency value.

The results indicate that the ensemble calibration of the rainfall-runoff models Sacramento and IhacresClassic can reasonably reproduce the observed monthly runoff series (NSE values generally greater than 0.7), but only satisfactorily reproduces the daily flow exceedance curves (NSE values generally greater than 0.9) for the purposes of simulating long-term average monthly and annual streamflow. The volumetric constraint used in the model calibration also ensures that the total modelled runoff is within 5 percent of the total observed runoff.

The calibration method places more importance on the simulation of high runoff, and therefore rainfall-runoff modelling of the medium and high runoff is considerably better than the modelling of low runoff. This is demonstrated by the relatively low NSE values for the monthly dry season and lower half of the daily flow exceedance curve. It should be noted, however, that while the relative difference between the observed and simulated low flow values may be large (which is what gives rise to the low monthly dry season NSE values for example), the absolute difference between the observed and simulated low flow values is generally small because both values are small. Nevertheless, an optimisation to reduce overall error variance can result in some underestimation of high runoff and overestimation of low runoff. This is evident in some of the scatter plots comparing the modelled and observed monthly runoff and many of the daily flow exceedance curves. In many of the catchments the disagreement between the modelled and observed daily runoff curves is discernable for runoff that at 1 percent of the time. This is accentuated in the plots because of the linear scale on the y-axis and normal probability scale on the x-axis. In any case, the volumetric constraint used in the model calibration ensures that the total modelled runoff is always within 5 percent of the total observed runoff.

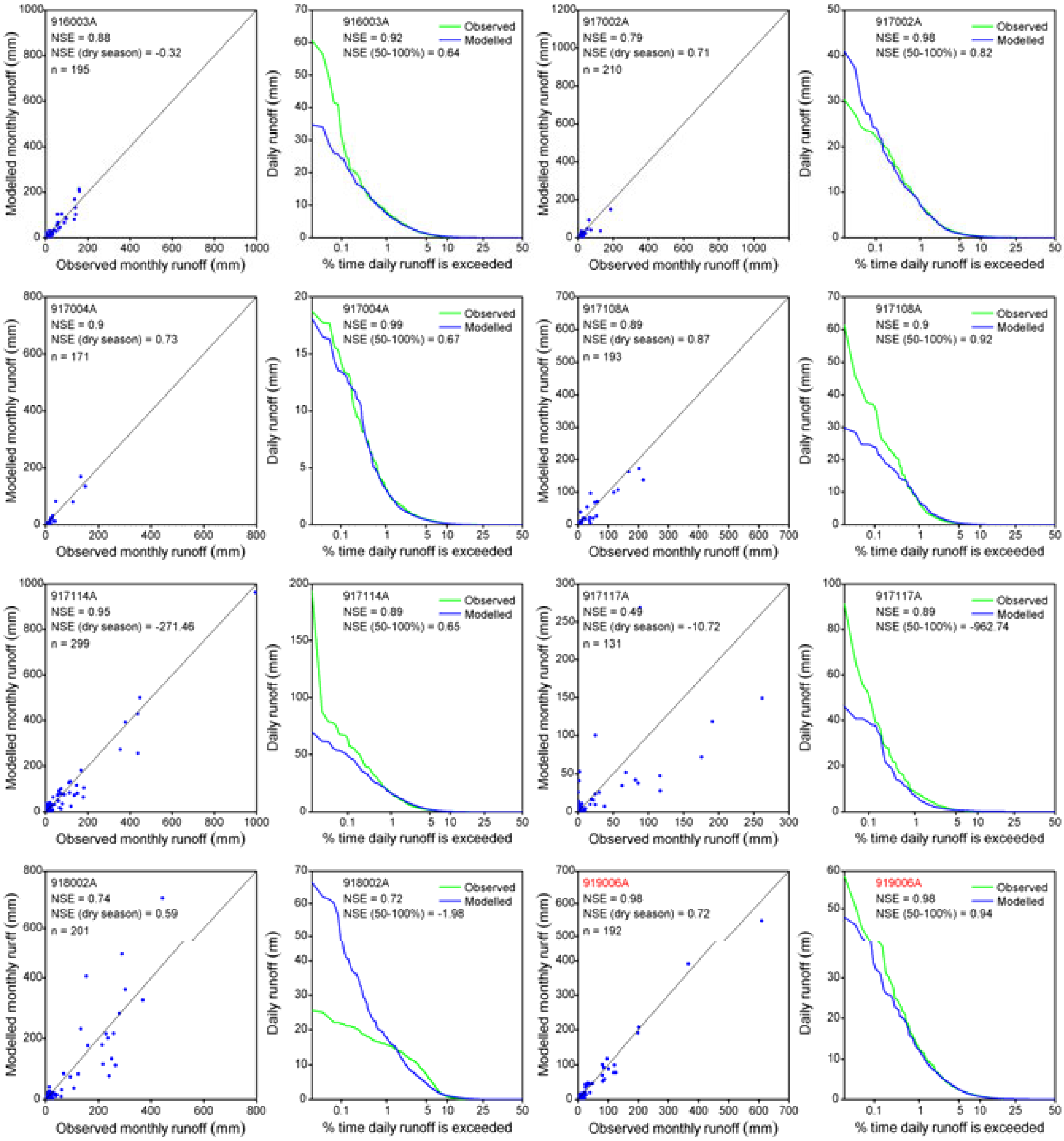

Figure SE-26. Modelled and observed monthly runoff and daily flow exceedance curve for each calibration catchment in the South-East Gulf region. (Red text denotes catchments located outside the region; blue text denotes gauges used to predict streamflow only)

### SE-3.5.3 Under historical climate

Figure SE-27 shows the spatial distribution of mean annual rainfall and runoff under Scenario A (averaged over 1930 to 2007) across the South-East Gulf region. Figure SE-28 shows the mean annual rainfall and runoff averaged over the region.

The mean annual rainfall and runoff averaged over the South-East Gulf region are 752 mm and 113 mm respectively. The mean wet season and dry season runoff averaged over the South-East Gulf region are 112 mm and 1 mm respectively.

 

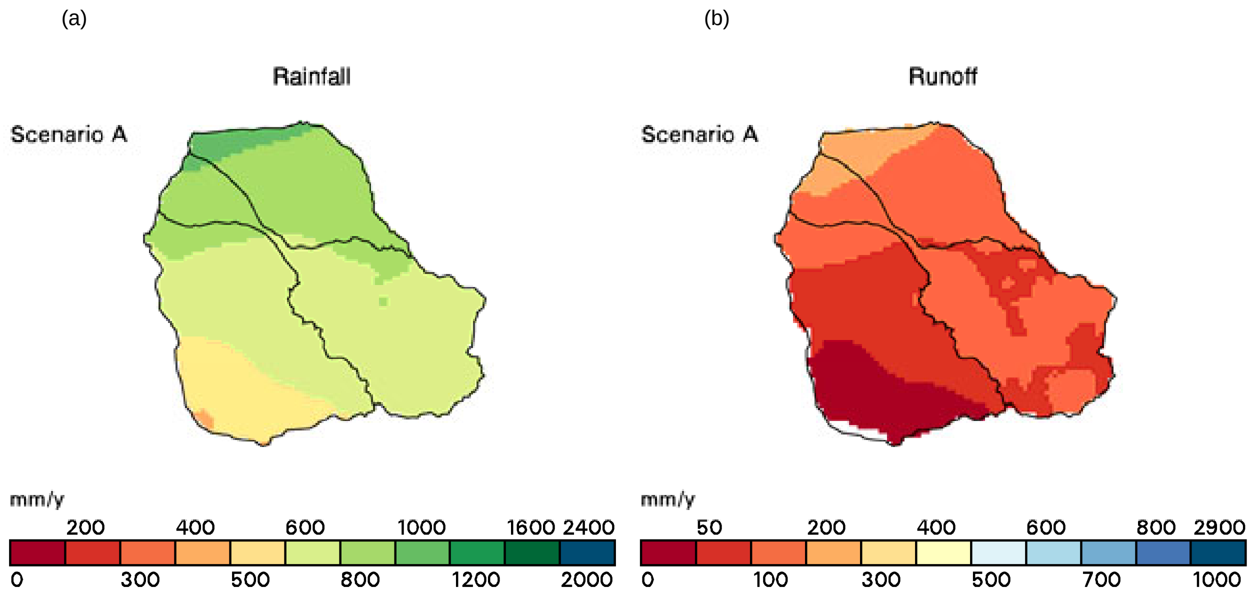


Figure SE-27. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the South-East Gulf region under Scenario A

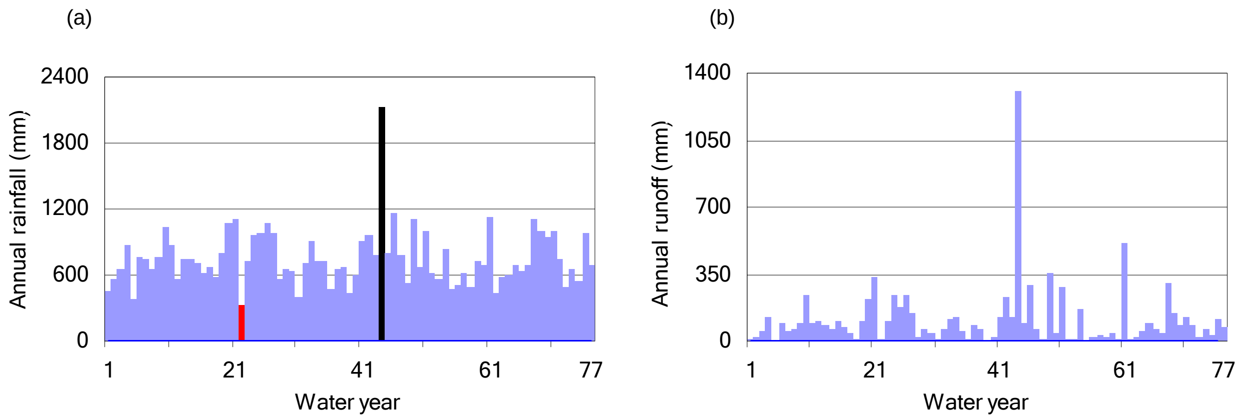


Figure SE-28. Annual (a) rainfall and (b) modelled runoff in the South-East Gulf region under Scenario A

In this project all runoff grids are presented as long-term mean annual values. However the distributions of monthly and annual runoff data in northern Australia can be highly skewed; consequently the median and additional percentile values spatially averaged over the region are also reported. The $10^{th}$ percentile, median and $90^{th}$ percentile annual runoff values across the South-East Gulf region are 244, 67 and 13 mm respectively. The median wet season and dry season runoff averaged over the South-East Gulf region are 67 mm and zero mm respectively.

The mean annual rainfall varies from nearly 1100 mm in the north-east to 700 mm in the south-east. The mean annual runoff varies from over 200 mm in the east to less than 25 mm in the south-east (Figure SE-27) and subcatchment runoff coefficients vary from less than 10 percent to nearly 30 percent of rainfall. The majority of rainfall and runoff occurs during the wet season months December to April (Figure SE-29). Rainfall and runoff can vary considerably from year to year with long periods over several years or decades that are considerably wetter or drier than others (Figure SE-28). The coefficients of variation of annual rainfall and runoff averaged over the South-East Gulf region are 0.34 and 1.50 respectively.

The South-East Gulf is one of 13 regions which cover the three divisions studied in this project. Mean annual rainfall and runoff, as well as coefficients of variation, have been calculated for all of these 13 regions, and it is useful to compare the South-East Gulf results to results across all 13 regions. Across all 13 regions in this project $10^{th}$ percentile, median and $90^{th}$ percentile values are 1371, 936 and 595 mm respectively for mean annual rainfall and 374, 153 and 78 mm respectively for mean annual runoff. The mean annual rainfall (752 mm) and runoff (113 mm) averaged over the South-

East Gulf region fall in the lower end of this range. Across all 13 regions in this project the 10th percentile, median and 90th percentile values are 0.34, 0.26 and 0.19 respectively for the coefficient of variation of annual rainfall and 1.39, 0.69 and 0.48 for the coefficient of variation of runoff. The coefficients of variation of annual rainfall (0.34) and runoff (1.50) averaged over the South-East Gulf region are the highest of the 13 reporting regions.

Figure SE-29(a,b) shows the minimum and maximum monthly rainfall and runoff and the range of values between the 25th and 75th percentile monthly rainfall and runoff. Figure SE-29(c,d) shows the mean and median monthly flows and the range of values between the 25th and 75th percentile monthly rainfall and runoff. The large difference in the mean and median wet season monthly runoff values indicates that the distribution of monthly runoff in the South-East Gulf region is highly skewed.

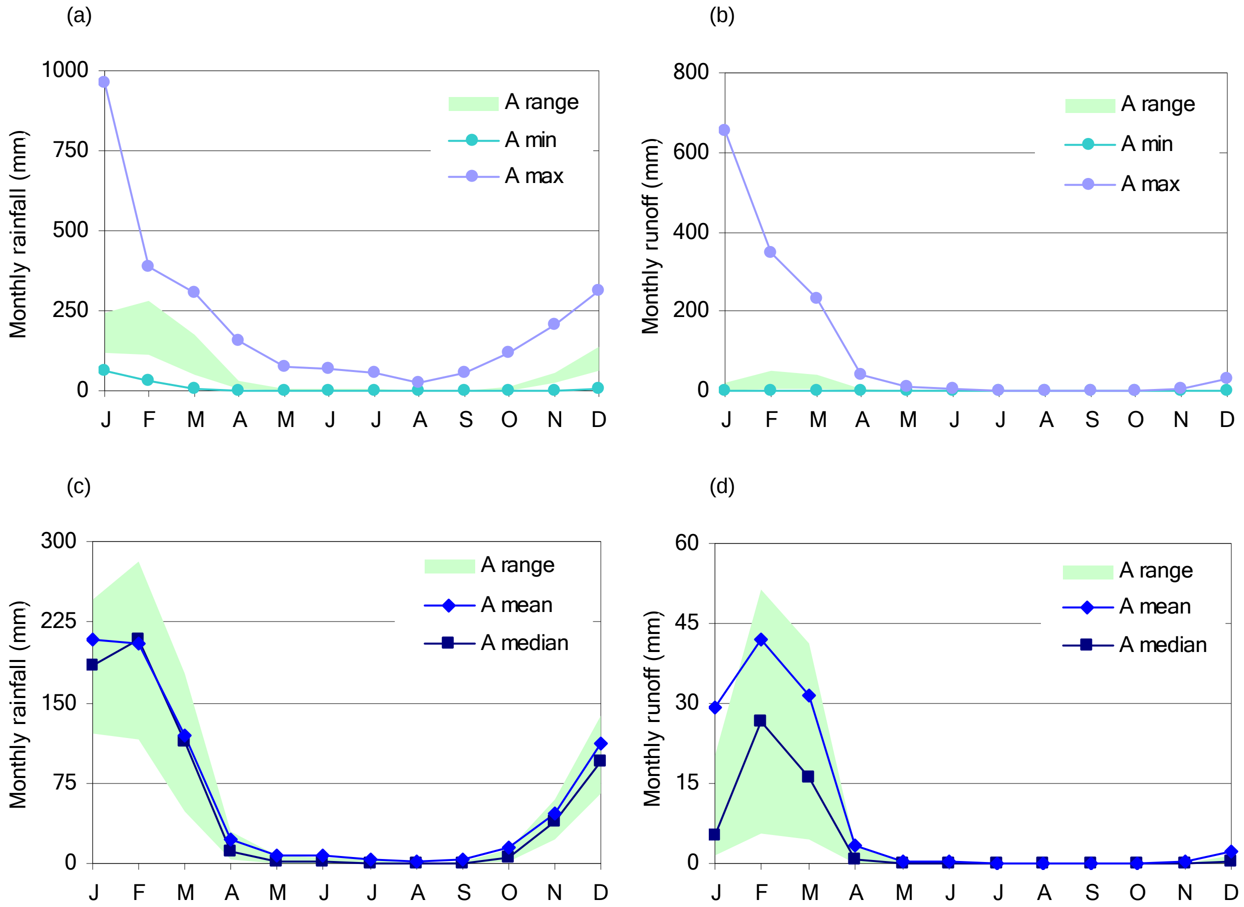


Figure SE-29. Minimum, maximum and A range monthly (a) rainfall and (b) modelled runoff; and mean, median and A range monthly (c) rainfall and (d) modelled runoff in the South-East Gulf region under Scenario A (A range is the 25th to 75th percentile monthly rainfall or runoff)

### SE-3.5.4 Under recent climate

The mean annual rainfall and runoff under Scenario B (1996 to 2007) are 7.4 percent higher and 13 percent lower respectively than the historical (1930 to 2007) mean values. While the percentage change in rainfall and runoff vary in direction and consequently the results seem improbable, it can be explained by the large rainfall event in Year 44, which was not used to construct the Scenario B sequence. The relative amount of runoff in Year 44 compared to the 77-year runoff sequence was greater than the relative amount of rainfall in Year 44 compared to the 77-year rainfall sequence. When Year 44 is excluded from the analysis, the mean annual rainfall and runoff under Scenario B are 10 percent and 4 percent higher respectively than the longer term mean (76-year sequence). The spatial distribution of rainfall and runoff across the South-East Gulf region under Scenario B is shown in Figure SE-30.



 

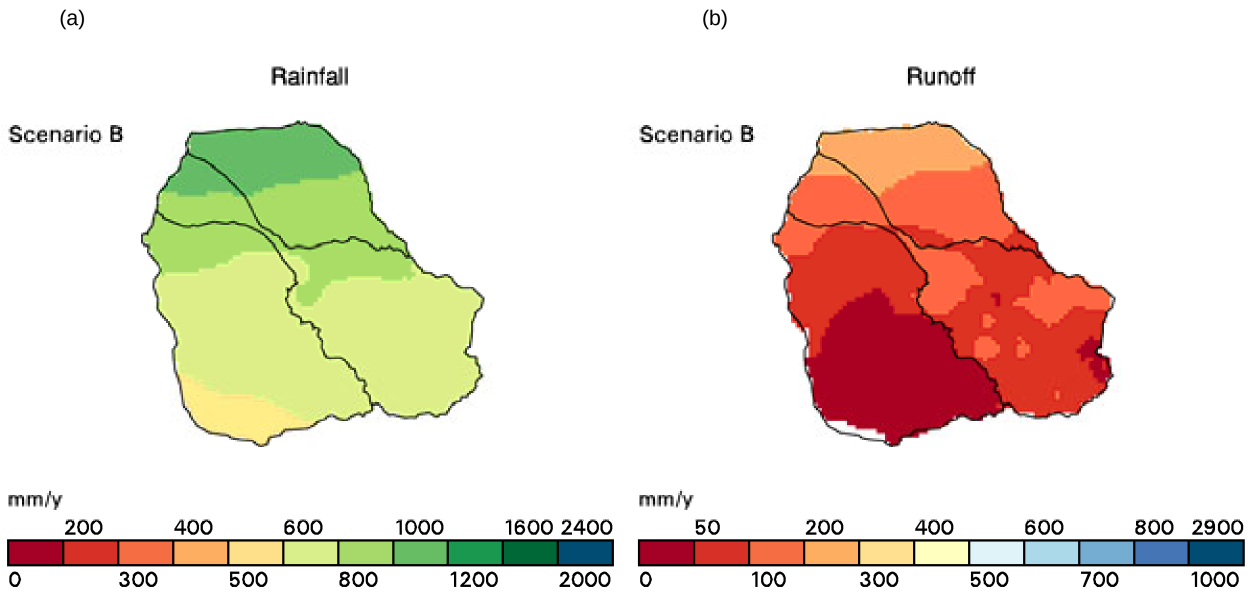


Figure SE-30. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the South-East Gulf region under Scenario B

## SE-3.5.5 Under future climate

Figure SE-31 shows the percentage change in the mean annual runoff averaged over the South-East Gulf region under Scenario C relative to Scenario A for the 45 scenarios (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). The percentage change in the mean annual runoff and rainfall from the corresponding GCMs are also tabulated in Table SE-10.

The figure and table indicate that the potential impact of climate change on runoff can be very significant. Although there is considerable uncertainty in the estimates, the results indicate that runoff in ~2030 in the South-East Gulf region is more likely to decrease than increase. Rainfall-runoff modelling with climate change projections from three-fifths of the GCMs shows a reduction in mean annual runoff, while rainfall-runoff modelling with climate change projections from two-fifths of the GCMs shows an increase in mean annual runoff. The wide range of mean annual runoff values shown in Figure SE-31 and Table SE-10 is primarily due to the wide range of future projections of rainfall by the 15 GCMs.

Because of the large variation between GCM simulations and the method used to obtain the climate change scenarios, the biggest increase and biggest decrease in runoff come from the high global warming scenario. For the high global warming scenario, rainfall-runoff modelling with climate change projections from six of the GCMs indicates a decrease in mean annual runoff greater than 10 percent while rainfall-runoff modelling with climate change projections from five of the GCMs indicates an increase in mean annual runoff greater than 10 percent.

In subsequent reporting here and in other sections, only results from an extreme ‘wet’, ‘mid’ and extreme ‘dry’ variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet, results from the second highest increase in mean annual runoff from the high global warming scenario are used. Under Scenario Cdry, results from the second highest reduction in mean annual runoff from the high global warming scenario are used. Under Scenario Cmid, the median mean annual runoff results from the medium global warming scenario are used. These are shown in bold in Table SE-10.

Under scenarios Cwet, Cmid and Cdry, mean annual runoff increases by 46 percent and decreases by 1 and 23 percent relative to Scenario A. The range based on the low global warming scenario is a 24 to -13 percent change in mean annual runoff, which is large relative to other regions in this project. Figure SE-32 shows the mean annual runoff across the South-East Gulf region under scenarios A and C. The linear discontinuities that are evident in Figure SE-32 are due to GCM grid cell boundaries.

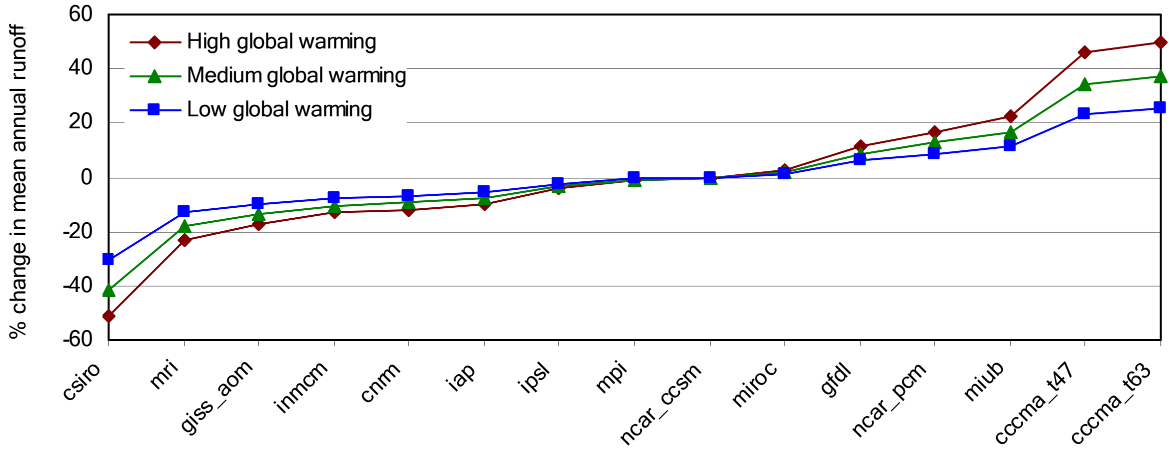


Figure SE-31. Percentage change in mean annual modelled runoff under the 45 Scenario C simulations (15 global climate models and three global warming scenarios) relative to Scenario A

Table SE-10. Summary results under the 45 Scenario C simulations for the modelling subcatchments (numbers show percentage change in mean annual rainfall and modelled runoff under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Runoff | GCM | Rainfall | Runoff | GCM | Rainfall | Runoff |
| csiro | -22% | -51% | csiro | -17% | -42% | csiro | -12% | -31% |
| mri | -7% | -23% | mri | -6% | -18% | mri | -4% | -13% |
| giss_aom | -5% | -17% | giss_aom | -4% | -14% | giss_aom | -3% | -10% |
| inmcm | -2% | -13% | inmcm | -1% | -10% | inmcm | -1% | -7% |
| cnrm | -2% | -12% | cnrm | -2% | -10% | cnrm | -1% | -7% |
| iap | -3% | -10% | iap | -2% | -8% | iap | -2% | -6% |
| ipsl | 1% | -4% | ipsl | 0% | -3% | ipsl | 0% | -2% |
| mpi | -1% | -1% | mpi | -1% | -1% | mpi | -1% | -1% |
| ncar_ccsm | 1% | -1% | ncar_ccsm | 1% | -1% | ncar_ccsm | 1% | 0% |
| miroc | 4% | 3% | miroc | 3% | 2% | miroc | 2% | 1% |
| gfdl | 0% | 11% | gfdl | 0% | 9% | gfdl | 0% | 6% |
| ncar_pcm | 7% | 17% | ncar_pcm | 5% | 13% | ncar_pcm | 4% | 9% |
| miub | 5% | 22% | miub | 4% | 17% | miub | 3% | 12% |
| cccma_t47 | 14% | 46% | cccma_t47 | 11% | 34% | cccma_t47 | 7% | 24% |
| cccma_t63 | 14% | 50% | cccma_t63 | 11% | 37% | cccma_t63 | 8% | 26% |

 

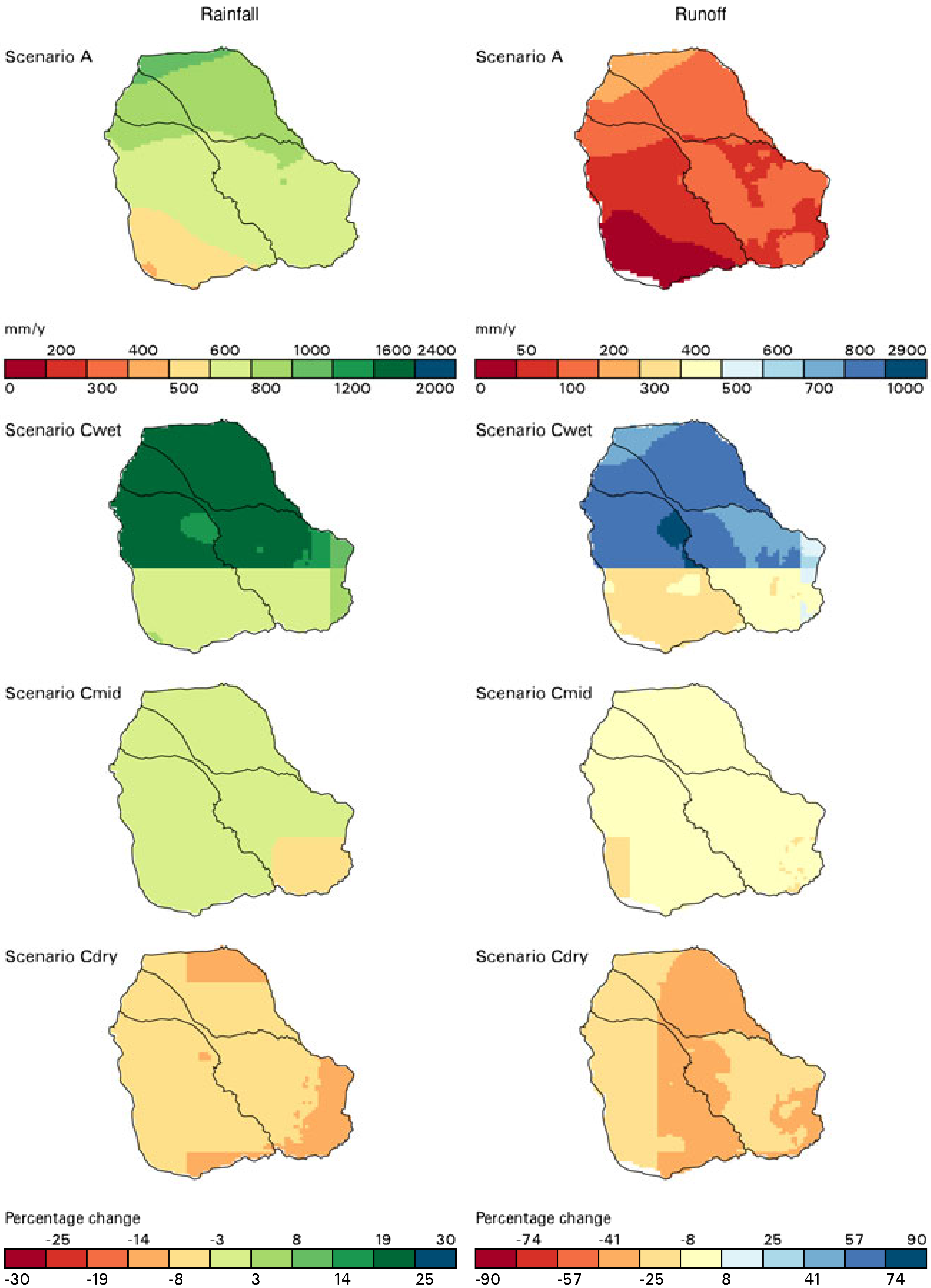


Figure SE-32. Spatial distribution of mean annual rainfall and modelled runoff across the South-East Gulf region under Scenario A and under Scenario C relative to Scenario A

### SE-3.5.6 Summary results for all scenarios

Table SE-11 shows the mean annual rainfall, runoff and actual evapotranspiration under Scenario A averaged over the South-East Gulf region, and the percentage changes in the rainfall, runoff and actual evapotranspiration under scenarios B and C relative to Scenario A. The Cwet, Cmid and Cdry results are based on the mean annual runoff, and the rainfall changes shown in Table SE-10 are the changes in the mean annual value of the rainfall series used to obtain the runoff under scenarios Cwet, Cmid and Cdry. The changes in mean annual rainfall do not necessarily translate directly to the changes in mean annual runoff because of changes in seasonal and daily rainfall distributions and the relationship between rainfall and runoff is non-linear. The latter factor usually results in small changes in rainfall to be amplified in runoff (Table SE-10).

Figure SE-33 shows the mean monthly rainfall and runoff under scenarios A and C averaged over the 77 years for the region. Figure SE-34 shows the daily rainfall and flow exceedance curves under scenarios A and C averaged over the region. In Figure SE-33 scenarios Cwet, Cmid and Cdry are selected on a month-by-month basis, while in Figure SE-34 scenarios Cwet, Cmid and Cdry are selected for every day of the daily flow exceedance curve.

Table SE-11. Water balance over the entire South-East Gulf region under Scenario A and under scenarios B and C relative to Scenario A

| Scenario | Rainfall | Runoff | Evapotranspiration |
|---|---|---|---|
| | | mm | |
| A | 752 | 113 | 640 |
| | | percent change from Scenario A | |
| B | 7% | -13% | 11% |
| Cwet | 14% | 46% | 8% |
| Cmid | -1% | -1% | -1% |
| Cdry | -7% | -23% | -4% |

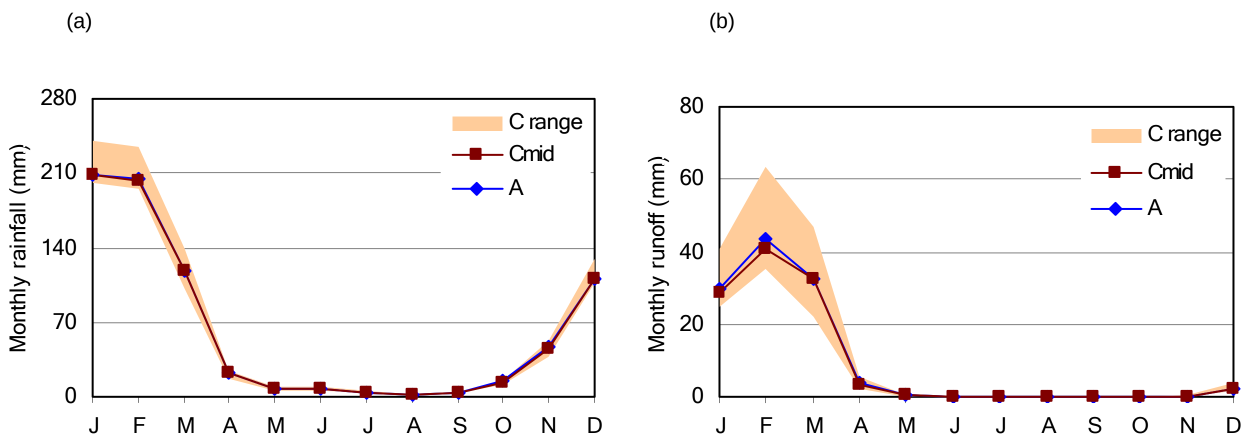


Figure SE-33. Mean monthly (a) rainfall and (b) modelled runoff in the South-East Gulf region under scenarios A and C

 

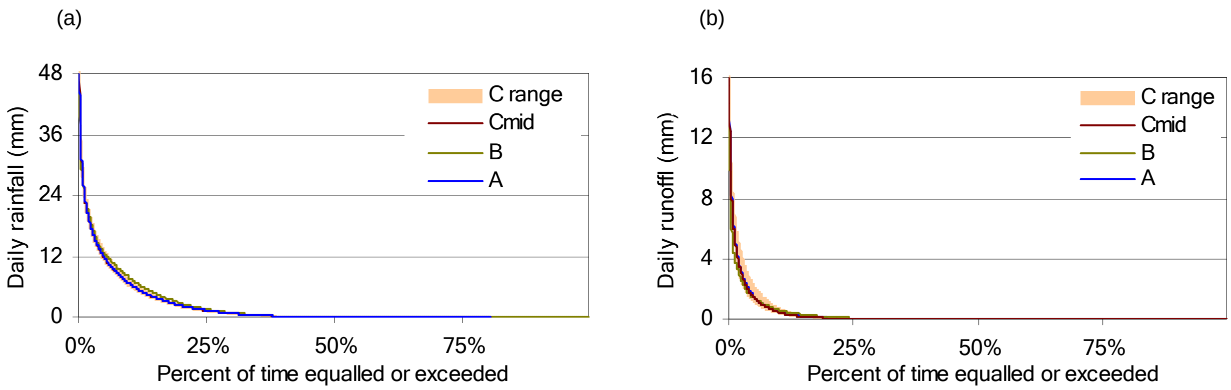


Figure SE-34. Daily flow exceedance curves for (a) rainfall and (b) modelled runoff in the South-East Gulf region under scenarios A, B and C. (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

### SE-3.5.7 Confidence levels

The level of confidence of the runoff estimates for the South-East Gulf region is variable. In the lower reaches (the Great Southern Aggregation), there are no high quality stations. Gauge 918002A, which was used to model the coastal plain regions, may be part of a distribution system of the Mitchell during very large flood events, though there is no clear evidence of large inflows in the observed record for this station. The rainfall-runoff modelling ensemble tended to under predict flows in this calibration catchment which may offset to some extent occasional distributary inflow. The majority of streamflow gauging stations are located in the upper reaches of the Gilbert. However, those gauges categorised as suitable have variable runoff characteristics, which makes transposing parameters from donor calibration catchments to target ungauged subcatchments problematic. The most downstream gauge in the Gilbert catchment was closed in 1989 and did not meet the criteria to be used in this project. Diagrams in Petheram et al. (2009a) illustrate which calibrated rainfall-runoff model parameter sets are used to model streamflow in which ungauged subcatchments in the South-East Gulf region.

The rainfall-runoff model verification analysis with data from 123 catchments from across all of northern Australia indicates that the mean annual runoff for ungauged catchments are under estimated or over estimated, when using optimised parameter values from a nearby catchment, by less than 20 percent in 40 percent of catchments and by less than 50 percent in 80 percent of the catchments.

Figure SE-35 illustrates the level of confidence in the modelling of the mid to high (i.e. peak flows) and dry season runoff events (respectively) for the subcatchments of the South-East Gulf region. It should be noted that these maps of level of confidence are not statistical confidence levels and are intended to only convey a broad reliability of prediction. The level of confidence in streamflow predictions will vary slightly from the level of confidence in runoff predictions shown below and as discussed in Section 2.2.6 of the division-level Chapter 2.

There is a high degree of confidence that dry season runoff in the South-East Gulf region is low because it is known that rainfall and baseflow are low during the dry season. The map of level of confidence for dry season flow shown in Figure SE-35 provides a relative indication of how well dry season metrics, such as cease-to-flow, are simulated.

Largely due to the very low level of confidence in modelling the Norman and Staatan catchments, the level of confidence in the long-term average monthly and annual results for the South-East Gulf region is low relative to other regions. As shown in Figure SE-35, in many areas of the South-East Gulf region localised studies will require more detailed analysis than undertaken and reported in this project and would most likely require the site to be visited and additional field measurements made.

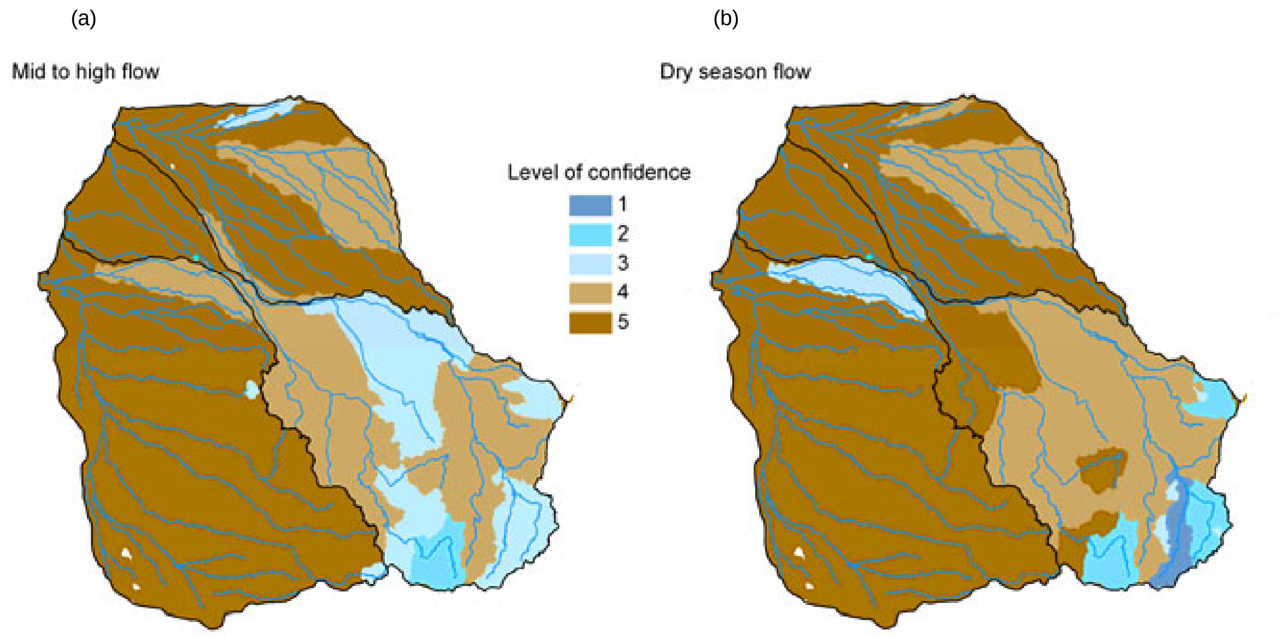


Figure SE-35. Level of confidence in the modelling of runoff for (a) mid- to high flow events and (b) monthly dry season flow events for the modelling subcatchments of the South-East Gulf region. 1 is the highest level of confidence, 5 is the lowest

 

# SE-3.6 River system water balance

The South-East Gulf region is comprised of three Australian Water Resource Council (AWRC) river basins, the Norman, Staatan and Gilbert, and has an area of 122,094 km$^2$. Under the historical climate the mean annual runoff across the region is 110 mm (Section SE-3.5.3), which equates to a mean annual streamflow across the region of 13,430 GL. The Gilbert is the only catchment represented by an IQQM model and is discussed in detail later in this section.

## Norman and Staatan river basins

For the Norman and Staatan river basins, no information on infrastructure, water demand and water management and sharing rules or future development were available, and consequently there is no river modelling section for these river basins. Streamflow time series have been generated for each streamflow reporting node (SRN) based on the upstream grid cell rainfall-runoff simulations, as described in Section 2.2.5 of the division-level Chapter 2. The locations of these nodes are shown in Figure SE-36. SRN for the Gilbert catchment are not shown on this figure. Summary streamflow statistics for each SRN are reported in Petheram et al. (2009a). In addition to the streamflow time series generated by the rainfall-runoff model ensemble, a range of hydrological metrics computed using regression analysis are also available for each SRN (as described in Section 2.2.7 of the division-level Chapter 2). The complete set of results for the multiple regression analysis is reported in SKM (2009). The merit of each approach is discussed in Section 2.2.7 of the division-level Chapter 2.

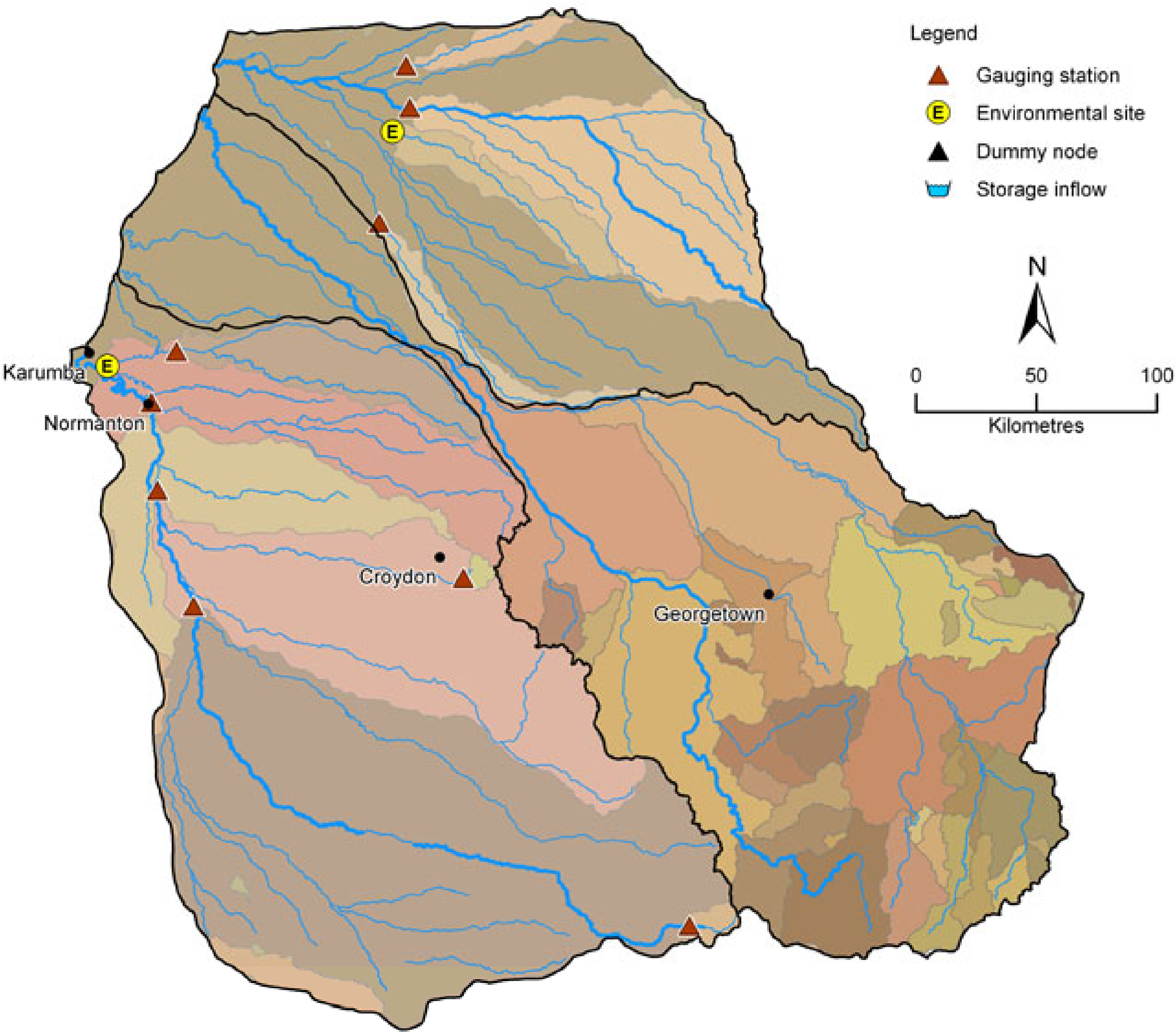


Figure SE-36. Location of streamflow reporting nodes (gauging stations, environmental sites, dummy nodes and storage inflows) in the Norman and Staatan catchments of the South-East Gulf region. (No dummy nodes or storage inflows are reported for this region)

## Gilbert catchment

General information about river modelling methods is presented at the division-level in Chapter 2. In that chapter, scenarios are defined in Section 2.1 and river modelling methods which apply to all regions are described in Section 2.2. The following section summarises this generic river modelling approach as applied to the South-East Gulf region. The river modelling results for the South-East Gulf River model is reported using a range of metrics, which were consistently applied across all regions. The use of a common set of metrics across the entire project area enables comparisons between regions.

In this section where annual data are reported, years are represented by numbers 1 through 77. Consistently throughout the report, annual data are based on the water year (1 September to 31 August) and the dry season is defined as 1 May to 31 October. Scenarios Cwet, Cmid and Cdry are selected on the basis of the ranked mean annual rainfall for the modelled subcatchments in Section SE-3.5.

River system models can be used to assess the implications of the changes in inflows on the reliability of water supply to users. They may also be used to support water management planning by assessing the trade-offs between supplies to various competing categories of users. These models describe infrastructure, water demands, and water management and sharing rules. Given the time constraints of the project, and the need to link the assessments to state water planning processes, it is necessary to use the river system models currently used by state agencies.

 

The Gilbert catchment is modelled using the IQQM program (version 6.42.2). The river basin boundaries and the subdivision of the river basin into subcatchments for modelling purposes are shown in Figure SE-25. The model was set up by Department of Environment and Resource Management (DERM) to support the Queensland Water Resource Planning Process. Results from this model for the period from January 1890 to June 2003 were used to establish the water sharing rules in the draft Gulf Resource Operations Plan (DNRW, 2008). The level of development represented by the model is based on the full use of existing entitlements.

As part of the Northern Australia Sustainable Yields Project input data for the model were extended so that they covered the period 1 January 1890 to 30 June 2008. The results for this project are presented over 77-year sequences for the common modelling period 1 September 2007 to 31 August 2084. Results presented in DERM reports (Water Assessment Group, 2006) may differ from numbers published in this report due to the different modelling period and different initial conditions.

In this project the river system modelling for the South-East Gulf regions consist of ten scenarios:

- Scenario A – historical climate and full use of existing entitlements
  This scenario assumes a full use of existing entitlements. Full use of existing entitlements refers to the total entitlements within a plan area including existing water authorisations and unallocated reserves. This refers to the water accounted for in the resources operation plan, but the licences are interim or not allocated as yet. The period of analysis commences on 1 September 2007 and the results are reported based on modelling the 77-year historical climate sequence between 1 September 2007 and 31 August 2084. This scenario is used as a baseline for comparison with all other scenarios.
- Scenario AN – historical climate and without development
  Current levels of development such as storages and demand nodes are removed from the model to represent without-development conditions. Inflows were not modified for groundwater extraction, major land use change or farm dam development because the impact of these factors on catchment yield are currently considered to be negligible. This scenario uses the historical flow and climate inputs used for Scenario A.
- Scenario BN – recent climate and without-development
  Current levels of development such as storages and demand nodes are removed from the model to represent without-development conditions. Inflows were not modified for groundwater extraction, major land use change or farm dam development because the impact of these factors on catchment yield are currently considered to be negligible. This scenario uses seven consecutive climate sequences between 1 September 1996 and 31 August 2007 to generate a 77-year climate sequence representative of the 'recent climate' (for more detail see Section 2.1.2 in the division-level Chapter 2).
- Scenario CN – future climate and without-development
  Current levels of development such as public storages and demand nodes are removed from the model to represent without-development conditions. Inflows were not modified for groundwater extraction, major land use change or farm dam development because the impact of these factors on catchment yield are currently considered to be negligible. Scenarios CNwet, CNmid and CNdry represent a range of future climate conditions that are derived by adjusting the historical climate and flow inputs used in Scenario A.
- Scenario B – recent climate and full use of existing entitlements
  This scenario assumes the full use of existing entitlements and uses seven consecutive climate sequences between 1 September 1996 and 31 August 2007 to generate a 77-year climate sequence representative of the 'recent climate' (for more detail see Section 2.1.2 in the division-level Chapter 2).
- Scenario C – future climate and full use of existing entitlements
  Scenarios Cwet, Cmid and Cdry represent a range of future climate conditions that are derived by adjusting the historical climate and flow inputs used in Scenario A. The level of development for Scenario C assumes the full use of existing entitlements, i.e. the same as for Scenario A.

The changes in inflows between scenarios reported in this chapter differ from the changes in runoff reported in Chapter SE-3.5. These differences are due to difference in the methods by which the GCMs were ranked and difference in areas that are considered to contribute runoff to the surface water model. In Chapter SE-3.5 the entire region is considered while a subset of this area is considered here. The scenarios presented in this project may not eventuate but they encompass consequences that might arise if no management changes are made. Consequently results from this assessment are designed to highlight pressure points in the system, both now and in the future. This assessment does not elaborate on what management actions might be taken to address any of these pressure points. Where management changes to mitigate the effects of climate change have recently been implemented, the impacts of the changes predicted in this section may be an overestimate.

### SE-3.6.1 River model configuration

#### Gilbert model description

The Gilbert region is described by the Gilbert IQQM system model (Water Assessment Group, 2006). The system is represented in the model by 43 river sections and 182 nodes. Figure SE-37 is a schematic of the Gilbert IQQM system model, showing the approximate location of main stream gauges and key demand and storage nodes.

The Miranda Downs gauge on the Gilbert River (917009A) is the most downstream flow monitoring station in the system. However this gauge was closed in 1989. The most downstream flow monitoring station which is still open is the Rockfields gauge on Gilbert River (917001D). The Gilbert River is the principal stream, and major tributaries are: Copperfield River, Einasliegh River, Etheridge River, Robertson River, Percy River, Little River, McKinnons Creek, Elizabeth Creek and Agate Creek. Copperfield Dam was constructed on the Copperfield River during 1984 to provide an assured freshwater supply for the Kidston Gold Mine, which is now closed. The dam has a storage capacity of 21,000 ML.

The development represented in the model is based on the full use of existing entitlements and therefore does not simulate current levels of development. Water use is modelled by 53 nodes as shown in Table SE-13. There is 1 node for a regulated supply from a private storage. Other extractions modelled include:

- 6 nodes for unregulated supplies from bedsand storage (there is significant natural storage in the bed sands of the Gilbert River)
- 35 nodes for unregulated supplies from run-of-river
- 11 nodes for high flow diversions (water harvesting).

There are 16 instream storages in the model. The only major storage is the Copperfield Dam on the Copperfield River. Details of storages are provided in Table SE-12. There is a passing flow requirement for Copperfield Dam that up to 1143 ML/day inflow is to be passed though the dam. The degree of regulation metric in Table SE-12 is the sum of the net evaporation and controlled released from the dam divided by the total inflows. Controlled releases exclude spillage. Storages with radial gates and without spillways are not reported in this table (there is only one known storage of this type in the project area, which is the Kununurra Diversion Dam in the Ord-Bonaparte region). The degree of regulation of Copperfield Creek Dam under the full use of existing entitlements is moderately high (0.3).



 

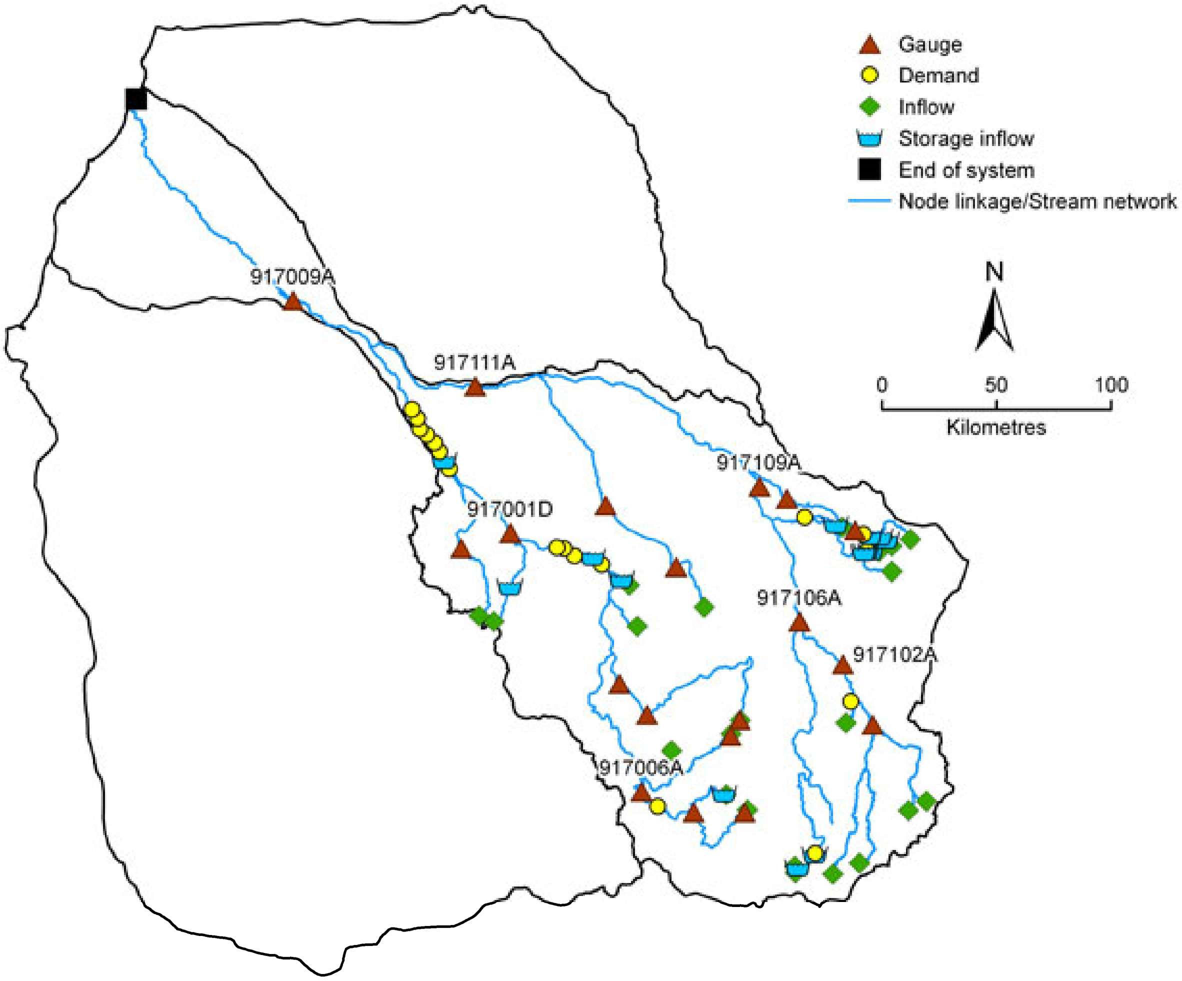


Figure SE-37. Schematic of the approximate location of gauging stations, main demand nodes and storages for the Gilbert system river model

Table SE-12. Storages in the Glibert system river model

| | Active storage | Mean annual Inflow | Mean annual release | Mean annual net evaporation | Degree of regulation |
|---|---|---|---|---|---|
| | GL | GL/y | | | |
| Major reservoirs | | | | | |
| Copperfield Dam | 18.5 | 127.2 | 38.3 | 2.6 | 0.3 |
| **Region total** | **18.5** | **127.2** | **38.3** | **2.6** | 0.3 |

In Table SE-13 and the sections that follow, ‘volumetric limit’ is defined as the maximum volume of water that can be extracted from a river system within this region under the resources operation plan. Unsupplemented water is defined as surface water that is not sourced from a water storage that is able to regulate or control supply to users.

Table SE-13. Modelled water use configuration in the Glibert system river model

| Water users | Number of nodes | Volumetric limit | Model notes |
|---|---|---|---|
| | | GL/y | |
| Town water supply | | | |
| Unsupplemented | 1 | 0.1 | Fixed demand |
| Agriculture | | | |
| General Security | 13 | 4.0 | No On Farm Storage |
| Unsupplemented | 19 | 29.9 | |
| Mining | | | |
| High Security | 2 | 7.3 | Fixed demand |
| Unsupplemented | 1 | 0.4 | Fixed demand |
| Other demands | | | |
| Unsupplemented | 17 | 0.3 | Fixed demand |
| **Total** | **53** | **42.136** | |

### Model setup

The original Gilbert systems river model and associated IQQM V6.42.2 executable code were obtained from DERM. The time series rainfall, evaporation and flow inputs to this model for the historical climate time series were set to cover the historical period from 1 September 1930 to 31 August 2007. The model was run for this period and validated against the original model run results for the same period.

For the scenarios that assume the full use of existing entitlements, the initial state of storages can influence the results obtained so the same initial storage levels were used for all scenarios. In this project all scenarios are reported for the 77-year period commencing on 1 September 2007. However, the demand simulated by an IQQM model for month *n* is dependent upon the simulation results for month *n-1*. For this reason the initial conditions (i.e. storage levels) are set to the levels simulated on the 1 August 2007 for all scenarios. The models are then run for 77 years and one month.

A without-development version of the Gilbert model was created by removing all instream storages, all irrigators and fixed demands.

Table SE-14. Gilbert system river model setup information

| Model setup information | | Version | Start date | End date |
|---|---|---|---|---|
| Gilbert | IQQM | 6.42.2 | 01/01/1890 | 30/06/2008 |
| Baseline models | | | | |
| Warm-up period | | | 1/08/2007 | 31/08/2007 |
| Gilbert | IQQM | 6.42.2 | 1/09/2007 | 31/08/2084 |
| Modifications for Scenario A | | | | |
| Data | Data extended by DRNW | | | |
| Inflows | No adjustment | | | |
| Initial storage volumes | set to level at 01/08/2007 | | | |
| Copperfield Dam | 19GL | | | |
| Other storages | set to level at 01/08/2007 | | | |

## SE-3.6.2 River system water balance

The mass balance table (Table SE-12) shows volumetric components for Scenario A as GL/year, with all other scenarios presented as a percentage change from Scenario A. Mass balance includes the change in storage that is averaged over the 77-year period and is shown as GL/year.

The directly gauged inflows represent the inflows into the model that are based on data from a river gauge. The indirectly gauged inflows include inflows that are derived to achieve a mass balance between mainstream gauges. Diversions are listed based on the different water products in the region. The modelled end-of-system is the Gilbert River at the outflow to the sea.

 

Mass balance tables for the 12 reported subcatchments are provided in Petheram et al. (2009b). The mass balance of each of these river reaches and the overall mass balance were checked by taking the difference between total inflows, outflows of the system and change in storage volumes. In all cases the mass balance error was zero. Unattributed fluxes in Table SE-15 are the modelled river losses. River losses are estimated from loss relationships that are determined during calibration of the IQQM model such that flow is conserved between upstream and downstream gauging stations.

Results in Table SE-15 show that under scenarios Cwet and Cdry inflows in the Gilbert catchment increase by 32 percent and decrease by 16 percent respectively. End-of-system flows increase by 34 percent and decrease by 17 percent under scenarios Cwet and Cdry respectively. There is minimal impact to total diversions (<4 percent) as demands in the catchment are much smaller than the total inflows. Consumptive use is discussed further in SE-3.6.5.

The reason for the large reduction in inflows under Scenario B is discussed in Section SE-3.5.4.

Table SE-15. Glibert system river model mean annual water balance under Scenario A and under scenarios B and C relative to Scenario A

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | | | | |
| Storage volume | | | | | |
| Change over period | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Inflows | | | | | |
| | GL/y | percent change from Scenario A | | | |
| Subcatchments | | | | | |
| Gauged | 774.8 | -17% | 9% | 8% | -16% |
| Ungauged | 5093.5 | -20% | 35% | 8% | -17% |
| **Sub-total** | **5868.2** | **-20%** | **32%** | **8%** | **-16%** |
| Diversions | | | | | |
| Town Water Supply | | | | | |
| Unsupplemented | 0.0 | 0% | 0% | 0% | 0% |
| Agriculture | | | | | |
| General Security | 3.0 | 0% | 0% | 0% | -2% |
| Unsupplemented | 18.7 | -2% | 0% | 1% | -4% |
| Mining | | | | | |
| High Security | 6.6 | 0% | 1% | 0% | -2% |
| Unsupplemented | 0.4 | -5% | 3% | -1% | -13% |
| Other Uses | | | | | |
| General Security | 0.2 | -1% | 1% | 0% | -1% |
| **Sub-total** | **29.0** | **-1%** | **0%** | **0%** | **-3%** |
| Outflows | | | | | |
| End-of-system flow | 5304.2 | -21% | 34% | 8% | -17% |
| **Sub-total** | **5304.2** | **-21%** | **34%** | **8%** | **-17%** |
| Net evaporation | | | | | |
| Storages | 5.0 | -2% | 1% | 3% | 9% |
| **Sub-total** | **5.0** | **-2%** | **1%** | **3%** | **9%** |
| Unattributed fluxes | | | | | |
| | **530.1** | **-7%** | **9%** | **2%** | **-8%** |

### SE-3.6.3 Inflows

#### Inflows

There are several ways that the total inflows into the river system can be calculated. The obvious way would be to sum all of the inflows in the model. This is 5868 GL/year for the Gilbert IQQM (Table SE-15). The table also shows that a large proportion of the inflow is indirectly gauged and therefore estimated as part of model calibration. The approach used to calibrate these inflows varies considerably between reaches and model implementations. In some cases inflows are inflated and subsequently compensated for by loss relationships. In other cases the losses are inherent in the inflows. Totalling inflows does not provide a consistent assessment of total river system inflows across different models because of the different approaches to calibration.

An alternative is to locate the point of maximum average annual flow in the river system under without-development conditions. The gauge with maximum average annual flow is a common reference across all models irrespective of how mass balance is calibrated. This is because all river models are calibrated to achieve mass balance at mainstream gauges. The without-development scenarios remove the influences of upstream extractions and regulation and gives a reasonable indication of total inflows. For the IQQM catchments in northern Australia, where there have been minimal modifications to subcatchment inflows due to farm dams, commercial forestry plantations and groundwater use, Scenario AN can be considered to be broadly representative of pre-European settlement conditions.

A comparison between scenarios for reaches along the Gilbert River is presented in Figure SE-38. This shows that the maximum average annual mainstream gauged flow occurs at the last gauge 917009 (Gilbert River at Miranda Downs) with a value of 3724 GL/year under Scenario AN. This is typical of the Gulf catchments as rainfall increases towards the valley's outlet.

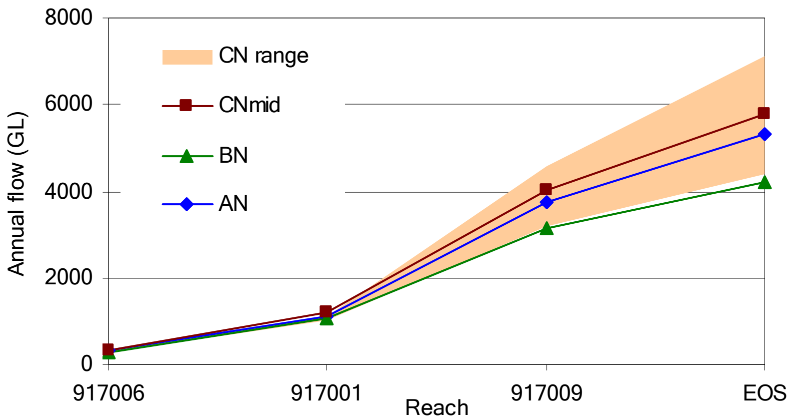


Figure SE-38. Transect of total mean annual river flow in the South-East Gulf region under scenarios AN, BN and CN

#### Water availability

In the Murray-Darling Basin Sustainable Yields Project, water availability was defined as the volume of water under the without-development scenario which occurs at the point of maximum mean annual flow along a river system. This generally occurred where a river system turned from a gaining reach to a losing reach. The major rivers in the Gulf of Carpentaria Drainage Division are, however, gaining systems, that is their highest mean annual flow occurs at their end-of-system. However end-of-system flow volumes are uncertain due to considerable ungauged flow contribution to these points. For this reason water availability is defined in this project as the volume of water under the without-development scenario which occurs at the gauged point of maximum mean annual flow along a river system. In the river systems of the Gulf of Carpentaria this point occurs at the most downstream gauge. When computing water availability for this project ecological, social, cultural and economic values are not considered.

It must also be noted, however, that not all of the water at the most downstream gauge is accessible for consumptive use. In the Gulf of Carpentaria the majority of suitable locations for large carry over storages are in the headwater catchments and not at or near the last gauge in the system. Further during large out of bank flows (flood flows) water harvesting operations, which are usually located in the lower reaches, are constrained by the rapid rise and fall in stage height (Petheram et al., 2008) and insufficient on-farm storage capacity.

A time series of total annual surface water availability under Scenario AN is shown in Figure SE-39. The lowest annual water availability was 98 GL in Year 22 while the greatest annual water availability was 30,149 GL in Year 44. Figure SE-40 shows the difference in annual total surface water availability under Scenario CN relative to Scenario AN.

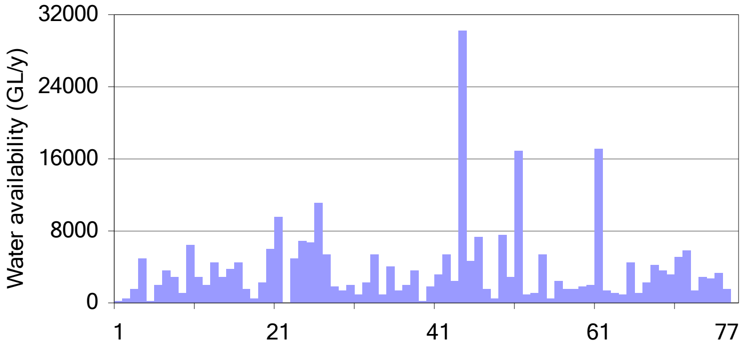


Figure SE-39. Annual water availability at streamflow gauging station 917009 under Scenario AN

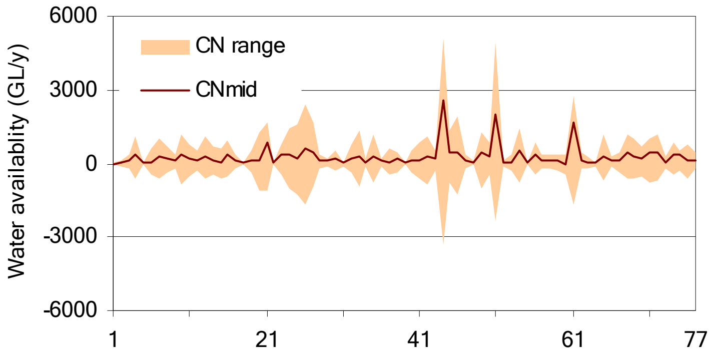


Figure SE-40. Change in total surface water availability at streamflow gauging station 917009 under Scenario CN relative to Scenario AN

## SE-3.6.4 Storage behaviour

The modelled behaviour of major storages indicates how reliable the storage is during extended periods of low or no inflow. Table SE-16 provides indicators for Copperfield Dam that show for each scenario the lowest recorded storage volume and the corresponding date. The average and maximum years between spills is also provided. A spill commences when the storage exceeds full supply volume and ends when the storage falls below 90 percent of full supply volume. The end condition is applied to remove the periods when the dam is close to full and oscillates between spilling and just below full which would otherwise distort the analysis. The period between spills is the length of time from when one spill ends (i.e. the storage falls below 90 percent of the fully supply volume) until the next spill commences (i.e. when the storage exceeds the full supply volume).

The storage behaviour under all scenarios is similar to that under Scenario A indicating good reliability for various climate conditions.

Table SE-16. Details of dam behaviour

| Copperfield Dam | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| Minimum storage volume (GL) | 1.6 | 1.6 | 1.6 | 1.6 | 1.5 |
| Minimum storage date | 29 Jan, Year 41 | 18 Jan, Year 65 | 18 Jan, Year 65 | 29 Jan, Year 41 | 18 Jan, Year 65 |
| Average years between spills | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| Maximum years between spills | 6.7 | 6.7 | 6.7 | 6.7 | 6.7 |

The time series of storage behaviour for Copperfield Dam for the maximum period between spills under each of the scenarios is shown in Figure SE-41.

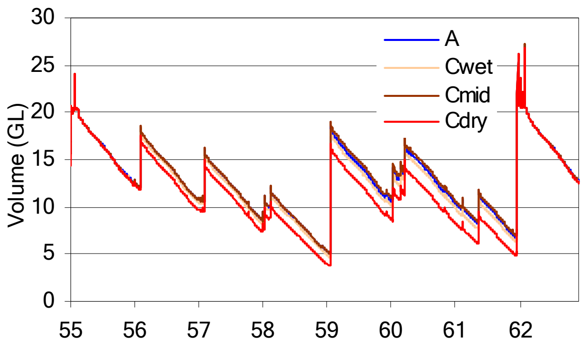


Figure SE-41. Storage behaviour over the maximum period between spills for Copperfield Dam under scenarios A and C

## SE-3.6.5 Consumptive water use

### Diversions

Table SE-17 shows the total mean annual diversions for each subcatchment (Figure SE-37) under Scenario A and the percentage change under scenarios B and C relative to Scenario A. Water harvesting of high river flows accounts for about 59 percent of total diversions (17.1 GL/year) under the full use of existing entitlements case. The change in total diversions decreases under Scenario Cdry because demands do not vary with change in climate, but less water is accessible for diversion.

 

Table SE-17. Mean annual diversions in each subcatchment in the South-East Gulf system under Scenario A and under scenarios B and C relative to Scenario A

| Reach | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | percent change from Scenario A | | | |
| 9170061 | 1.8 | -1% | 0% | 1% | -3% |
| 9170131 | 0.0 | | | | |
| 9170011 | 14.3 | -2% | 0% | 1% | -4% |
| 9171081 | 0.0 | 0% | 0% | 0% | 0% |
| 9171021 | 4.3 | -1% | 0% | 0% | -2% |
| 9171061 | 4.6 | 0% | 0% | 0% | 0% |
| 9171091 | 1.0 | 0% | 0% | -1% | -1% |
| 9171121 | 2.8 | -1% | 2% | -1% | -7% |
| 9171131 | 0.2 | -1% | 1% | 0% | -1% |
| 9171111 | 0.0 | -1% | 2% | 0% | -5% |
| 9170091 | 0.0 | | | | |
| 9179991 | 0.0 | | | | |
| **Total** | **29.0** | **-1%** | **0%** | **0%** | **-3%** |

Figure SE-42 shows total average annual diversions under scenarios A, B and C for subcatchment reaches. The subcatchment with the most diversions is the Gilbert River between Percy Junction gauge (917006a) and Rockfields gauge (917001d).

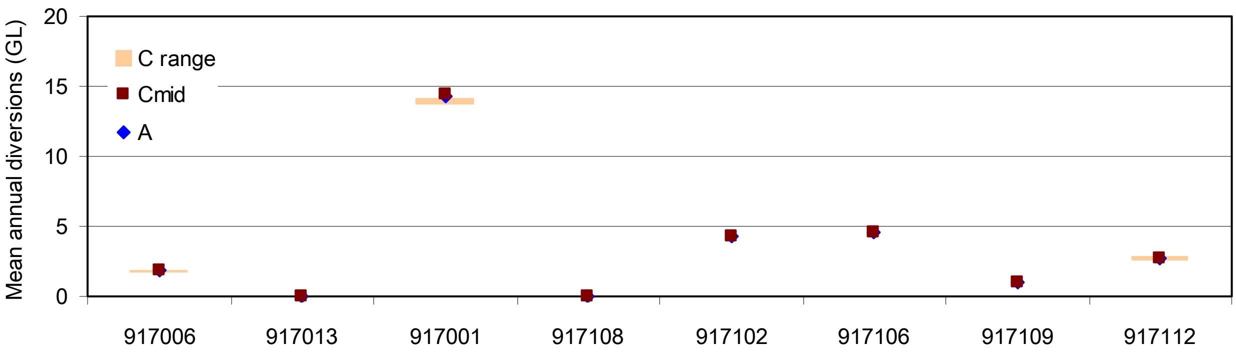


Figure SE-42. Total mean annual diversions for each subcatchment in the South-East Gulf system under scenarios A and C

Figure SE-43 shows the annual time series of total diversions under Scenario A and the difference between Scenario A and Scenario C. The maximum and minimum diversions under Scenario A are 35.1 GL in Year 44 and 9.7 GL in Year 22 respectively. The change in diversions is within 5 GL/year under scenarios Cwet, Cmid and Cdry.

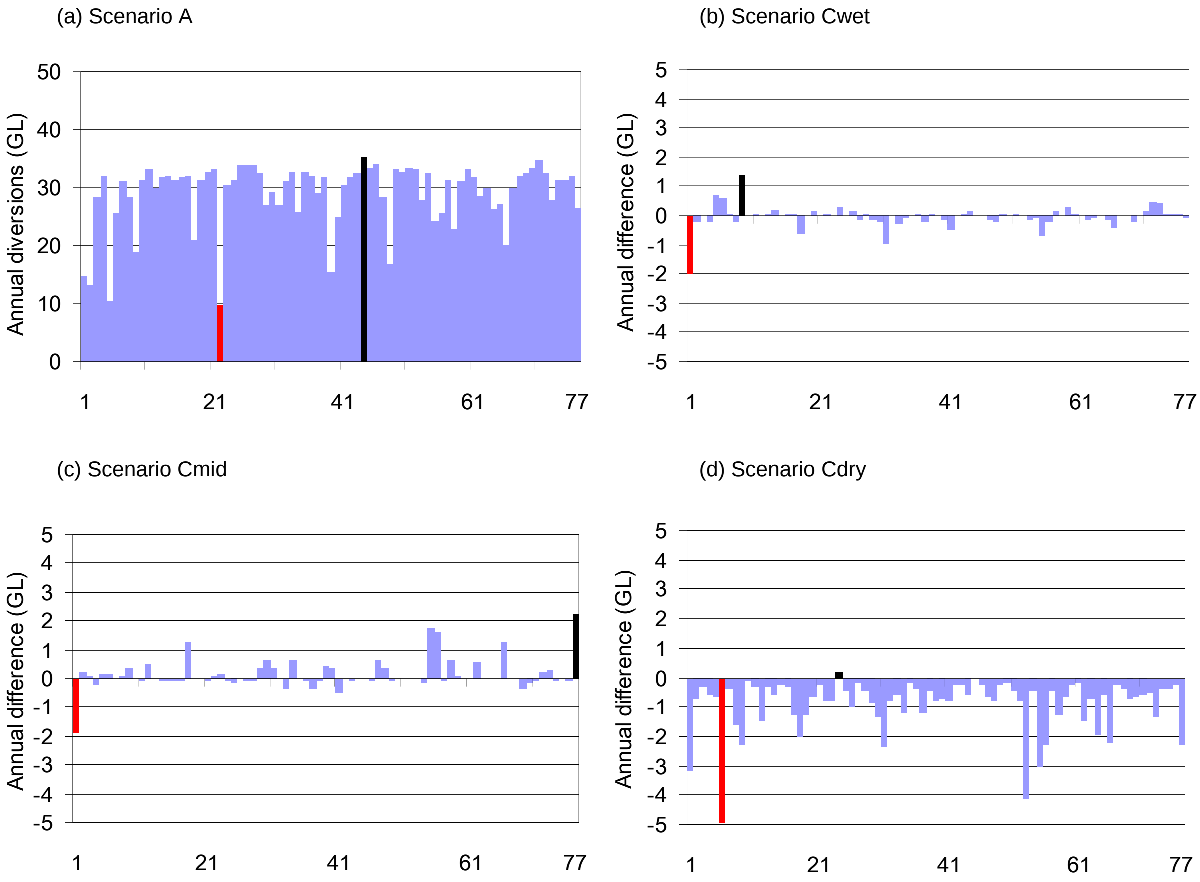


Figure SE-43. Total annual diversions under (a) Scenario A; and difference from Scenario A under (b) Scenario Cwet, (c) Scenario Cmid and (d) Scenario Cdry

## Level of use

The level of use for the region is indicated by the ratio of total use to surface water availability. Total use comprises subcatchment use and streamflow extractions. There is no subcatchment use (i.e. water intercepted by farm dams or used by commercial forestry operations) within the Gilbert system. Streamflow extractions include total net diversions, which are defined as the net water diverted for the full range of water products. Streamflow use includes total net diversions, which are defined as the net water diverted for the full range of water products. Net diversion is the sum of the diversions minus the return flows. It should be noted, however, there are no return flows in the Gilbert IQQM. Net diversions are used to reflect the change in mass balance of the system. They do not consider the difference in water quality that may exist between diversions and returns.

Level of use is presented in two ways for this region. The first approach is the same as presented in the Murray-Darling Basin Sustainable Yields Project: the ratio of total use to total surface water availability (Table SE-18). The second is to present a transect of level of use at each main river gauge, which compares the cumulative diversions up to the gauge (including use on effluents and tributaries) with the average annual river flow at the gauge. This approach shows the spatial variation of use (Figure SE-44).

The level of use throughout the Gilbert region is low with 1 percent of the available surface water resource diverted for use. As use is low in the region, demands are able to be met under various climate scenarios. In Table SE-18 the total use is lowest under Scenario Cdry for the reasons outlined in the above section on diversions.

Current utilisation of licences is estimated by considering the unallocated water reserves from the *Gulf Draft Resource Operations Plan* (DNRW, 2008) and the volumetric limits. For the Gilbert catchment the long-term allowable diversions are 42 GL/year (Table SE-13), and the unallocated reserves are reported to be 10 GL/year. Based on these values it is estimated that current usage is approximately 32 GL/year. Allowable usage or total average diversions from IQQM are for the historical period (1930 to 2007) and therefore may differ to the volumes used to develop the resource operations plan.

Table SE-18. Relative level of surface water use in the South-East Gulf system under Scenario A and scenarios B and C relative to Scenario A

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | | | GL/y | | |
| Total surface water availability | 3724 | 3143 | 4570 | 4001 | 3184 |
| Streamflow use | | | | | |
| Total net diversions | 29 | 29 | 29 | 29 | 28 |
| **Total use** | **29** | **29** | **29** | **29** | **28** |
| | | | percent | | |
| Relative level of use | 1% | 1% | 1% | 1% | 1% |

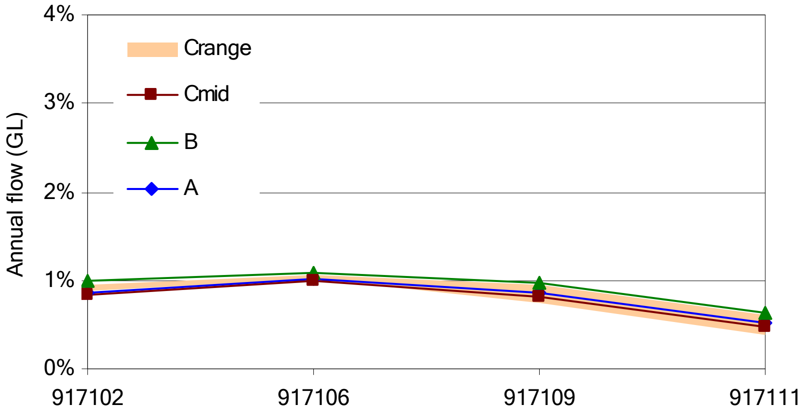


Figure SE-44. Transect of relative level of surface water use in the South-East Gulf region under scenarios A, B and C

## Use during dry periods

Table SE-19 shows the average annual diversions, as well as the annual diversions for the lowest 1-, 3- and 5-year periods under Scenario A and the percentage change from Scenario A under each other scenario.

Table SE-19. Indicators of diversions during dry periods in the South-East Gulf system under Scenario A and under scenarios B and C relative to Scenario A

| Annual diversion | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | percent change from Scenario A | | | |
| Lowest 1-year period | 10 | -1% | 1% | 1% | -8% |
| Lowest 3-year period | 19 | -3% | -4% | -3% | -8% |
| Lowest 5-year period | 20 | -2% | -2% | -2% | -6% |
| Average | 29 | -1% | 0% | 0% | -3% |

## Reliability

The average reliability of water products can be indicated by the ratio of total diversions to the volumetric limit. For the Gilbert region, high security use is compared against licence volume; volumetric limits for town water supply, mining and other uses are compared against a reference demand that is associated with a fixed demand pattern; and agricultural usage is compared against maximum area planted by an application rate or a specified licence capacity. Table SE-20 shows the average reliability under Scenario A and the percent change under scenarios B and C. Results indicate that generally reliability is good for all water products.

Table SE-20. Average reliability of water products in the South-East Gulf system under Scenario A and under scenarios B and C relative to Scenario A

| | A | | | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| | Volumetric limit | Mean annual diversions | Fraction diverted per 1ML allocated | | | | |
| | GL/y | | | percent change from Scenario A | | | |
| Licensed private usage | | | | | | | |
| Town water supply | | | | | | | |
| Unsupplemented | 0.1 | 0.0 | 0.00 | | | | |
| Mining | | | | | | | |
| High security | 7.3 | 6.6 | 0.90 | 0% | 1% | 0% | -2% |
| Unsupplemented | 0.4 | 0.4 | 1.00 | 0% | 8% | 4% | -9% |
| Agriculture | | | | | | | |
| General security | 4.0 | 3.0 | 0.75 | 0% | 0% | 0% | -2% |
| Unsupplemented | 29.9 | 18.7 | 0.63 | -2% | 0% | 1% | -4% |
| Other demands | | | | | | | |
| Unsupplemented | 0.3 | 0.2 | 0.67 | -1% | 1% | 0% | -1% |

There is a difference in most systems between the water that is available for use, as modelled in the Gilbert IQQM as full entitlements are modelled, and the water that is actually diverted for use. These differences may be due to a range of factors including underutilisation of licences, unallocated water reserves and water being provided from other sources such as rainfall. The difference between available and diverted water will vary considerably across water products and time.

### SE-3.6.6 River flow behaviour

There are many ways of considering the flow characteristics in river systems. For this report three different indicators are provided: daily flow exceedance, seasonal plot and daily event frequency. These are considered at the end-of-system. Figure SE-45(a) shows the flow exceedance curve.

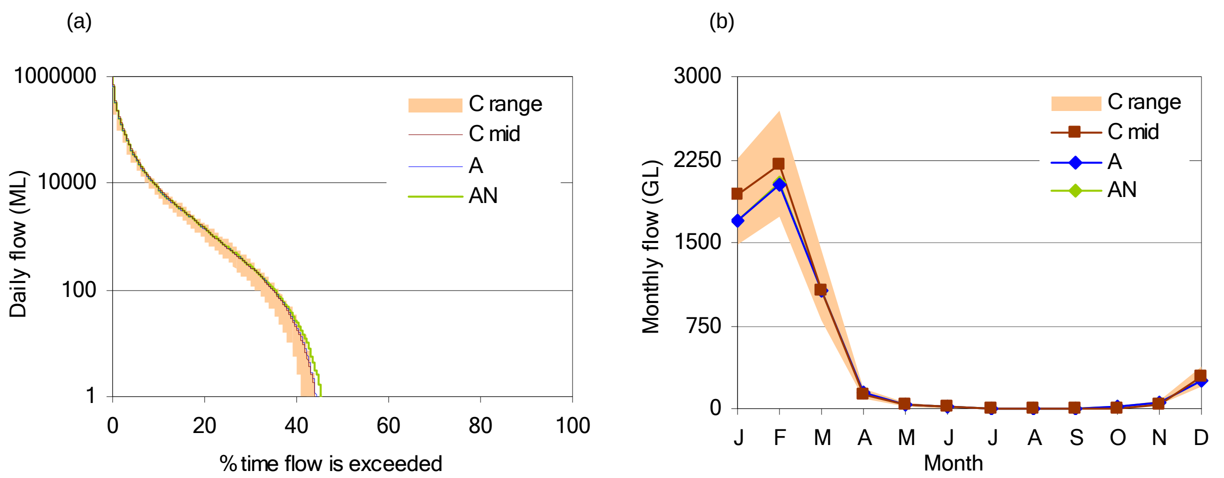


Figure SE-45. (a) Daily flow exceedance curves and (b) mean monthly modelled flow for the South-East Gulf end-of-system under scenarios AN, A and C



 

Figure SE-45(b) gives the mean monthly flow under scenarios AN, A and C at the end-of-system. There is a strong seasonality at the end-of-system gauge reflecting the wet and dry seasons. This figure also shows minimal change in the seasonality at the end-of-system compared to without-development conditions under all scenarios. The percentage of time that flow is greater than 1 ML/day under these scenarios is presented in Table SE-21. Under climate scenarios there is not a large impact to low flow at the end-of-system.

Table SE-21. Percentage of time modelled flow at the South-East Gulf end-of-system is greater than 1 ML/day under scenarios AN, A, B and C

| Catchment | AN | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|
| Gilbert | 65% | 64% | 63% | 65% | 64% | 60% |

## SE-3.6.7 Share of water resource

### Non-diverted water shares

There are several ways of considering the relative level of impact on non-diverted water. Table SE-22 presents two indicators for:

- the average annual non-diverted water as a proportion of the available water
- average annual non-diverted water under each scenario compared with average annual non-diverted water under Scenario A.

Table SE-22. Relative level of non-diverted water in the South-East Gulf system under scenarios A, B and C

| Gilbert | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| Non-diverted water as a percentage of total available water | 99% | 99% | 99% | 99% | 99% |
| Non-diverted share relative to Scenario A non-diverted share | 100% | 84% | 123% | 107% | 85% |

Most water in the Gilbert river basin is not diverted (99 percent), therefore the comparison between scenarios relative to Scneario A predominately reflects changes due to climate.

### Combined water shares

Figure SE-46 combines the results from water availability, level of development and non-diverted water. The size of the bars indicates total water availability and the subdivision of the bars indicates the diverted and non-diverted fractions. It should be noted, however, that water availability is based on the mean annual volume of water at the last gauge in the system. For the reasons discussed in SE-3.6.3 it is unlikely that this volume of water is accessible for consumptive use.

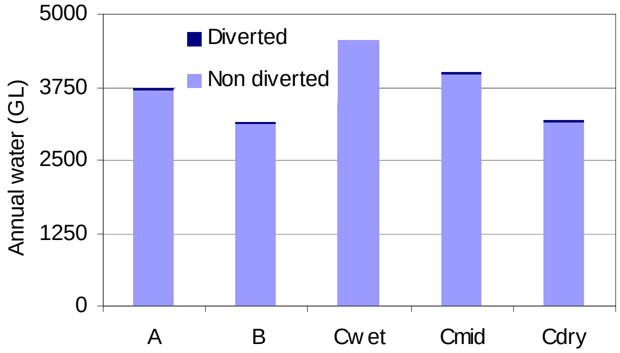


Figure SE-46. Comparison of diverted and non-diverted shares of water in the South-East Gulf system under scenarios A, B and C

## SE-3.7 Changes to flow regime at environmental assets

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Three environmental assets have been shortlisted in the South-East Gulf region: Dorunda Lakes Area, Smithburne–Gilbert Fan Aggregation, and Southern Gulf Aggregation. The locations of these assets are shown in Figure SE-1 and these assets are characterised in Chapter SE-2.

This section presents the assessment of these shortlisted assets and reports metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis. Confidence in results for low flows and high flows was calculated separately on a scale of 1 to 5, with 1 indicating results with the highest confidence (as described in Section 2.2.6 of the division-level Chapter 2). Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are 1, 2 or 3. If confidence levels in the low flows or high flows are ranked 4 or 5, results are not reported and are labelled NR (not reported).

Some of the assets in this region have multiple nodes at which streamflow modelling results are available. When reporting hydrological regime metrics for such assets a single node was selected. The selected node was that with the highest streamflow confidence level and the largest proportion of streamflow to the asset. Results for all nodes are presented in McJannet et al. (2009).

In the absence of site-specific metrics for the South-East Gulf region a set of standard metrics related to high and low flows have been utilised. However the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and ecology.

### SE-3.7.1 Standard metrics

#### Dorunda Lakes Area

The surface water flow confidence level for this asset is considered unreliable (4 or 5) for both wet season and dry season flows which is too unreliable to allow environmental flow metrics to be calculated for this asset.

#### Smithburne – Gilbert Fan Aggregation

The surface water flow confidence level for this asset is considered unreliable (4 or 5) for both wet season and dry season flows which is too unreliable to allow environmental flow metrics to be calculated for this asset.

#### Southern Gulf Aggregation

The surface water flow confidence level for this asset is considered unreliable (4 or 5) for both wet season and dry season flows which is too unreliable to allow environmental flow metrics to be calculated for this asset.

 

## SE-3.8 References


Crosbie RS, McCallum JL, Walker GR and Chiew FHS (2008) Diffuse groundwater recharge modelling across the Murray-Darling basin. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia. 108pp.

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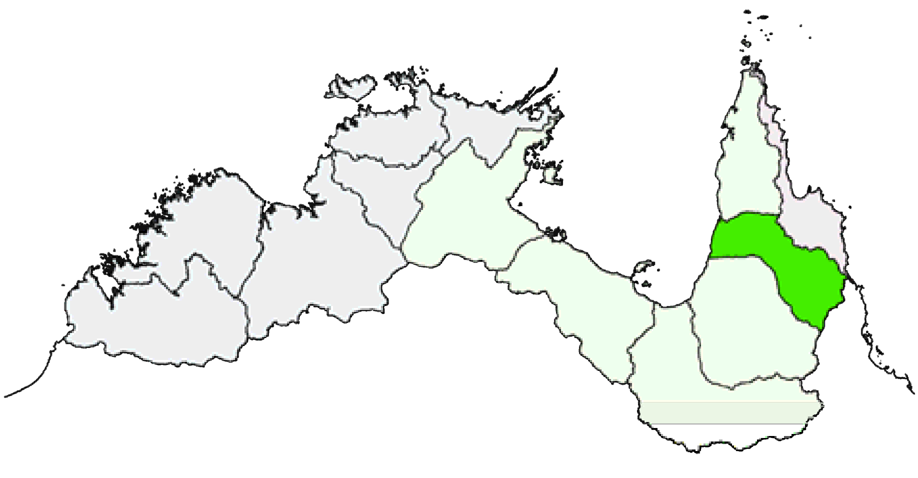
# Water in the Mitchell region



# MI-1 Water availability and demand in the Mitchell region

The first part of this report (the Preamble, Chapter 1 and Chapter 2) reports at the division level, inc luding division-wide descriptions of climate and geology and methods which apply to all regions. Subsequent chapters report at the region level. In particular, Chapters MI-1, MI-2 and MI-3 focus on the Mitchell region (Figure MI-1).

This chapter summarises the water resources of the Mitchell region, using information from Chapter MI-2 and Chapter MI-3, and directly addresses the Terms of Reference, specifically terms 3, 4 and 5 as listed in the Preamble. Essentially, this chapter provides a synoptic view of the region and covers:

- regional observations
- water resource assessment
- seasonality of water resources
- surface–groundwater interaction
- changes to flow regime at environmental assets
- water storage options
- data and knowledge gaps.

For further details on the context of the region (physical and climate descriptions, hydrogeology and legislation) see Chapter MI-2. Region-specific methods and results are provided in Chapter MI-3. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2.

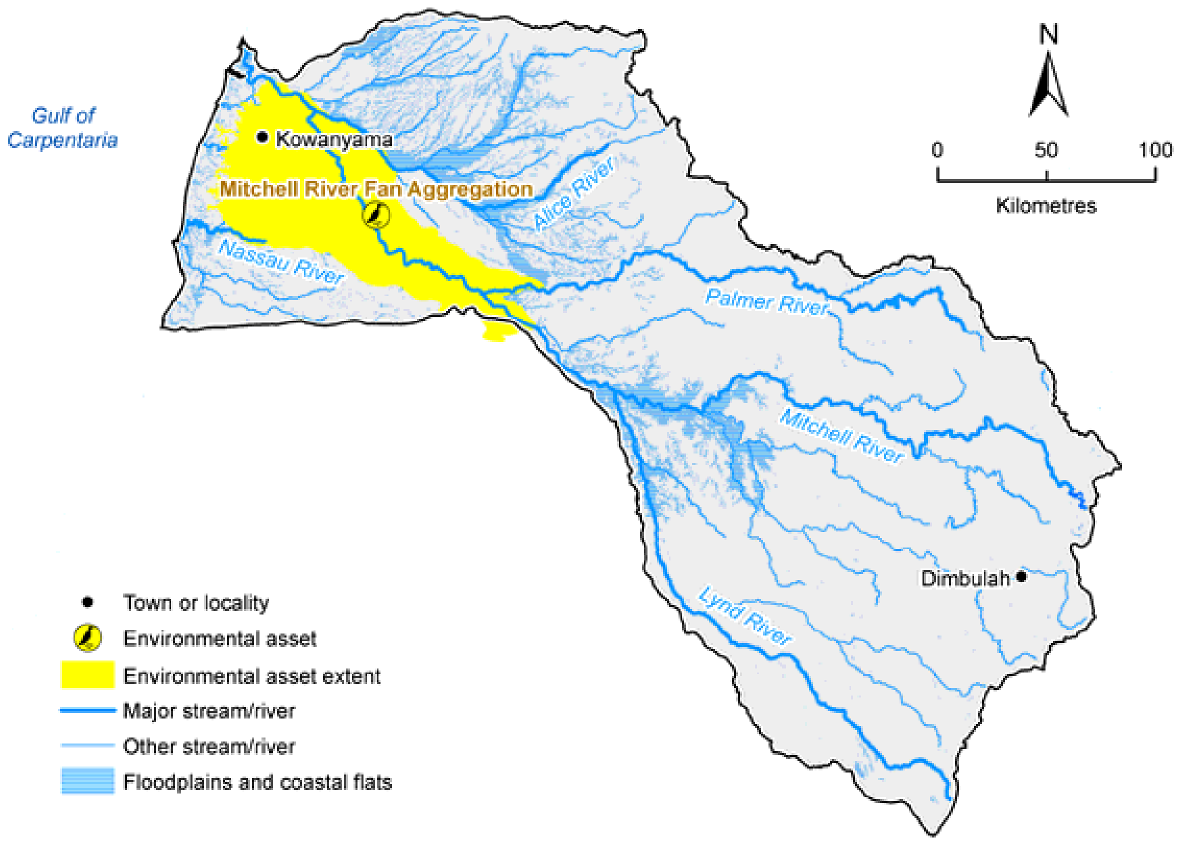



Figure MI-1. Major rivers, towns and location of environmental assets selected for assessment of changes to hydrological regime in the Mitchell region

## MI-1.1 Regional summary

These regional observations summarise key modelling results and other relevant water resource information about the Mitchell region.

The Mitchell region has a high inter-annual variability in rainfall and hence runoff and groundwater recharge. Coefficients of variation are 0.26 and 0.75, respectively. These are among the highest of the regions across northern Australia and reflect multiple years of significantly below average and above average rainfall.

Mean annual rainfall for the region is 965 mm. Mean annual areal potential evapotranspiration (APET) is 1905 mm. The mean annual runoff averaged over the modelled area of the Mitchell region is 198 mm, 30 percent of rainfall. Rainfall and runoff both decline with distance from the west coast, but increase again across the eastern divide. The runoff proportion of rainfall varies from 15 to 60 percent. Under the historical climate the mean annual streamflow over the Mitchell region is estimated to be 14,301 GL.

The region is water-limited; in other words there is more energy available to remove water than there is water available to be removed.

There is a strong seasonality in rainfall patterns, with 95 percent of rainfall falling between November and May, and a very high dry season (May to October) potential evapotranspiration. The region has a relatively high rainfall intensity, and hence rapid runoff and short lag between rainfall and runoff with a slightly increasing amount and intensity of rainfall over the period from 1930 to 2007.

The Mitchell region has a recent (1996 to 2007) climate record that is statistically indistinguishable from the historical (1930 to 2007) record in the east, but slightly wetter in the west. Modelling suggests that the future (~2030) rainfall conditions will be similar to historical conditions; hence, future runoff and recharge is likely to be similar to historical levels. Future APET is expected to be slightly (about 1 percent) higher than historical records.

There is a strong east–west rainfall gradient and between 15 and 60 percent of precipitation flows as runoff. Lower reaches are strongly flood-influenced. Approximately half of the runoff in the Mitchell is thought to be generated in the ungauged bottom half of the catchment. There are few opportunities for surface water storage except in the eastern, wetter headwater areas.

Aquifers within the Great Artesian Basin and deep Tertiary sediments contain the largest storages of water in the region. These aquifers are actively recharged, although much of the recharge occurs remote from the areas of utilisation. Because the Mitchell region is near the bottom end of the onshore GAB system there is some justification for utilising through-flow which would otherwise be lost to submarine discharge, provided seawater intrusion can be avoided and spring flows maintained.

Groundwater resources in other aquifers are limited. The shallow alluvial aquifers are characterised by variable thickness and groundwater quality and are a relatively undeveloped groundwater resource.

The Mitchell River flows through the dry season due to groundwater discharge from the Tertiary sediments and Great Artesian Basin aquifers. Springs discharging from the Great Artesian Basin provide an important source of water for both environmental and pastoral purposes.

Flows at environmental assets are highly dominated by wet season (November to April) flows, with dry season (May to October) flows being only a small fraction of total annual flow. Environmental assets depend on this strong seasonality, however, and any significant changes in the frequency and duration of wet season high flows and dry season low flows are likely to have an environmental impact. In the recent past flow has not changed much; therefore there is little change in low or high flow days. Although low or zero flow days are rare on average, under a future climate and full allocation of existing entitlements there is a very large (44 percent) increase in days where flows are below the low flow threshold, and an increase in days of zero flow. In these locations ecological assets attuned to the rare occurrence of zero flow conditions may be highly impacted. There are large changes to the high flow threshold exceedance under the wet and dry extreme future climate with full allocation of existing entitlements.

The region is generally datapoor, particularly the lower reaches, which are completely ungauged. Rainfall data across the important headwaters on the Great Dividing Range are noticeably poor.

## MI-1.2 Water resource assessment

Term of Reference 3a

### MI-1.2.1 Under historical climate and current development

Term of Reference 3a (i)

The mean annual rainfall and runoff averaged over the modelled area of the Mitchell region (which excludes the coastal floodplains in the west) are 965 mm and 198 mm, respectively. Rainfall is very seasonal and runoff is highest in January and February.

Current average surface water availability is 6786 GL/year and on average about 81 GL/year (or 1 percent) of this water is allocated under full use of existing entitlements. This is a low level of development.

Licensed groundwater extraction is currently very low in the Mitchell region. Use for stock and domestic purposes accounts for the majority of current groundwater extraction, and this is primarily associated with the Tertiary aquifers of the Karumba Basin. Natural groundwater discharge from both the Tertiary aquifers and deeper Great Artesian Basin (GAB) aquifers plays an important role in maintaining dry season flows in the Mitchell, Palmer and Walsh rivers and many of their tributaries, as reflected in the modelled dry season baseflows (Table MI-1 and Figure MI-2).

Table MI-1. Estimated groundwater contribution (baseflow) to streamflow, modelled diffuse recharge and groundwater extraction for the Mitchell region under historical climate

| Station | River | Station name | Annual BFI * | Dry season BFI * | Dry season baseflow * |
|---|---|---|---|---|---|
| | | | | | GL |
| 919002A | Lynd | Lyndbrook | 0.15 | 0.46 | 0.7 |
| 919003A | Mitchell | O.K. Br | 0.21 | 0.63 | 47.6 |
| 919004A | Tate | Ootann | 0.16 | 0.22 | 1.5 |
| 919005A | Rifle Ck | Fonthill | 0.25 | 0.69 | 15.6 |
| 919006A | Lynd | Torwood | 0.17 | 0.51 | 12.8 |
| 919007A | Hodgkinson | Piggy Hut | 0.10 | 0.24 | 0.1 |
| 919011A | Mitchell | Gamboola | 0.20 | 0.60 | 62.2 |
| 919013A | McLeod | Mulligan HWY | 0.34 | 0.70 | 21.5 |
| 919201A | Palmer | Goldfields | 0.14 | 0.57 | 1.9 |
| 919202A | Palmer | Maytown | 0.13 | 0.40 | 1.6 |
| 919305B | Walsh | Nullinga | 0.24 | 0.49 | 2.4 |
| 919309A | Walsh | Trimbles Crossing | 0.19 | 0.47 | 11.0 |
| 919310A | Walsh | Rookwood | 0.20 | 0.51 | 7.5 |
| 919311A | Walsh | Flatrock | 0.17 | 0.49 | 7.0 |
| | | Historical recharge ** | Estimated groundwater extraction | | |
| | | GL/y | | | |
| Entire Mitchell region | | 8730 | | | 4.5 |

* BFI (baseflow index) and baseflow volume derived from gauged data.
** Aggregated recharge using Zhang and Dawes (1998).

Recharge to the shallow alluvial aquifer systems is unlikely to change under a continued historical climate and, with current levels of development, groundwater conditions are likely to remain stable in these aquifers. The GAB aquifers are recharged via ‘intake beds’ located where the Gilbert River Formation outcrops through the centre of the Mitchell region. The scale and inertia of the GAB groundwater system means that under a continued historical climate the groundwater balance of this resource is unlikely to measurably change by 2030. Furthermore, because the resource is largely undeveloped in this region, continued groundwater extraction at current levels is unlikely to have an adverse effect on groundwater levels.

### MI-1.2.2 Under recent climate and current development

Term of Reference 3b

The mean annual rainfall and runoff under the recent (1996 to 2007) climate are 6 percent and 16 percent higher, respectively, than the historical (1930 to 2007) mean values. Whilst most of the region experienced higher than average rainfall, the eastern uplands region experienced reduced rainfall.

If future climate is similar to that experienced recently, mean annual groundwater recharge to the surficial aquifers of the Mitchell region is likely to be similar to the historical value.

### MI-1.2.3 Under future climate and current development

Term of Reference 3a (ii)

Future (~2030) climate is expected to be similar to historical climate. Under the wet extreme, median and dry extreme future climates, annual rainfall is 1098, 970 and 885 mm, respectively. Corresponding APET values under these scenarios are 1935, 1960 and 1982 mm, respectively. Rainfall-runoff modelling with climate change projections from global climate models indicates that future runoff in the Mitchell region is slightly more likely to decrease than increase. Two-thirds of the modelling results show a decrease in runoff and one-third show an increase in runoff. The median estimate is for a 1 percent decrease in the mean annual runoff by 2030. The extreme estimates, which come from the high global warming scenario, range from a 42 percent increase to a 24 percent decrease in mean annual runoff. By comparison, the range from the low global warming scenario is a 14 percent decrease to a 22 percent increase.

Under the median future climate there would be a 4 percent reduction in water availability and no change to diversions for all water products.

The climate extremes for 2030 indicate:

- under the wet extreme future climate, water availability increases 41 percent and total diversions increase 1 percent
- under the dry extreme future climate, water availability decreases 25 percent and total diversions decrease 2 percent
- under the dry extreme future climate, town water supplies decrease by less than 1 percent. There would be no change in high security uses from Southedge Dam under all climate scenarios.

If future climate is similar to that experienced recently, mean annual groundwater recharge to the shallow alluvial aquifers of the Mitchell region may be slightly higher than the historical average in the west, but will be slightly lower in the east, and hence recharge to the GAB may be reduced. Without appropriate numerical groundwater flow models it is difficult to predict what level of resource condition change could be expected under this scenario, even under current levels of development.

### MI-1.2.4 Under future climate and future development

Term of Reference 3a (iii)

Without appropriate numerical groundwater flow models it is difficult to predict what changes in groundwater resource condition could be expected under this scenario, regardless of the scale of potential future development. Nevertheless, there is scope for future development of water supplies from the GAB aquifer providing seawater intrusion is avoided and spring flows are maintained within ecological thresholds. Additional groundwater development in the GAB aquifer would also reduce the upward leakage to overlying aquifers.

## MI-1.3 Changes to flow regime at environmental assets

Term of Reference 3a (iv)

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. One environmental asset was shortlisted for the Mitchell region: the Mitchell River Fan Aggregation. This asset is characterised in Chapter MI-2.



In deciding whether it is feasible to report hydrological regime metrics for these shortlisted assets, it is important to consider the confidence levels in modelled streamflow (as described in Section 2.2.6 of the division-level Chapter 2). Confidence in results for low flows and high flows was calculated separately. Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are sufficiently high. If confidence in the low flow or high flow is too low, metrics are not reported, and hence an important gap in our knowledge is identified.

Reporting against the Mitchell River Fan Aggregation is generated via a river systems model. Thus, confidence levels for reporting are considered at least moderately reliable for both low flows and high flows.

Annual flow into this asset is highly dominated by wet season flows (97 percent) which have been only 3 percent higher under recent climate relative to historical levels. Dry season flows have also been marginally higher (2 percent) in the recent past. Annual and seasonal flows do not change much under the future (~2030) climate (6 to 12 percent) but there are large increases under the wet extreme future climate with full allocation of existing entitlements (29 to 40 percent). Under the dry extreme future climate with full allocation of existing entitlements there is a moderate decrease in wet season flow (26 percent) and larger decrease in dry season flow (37 percent). The number of days with flow below the low flow threshold more than doubles under this scenario, though there is little change under the wet extreme future climate.

Zero flow days follow a similar pattern, but occur only about 2 percent of the time. In contrast, there are large increases and decreases in the high flow threshold exceedance under the wet and dry extreme future climates, respectively.

## MI-1.4 Seasonality of water resources

Term of Reference 4

Approximately 95 percent of rainfall and 98 percent of runoff occurs during the wet season months under both the historical and recent climate. Identical seasonal percentages of rainfall and runoff are projected to occur at 2030.

The rivers have a marked seasonal flow regime of high water levels and extensive flooding during the wet season (November to April) and decreased water flow and river stage towards the end of the dry season.

## MI-1.5 Surface–groundwater interaction

Term of Reference 4

Surface–groundwater interactions are likely to be negligible in the east of the region where the basement rocks outcrop. The watertable is typically well below the stream bed elevation and there is no reported evidence of the contribution of baseflow to major watercourses (DNRW, 2006).

The Mitchell River is perennial due to a combination of high rainfall in the headwaters during the wet season, and year-round groundwater discharge from both local and regional aquifers. The GABCC (1998) recognised a significant contribution of groundwater discharge from the Gilbert River Formation to the Mitchell River based on stream gauging data. They reported that baseflow contributions to river flow are highest in the driest month (November) and amount to about 50 GL/year (cf. 48 to 62 GL/year model results in Table MI-1 and Figure MI-2). DNRM (2005) recognised the contribution of baseflows to the lower reaches of the Mitchell River from the Bulimba Formation, as a consequence of spring discharge and ‘rejected recharge’ (Figure MI-3).

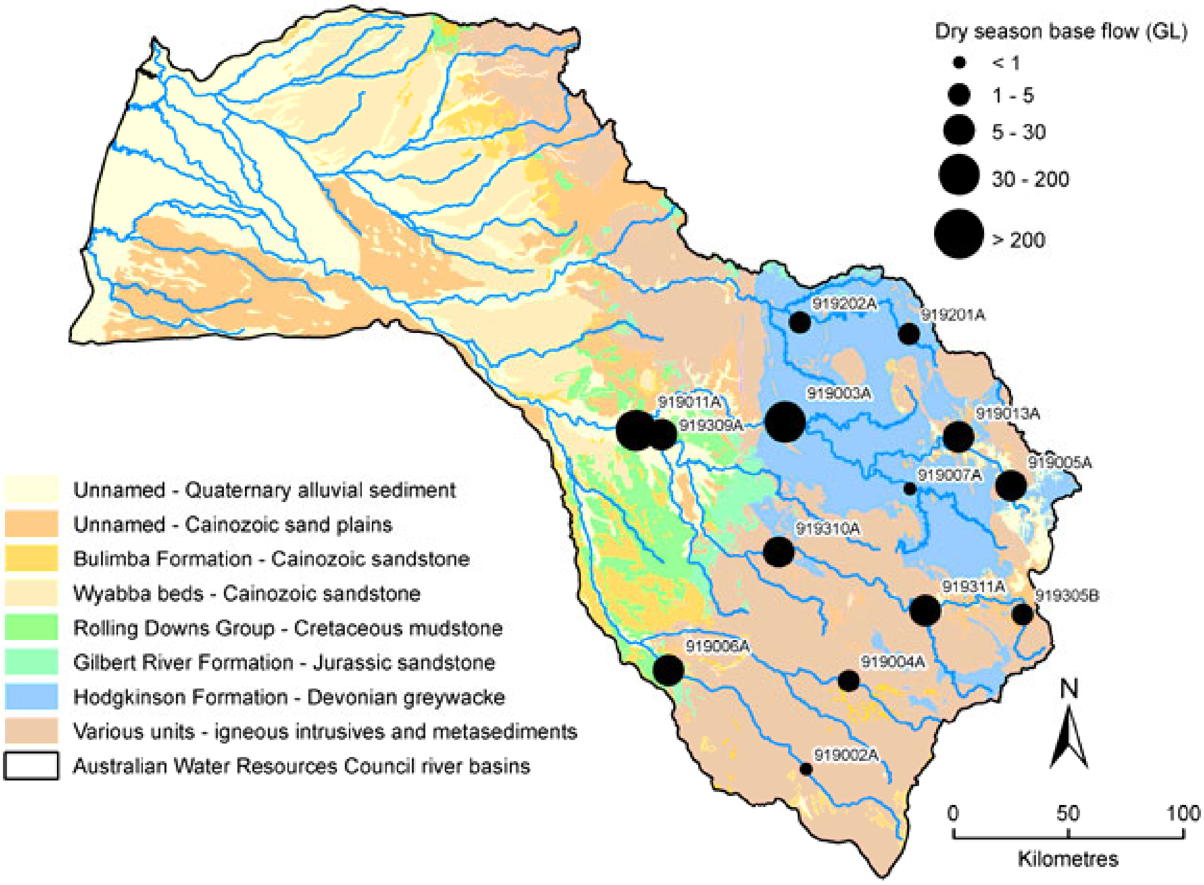



Figure MI-2. Surface geology and modelled mean dry season baseflow of the Mitchell region

The other main watercourses cease to flow towards the end of the dry season, or in times of drought. Permanent waterholes maintained by seepage through the thick sands in the beds of the watercourses are common in the Palmer and Walsh rivers and major creeks. Their tributaries (unless spring fed) are generally dry before the end of the dry season. Numerous permanent and semi-permanent springs rise from the base of the Gilbert River Formation (Bultitude et al., 1996).

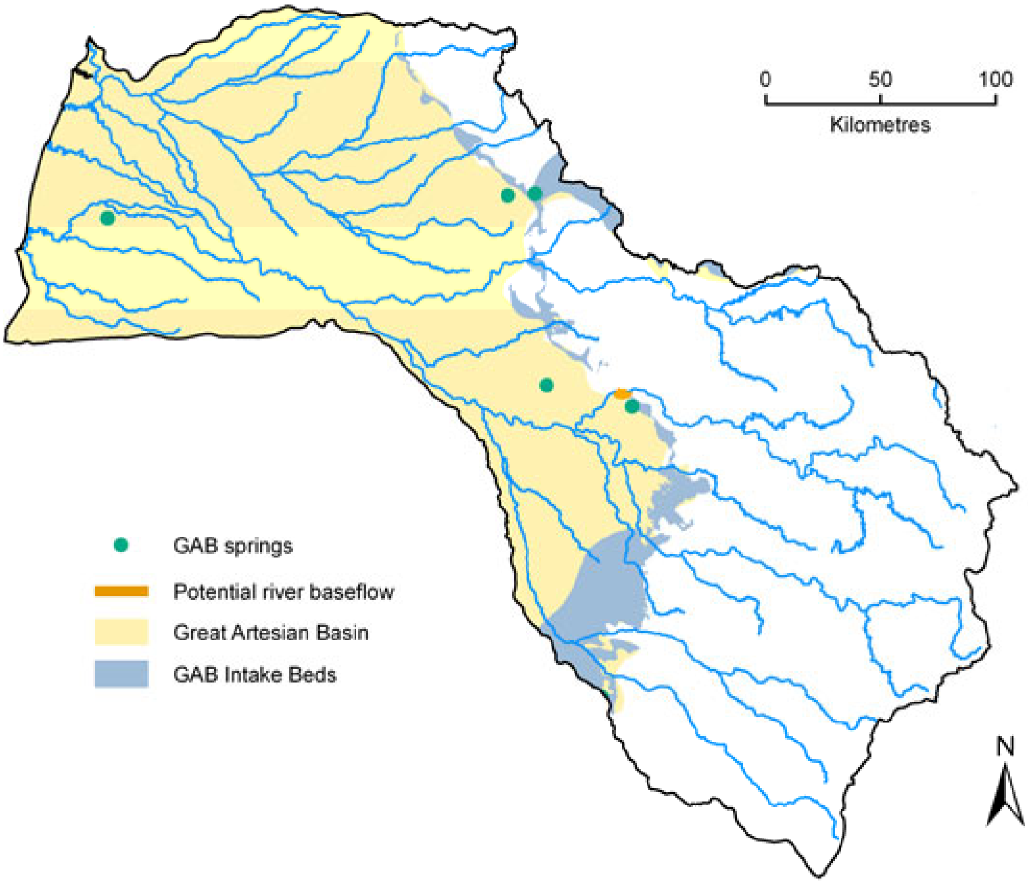



Figure MI-3. Locations of spring groups of the Great Artesian basin and potential river baseflow within the Mitchell region (after DNRM, 2005)

## MI-1.6 Water storage options

Term of Reference 5

### MI-1.6.1 Surface water storages

There are currently four major water storages in the Mitchell catchment, with a combined capacity of over 140,000 ML (Section MI-2.4.3). The largest is Southedge Dam, which is privately owned (Quaids). The SDPC Ornamental Lakes are licensed, but not yet constructed. The series of small weirs (total storage of over 2000 ML) on the upper Walsh River contribute to the Mareeba Dimbulah Water Supply Scheme.

Flows in the Mitchell River are not regulated, except for a future usage from Southedge Dam (Lake Mitchell). Results show this is fully utilised for this future demand.

### MI-1.6.2 Groundwater storages

Tertiary aquifers of the Karumba Basin are the main groundwater resources in the Mitchell region. However, groundwater development in the region is low and groundwater recharge rates are high. Under current development managed aquifer recharge (MAR) would have limited applicability as storages in the Tertiary sediments (i.e., Bulimba Formation and Wyaaba Beds) are likely to be at full capacity by the end of the wet season when surface water is available for injection. The only possible opportunity for MAR in the Mitchell region is if future climate or development of the Tertiary aquifer leads to groundwater levels not fully recovering each wet season. This situation is most likely to arise around localised industry developments.

## MI-1.7 Data gaps

Term of Reference 1e

There are no streamflow gauging stations in the lower half of the catchment; this is likely to be due to the difficulty of siting stations in this environment. Rainfall estimates in the mountainous headwaters are poor.

Time series groundwater level and salinity data is required for each of the main aquifer types in the Mitchell region to provide greater understanding of recharge processes and inter-aquifer leakage, particularly for the Great Artesian Basin aquifers.

## MI-1.8 Knowledge gaps

Term of Reference 1e

At least half of the runoff generated in the Mitchell is thought to be generated in the lower reaches. However, most of the lower reaches of the Mitchell region are ungauged, in part due to the difficulty of gauging streamflow on flat coastal floodplains in the tropics.

Dry season flows are poorly understood in this region therefore the ability to predict the potential impacts of the various scenarios on low or zero flows at environmental assets is very limited. Improved monitoring of low streamflow conditions is needed along with the development of hydrological models that combine surface and groundwater regimes. Further monitoring of groundwater levels is also required so that the potential impacts of climate and development changes on groundwater-dependent ecosystems can be better understood.

Diffuse upward leakage of water out of the Great Artesian Basin aquifers and into overlying Tertiary sediments is yet to be quantified. Further research is required to estimate these discharge fluxes so that a detailed groundwater balance can be developed for the aquifers to guide future management in the region.

None of the environmental assets in this region have any site-specific metrics by which to gauge the potential impacts of future climate and development changes. In the absence of site-specific metrics a set of standard metrics related to high and low flows have been utilised. However the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and specific ecological entities (for example, macrophyte populations, fish passage, faunal and floral habitats, etc.).

Many environmental assets depend not simply on duration above or below certain flow levels, but on triggers (e.g. for reproduction or migration) set by the rate of change of flow. In addition, some environmental assets depend on the frequency and duration of events that occur less than annually (i.e. once every 5, 10 or 20 years or more). Further analysis is therefore required to look at how the timing, duration and rate of rise and fall in flow rates at critical times of the season will vary under the various scenarios.

Flooding is an important factor that sustains many environmental assets and this occurs when the stream breaks out of its banks (a level known as bankfull stage or discharge). However, bank full discharge is not known for many streams, nor is the dependence of area flooded on increasing stream depth, so it is difficult to predict when assets are inundated. Further information about bank full stage and discharge are needed for most environmental assets.

## MI-1.9 References

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# MI-2 Contextual information for the Mitchell region

This chapter summarises the background information for the region, outlining existing knowledge of water resources and prior and current investigations relevant to the water resources of the region. This chapter also outlines the current and potential future legislation, water plans and other water resource management arrangements. This chapter is arranged into four sections:

- physical and climate descriptions
- data availability
- hydrogeology
- legislation, water plans and other arrangements.

# MI-2.1 Overview of the region

## MI-2.1.1 Geography and geology

The Mitchell region incorporates the drainage of five major river systems: the Mitchell, Alice, Palmer, Walsh and Lynd. The catchment covers 72,229 km$^2$ and traverses the base of Cape York. The eastern margin, in the Atherton Tablelands along the Great Dividing Range, extends to within 30 km of the Coral Sea Coast (and 50 km from Cairns). The rivers flow west 500 km to discharge into the Gulf of Carpentaria 30 km north-east of Kowanyama (Figure MI-4). The rivers carve rugged gorges through the eastern sedimentary and metamorphic highlands of the Great Dividing Range (Figure MI-4), flowing west through undulating metamorphic and granitic country and onto Tertiary sediments of the western plains before the rivers join in the Lower Mitchell Plains, consisting of thick sequences of alluvial sands, silts and clays only a few metres above sea level.

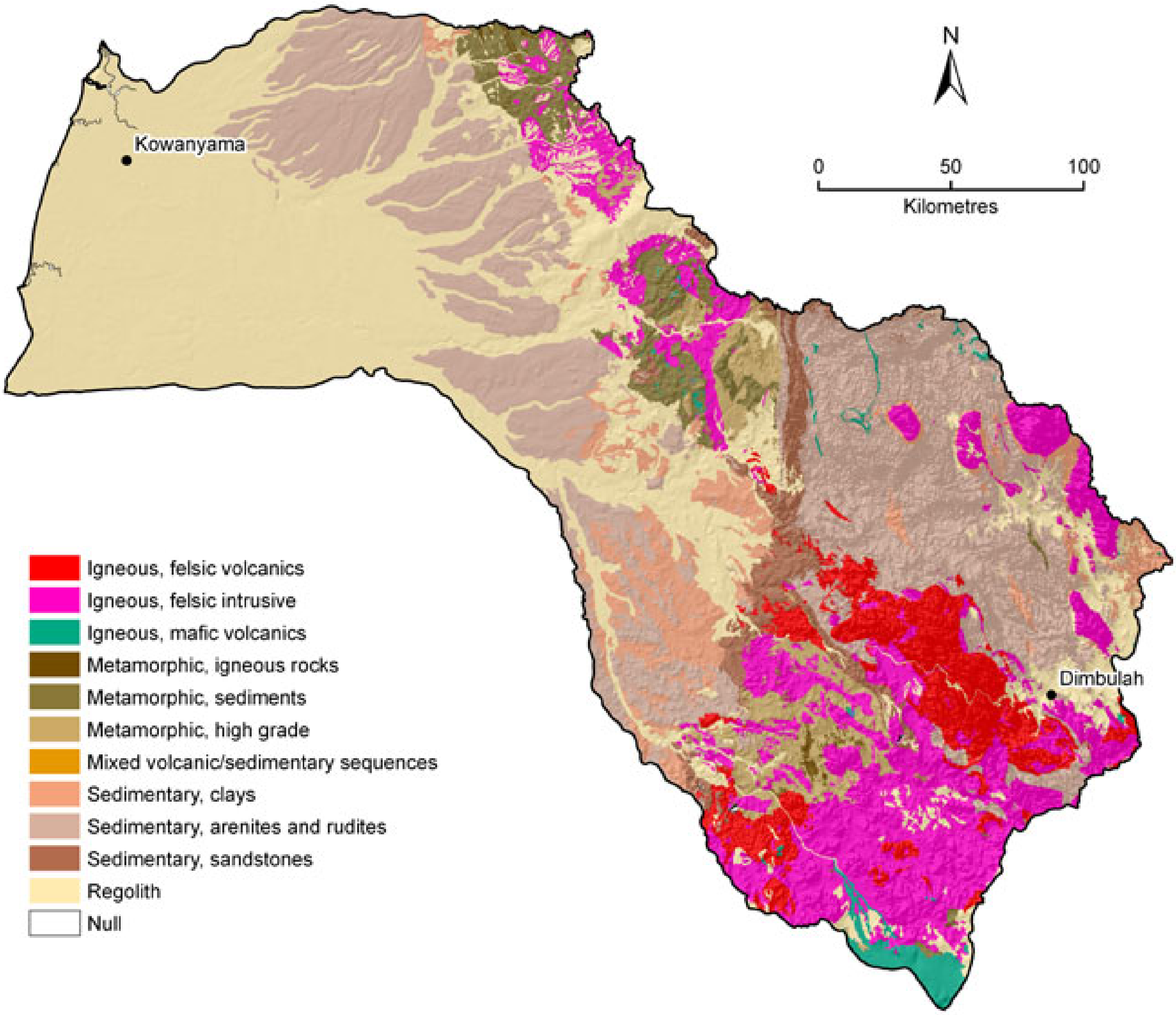


Figure MI-4. Surface geology of the Mitchell region overlaid on a relative relief surface

## MI-2.1.2 Climate, vegetation and land use

The Mitchell region receives an average of 960 mm of rainfall over a water year (September to August), most of which (905 mm) falls in the wet season (November to April) (Figure MI-5). Across the region there is a moderate north-west to south-east gradient in annual rainfall, ranging from 1620 mm in the north to 715 mm in the south. During the historical (1930 to 2007) period, annual rainfall was reasonably constant overall. However in the 1970s and around the turn of the century annual rainfall was high on average, with the two decades in between experiencing relatively dry conditions. The highest yearly rainfall received was 1945 mm which fell in 1974, and the lowest was 525 mm in 1952. Areal potential evapotranspiration (APET) is very high across the region, averaging 1895 mm over a water year, and varies moderately across the seasons. APET is higher than rainfall throughout most of the year, resulting in year-round water-limited conditions, but from January until March conditions are energy-limited, meaning rainfall has relatively less effect on actual evapotranspiration rates during this period. The vegetation of the region has adapted to such cyclical conditions in water availability.

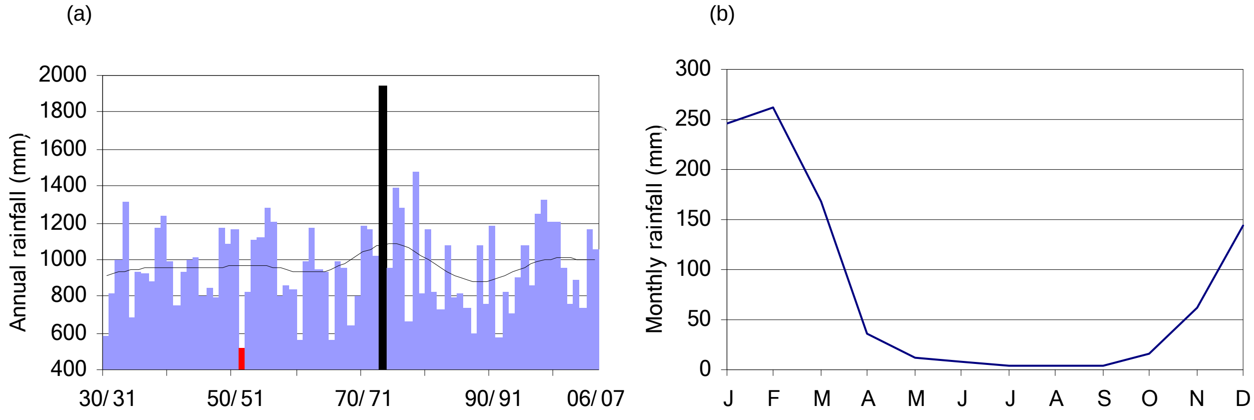


Figure MI-5. Historical (a) annual and (b) mean monthly rainfall averaged over the Mitchell region. The low-frequency smoothed line in (a) indicates longer term variability

The Mitchell River catchment occupies an area across both the Einasleigh Uplands and Gulf Plains bioregions and abuts the Cape York Peninsula bioregion on its northern boundary. The annual monsoonal wet season provides a pulse of water that transports sediments and organic matter as well as chemical residues from agriculture and mining in the upper catchment. The Mitchell flows year-round, due in part to high rainfall conditions in the headwaters, but sustained by a modest input from groundwaters through the dry season (May to October).

The Mitchell region contains tropical rainforest, wet sclerophyll forest, a variety of woodland types, savannah and tidal plains, as well as extensive wetlands, estuaries and mangroves (Figure MI-6).

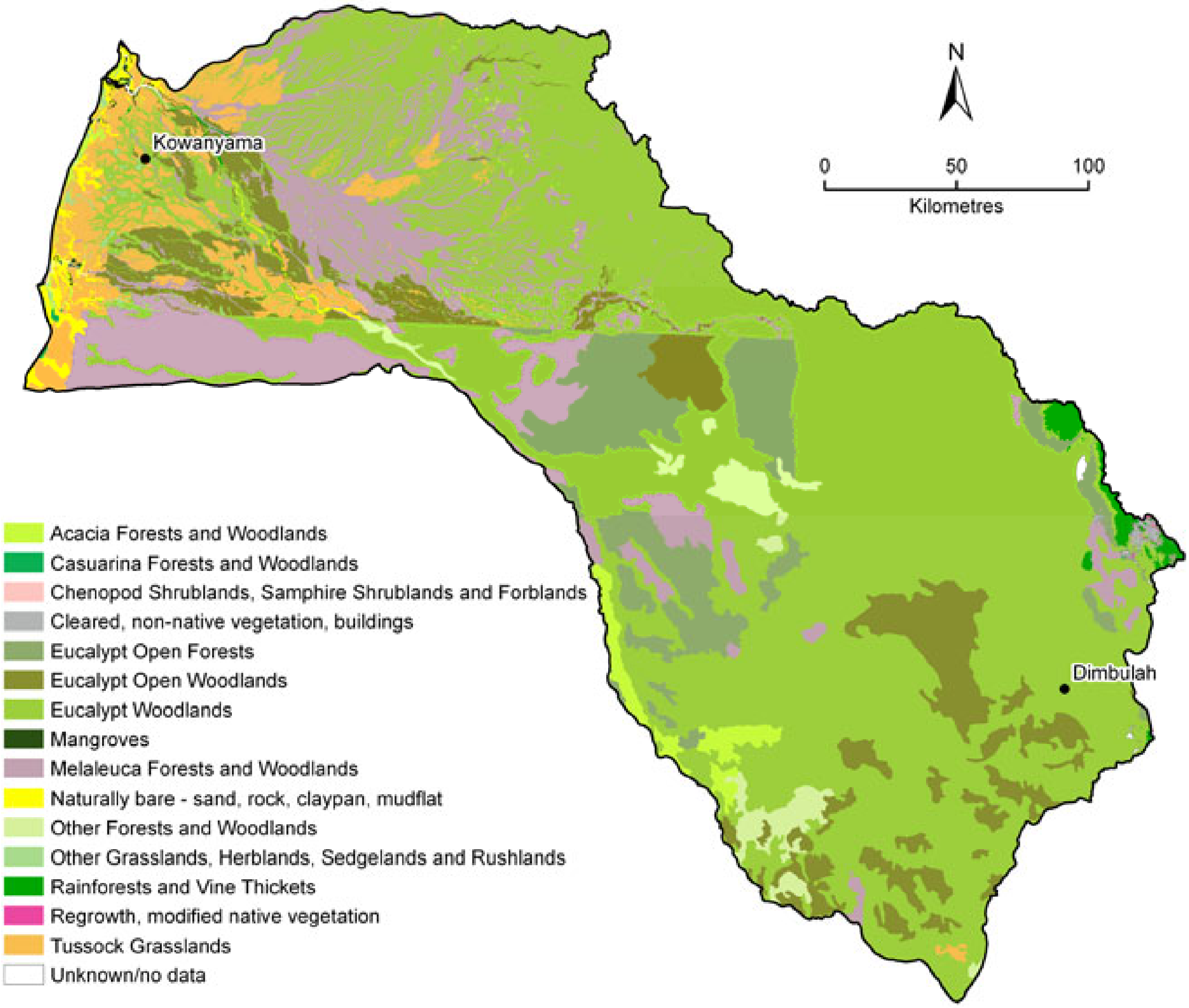


Figure MI-6. Map of current vegetation types across the Mitchell region (source DEWR, 2005)

Europeans moved into the region in the late 1800s in search of gold. Significant conflicts with Indigenous groups ensued, but increasing demand for services and support for the mining industry resulted in agricultural development, particularly in grazing. The population is just over 5,400, with the largest settlements at Kowanyama (1000), 20 km from the Gulf coast, and Dimbulah (400), on the Walsh River in the eastern highlands.

Grazing remains the most extensive land use in the catchment area whilst mining activities are making a resurgence due to high base metal prices. The Mareeba Dimbulah Water Supply Scheme established in the 1950s has also made the upper catchment of the Mitchell and Walsh rivers viable for agriculture, horticulture and small-scale cattle fattening projects. Furthermore, tourism and fishing have risen in prominence in recent years.

The Mitchell River Catchment area consists of mainly large grazing leases, although the exceptions are the Kowanyama Aboriginal Community Deed of Grant in Trust and the freehold areas of Southedge Station, part of Wrotham Park Station and many smaller blocks in the East of the catchment near Mareeba. Additionally, Indigenous people own several holdings in the catchment (MRWMG, 2009).

The Catchment area also contains a number of National Parks, including Hann Tableland National Park Mitchell; Alice Rivers National Park; Chillagoe-Mungana Caves National Park; part of Bulleringa National Park to the South and most of the 40 Mile Scrub National Park.

 

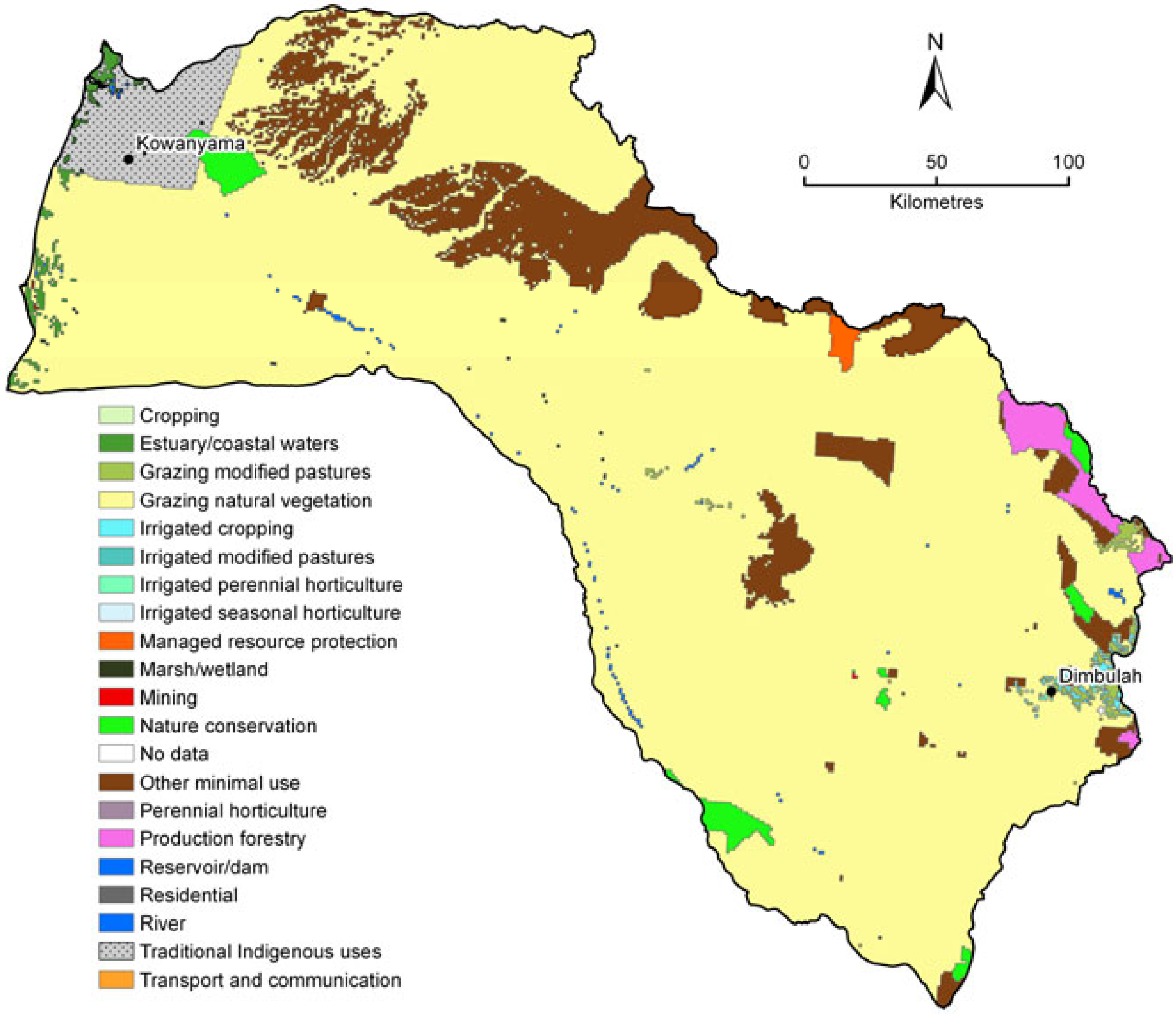


Figure MI-7. Map of dominant land uses of the Mitchell region (after BRS, 2002)

### MI-2.1.3 Regional environmental asset description

Environmental assets were chosen from wetlands which are listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001). From this directory, environmental assets were shortlisted for assessing changes to the hydrological regime under the climate and development scenarios. The selection of this shortlist was undertaken in consultation with state governments and the Australian Government through direct discussions and through internal reviews (see Section 1.3 in the division-level Chapter 1 for further detail).

All nationally, or internationally, important wetlands listed for the Mitchell region in the Directory of Important Wetlands in Australia (Environment Australia, 2001) are detailed in Table MI-2, with an asterisk identifying the one shortlisted asset: Mitchell River Fan Aggregation. The location of this shortlisted wetland is shown in Figure MI-1. There are no wetlands classified as Ramsar sites in this region. Wetlands may be nationally or regionally significant depending on more locally specific criteria. All wetlands are important for a variety of ecological reasons or because they bear historical significance or have high cultural value, particularly to Indigenous people.

The following section characterises these shortlisted wetlands and is based largely on the description of these assets as outlined by Environment Australia (2001). Chapter MI-3 presents the assessment of those shortlisted assets, and reports hydrological regime metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis.

Table MI-2. List of Wetlands of National Significance located within the Mitchell region

| Site code | Name | Area | Ramsar site |
|---|---|---|---|
| | | ha | |
| QLD109* | Mitchell River Fan Aggregation | 715,000 | No |
| QLD067 | Northeast Karumba Plain Aggregation | 183,000 | No |
| QLD113 | Southeast Karumba Plain Aggregation | 336,000 | No |
| QLD093 | Spring Tower Complex | 75 | No |

* Asterisk against the site code identifies those assets which are shortlisted for assessment of changes to flow regime.

In the Mitchell region, only the Mitchell River Fan Aggregation was chosen for assessment of changes to hydrological regime under the different scenarios. The following section briefly characterises this wetland and is based largely on the description of this asset as outlined by Environment Australia (Environment Australia, 2001).

## Mitchell River Fan Aggregation

The site is part of a huge alluvial fan bounded by the Mitchell and Alice Rivers and Yanko Creek to the north, and the Nassau River and Sergents Creek in the south. This site has an area of 715,000 ha and an elevation ranging between zero and 70 m above sea level (Figure MI-8). It is a complex disjunct aggregation of freshwater streams and closed depressions (Blackman et al., 1992). It comprises a complex system of deeply incised stream lines with many permanent waterholes, levees and seasonally flooded back plains, shallow incised valleys with waterholes, and numerous circular depressions, some with permanent water. The major catchments are those of the Lynd and Mitchell rivers rising far to the south-east, and the Palmer River to the east. Both the Palmer and Lynd rivers flow into the Mitchell River. The alluvial plain also acts as a local catchment for the many wetlands of the aggregation.

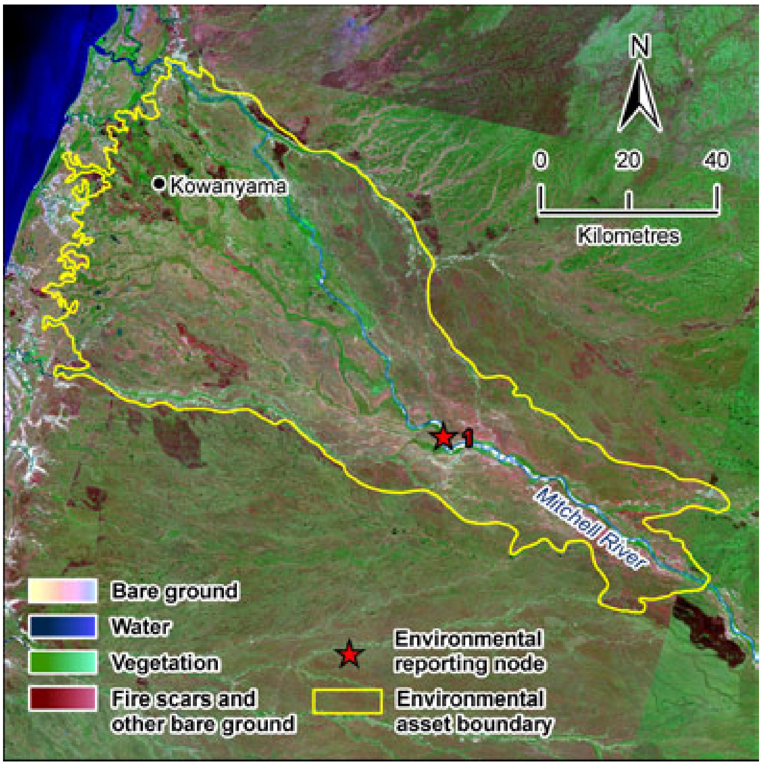


Figure MI-8. False colour satellite image of the Mitchell River Fan Aggregation (derived from ACRES, 2000). Clouds may be visible in image

The Mitchell River Fan Aggregation is an outstanding example of a diverse and rich array of alluvial plain wetlands and deep water habitats which characterise the northern portions of the Mitchell-Gilbert Fan province of the Gulf Plains bioregion. It provides extensive areas of seasonal, semi-permanent and permanent habitat which is used particularly as breeding, roosting, feeding and moulting habitat for a wide range of waterbirds. Much of the area is of very high significance to Indigenous Australians of the area, notably those associated with the Kowanyama Community.

## MI-2.2 Data availability

### MI-2.2.1 Climate

The rainfall-runoff modelling uses historical daily climate data (Scenario A) from the SILO database for the period 1 September 1930 to 31 August 2007 at 0.05 x 0.05 degree (~ 5 x 5 km) grid cells. Full details and characterisation of the SILO database are provided at the division level in Section 2.1 of Chapter 2. Scenario B and Scenario C climate data are rescaled versions of the Scenario A data; this is also discussed in Section 2.1 of Chapter 2.

### MI-2.2.2 Surface water

Streamflow gauging stations are or have been located at 27 locations within the Mitchell region. Seven of these gauging stations have insufficient data because they are either flood warning stations and measure stage height only, or have less than ten years of measured data. Of the remaining 20 stations, seven recorded more than half of their total volume of flow during events that exceed the maximum gauged stage height (MGSH) reducing our confidence in the data. The majority of streamflow gauging stations in the Mitchell are located in the mid to upper reaches of the catchment, with very large ungauged tributary inflows in the lower part of the catchment. Figure MI-9 shows the spatial distribution and quality of surface water data for flow above MGSH.

There are 12 gauging stations currently operating in the Mitchell region at density of one gauge for every 6000 km$^2$. For the 13 regions the median number of current gauging stations per region is 12 and the median density of current gauging stations per region is one gauge for every 9700 km$^2$. Although the Mitchell region has a high density of current gauging stations relative to other regions across northern Australia, the density is low relative to the MDB average. The mean density of current stream gauging stations across the entire MDB is one gauge for every 1300 km$^2$.

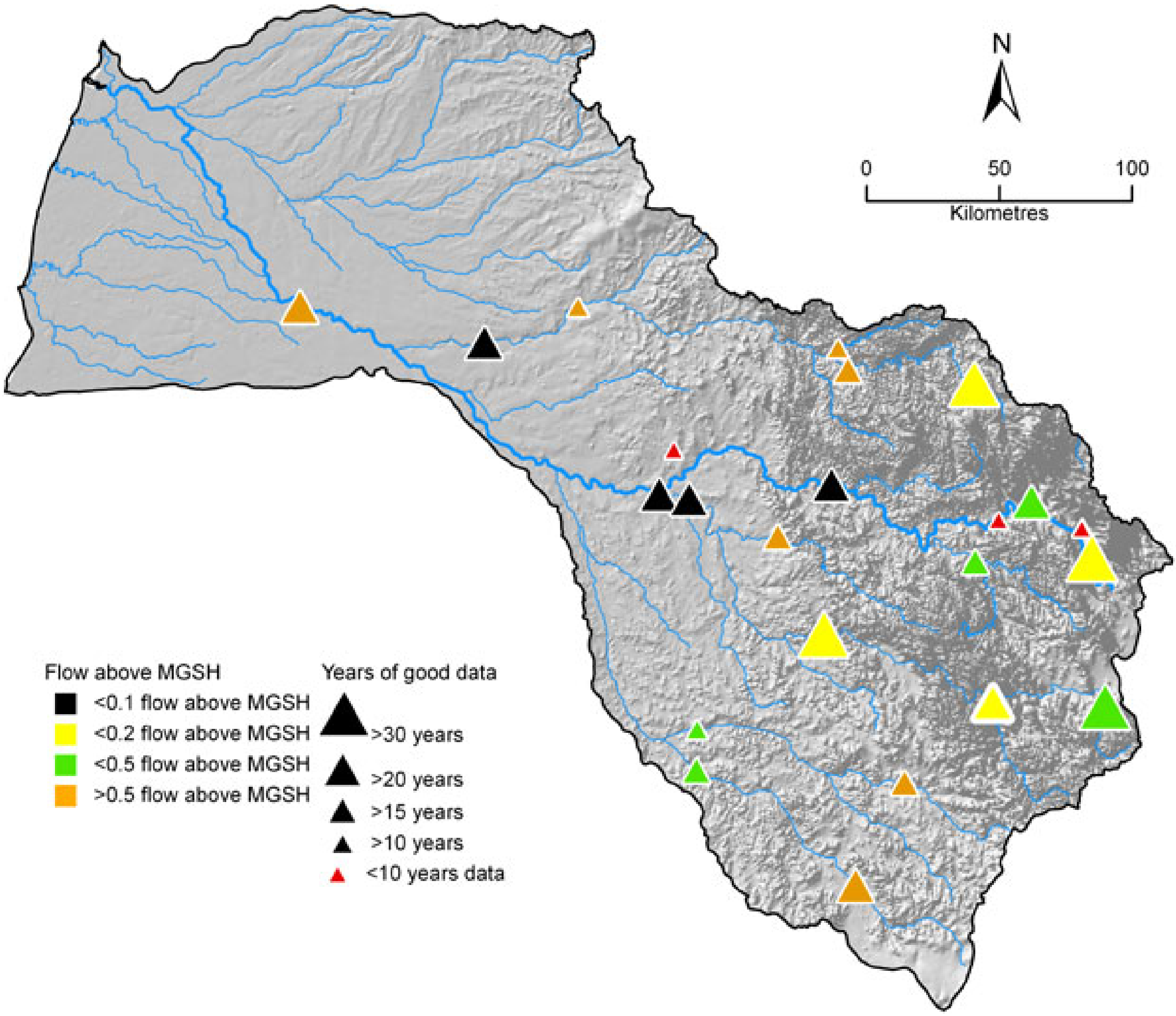


Figure MI-9. Location of streamflow gauging stations overlaid on a relative relief surface showing the proportion of gauges with flow above maximum gauged stage height across the Mitchell region

 

## MI-2.2.3 Groundwater

The Mitchell region contains a total 635 registered groundwater bores. Of these, 429 have surveyed elevations that could enable a water table surface (piezometric surface in the case of confined aquifers) to be constructed for the main aquifers. However, these bores are not all monitored on a regular basis. According to Queensland Government databases there are 102 water level monitoring bores in the region; 16 are historical and 86 are current (Figure MI-10) with nearly all the bores located in the headwater areas of the Mitchell River catchment. Of the 86 current monitoring bores, 6 are for the Great Artesian Basin (GAB) aquifer and 80 are for sub-artesian aquifers. It should be noted that the Gilbert River Formation of the GAB is sub-artesian in some places, thus current monitoring of this formation falls into both categories shown on the map.

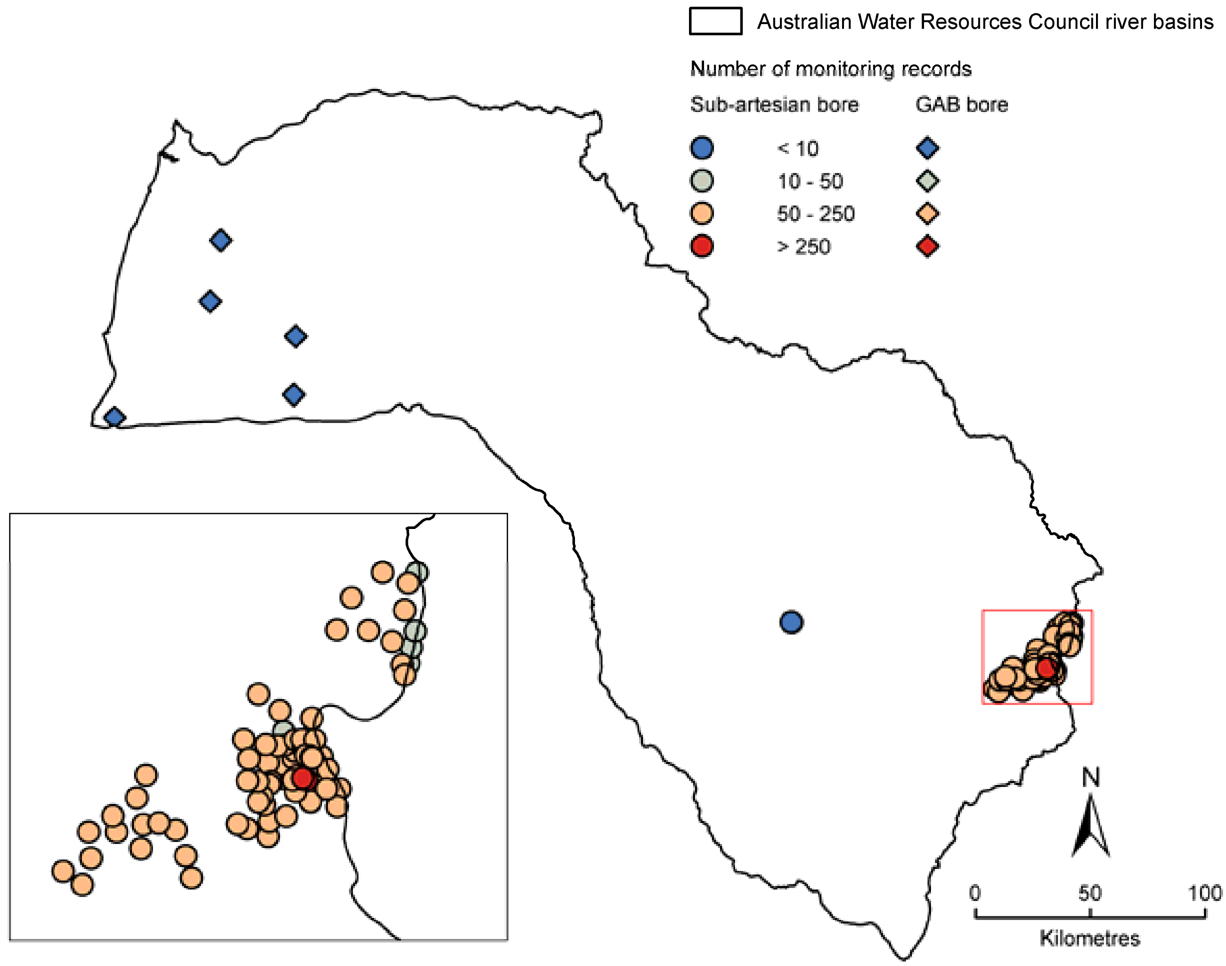


Figure MI-10. Current groundwater monitoring bores in the Mitchell region

## MI-2.2.4 Data gaps

Time series groundwater level and salinity data is currently available for some parts of the GAB and sub-artesian aquifers in the Dimbulah - upper Walsh River area. However, improved coverage of data beyond these areas would provide enhanced understanding of recharge processes and inter-aquifer leakage, particularly for the Great Artesian Basin aquifers.

# MI-2.3 Hydrogeology

## MI-2.3.1 Aquifer types

The Mitchell region comprises four main types of aquifers: (i) fractured rock basement; (ii) sandstones within the Carpentaria Basin of the Great Artesian Basin; (iii) Tertiary sediments, and (iv) Quaternary alluvium and beach ridge deposits.

### Basement aquifers

The Mitchell River flows westward from the Great Dividing Range and across the Hodgkinson (geological) Province. The Hodgkinson Province extends from the east coast to the major north-south trending Palmerville Fault located about a third of the way across the Mitchell region (Figure MI-2). The Hodgkinson Province comprises Silurian-Devonian age marine deposits (Bultitude et al., 1996). Aquifers of the province are unconfined fractured rock aquifers, with variable permeability and low storage. Secondary porosity, in the form of bedding planes, joints, faults and voids, allow groundwater to occur throughout the entire Hodgkinson Formation. Yields are commonly in the order of 5 L/second (Horn et al., 1995).

### Carpentaria Basin

The Carpentaria Basin is the most northerly tectonic unit within the Great Artesian Basin (GAB) and underlies approximately the western two-thirds of the Mitchell region. The sediments are Jurassic to Early Cretaceous in age and the Gilbert River Formation is the main unit, outcropping along the western edge of the Great Dividing Range (Figure MI-2) The aquifer in these parts of the region is mainly unconfined. Elsewhere the aquifer is confined and artesian, meaning the groundwater is under hydrostatic pressure and hence rises above the ground surface in boreholes located down gradient from its outcrop / recharge areas.

### Karumba Basin

The Karumba Basin overlies the Carpentaria Basin, and is a broad, shallow, saucer-shaped depression of uncertain maximum depth. The Karumba Basin aquifers are considered the most significant water resource in Cape York and consist of two units of Tertiary age, the Bulimba Formation and the Wyaaba Beds (Figure MI-2). The Bulimba Formation is more significant in areal extent and capacity.

The Bulimba Formation comprises fluvial sediments derived from the weathering of the Gilbert River Formation outcrop in the eastern part of the region. Aquifers are typically constrained to palaeochannels meandering through a matrix of clayey, less transmissive sediments and hence they are not continuous and not always in hydraulic connection with each other. Productive aquifers appear limited to the area approximated by the current Mitchell River Delta.

The Bulimba Formation constitutes the most extensive and productive aquifer systems in the Karumba Basin, extending from the top of Cape York Peninsula down to Georgetown and from the Great Dividing Range out to the Gulf of Carpentaria (Hillier, 1977). It is present essentially across the entire Mitchell region.

The Wyaaba Beds are up to 120 m thick with limestone aquifers up to 50 m thick (DNRW, 2006). The limestone aquifer is limited to the present day coastline and only supplies artesian water 50 km inland from the coast (Horn et al, 1995). The Wyaaba Beds are not considered a significant groundwater resource outside the area where the limestone occurs.

### Quaternary aquifers

To the west of where the Gilbert River Formation outcrops, the surface of the Mitchell region is dominated by thin (often only 1 m deep) Quaternary fans of very low relief, deposited by the Mitchell River and its tributaries in occasional floods. Little is known about the deposits, but they appear to offer poor prospects for anything but small stock supplies (Hillier, 1977).

 

The beach ridge coastal deposits represent episodes of advance and retreat by the sea in the Quaternary. Groundwater supplies from the beach ridge and dunes have had little quantitative documentation; however general interpretations indicate that they are an important source of water for domestic use (Horn et al., 1995).

### MI-2.3.2 Inter-aquifer connection and leakage

There may be upward leakage from the Gilbert River Formation and Bulimba Formation into the overlying alluvial sediments. Despite the low permeability of the aquitard, and hence low percolation rates, this leakage probably accounts for considerable volumes of discharge (DNRM, 2005). The presence of a spring group in the west of the Mitchell region (Figure MI-3) may be indicative of leakage from the confined aquifers to the overlying aquifers.

Tidal influences have been recognised in bores constructed in the Wyaaba Beds. Horn et al. (1995) interpreted these influences to infer aquifer outcrop on the seabed to the west, however this hypothesis is yet to be proven.

### MI-2.3.3 Recharge, discharge and groundwater storage

#### Basement aquifers

Recharge to the fractured rock aquifers that outcrop in the east of the Mitchell region occurs principally via direct infiltration of rainfall. The local watertable in these aquifers responds rapidly to periods of intense rainfall (Figure MI-11). The longer-term responses in groundwater storage reflect long-term rainfall patterns as is illustrated by the long-term trace of cumulative deviations from mean monthly rainfall.

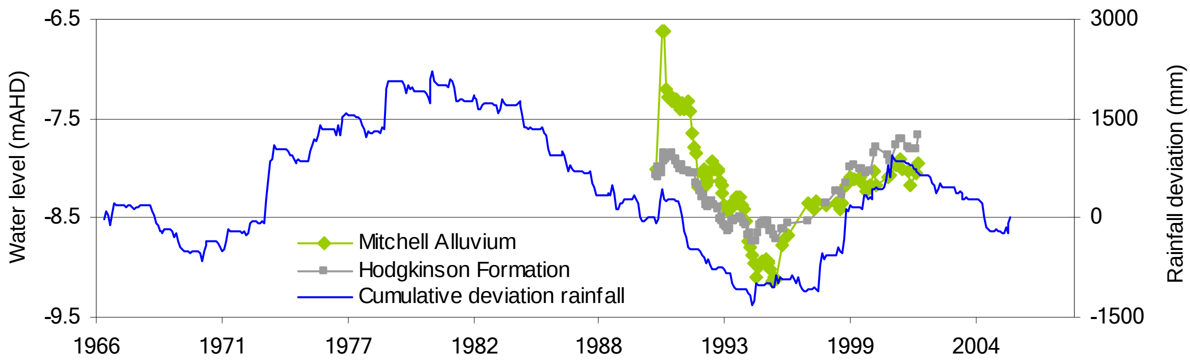


Figure MI-11. Observed groundwater levels in the Hodgkinsons Formation and Mitchell River Alluvium and cumulative deviation from mean monthly rainfall

#### Carpentaria Basin

Recharge to the GAB aquifers is by infiltration of rainfall and leakage from streams into outcropping sandstone. In the Mitchell region, this recharge occurs primarily along the elevated margins of the basin on the western slopes of the Great Dividing Range, in areas referred to as 'recharge beds' or 'intake beds' (Figure MI-2).

Discharge from the GAB occurs several ways, including natural discharge from springs, upward leakage through the confining beds towards the regional watertable, subsurface outflow into the Gulf of Carpentaria (although little is known about the volume or significance of this form of discharge) and artificial discharge via artesian flow and pumping from bores.

#### Karumba Basin

The Bulimba Formation is predominantly recharged via the vertical infiltration of rainfall in outcrop areas. Some recharge also may occur via upward leakage from GAB aquifers, although this has not been quantified. Discharge occurs as spring flows and rejected recharge, which contributes to baseflows in several rivers including the Mitchell and Palmer.

The Wyaaba limestone aquifer is completely confined and has no known onshore outcrop. The primary recharge mechanism is thought to be lateral groundwater inflow from the east (DNRW, 2006).

#### Quaternary aquifers

Recharge to the Mitchell River alluvial sands and gravels predominantly occurs via lateral flow through the sandy river beds during the wet season high river flows, via vertical infiltration on the extensive floodplain during flood events and, to a lesser degree, via vertical infiltration of rainfall. The alluvial aquifers also receive recharge from the Bulimba Formation and to a limited extent the Gilbert River Formation, where confining beds are relatively thin.

Discharge from the alluvium predominantly occurs in the form of evapotranspiration; however during the dry season discharge to the rivers also occurs.

### MI-2.3.4 Groundwater quality

#### Basement aquifers

Groundwater from the Hodgkinson Province is generally of good quality, with an average electrical conductivity (EC) of 700 µS/cm, and thus suitable for all purposes (Horn et al., 1995).

#### Carpentaria Basin

Very little is known about water quality for the Carpentaria Basin as there is very limited extraction from the GAB in this region.

#### Karumba Basin

Groundwater quality in the Karumba Basin is generally good and although the EC of the Wyaaba Beds is low, it is generally higher than that of the Bulimba Formation. The quality of groundwater from the Bulimba Formation is suitable for all purposes and has EC ranging from 210 µS/cm to 700 µS/cm. The poorer quality of the Wyaaba beds ranges from 700 µS/cm to 2,500 µS/cm (Horn et al., 1995).

#### Quaternary aquifers

Groundwater quality of the Quaternary alluvium is likely to be variable, though little specific data is available. Good water supplies exist in the shallow alluvial sand and gravel deposits associated with the Mitchell River in the Walsh area and it is likely that similar lenses occur over the length of the Mitchell River floodplain.

Figure MI-12 shows groundwater salinity for 290 bores across the Mitchell region. The median depth of these bores is 32 m (below ground) and the stratigraphic logs suggest they predominantly access groundwater from the Hodgkinson Formation and the Bulimba Formation, with fewer bores tapping the GAB aquifers, the Wyaaba beds and alluvial aquifers. Groundwater salinity is typically less than 750 µS/cm, which is consistent with the summary of salinity ranges above. Higher groundwater salinities measured in the upper reaches of the catchment (to the east) are most likely associated with deep drainage accessions beneath the Mareeba - Dimbulah Water Supply Scheme.

 

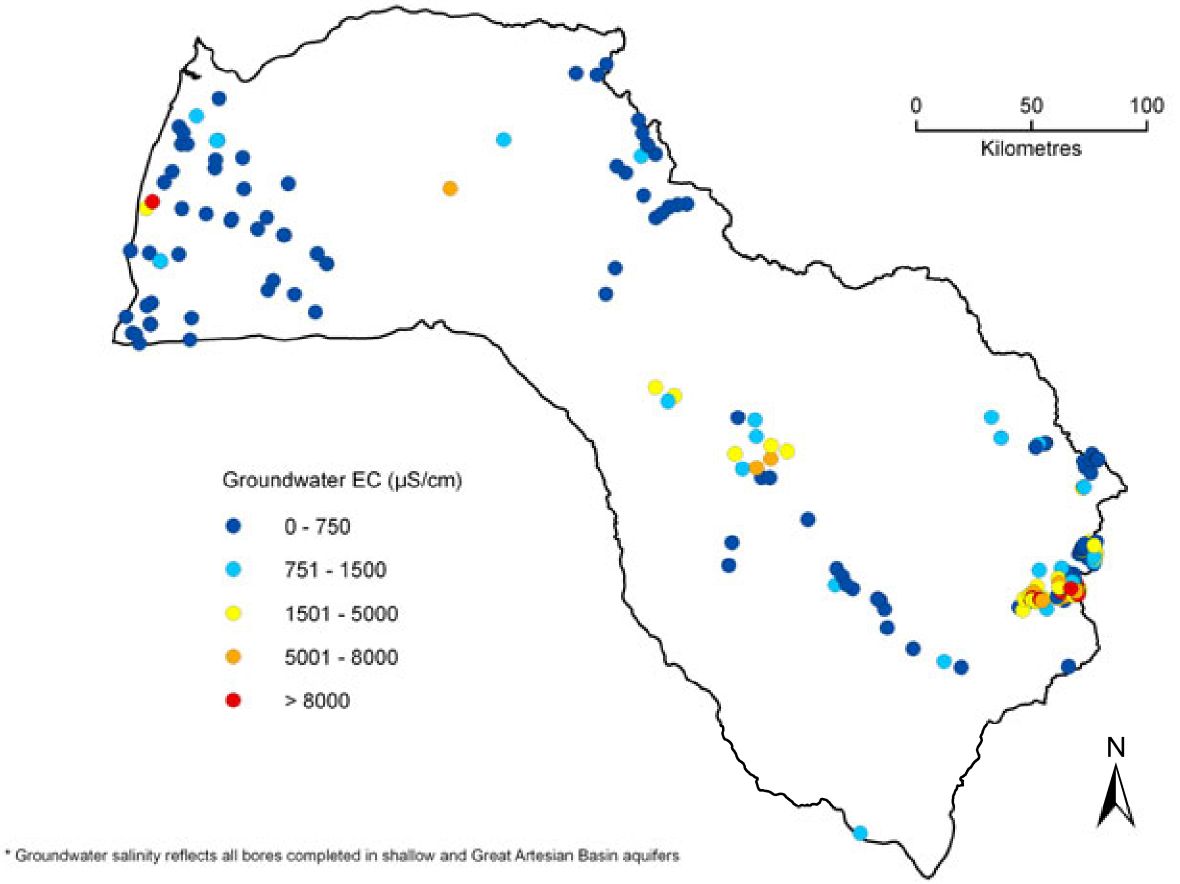


Figure MI-12. Groundwater salinity (as electrical conductivity – EC) distribution for all bores drilled in the Mitchell region

## MI-2.4 Legislation, water plans and other arrangements

### MI-2.4.1 Legislated water use, entitlements and purpose

Water entitlements and use in the Mitchell region are governed by the *Water Resources (Mitchell) Plan* (DNRW, 2007), which deals with surface water and groundwater in aquifers that are not connected with the GAB. The *Water Resource (Great Artesian Basin) Plan 2006* deals with groundwater in the GAB aquifers. The *Water Resource (Barron) Plan 2002* deals with that part of the upper Mitchell and Walsh River catchments that receive supplemented water from the Barron River system as part of the Mareeba Dimbulah Water Supply Scheme.

The distribution and magnitude of current surface water allocations and unallocated surface water is shown in Figure MI-13. In this figure, green indicates current allocation and red indicates unallocated water. Values at the bottom of the catchment indicate water without a specific extraction location. Blue indicates the location of a specific node. The yellow area is considered part of the Cape York Peninsula region.

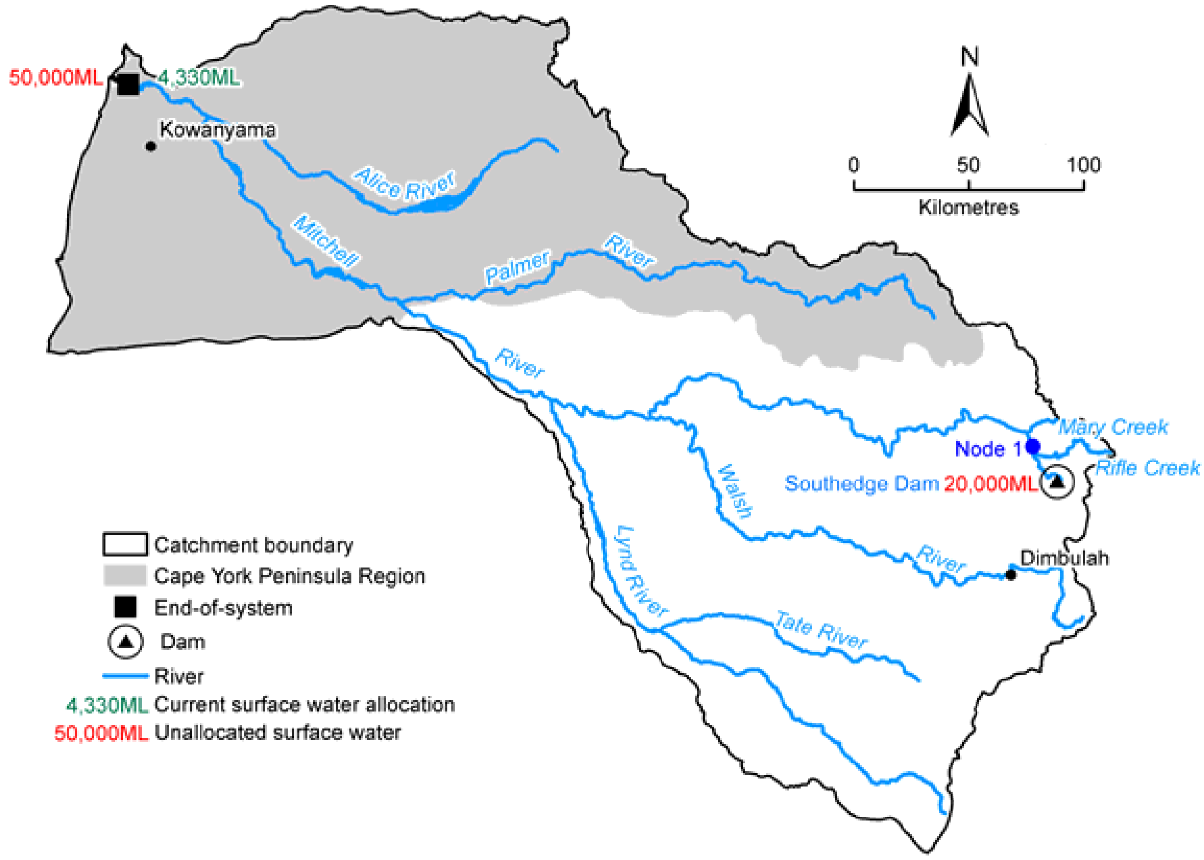


Figure MI-13. Existing surface water allocations (green) and unallocated water (red) in the Mitchell region. The yellow region highlights part of the Mitchell region that falls within the Cape York Peninsula region (*after Water Resource (Mitchell) Plan* (DNRW, 2007)). Note that the figures at the mouth of the Mitchell refer to volumes allocated and unallocated across the entire region

### MI-2.4.2 Groundwater use and entitlements

Groundwater entitlement volumes and estimated stock and domestic use volumes were reported as part of the *Water Resource (Great Artesian Basin) Plan 2006*. This information was collated in terms of the management areas defined for the GAB in Queensland and has been reconfigured by the Queensland Department of Environment and Resource Management (DERM), to estimate volumes for the Northern Australia Sustainable Yield Project reporting regions.

Groundwater of the GAB is vital to the outback regions of Queensland, as it is often the only water supply available for towns and properties for their stock and domestic requirements. It also supplies water for industrial purposes such as:

 

Groundwater of the GAB is vital to the outback regions of Queensland, as it is often the only water supply available for towns and properties for their stock and domestic requirements. It also supplies water for industrial purposes such as: mining, power generation, aquaculture, feedlots and piggeries. Generally, the predominant use of groundwater from the GAB aquifers is for stock and domestic purposes.

For the Mitchell region the estimated volume of stock and domestic use is approximately 4 GL/year and the volume of licensed entitlements is about 0.5 GL/year (Table MI-3). This table shows that approximately 85 percent of stock and domestic use and 100 percent of groundwater entitlements are associated with the Karumba Basin aquifers (i.e. the Bulimba Formation and Wyaaba Beds). Less than 5 percent of stock and domestic use is derived from the GAB aquifers.

### Basement aquifers

Groundwater extraction from the Hodgkinson Province is typically restricted to stock and domestic bores, and small irrigation developments, due to the lower yielding nature of the aquifers.

Table MI-3. Estimated stock and domestic groundwater use and groundwater entitlements in the Mitchell region

| Formation | Stock and domestic use | Entitlement |
| --- | --- | --- |
| | GL/y | |
| Quaternary alluvium | 0.02 | 0 |
| Cainozoic sediments/basalt (including Karumba Basin) | 3.39 | 0.500 |
| Jurassic sedimentary rocks | 0.00 | 0 |
| Jurassic – early cretaceous Great Artesian Basin aquifers | 0.15 | 0 |
| Palaeozoic rocks | 0.40 | 0 |
| Proterozoic rocks | 0.01 | 0 |
| **Total volume** | **3.97** | **0.500** |

### Carpentaria and Karumba basins

There is currently limited extraction from the GAB Gilbert River Formation (Table MI-3). This is primarily due to the great depth to aquifers over a large part of the area, and the availability of either shallower supplies from the Karumba Basin sediments, or surface water.

The town of Kowanyama obtains its water supply from the Bulimba Formation, as do numerous stock and some domestic bores.

The rehabilitation of several large flowing bores constructed in the Bulimba Formation has restored heads and pressures to levels recorded during initial development. Near continuous pumping for the Kowanyama community water supply has, however, resulted in a localised depression of approximately 25 m in potentiometric head. This drop in pressure has not been measured in bores outside the Kowanyama town area, suggesting that there is very limited connectivity between the discontinuous aquifers of the Bulimba Formation (DNRM, 2005).

The community of Pormpuraaw (located just outside the Mitchell region) sources its water supply from the Wyaaba Beds. Several community outstations and some cattle stations also take domestic and stock water supplies from this system. It is likely that large-scale extraction of water from the Wyaaba Beds limestone aquifers is unsustainable due to the limited, or non-existent, opportunities for recharge (DNRM, 2005). Current extraction for water supply may be ‘mining’ the aquifer and promoting seawater intrusion.

### Quaternary aquifers

The beach ridge and coastal dune deposits found along the coastline, as well as the floodplain and stream bed deposits associated with rivers, are all characterised by groundwater of variable quality. Little documentation exists for these Quaternary deposits, as they provide only a limited amount of groundwater for stock watering and domestic use.

## MI-2.4.3 Rivers and storages

There are currently four major water storages in the Mitchell catchment, with a combined capacity of over 140,000 ML (Table MI-4). The largest is Southedge Dam, which is privately owned (Quaids). The SDPC Ornamental Lakes are licensed, but not yet constructed. The series of small weirs (total storage of over 2000 ML) on the upper Walsh River contribute to the Mareeba Dimbulah Water Supply Scheme.

Flows in the Mitchell River are largely unimpeded, except for the Southedge Dam (Lake Mitchell)(Table MI-4).

Table MI-4. Instream storages on the Mitchell River (within the IQQM modelled area)

| Storage name | River | Capacity |
|---|---|---|
| | | ML |
| Southedge Dam | Mitchell River | 129,000 |
| SDPC Ornamental Lakes | Big Mitchell Creek | 7,645 |
| Palmer River storages | Palmer River | 2,639 |
| Tate catchment storages | Tate River | 1,397 |
| Bruce Weir | Upper Walsh River | 970 |
| Collins Weir | Upper Walsh River | 600 |
| Solanum Weir | Eureka Creek | 345 |
| Gold Leaf Weir | Upper Walsh River | 260 |
| Bushy Creek storage | Bushy Creek | 20 |
| Upstream Bushy Creek Storage | Rifle Creek | 5 |
| **Total** | | **142,881** |

## MI-2.4.4 Unallocated water

Unallocated water is the water which is identified within the DERM water resource plans as water potentially available for future allocation.

Unallocated water can be held as a:

- general reserve (general unallocated water) which may be granted for any purpose
- Indigenous reserve (Indigenous unallocated water) which may be granted only for helping Indigenous communities in the Cape York Peninsula Region area to achieve their economic and social aspirations, or
- strategic reserve (strategic unallocated water) which may only be granted for a state purpose. State purpose means (i) a project of state significance; or (ii) a project of regional significance; or (iii) town water supply; or (iv) ecotourism in a wild river area.

Unlicensed extractions of overland flow are allowed for stock and domestic purposes or any other purpose using works that allow the taking of overland flow water and have a capacity of not more than 250 ML. For future works with a capacity greater than 250 ML, the taking of overland flow requires a water licence. Any such future uses must obtain an entitlement from the general unallocated water reserve.

Stock and domestic water is mainly sourced from artesian GAB aquifers. There is currently 1.1 GL of unallocated water in general reserve in the Gulf Management Area, and 10 GL of State Reserve available across the entire GAB.

The *Water Resource (Great Artesian Basin) Plan 2006* separates groundwater from surface water. In the case of the *Water Resources (Mitchell) Plan 2007* there is no separation of surface water and groundwater within the unallocated water – the allocation limit given is for combined extraction. However:

- it is anticipated by the state that the vast majority of water will be taken from surface water sources, utilising flood harvesting and extraction from major surface water bodies
- any groundwater extractions taken close to a major surface water source are treated as if the extraction came from the surface water source
- for the purposes of this project, all unallocated water is assumed to be taken as a surface water diversion.

### MI-2.4.5 Social and cultural considerations

Indigenous land holdings, which are a perpetual Deed of Grant in Trust from the Queensland Government, include the Mitchell River delta and the lower reaches of the Alice River. The Kowanyama community has control of approximately 4000 $km^2$ (Monaghan, 2001). Kowanyama is a former mission community containing three different language groups, the Yir Yoront, the Kokobera and the Kunjen people.

The Kowanyama Land and Natural Resource Management Office has produced an atlas of wetlands and undertook a preliminary assessment of their value to the Indigenous community at Kowanyama. Monaghan (2001) outlines four ways in which wetlands are central to the local Indigenous livelihoods:

- The location of many sacred sites such as increase or conception centres, poison places or burials and are significant places in local mythology.
- Wetlands are the focus of subsistence hunting and fishing.
- Seasonal wetlands are important and productive cattle grazing areas.
- Seasonal patterns of inundation affect mobility around the landscape and access to traditional country from the Kowanyama township.

The atlas notes that the community and its resource agency lack data on: i) wetlands distribution, hydrology and seasonal persistence; ii) natural resource values of wetlands and iii) the current ecological condition of wetlands. The atlas includes a biogeographic regionalisation of wetlands. Ethnographic data are included for over 400 wetland locations. Most are the location of traditional campsites, or are story places or ritual sites. A number of wetlands in Kowanyumal Pocket, Kokomenjen and Wallaby Islands and Pormpuraaw were identified as being of 'highest cultural significance' (Monaghan, 2001). Their future existence is threatened by severe degradation from feral animals and domestic cattle.

Strang (2005) examined meanings and values encoded in water by a range of water-using groups along the Mitchell River. She examined the meaning of water as the generative basis for 'wealth and health' amongst the Indigenous language groups resident in the Kowanyama area near the river's estuary and the non-Indigenous society, particularly pastoralists.

Strang (2005) notes that Indigenous people in the Cape York region 'share with other Australian Indigenous communities a cosmology in which the landscape and its waterways are the products of ancestral creativity, in what is locally called the 'Story Time''. Water is presented as the substance through which all aspects of life are generated, and inter-generationally recreated. Water sources are the most 'powerful' places in the landscape, acting as points of concentration for the ancestral forces that – like water, or one might say as water – permeate the landscape as a whole. Symbolically they provide human being, social and spiritual existence, and all of the material and intellectual resources upon which the community depends. Through ritual activity, and through everyday management of the environment, people engage with ancestral forces to maintain or increase resources and ensure social and environmental health and well-being.

In the 1990s the community at Kowanyama established a Land and Resource Management Office and created the Mitchell River Watershed Management Group in an effort to increase control over land and resources under increasing pressure from fishing and other uses.

The diverse views regarding water resource management has led to competition for legitimacy and agency and for the power to direct relationships with the environment and define what is 'valuable'.

### MI-2.4.6 Changed diversion and extraction regimes

There are restrictions on extracting of groundwater in the Mitchell region under the *Water Resources (Mitchell) Plan 2007* and *Water Resources (Great Artesian Basin) Plan 2006*. Volumetric limits exist on all entitlements under the *Water Resource (Great Artesian Basin) Plan 2006*. Sock and domestic bores don't require a volumetric entitlement and can access water if they meet criteria in regard to distance from existing bores and springs to protect existing users and groundwater dependent ecosystems.

### MI-2.4.7 Changed land use

Although intensive agriculture is a commercially significant land use in the Mitchell River catchment, it represents less than two percent of the total catchment area. It is mainly limited to the Upper Walsh portion of the Mareeba-Dimbulah Water Supply Scheme and the Upper Mitchell Catchment north of Mareeba at Biboohra, Julatten and Maryfarms. Intensive agriculture can impact on its surrounding environment and downstream waterways in several ways.

Mining is a significant industry in the Mitchell River catchment. It is the oldest non-aboriginal land use in the catchment, being a significant activity in the region for more than 120 years. Small scale alluvial and hardrock gold and tin operations have dominated mining activities in recent times. However, increases in some metal prices have led to an increased interest in other mineral deposits and large-scale mining may commence, or recommence, in some parts of the catchment.

### MI-2.4.8 Environmental constraints and implications of future development

Volumetric limits exist on all groundwater entitlements under the *Water Resource (Great Artesian Basin) Plan 2006*. Stock and domestic bores don't require a volumetric entitlement and can access water if they meet criteria in regard to distance from existing bores and springs to protect existing users and groundwater dependent ecosystems.

Importance is placed on perennial reaches of the Mitchell River and its tributaries for ecosystem protection. The *Water Resource (Mitchell) Plan 2007* ensures that total consumptive extractions will be limited to less than one percent of the total mean annual flow for this region.

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# MI-3 Water balance results for the Mitchell region

This chapter describes modelling results and the assessment of the water resources undertaken by this project for the Mitchell region. Detailed, quantified assessments are made where possible, and relevant, and confidence is estimated. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2. This chapter is sub-divided into:

- climate
- recharge estimation
- conceptual groundwater models
- groundwater modelling results
- rainfall-runoff modelling results
- river system water balance
- changes to flow regimes at environmental assets.

## MI-3.1 Climate

### MI-3.1.1 Historical climate

The Mitchell region receives an average of 965 mm of rainfall over the September to August water year (Figure MI-14), most of which (917 mm) falls in the November to April wet season (Figure MI-15). Across the region there is a strong north-west to south-east gradient in annual rainfall (Figure MI-16), ranging from 1615 mm in the north-west to 714 mm in the south-east. Since the beginning of the historical (1930 to 2007) period, rainfall has been relatively constant but the 1970s were wetter than average followed by a drier period in the 1980s and 1990s. The highest yearly rainfall received was 1945 mm which fell in 1974, and the lowest was 525 mm in 1952.

Areal potential evapotranspiration (APET) is very high across the region, averaging 1905 mm over a water year (Figure MI-14), and varies moderately across the seasons (Figure MI-15). APET generally remains higher than rainfall for most of the year resulting in nearly year-round water-limited conditions. The exceptions to this are the months January to March, when more rain falls than can potentially be evaporated.

 

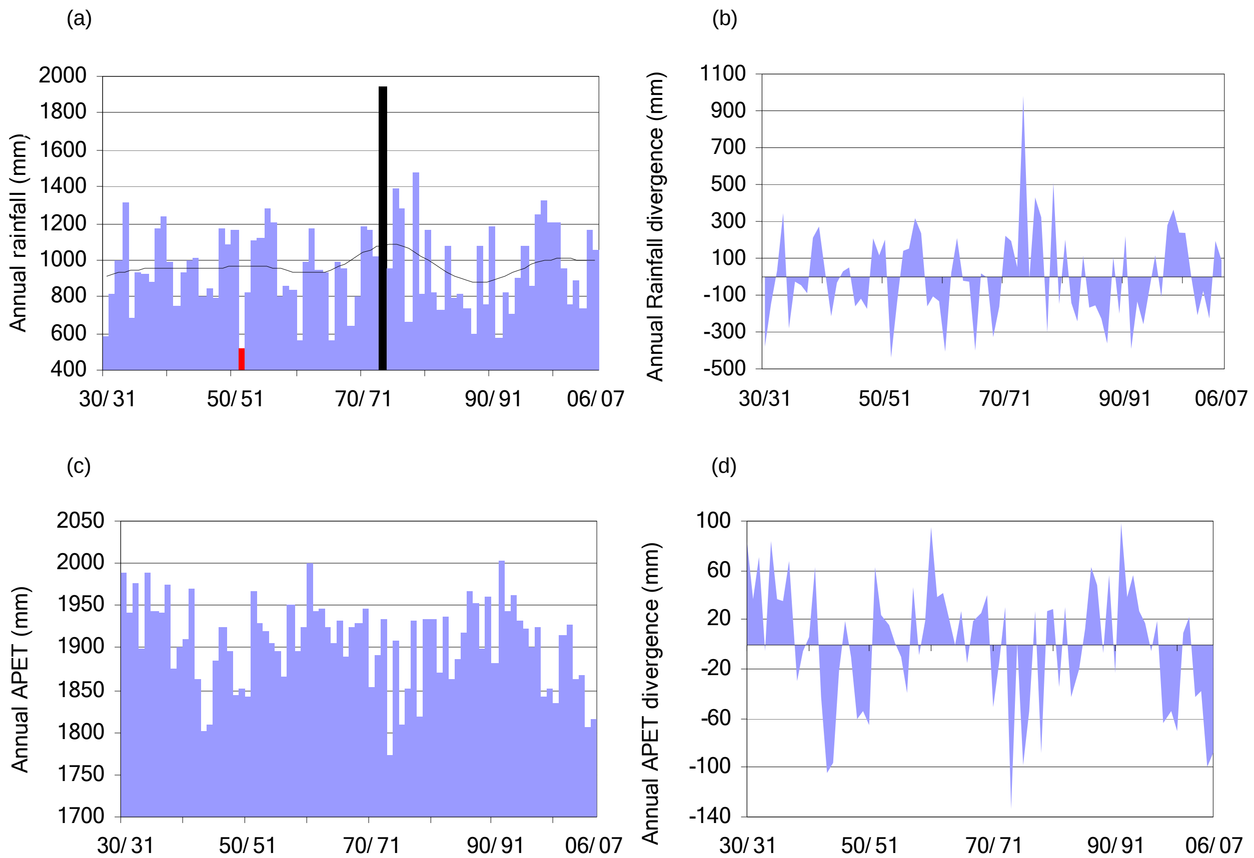


Figure MI-14. (a) Historical annual rainfall and (b) its divergence from the long-term mean; and (c) historical annual areal potential evapotranspiration and (d) its divergence from the long-term mean averaged over the Mitchell region. The low-frequency smoothed line in (a) indicates longer term variability

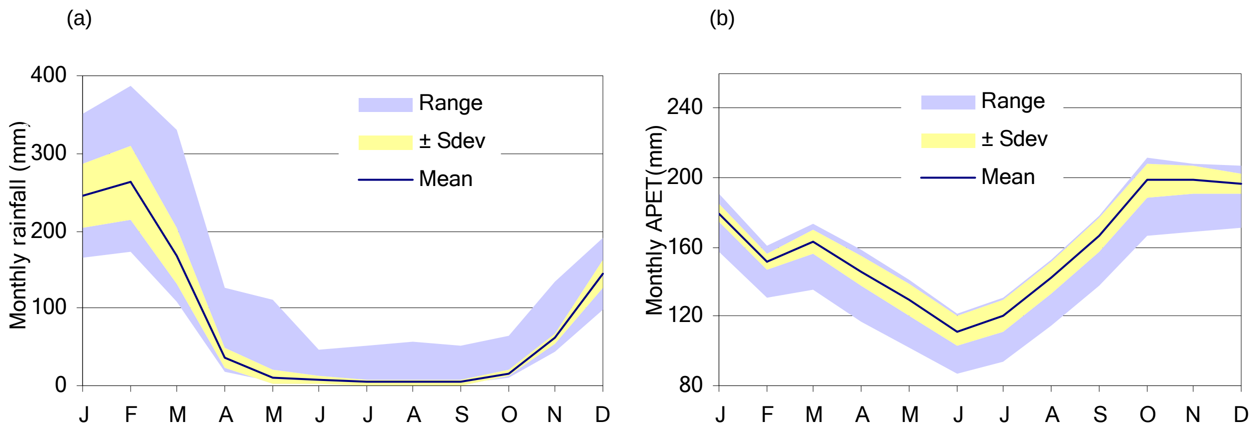


Figure MI-15. Historical mean monthly (a) rainfall and (b) areal potential evapotranspiration and their temporal variation (range and ± one standard deviation) averaged over the Mitchell region

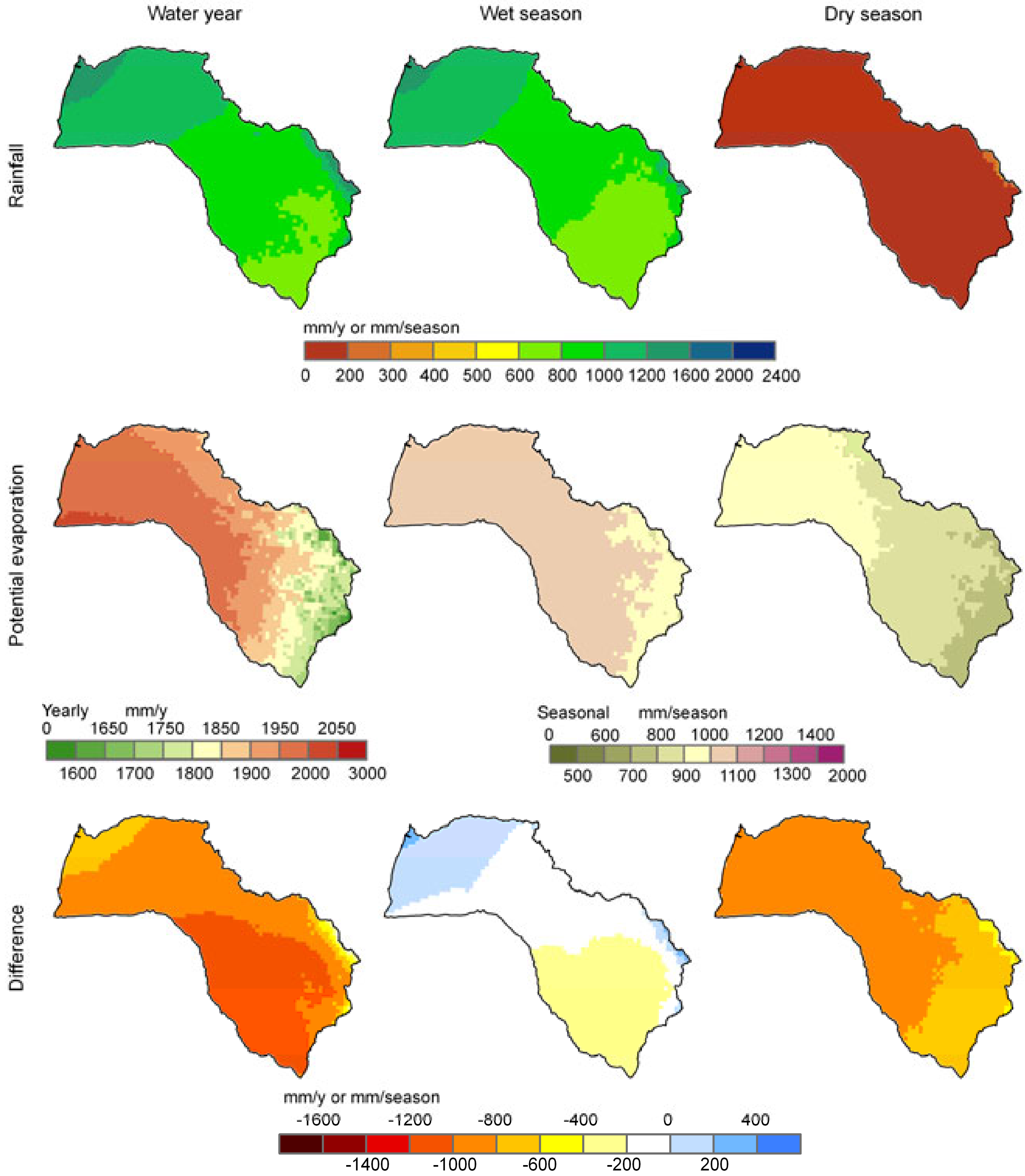


Figure MI-16. Spatial distribution of historical mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration (potential evaporation) and their difference (rainfall less areal potential evapotranspiration) across the Mitchell region

### MI-3.1.2 Recent climate

Figure MI-17 compares recent (1996 to 2007) to historical (in this case the 66-year period 1930 to 1996) mean annual rainfall for the Mitchell region. The difference varies between increases of 20 percent in the north-west and decreases of up to 10 percent in the south-east. Changes in rainfall are statistically significant only in the north-west.

 

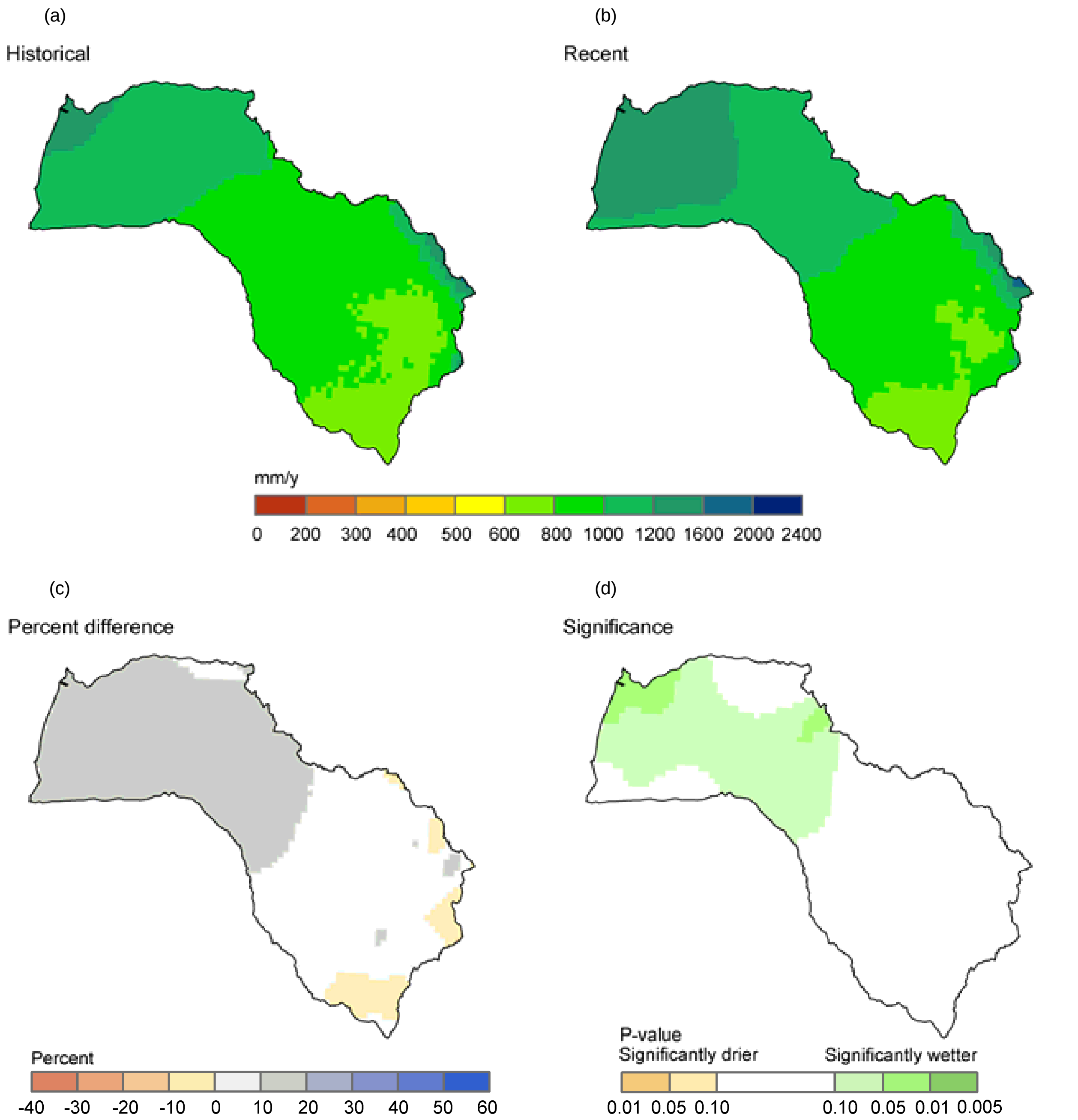


Figure MI-17. Spatial distribution of (a) historical and (b) recent mean annual rainfall; and (c) their relative percent difference and (d) the statistical significance of these differences across the Mitchell region. Note that historical in this case is the 66-year period from 1930 to 1996

## MI-3.1.3 Future climate

Under Scenario C annual rainfall varies between 885 and 1098 mm (Table MI-6) compared to the historical mean of 965 mm. Similarly, APET ranges between 1935 and 1982 mm compared to the historical mean of 1905 mm.

A total of 45 variants of Scenario C were modelled (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). Subsequently, results from an extreme ‘wet’, median and extreme ‘dry’ variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet annual rainfall and APET increase by 14 percent and 2 percent, respectively. Under Scenario Cmid annual rainfall and APET increase by 1 percent and 2 percent, respectively. Under Scenario Cdry annual rainfall decreases by 8 percent and APET increases by 4 percent.

Under Scenario Cmid long-term monthly averages of rainfall and APET do not differ much from historical values (Figure MI-19). Under Scenario Cmid APET is consistently higher than the historical value, which is at the lower bound of the range in values for 45 Scenario C variants. Rainfall under Scenario Cmid lies within the range in values from these 45 variants. The seasonality of rainfall is expected to decrease slightly due to slight reductions in wet season rainfall. Similarly, APET may become slightly more seasonal as a result of increased wet season APET.

The spatial distributions of rainfall and APET under Scenario C are compared to the historical distribution in Figure MI-20 and Figure MI-21. Under Scenario C the strong north-west to south-east gradient in rainfall is retained in the wet season, but with a southwards shift under Scenario Cwet and a northwards shift under Scenario Cdry. The spatial distribution of APET under Scenario C is similar to the highly regionalised historical distribution. The greatest changes to APET occur in the west of the region.

Table MI-5. Mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration averaged over the Mitchell region under historical climate and Scenario C

| | Water year* | Wet season | Dry season |
|---|---|---|---|
| | mm/y | mm/season | |
| Rainfall | | | |
| Historical | 965 | 917 | 48 |
| Cwet | 1098 | 1034 | 51 |
| Cmid | 970 | 909 | 49 |
| Cdry | 885 | 836 | 38 |
| Areal potential evapotranspiration | | | |
| Historical | 1905 | 1036 | 870 |
| Cwet | 1935 | 1041 | 891 |
| Cmid | 1960 | 1067 | 889 |
| Cdry | 1982 | 1078 | 901 |

* Note that the sum of the wet season and dry season values does not always equal the water year values because the combined wet season and dry season period (November to October) is different to the water year period (September to August).

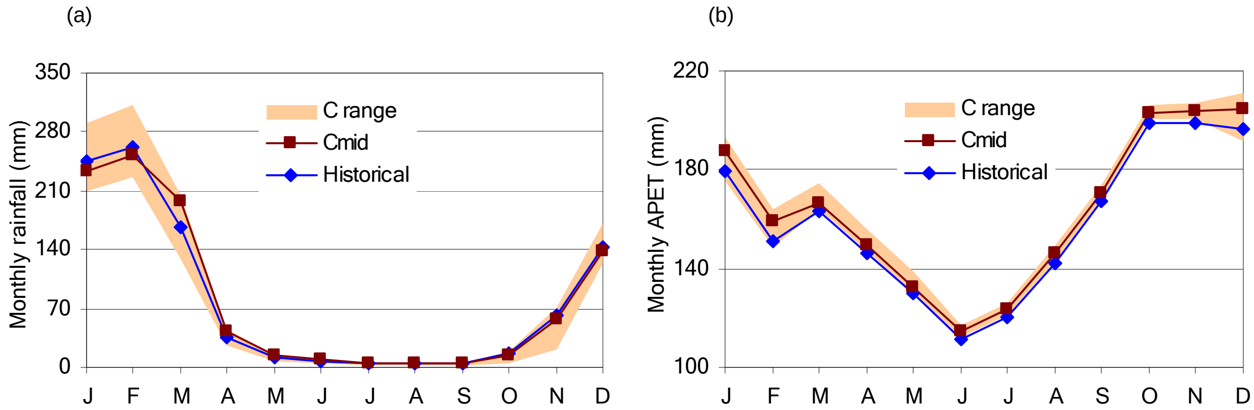


Figure MI-18. Mean monthly (a) rainfall and (b) areal potential evapotranspiration averaged over the Mitchell region under historical climate and Scenario C. ((C range is the range under the 45 Scenario C simulations – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

## MI-3.1.4 Confidence levels

Analysis of confidence of the climate data is presented at the division level and is reported in Section 2.1.4 in Chapter 2.

 

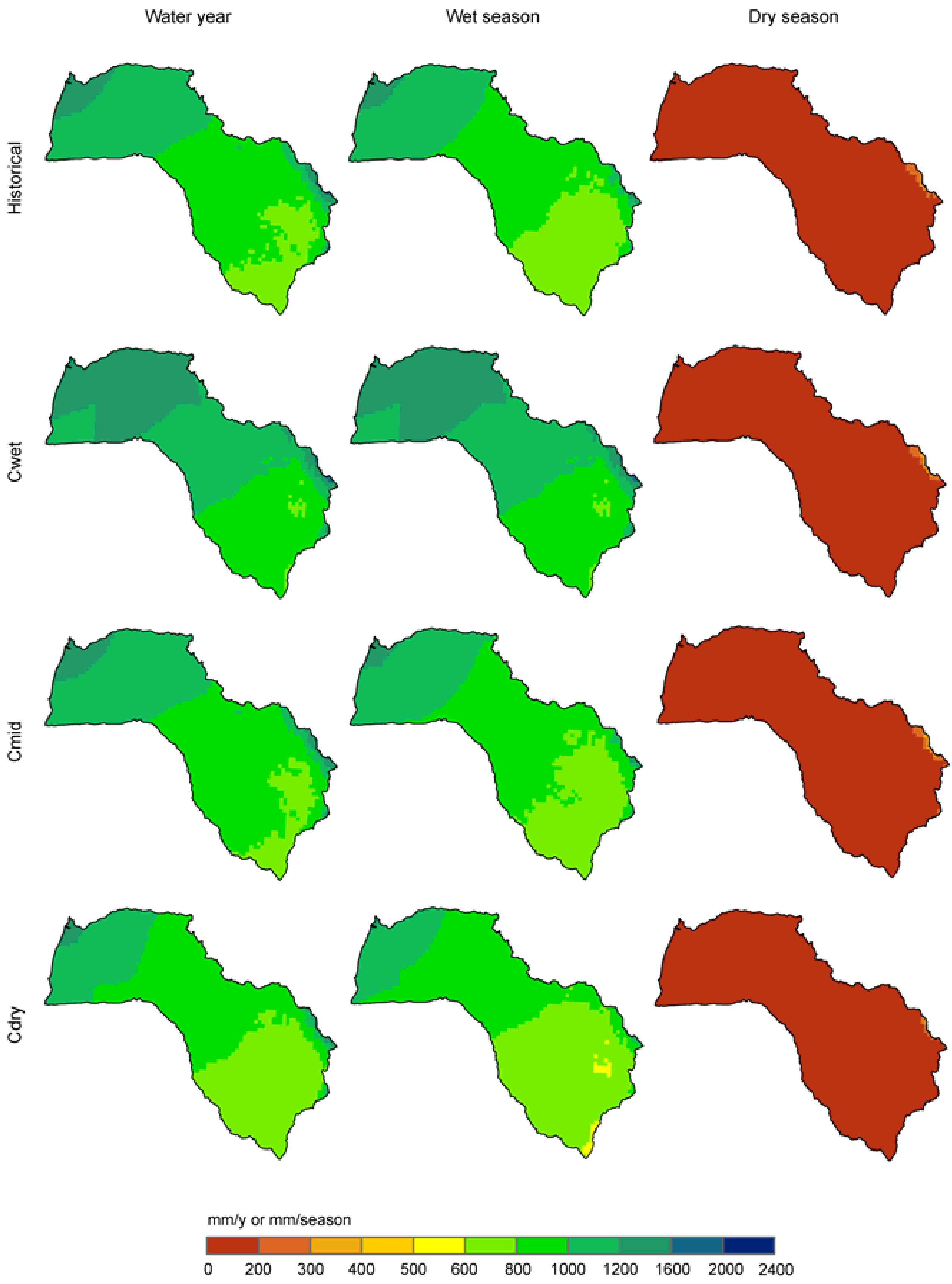


Figure MI-19. Spatial distribution of mean annual (water year), wet season and dry season rainfall across the Mitchell region under historical climate and Scenario C

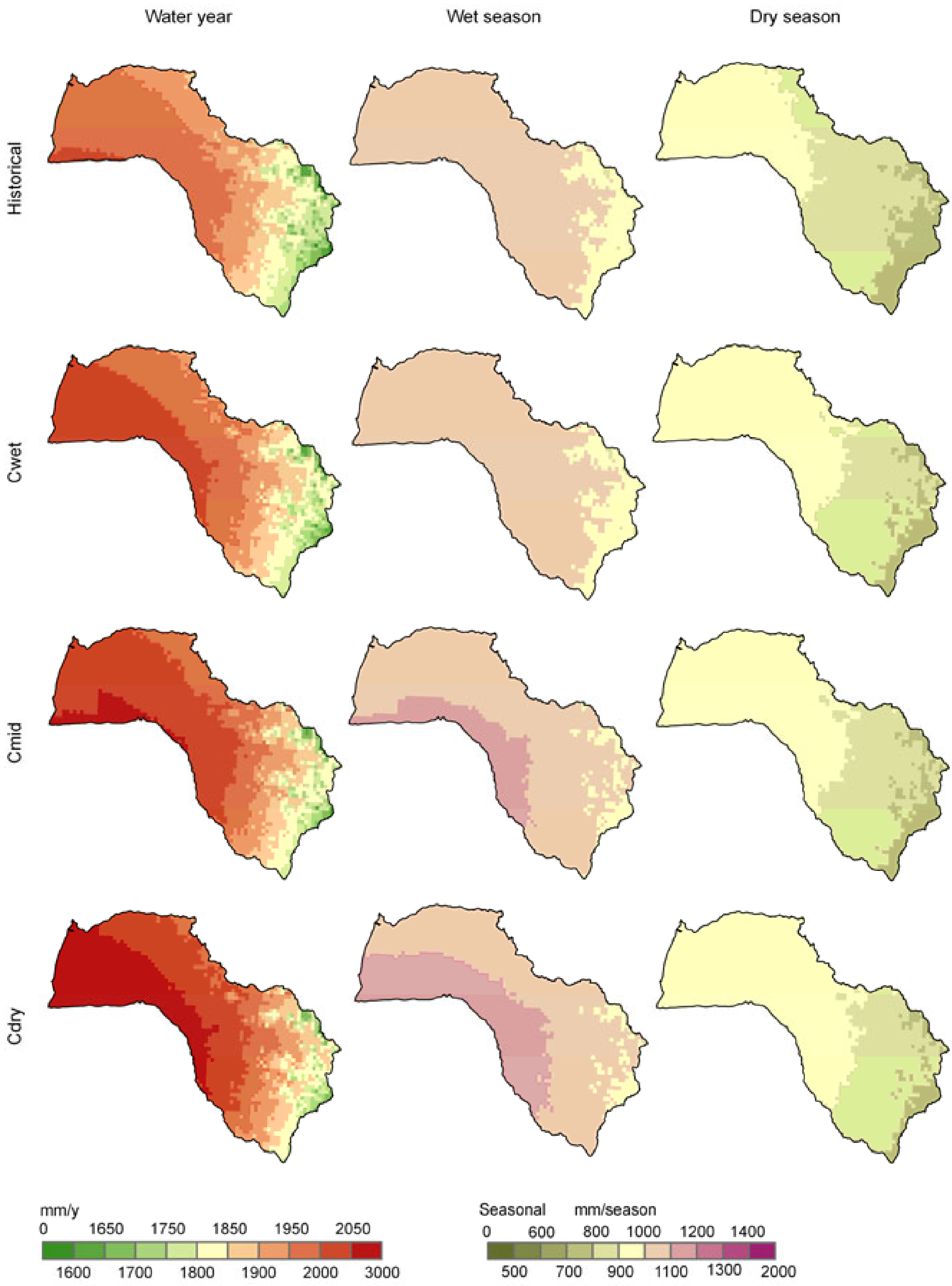


Figure MI-20. Spatial distribution of mean annual (water year), wet season and dry season areal potential evapotranspiration across the Mitchell region under historical climate and Scenario C

 

# MI-3.2 WAVES potential diffuse recharge estimation

The WAVES model (Zhang and Dawes, 1998) is used to estimate the change in groundwater recharge across the Mitchell region under a range of different climate scenarios. WAVES is a vertical recharge flux model that can model plant physiological feedbacks in response to increased $CO_2$, as well as modelling the water balance of different soil, vegetation and climate regimes. This model is chosen for its balance in complexity between plant physiology and soil physics. It was also used to assess recharge for the Murray-Darling Basin Sustainable Yields Project (Crosbie et al., 2008).

## MI-3.2.1 Under historical climate

The modelled mean annual historical (1930 to 2007) recharge (Scenario A) in the Mitchell region was determined to be 122 mm/year, which is close to the median value for all the regions in this project. Recharge is lowest near the coast and highest in the east of the region, and in the distributary fans on the western coastal plain (Figure MI-21). The historical record is assessed to establish any difference between wet and dry periods of recharge. A 23-year period is used, which allows the projection of recharge estimates to 2030 – in other words, to estimate recharge in 2030 assuming future climate is similar to historical climate (Scenario A). For three variants of Scenario A, based on the historical climate record, mean annual recharge is slightly different for a 23-year period than for the 77-year historical period.

For recharge that is exceeded in 10 percent of 23-year periods (Scenario Awet), recharge is (on average) 12 percent greater that the 77-year average (i.e., a recharge scaling factor, RSF, averaged across the region of 1.12). For recharge that is exceeded in 50 percent of 23-year periods (Scenario Amid), recharge is 3 percent lower (average RSF of 0.97) than the 77-year average. For recharge that is exceeded in 90 percent of 23-year periods (Scenario Adry), recharge is 14 percent lower (average RSF of 0.86) than the 77-year average (Table MI-6).

Table MI-6. Recharge scaling factors in the Mitchell region for scenarios A, B and C

| Region | Awet | Amid | Adry | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| Mitchell | 1.12 | 0.97 | 0.86 | 0.96 | 1.54 | 1.11 | 0.92 |

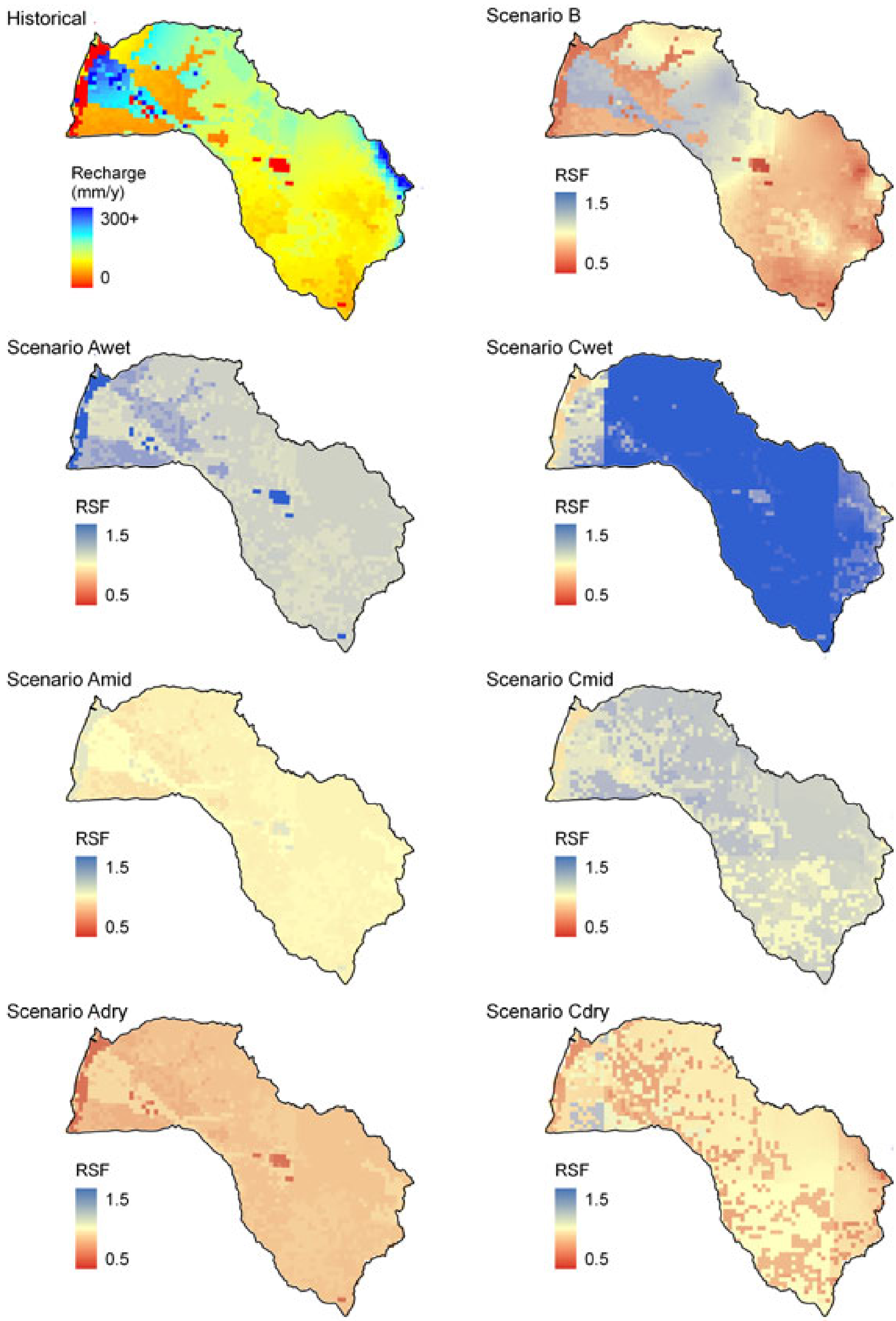


Figure MI-21. Spatial distribution of historical mean recharge rate; and recharge scaling factors across the Mitchell region under scenarios A, B and C. Recharge scaling factors are the ratio of the projected recharge in a scenario to that under Scenario A. Note: The vertical edges in the Scenario C maps are due to the cell size of global climate models

 

## MI-3.2.2 Under recent climate

The mean annual modelled recharge for 1996 to 2007 (Scenario B) in the Mitchell region is (on average) 4 percent lower than under Scenario A (Table MI-6). This decrease is not spatially uniform, however, with some areas in the west of the catchment showing an increase in recharge (Figure MI-21).

## MI-3.2.3 Under future climate

Figure MI-22 shows the percentage change in modelled mean annual recharge averaged over the Mitchell region under Scenario C relative to Scenario Amid for the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The percentage changes in mean annual rainfall and recharge from the corresponding GCMs are also tabulated in Table MI-7. Under some scenarios the recharge is projected to increase despite a decrease in rainfall. This is because total rainfall is not the only climate variable that has an influence over recharge. Daily rainfall intensity, temperature and $CO^2$ concentration are also important drivers (see Section 2.3.3 in the division-level Chapter 2), and specific situations can result in this counter-intuitive result. In particular, rainfall intensity is seen as a significant factor in this relationship.

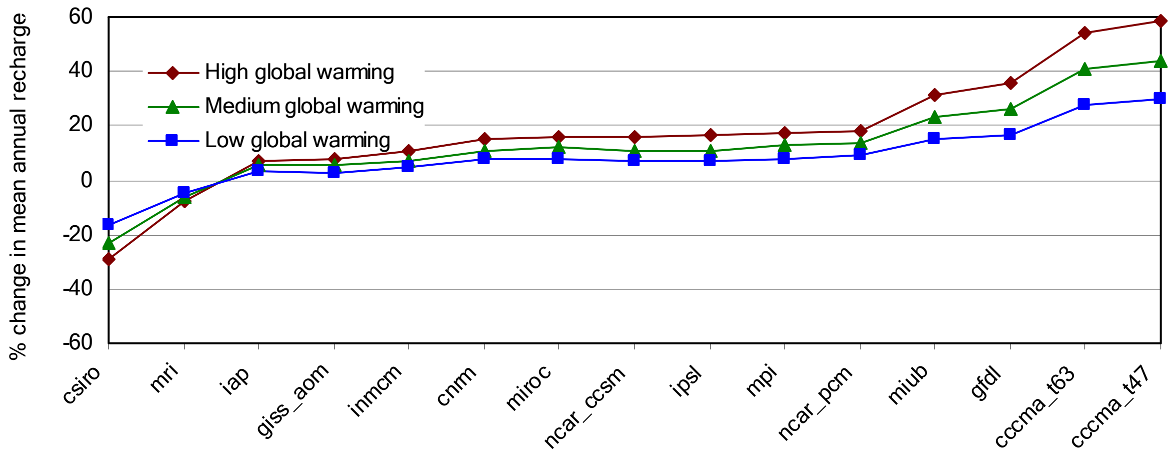


Figure MI-22. Percentage change in mean annual recharge under the 45 Scenario C simulations (15 global climate models and three global warming scenarios relative to Scenario A recharge)

Table MI-7. Summary results under 45 Scenario C simulations (numbers show percentage change in mean annual rainfall and recharge under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Recharge | GCM | Rainfall | Recharge | GCM | Rainfall | Recharge |
| csiro | -21% | -29% | csiro | -16% | -23% | csiro | -11% | -17% |
| **mri** | -8% | **-8%** | mri | -6% | -6% | mri | -4% | -5% |
| iap | -1% | 7% | iap | -1% | 5% | iap | -1% | 3% |
| giss_aom | -2% | 8% | giss_aom | -1% | 5% | giss_aom | -1% | 3% |
| inmcm | 1% | 11% | inmcm | 1% | 7% | inmcm | 1% | 4% |
| cnrm | 0% | 15% | cnrm | 0% | 11% | cnrm | 0% | 8% |
| miroc | 1% | 16% | miroc | 0% | 12% | miroc | 0% | 8% |
| ncar_ccsm | 3% | 16% | **ncar_ccsm** | 2% | **11%** | ncar_ccsm | 2% | 7% |
| ipsl | 2% | 17% | ipsl | 1% | 11% | ipsl | 1% | 7% |
| mpi | -2% | 17% | mpi | -1% | 13% | mpi | -1% | 8% |
| ncar_pcm | 4% | 18% | ncar_pcm | 3% | 13% | ncar_pcm | 2% | 9% |
| miub | 4% | 31% | miub | 3% | 23% | miub | 2% | 15% |
| gfdl | 0% | 36% | gfdl | 0% | 26% | gfdl | 0% | 17% |
| **cccma_t63** | 14% | **54%** | cccma_t63 | 11% | 41% | cccma_t63 | 7% | 28% |
| cccma_t47 | 17% | 58% | cccma_t47 | 13% | 44% | cccma_t47 | 9% | 30% |

Under Scenario Cwet recharge increases on average by 54 percent; this is greater in the east of the region, while some areas along the coast are projected to have a decrease in recharge (Figure MI-21). Under Scenario Cmid recharge increases on average by 11 percent. Under Scenario Cdry recharge decreases by 8 percent. The sharp vertical lines seen in the Scenario C maps in Figure MI-21 are due to GCM grid cell boundaries. It is worth noting that although recharge is predicted to substantially increase in this region, not all of this would find its way to aquifers, with some potentially being 'rejected' and finding its way to streamflow.

### MI-3.2.4 Confidence levels

Potential diffuse recharge from WAVES is only indicative of the actual recharge and has not been validated with field measurements. A steady state groundwater chloride mass balance was performed as an independent estimate of recharge (Crosbie et al., 2009). The results in the Mitchell region show that the historical estimate of potential diffuse recharge using WAVES (122 mm/year) is within the range of estimates made using the chloride mass balance (zero to 233 mm/year).

 

## MI-3.3 Conceptual groundwater models

Recharge to the Great Artesian Basin (GAB) aquifers occurs via infiltration of rainfall and leakage from streams into outcropping sandstone. Discharge from these aquifers occurs as: discharge from springs; upward vertical leakage towards the regional watertable; as subsurface outflow to neighbouring basins and the Gulf of Carpentaria and via groundwater extraction from bores. Groundwater from the Gilbert River Formation aquifer (within the GAB aquifer sequence) provides baseflow to the Mitchell River in the east (DNRM, 2005). Groundwater movement is from the recharge areas in the east of the region, to the major spring areas and to the Gulf of Carpentaria.

The Wyaaba Beds of the Karumba Basin provide a limited groundwater resource. Recharge to the limestone aquifer is limited, with no occurrence of outcrop inland. The limestone is thought to outcrop offshore and hence is hydraulically connected with the sea and susceptible to seawater intrusion. The primary recharge mechanism is thought to be lateral groundwater inflow from the east (DNRW, 2006). Hydraulic parameters of the limestone aquifer exist for the nearby Pormpuraaw town area (outside the Mitchell region) where transmissivity is between 300 and 700 $m^2$/day and the storage coefficient is between $1{\times}10^{-3}$ and $1{\times}10^{-4}$ (Horn et al., 1995). Bore yields are variable, ranging from less than 5 L/second to more than 20 L/second.

The Bulimba Formation constitutes the main aquifer system in the Karumba Basin, however aquifers are not continuous and not always in hydraulic connection with each other. The formation exceeds 150 m thickness in the central onshore part of the basin and is essentially present across the entire Mitchell region, west of the basement margin. The Bulimba Formation provides medium to large flows (5 to >40 L/second) of excellent quality water. Aquifer parameters for the Bulimba Formation are reasonably well defined given a substantial amount of available data. Where the Bulimba Formation is unconfined, the transmissivity ranges from 10 to 1000 $m^2$/day and storage coefficients range from $2{\times}10^{-2}$ and $1{\times}10^{-1}$. Where it is confined, the transmissivity ranges from 5 to 1100 $m^2$/day (Horn et al., 1995).

Recharge to the Bulimba Formation is via the infiltration of rainfall, whilst discharge occurs as flow to the Gulf and as baseflow to rivers, including the Mitchell.

The Mitchell region has a surface geology dominated by alluvial fan, floodplain and coastal deposits. Although alluvial aquifers are used only to a limited extent as water supply, they are vital in maintaining surface water flows into the dry season (May to October). The Mitchell River has perennial reaches. This means that even after the wet season rainfall has ended, the alluvial aquifers continue to discharge groundwater to the river. This discharge is maintained by upward leakage of groundwater from deeper, confined aquifers, into the alluvial aquifers. A schematic representation of the hydrogeological cycle in this region is shown in Figure MI-23.

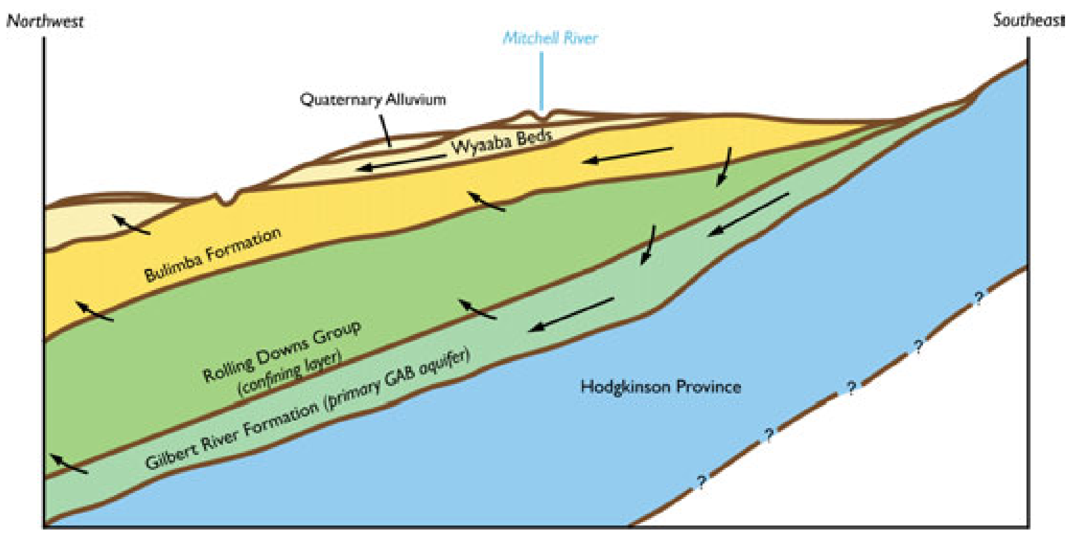


Figure MI-23. Schematic hydrogeological cross-section of the Mitchell region

### MI-3.3.1 Baseflow index analysis

The results of the baseflow index (BFI) analysis for suitable gauges in the Mitchell region are provided in Table MI-1. The annual BFI values range from 0.10 to 0.34 (n=14, median=0.18). Figure MI-2 shows the surface geology of the Mitchell region and the average volume of dry season baseflow to rivers. The volume of dry season baseflow is highly variable in this region, ranging from less than 1 GL to 200 GL. The most significant dry season baseflow volumes (30 to 200 GL) occur from the GAB aquifer and the Hodgkinson fractured rock aquifer.

## MI-3.4 Groundwater modelling results

### MI-3.4.1 Historical groundwater balance

This assessment is categorised as a Tier 4 water balance, based on very limited datasets and no field testing. Accordingly, the results should only be used for conceptualisation of the groundwater systems, and not for water allocation planning.

In order to determine the relative importance of the various hydrogeological processes in the Mitchell region, a groundwater balance is calculated for the two dominant aquifer systems; the artesian Bulimba Formation and the Gilbert River Formation of the GAB. A detailed breakdown of each component of the water balance for each aquifer in both wet and dry seasons is provided in Table MI-8. The total sum of all inputs and outputs is then summarised in Table MI-9. Whilst detailed methods of this water balance are presented in Harrington et al. (2009) it is worth noting that the adopted mean annual recharge rates for both the Bulimba Formation and Gilbert River Formation aquifers are much lower than the mean recharge rate determined for the entire region from WAVES (see section MI-3.2.1). Instead the adopted rates were based on chloride mass balance results (Crosbie et al., 2009) and the estimations of recharge as reported in Kellett et al. (2003), even though the latter study focussed on GAB intake beds further south.

Table MI-8. Groundwater inputs and outputs for the aquifers in the Mitchell region

| | Rainfall recharge | | River recharge / groundwater discharge | | Evapo transpiration | | Vertical leakage | | Throughflow | | Discharge to springs | | Groundwater extraction | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm* | GL* | mm* | GL* | mm* | GL* | mm* | GL* | mm* | GL* | mm* | GL* | mm* | GL* |
| Bulimba Formation aquifer | | | | | | | | | | | | | | |
| Wet season | 40 | 100.0 | 0.0 | 33.3 | -20.0 | -50.0 | -0.0 | -6.5 | -0.0 | -0.1 | -0.0 | -1.0 | 0 | -1.0 |
| Dry season | 0 | 0.0 | -0.0 | -50.0 | -5.0 | -12.5 | -0.0 | -6.5 | -0.0 | -0.1 | -0.0 | -1.0 | -0.1 | -2.9 |
| Gilbert River Formation (GAB) | | | | | | | | | | | | | | |
| Wet season | 15 | 22.5 | 0.0 | 6.7 | -10 | -15.0 | 0.0 | 6.5 | -0.1 | -2.1 | -0.1 | -2.3 | 0 | 0.0 |
| Dry season | 0 | 0.0 | -0.0 | -10.0 | -3 | -4.5 | 0.0 | 6.5 | -0.1 | -2.1 | -0.1 | -2.3 | -0.0 | -0.1 |

* Values are totals for the entire wet or dry season, i.e. mm/6 months, GL/6 months.

Table MI-9. Summary of groundwater inputs and outputs for the aquifers in the Mitchell region

| | Inputs | Outputs | Difference |
|---|---|---|---|
| | GL/y | | percent |
| Bulimba Formation aquifer | | | |
| Wet season | 133.3 | 58.6 | |
| Dry season | 0 | 73.1 | |
| **Total** | **133.3** | **131.7** | **1.2%** |
| Gilbert River Formation aquifer | | | |
| Wet season | 35.7 | 19.4 | |
| Dry season | 6.5 | 19.0 | |
| **Total** | **42.2** | **38.4** | **9.0%** |

 

These tables show that the major processes in the primary aquifers of the Mitchell region are rainfall recharge and evapotranspiration, and river discharge and recharge. In the recharge areas, downward vertical leakage from the Bulimba Formation to the underlying Gilbert River Formation is another important process assuming (based on limited data) that the vertical hydraulic gradient between the two aquifers is downward. Towards the coast this situation would be reversed – that is, upward leakage of water out of the Gilbert River Formation. There is net groundwater discharge to rivers from both the Gilbert River and Bulimba formation aquifers, reflecting the importance of groundwater discharge for maintaining flow in the Mitchell River through the dry season.

### MI-3.4.2 Surface–groundwater interaction

In this section, the impact of groundwater extractions on surface water yields is considered. The 'impact' is to stream depletion whereby pumped groundwater eventually is sourced from a nearby river. The distance between a groundwater pump and a nearby river greatly affects the timing of its impacts on that river. Groundwater development within the Mitchell region is currently limited. Hence, this section will focus on hypothetical analyses that can be used for managing future groundwater developments. Figure MI-24 shows results of stream depletion calculations for hypothetical scenarios in the unconfined alluvial aquifer to provide some insight into the potential future impacts of further development. It is assumed this aquifer is in direct connection with the river.

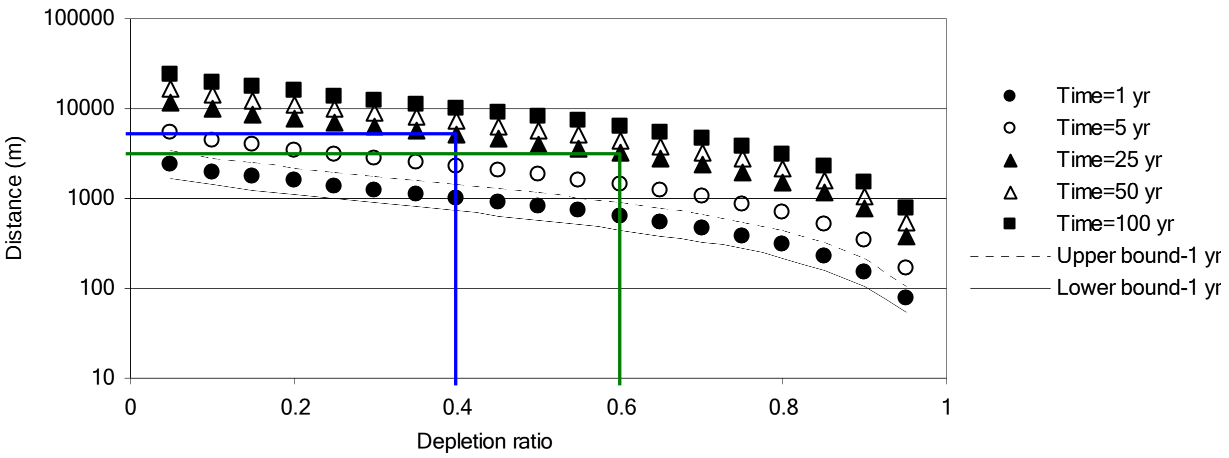


Figure MI-24. Impact of hypothetical scenarios in an unconfined alluvial aquifer on stream depletion. See text for discussion

Figure MI-24 can be used as a management tool in two different ways:

- locating bores to minimise stream depletion. For example, if a proponent wanted to pump groundwater at 10,000 $m^3$/day and was not allowed to deplete the river by more than 4,000 $m^3$/day (i.e. depletion ratio = 0.4) on any occasion during the next 25 years, the pumping bores would need to be located no closer than 5 km from the river (see blue lines in Figure MI-24).
- determining maximum groundwater pumping rates at specified distances from the stream. For example, if someone wanted to pump groundwater from a bore located 3 km from a river and was not permitted to deplete the river by more than 4000 $m^3$/day on any occasion during the next 25 years, the corresponding depletion ratio would be 0.6 (see green lines in Figure MI-24) and the maximum pumping rate would be 4000 / 0.6 = 6666 $m^3$/day.

There is great uncertainty in estimating representative aquifer parameters for this analysis. Upper and lower limits for this uncertainty can be defined and hence upper and lower bounds for impacts can be estimated. The example curves shown in Figure MI-24 represent the likely impacts (after 1 year) for a 100 percent uncertainty in aquifer transmissivity.

Any new groundwater developments in the unconfined alluvial aquifers should be located as far as possible from rivers to minimise the short term (seasonal) impact, which can potentially reduce flow during the dry season. By locating developments away from the river, the impacts would be delayed but the aquifer is depleted (rather than the river). However, the aquifer is likely to be recharged during the wet season.

# MI-3.5 Rainfall-runoff modelling results

In this section the term runoff is the sum of overland flow, interflow and baseflow. It is equivalent to streamflow expressed as a mm depth equivalent. All plots show data averaged over the modelled subcatchments of the Mitchell region. For this reason rainfall reported in this section may vary slightly from that reported elsewhere due to differences between the catchment boundaries (shown in Figure MI-1) and the DEM-derived catchment boundaries used here. In this section, where annual data are reported years are represented by numbers 1 through 77. Consistently throughout this report, annual data are based on the water year (1 September to 31 August) and the dry season is defined as 1 May to 31 October. Unless stated otherwise scenarios Cwet, Cmid and Cdry are selected on the basis of the ranked mean annual runoff. For more details on methods refer to Section 2.2 of the division-level Chapter 2.

## MI-3.5.1 Regional synopsis

The rainfall-runoff modelling is carried out to estimate runoff in 0.05 degree (approximately 25 $km^2$) grid cells in 27 subcatchments which were defined to coincide with the subcatchments for the river system modelling (Figure MI-25). Optimised parameter values from nine calibration catchments are used. Eight of these calibration catchments are in the Mitchell catchment and one is in the South-East Gulf region, south of the Mitchell. The calibration catchments are primarily located in mid to upper reaches of the catchment. The unshaded area represents the coastal zone, which is assigned parameter sets from the calibration gauge in the South-East Gulf (918002A).

## MI-3.5.2 Model calibration

Figure MI-26 compares the modelled and observed monthly runoff and the modelled and observed daily flow exceedance curves for the nine calibration catchments. Nash-Sutcliffe efficiency (NSE) values provide a quantitative measure of how well simulated values match observed values. NSE is described in more detail in Section 2.2.3 of the division-level Chapter 2. On the monthly plots NSE is the monthly Nash-Sutcliffe efficiency value and NSE (dry season) is the dry season monthly Nash-Sutcliffe efficiency value. On the daily flow exceedance plots, NSE is the daily flow exceedance curve Nash-Sutcliffe efficiency value and NSE (50 to 100 percent) is the lower half of the daily flow exeedance curve Nash-Sutcliffe efficiency value.

The results indicate that the ensemble calibration of the rainfall-runoff models Sacramento and IhacresClassic can reasonably reproduce the observed monthly runoff series (NSE values generally greater than 0.9) and the daily flow exceedance curve (NSE values generally greater than 0.9). The volumetric constraint used in the model calibration also ensures that the total modelled runoff is within 5 percent of the total observed runoff.

The calibration method places more importance on the simulation of high runoff, and therefore rainfall-runoff modelling of the medium and high runoff is considerably better than the modelling of low runoff. It should be noted, however, that while the relative difference between the observed and simulated low flow values may be large (which is what gives rise to the low monthly dry season NSE values for example), the absolute difference between the observed and simulated low flow values is generally small because both values are small. Nevertheless, an optimisation to reduce overall error variance can result in some underestimation of high runoff and overestimation of low runoff. This is evident in some of the scatter plots comparing the modelled and observed monthly runoff and many of the daily flow exceedance curves. For the majority of calibration catchments the disagreement between the modelled and observed daily runoff curves is discernable for runoff that is exceeded less than 1 percent of the time. This is accentuated in the plots because of the linear scale on the y-axis and normal probability scale on the x-axis. In any case, the volumetric constraint used in the model calibration ensures that the total modelled runoff is always within 5 percent of the total observed runoff. As indicated by the relatively low NSE values for the lower half of the daily flow exceedance curve and monthly dry season there may be considerable disagreement between observed and modelled low flow values (i.e. cease-to-flow). Overall the monthly NSE values are considered sufficient for the general purposes of estimating long-term mean annual runoff.

 

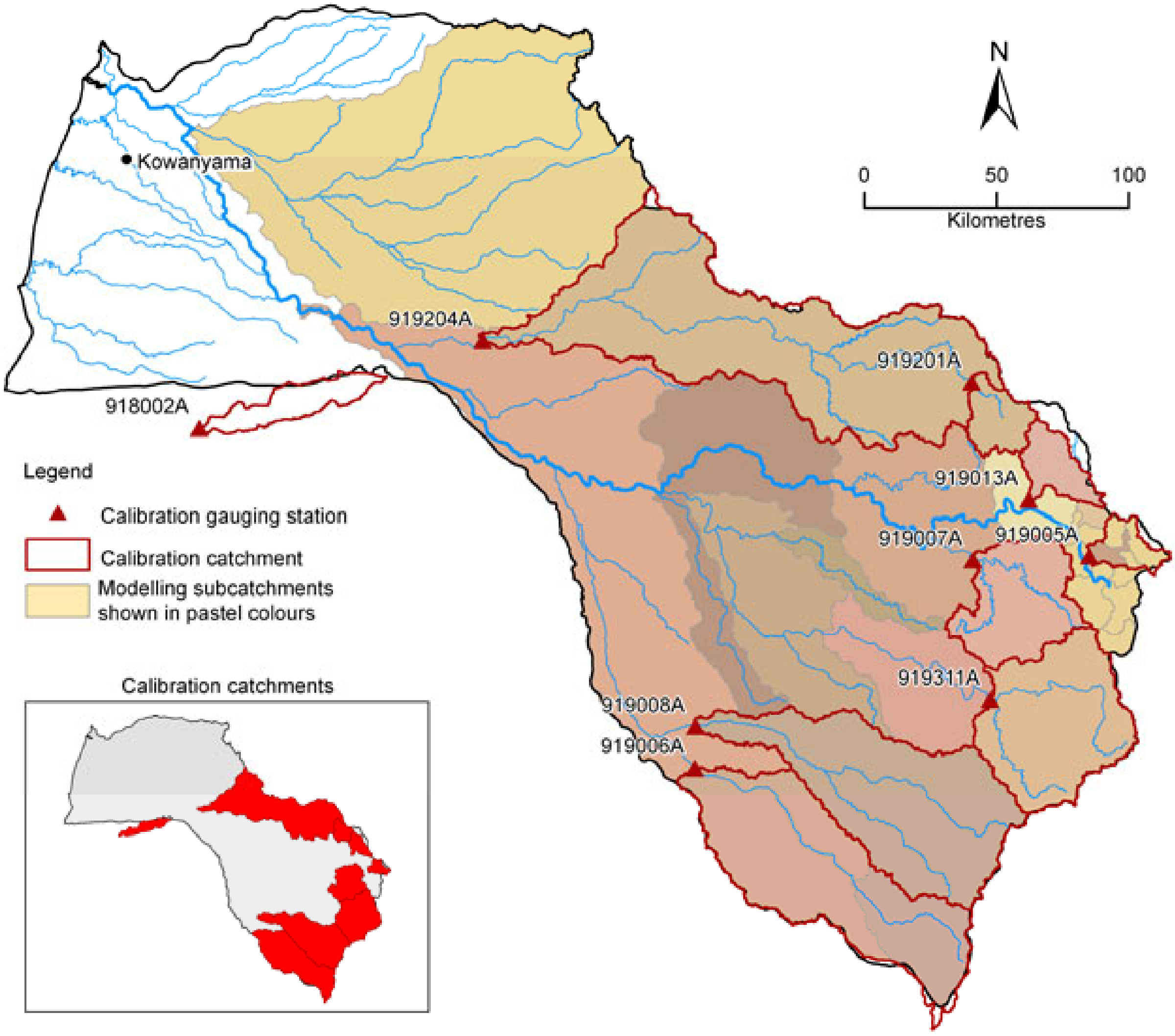


Figure MI-25. Map of the modelling subcatchments, calibration catchments and calibration gauging stations used for the Mitchell region with inset highlighting (in red) the extent of the calibration catchments

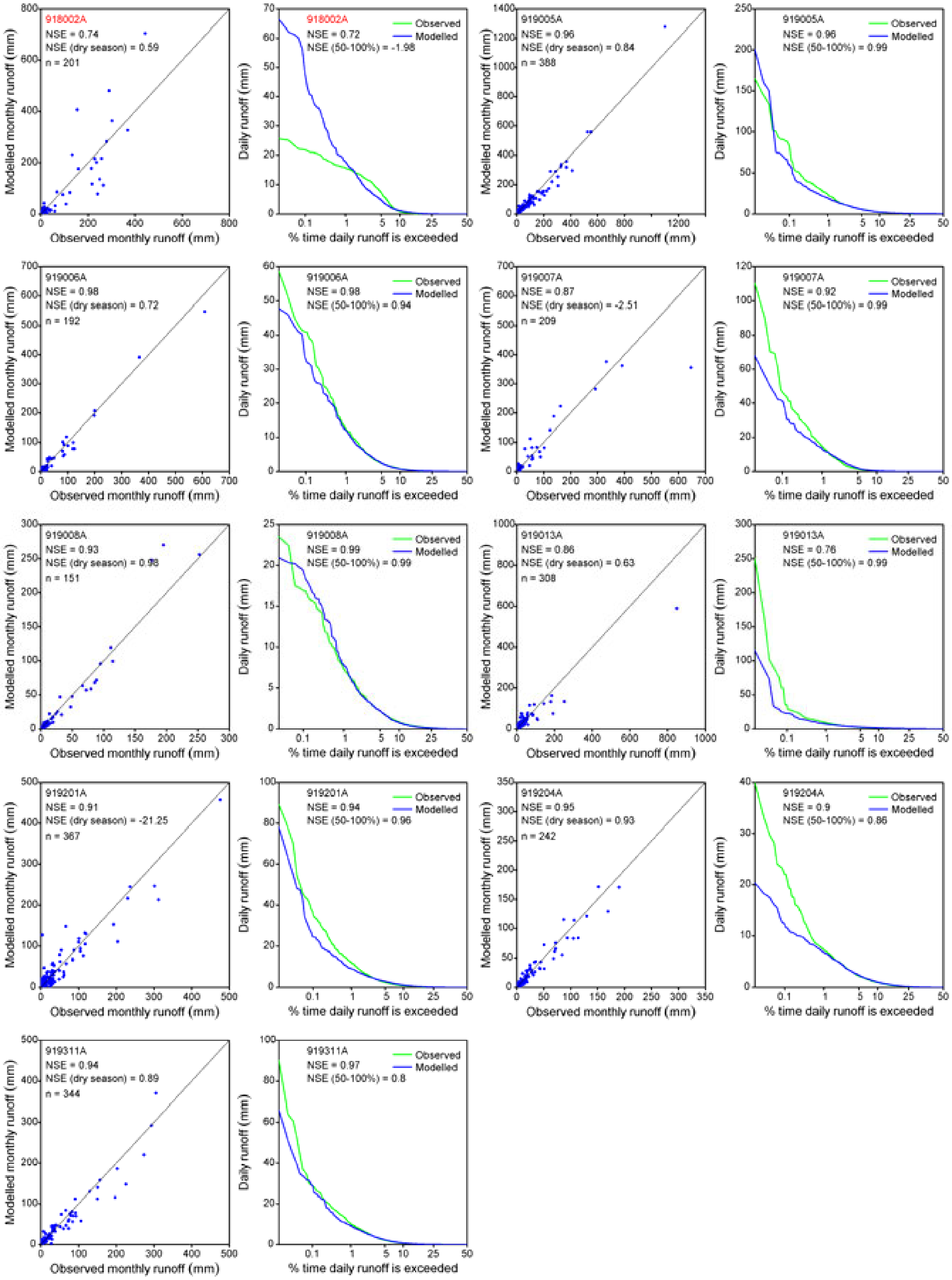


Figure MI-26. Modelled and observed monthly runoff and daily flow exceedance curve for each calibration catchment in the Mitchell region. (Red text denotes catchments located outside the region; blue text denotes catchments used for streamflow modelling only)

### MI-3.5.3 Under historical climate

Figure MI-27 shows the spatial distribution of mean annual rainfall and runoff under Scenario A (averaged over 1930 to 2007) across the Mitchell region. Figure MI-28 shows the mean annual rainfall and runoff averaged over the region.

The mean annual rainfall and runoff averaged over the Mitchell region are 965 mm and 198 mm respectively. The mean wet season and dry season runoff averaged over the Mitchell region are 194 mm and 4 mm respectively.

In this project, all runoff grids are presented as long-term mean annual values. However, the distributions of monthly and annual runoff data in northern Australia can be highly skewed; consequently the median and additional percentile values spatially averaged over the region are also reported. The 10$^{th}$ percentile, median and 90$^{th}$ percentile annual runoff values across the Mitchell region are 326, 178 and 43 mm respectively. The median wet season and dry season runoff averaged over the Mitchell region are 172 mm and 3 mm respectively.

The mean annual rainfall varies from over 1700 mm on the mountainous peaks in the east to less than 800 mm in the south-east. The mean annual runoff varies from over 700 mm to the east to less than 100 mm in the south-east (Figure MI-27) and subcatchment runoff coefficients vary from about 12 percent to nearly 50 percent of rainfall. The majority of rainfall occurs during the wet season months November to April and the majority of runoff occurs during January to March (Figure MI-28). Rainfall and runoff can vary considerably from year to year with long periods over several years or decades that are considerably wetter or drier than others (Figure MI-27 and Figure MI-28). The coefficients of variation of annual rainfall and runoff averaged over the Mitchell region are 0.26 and 0.75 respectively.

The Mitchell is one of 13 regions which cover the three divisions studied in this project. Mean annual rainfall and runoff, as well as coefficients of variation, have been calculated for all of these 13 regions, and it is useful to compare the Mitchell results to results across all 13 regions. Across all 13 regions in this project 10$^{th}$ percentile, median and 90$^{th}$ percentile values are 1371, 936 and 595 mm respectively for mean annual rainfall and 374, 153 and 78 mm respectively for mean annual runoff. The mean annual rainfall (965 mm) and runoff (198 mm) averaged over the Mitchell region are slightly higher than the median values of the 13 regions. Across all 13 regions in this project the 10$^{th}$ percentile, median and 90$^{th}$ percentile values are 0.34, 0.26 and 0.19 respectively for the coefficient of variation of annual rainfall and 1.39, 0.69 and 0.48 for the coefficient of variation of runoff. The coefficients of variation of annual rainfall (0.26) and runoff (0.75) averaged over the Mitchell region are in the middle of the range of the 13 reporting regions.

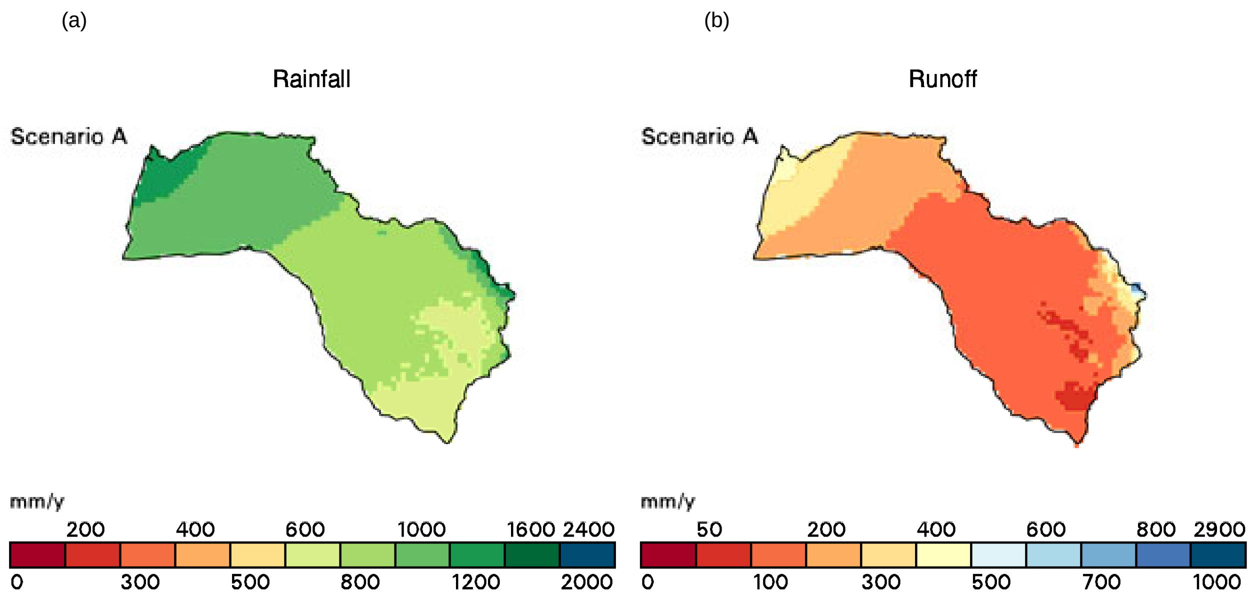


Figure MI-27. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the Mitchell region under Scenario A

Figure MI-28 illustrates the importance of the timing and intensity of rainfall for runoff generation in the Mitchell region. For example, the third highest annual runoff value corresponds to the 14th highest annual rainfall value.

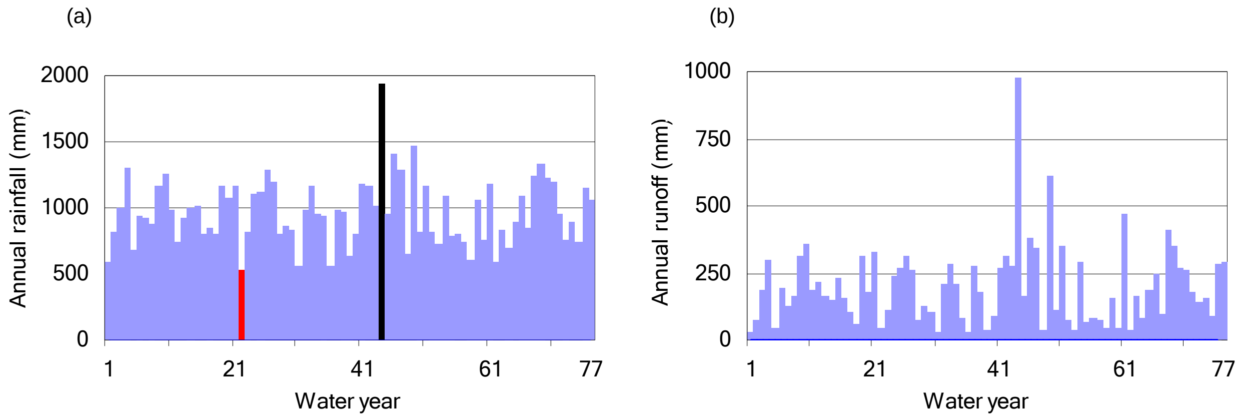


Figure MI-28. Annual (a) rainfall and (b) modelled runoff in the Mitchell region under Scenario A

Figure MI-29(a, b) shows the minimum and maximum monthly rainfall and runoff and the range of values between the 25th and 75th percentile monthly rainfall and runoff. Figure MI-29(c, d) shows the mean and median monthly flows and the range of values between the 25th and 75th percentile monthly rainfall and runoff.

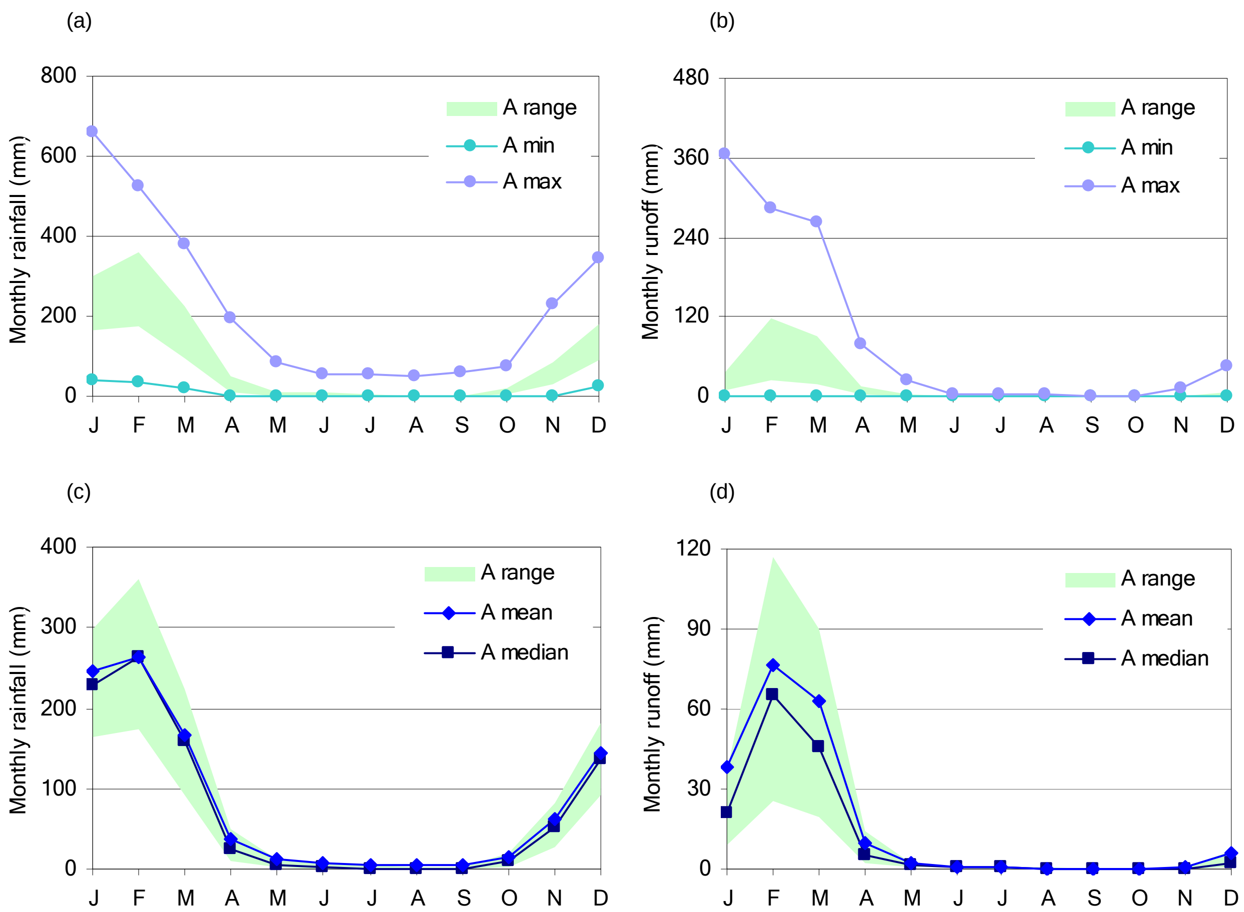


Figure MI-29. Minimum, maximum and A range monthly (a) rainfall and (b) modelled runoff; and mean, median and A range monthly (c) rainfall and (d) modelled runoff in the Mitchell region under Scenario A (A range is the 25th to 75th percentile monthly rainfall or runoff)

 

### MI-3.5.4 Under recent climate

The mean annual rainfall and runoff under Scenario B (1996 to 2007) are 8 percent and 16 percent higher respectively than the historical (1930 to 2007) mean values. The spatial distribution of rainfall and runoff across the Mitchell region under Scenario B is shown in Figure MI-30.

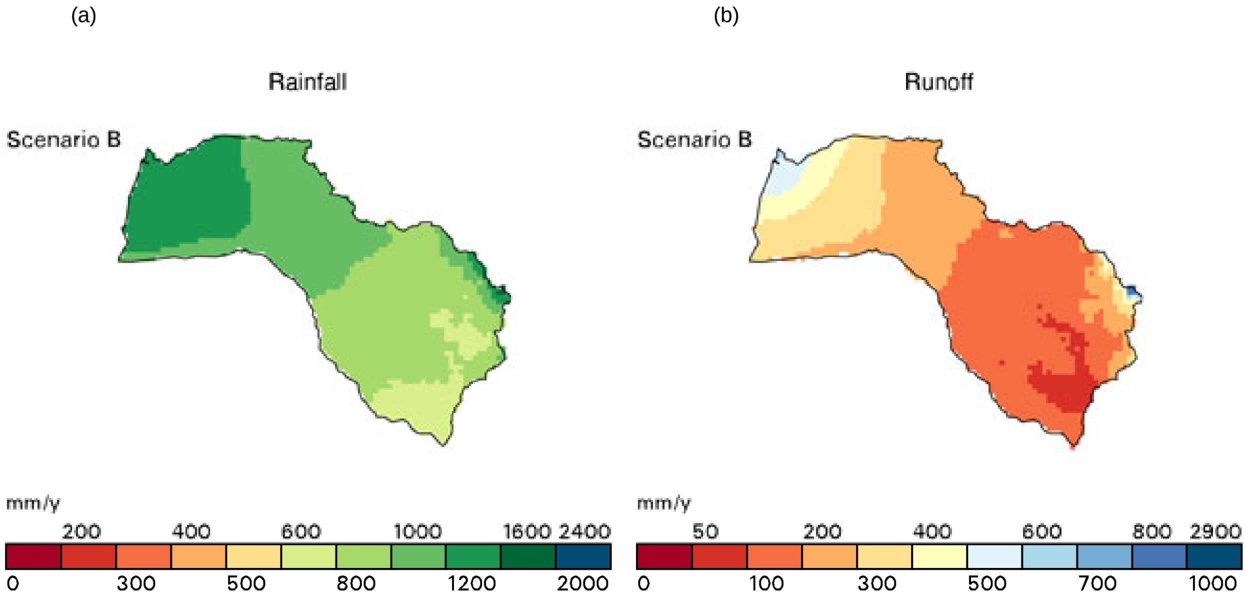


Figure MI-30. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the Mitchell region under Scenario B

### MI-3.5.5 Under future climate

Figure MI-31 shows the percentage change in the mean annual runoff averaged over the Mitchell region under Scenario C relative to Scenario A for the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The percentage change in the mean annual runoff and rainfall from the corresponding GCMs are also tabulated in Table MI-10.

The figure and table indicate that the potential impact of climate change on runoff can be very significant. Although there is considerable uncertainty in the estimates, the results indicate that runoff in ~2030 in the Mitchell region is more likely to decrease than increase. Rainfall-runoff modelling with climate change projections from two-thirds of the GCMs shows a reduction in mean annual runoff, while rainfall-runoff modelling with climate change projections from one-third of the GCMs shows an increase in mean annual runoff. The wide range of mean annual runoff values shown in Figure MI-31 and Table MI-10 is primarily due to the wide range of future projections of rainfall by the 15 GCMs.

Because of the large variation between GCM simulations and the method used to obtain the climate change scenarios, the biggest increase and biggest decrease in runoff come from the high global warming scenario. For the high global warming scenario, rainfall-runoff modelling with climate change projections from two of the GCMs indicates a decrease in mean annual runoff greater than 10 percent while rainfall-runoff modelling with climate change projections from four of the GCMs indicates an increase in mean annual runoff greater than 10 percent.

In subsequent reporting here and in other sections, only results from an extreme 'wet', 'mid' and extreme 'dry' variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet, results from the second highest increase in mean annual runoff from the high global warming scenario are used. Under Scenario Cdry, results from the second highest reduction in mean annual runoff from the high global warming scenario are used. Under Scenario Cmid, the median mean annual runoff results from the medium global warming scenario are used. These are shown in bold in Table MI-10.

Under scenarios Cwet, Cmid and Cdry, mean annual runoff changes by 42, -1 and -24 percent relative to Scenario A. By comparison, the range based on the low global warming scenario is a 22 to -14 percent change in mean annual runoff. Figure MI-32 shows the mean annual runoff across the Mitchell region under scenarios A and C. The linear discontinuities that are evident in Figure MI-32 are due to GCM grid cell boundaries.

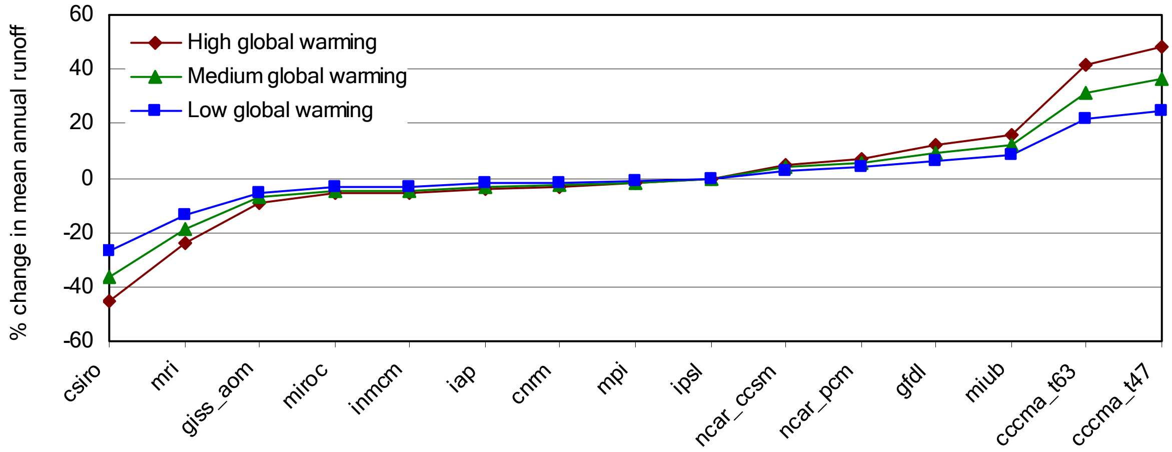


Figure MI-31. Percentage change in mean annual modelled runoff under the 45 Scenario C simulations (15 global climate models and three global warming scenarios) relative to Scenario A

Table MI-10. Summary results under the 45 Scenario C simulations for the modelling subcatchments (numbers show percentage change in mean annual rainfall and modelled runoff under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Runoff | GCM | Rainfall | Runoff | GCM | Rainfall | Runoff |
| csiro | -21% | -45% | csiro | -16% | -37% | csiro | -11% | -27% |
| **mri** | **-8%** | **-24%** | mri | -6% | -19% | mri | -5% | -14% |
| giss_aom | -2% | -9% | giss_aom | -1% | -7% | giss_aom | -1% | -5% |
| miroc | 0% | -6% | miroc | 0% | -5% | miroc | 0% | -4% |
| inmcm | 1% | -6% | inmcm | 1% | -5% | inmcm | 1% | -3% |
| iap | -2% | -4% | iap | -1% | -3% | iap | -1% | -2% |
| cnrm | 0% | -4% | cnrm | 0% | -3% | cnrm | 0% | -2% |
| mpi | -2% | -2% | **mpi** | **-1%** | **-1%** | mpi | -1% | -1% |
| ipsl | 1% | -1% | ipsl | 1% | -1% | ipsl | 1% | 0% |
| ncar_ccsm | 3% | 5% | ncar_ccsm | 2% | 4% | ncar_ccsm | 2% | 3% |
| ncar_pcm | 4% | 7% | ncar_pcm | 3% | 5% | ncar_pcm | 2% | 4% |
| gfdl | 0% | 12% | gfdl | 0% | 9% | gfdl | 0% | 6% |
| miub | 4% | 16% | miub | 3% | 12% | miub | 2% | 8% |
| **cccma_t63** | **14%** | **42%** | cccma_t63 | 11% | 31% | cccma_t63 | 7% | 22% |
| cccma_t47 | 17% | 48% | cccma_t47 | 13% | 36% | cccma_t47 | 9% | 25% |

 

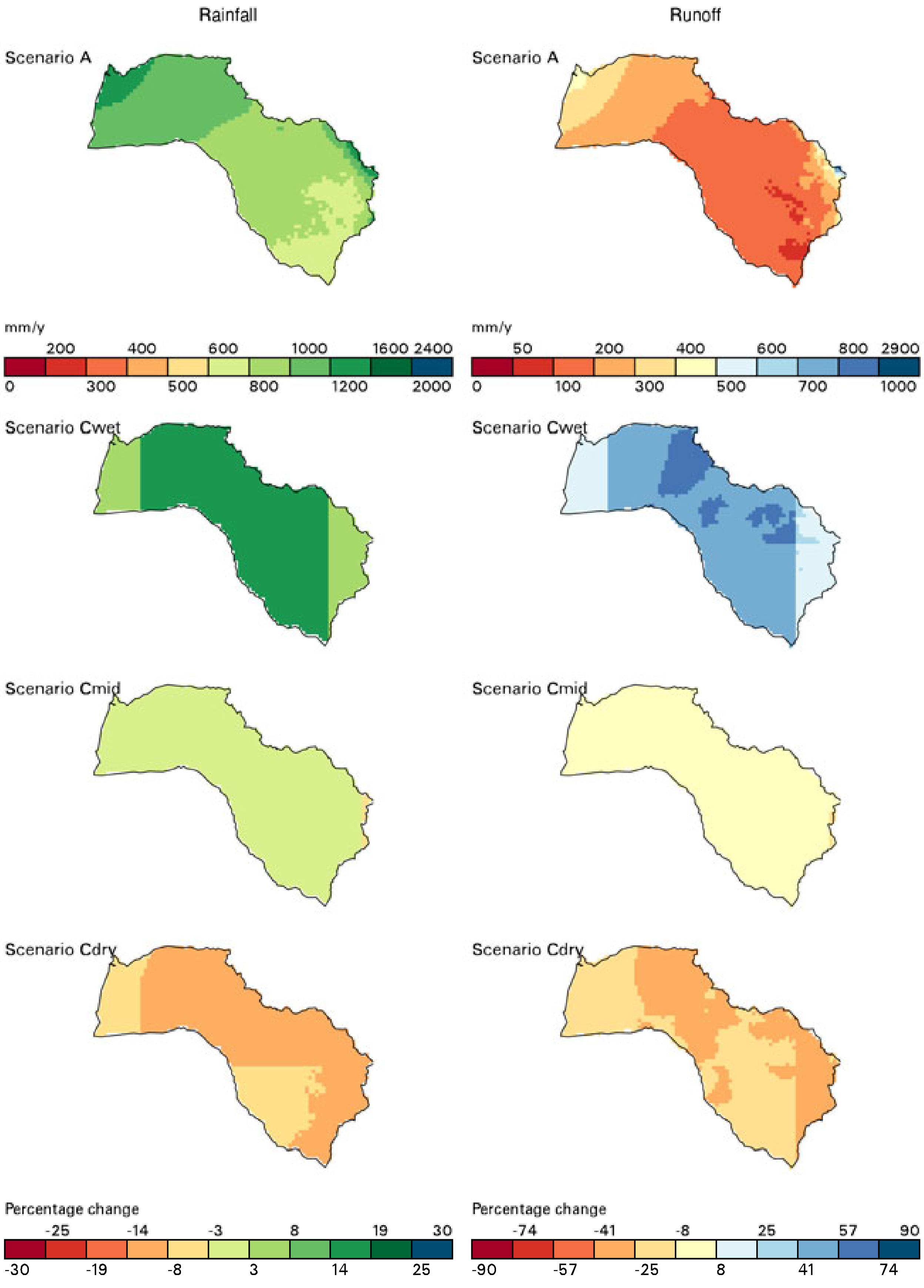


Figure MI-32. Spatial distribution of mean annual rainfall and modelled runoff across the Mitchell region under Scenario A and under Scenario C relative to Scenario A

### MI-3.5.6 Summary results for all scenarios

Table MI-11 shows the mean annual rainfall, runoff and actual evapotranspiration under Scenario A averaged over the Mitchell region, and the percentage changes in the rainfall, runoff and actual evapotranspiration under scenarios B and C relative to Scenario A. The Cwet, Cmid and Cdry results are based on the mean annual runoff, and the rainfall changes shown in Table MI-10 are the changes in the mean annual value of the rainfall series used to obtain the runoff under scenarios Cwet, Cmid and Cdry. The changes in mean annual rainfall do not necessarily translate directly to the changes in mean annual runoff because of changes in seasonal and daily rainfall distributions and the relationship between rainfall and runoff is non-linear. The latter factor usually results in small changes in rainfall to be amplified in runoff (Table MI-10).

Figure MI-33 shows the mean monthly rainfall and runoff under scenarios A and C averaged over 1930 to 2007 for the region. Figure MI-34 shows the daily rainfall and flow exceedance curves under scenarios A and C averaged over the region. In Figure MI-33 Cwet, Cmid and Cdry are selected on a month-by-month basis, while in Figure MI-34 Cwet, Cmid and Cdry are selected for every day of the daily flow exceedance curve.

Table MI-11. Water balance over the entire Mitchell region under Scenario A and under scenarios B and C relative to Scenario A

| Scenario | Rainfall | Runoff | Evapotranspiration |
|---|---|---|---|
| | mm | | |
| A | 965 | 198 | 767 |
| | percent change from Scenario A | | |
| B | 8% | 16% | 5% |
| Cwet | 14% | 42% | 7% |
| Cmid | -1% | -1% | -1% |
| Cdry | -8% | -24% | -4% |

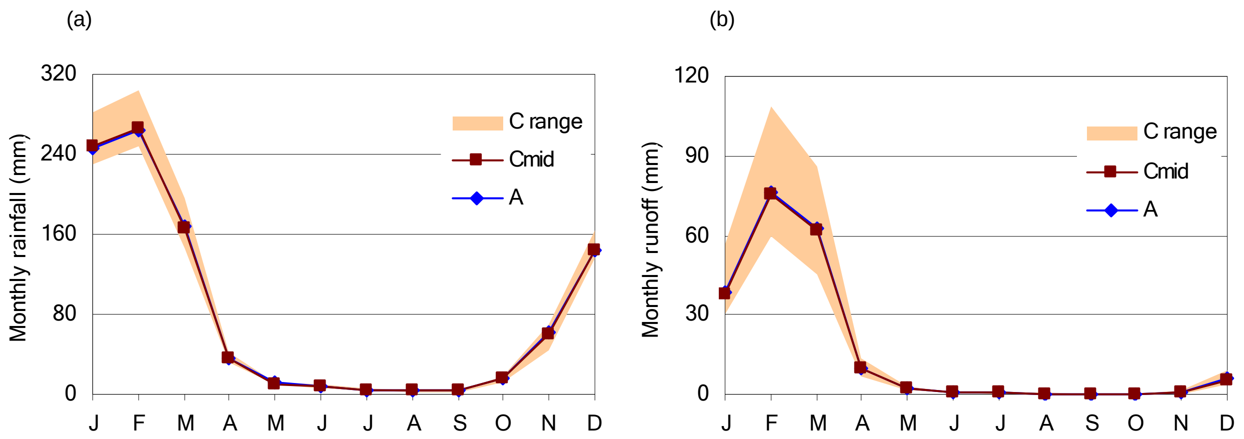


Figure MI-33. Mean monthly (a) rainfall and (b) modelled runoff in the Mitchell region under scenarios A and C. (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

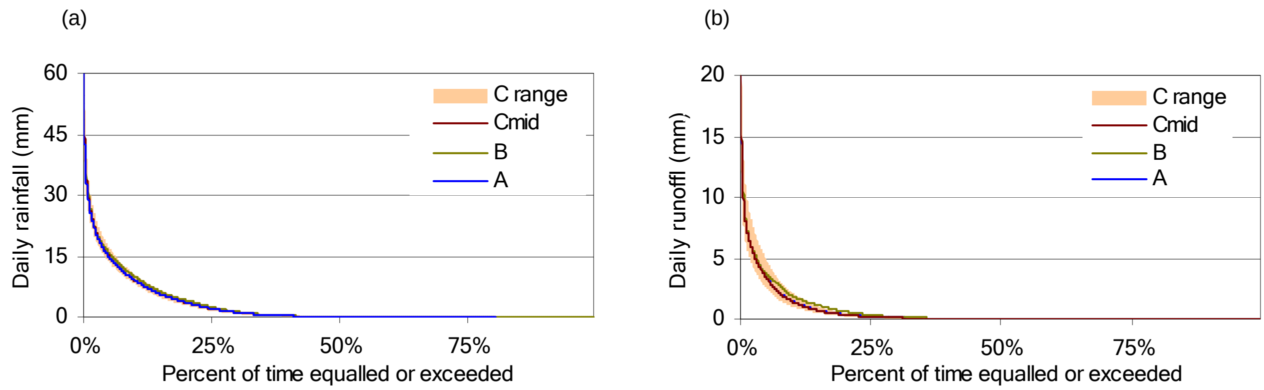


Figure MI-34. Daily flow exceedance curves for (a) rainfall and (b) modelled runoff in the Mitchell region under scenarios A, B and C



### MI-3.5.7 Confidence levels

The runoff estimates for the Mitchell region are variable. In the mid to upper reaches where there is a high density of good gauging stations runoff predictions are reasonable for mid to high runoff events and dry season runoff. However, in the lower ungauged reaches runoff predictions are poor. It is estimated that greater than half of the runoff in the Mitchell is generated below the lowest gauge (919204A). Diagrams in Petheram et al. (2009a) illustrate which calibrated rainfall-runoff model parameter sets are used to model streamflow in ungauged subcatchments in the Mitchell region.

The rainfall-runoff model verification analysis with data from 123 catchments from across all of northern Australia indicates that the mean annual runoff for ungauged catchments are under estimated or over estimated, when using optimised parameter values from a nearby catchment, by less than 20 percent in 41 percent of catchments and by less than 50 percent in 81 percent of the catchments. In the Mitchell region transposing parameter sets from calibration catchments to ungauged subcatchments appears to result in reasonable runoff predictions.

Figure MI-35 illustrates the level of confidence in the modelling of the mid to high runoff events (i.e. peak flow) and dry season runoff (respectively) for the subcatchments of the Mitchell region. It should be noted that these maps of level of confidence are not statistical confidence levels and are intended to only convey a broad reliability of prediction. Note the level of confidence in streamflow predictions will vary slightly from the level of confidence in runoff predictions shown below and as discussed in Section 2.2.6 of the division-level chapter.

There is a high degree of confidence that dry season runoff in the Mitchell region is very low (i.e. less than several millimetres of runoff), because it is known that rainfall and groundwater baseflow is low during the dry season. The map of level of confidence for dry season flow shown in Figure MI-35 provides a relative indication of how well dry season metrics, such as cease-to-flow, are simulated.

Across the entire Mitchell region there is a relatively low level of confidence in the long-term average monthly and annual summary statistics reported in this section due to the large ungauged area in the lower half of the catchment and that this area is modelled using one set of parameters (918002A). Hence the accuracy of the results in this section is largely dependent upon how well this parameter set can simulate runoff in the lower reaches of the catchment. As shown in Figure MI-35, in many areas of the Mitchell region localised studies will require more detailed analysis than undertaken and reported here and would most likely require the site to be visited and additional field measurements made.

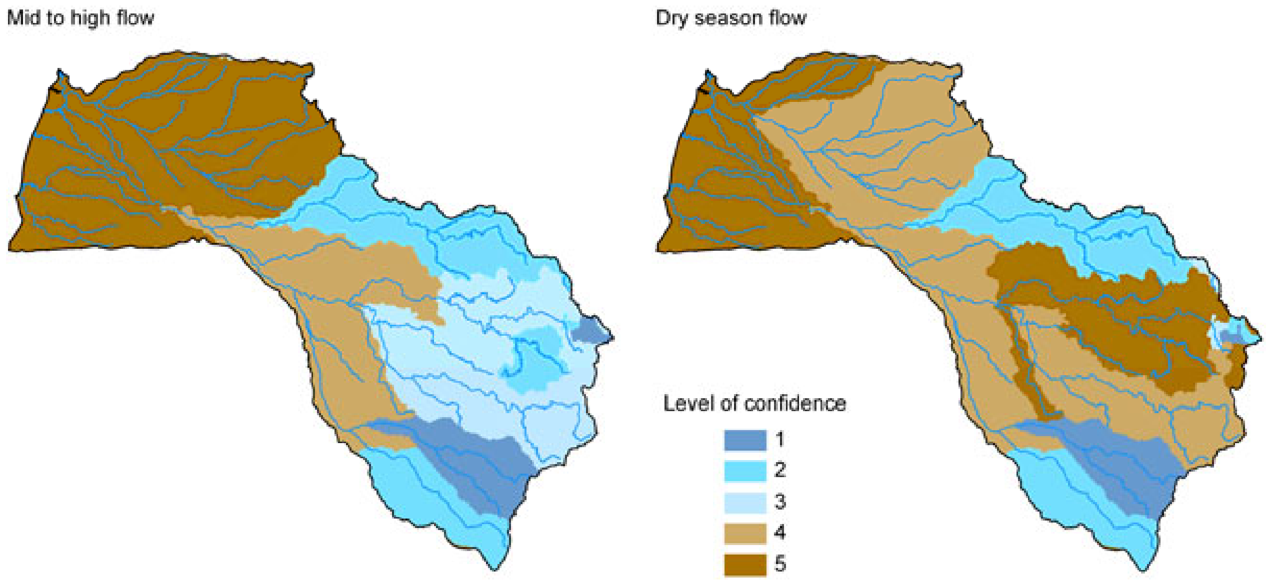


Figure MI-35. Level of confidence in the modelling of runoff for (a) mid- to high flow events and (b) monthly dry season flow events for the modelling subcatchments of the Mitchell region. 1 is the highest level of confidence and 5 is the lowest

## MI-3.6 River system water balance

General information about river modelling methods is presented at the division-level in Chapter 2. In that chapter, scenarios are defined in Section 2.1 and river modelling methods which apply to all regions are described in Section 2.2. The following section summarises this generic river modelling approach as applied to the Mitchell region. The river modelling results for the Mitchell river model is reported using a range of metrics, which were consistently applied across all regions. The use of a common set of metrics across the entire project area enables comparisons between regions.

In this section where annual data are reported, years are represented by numbers 1 through 77. Consistently throughout the report, annual data are based on the water year (1 September to 31 August) and the dry season is defined as 1 May to 31 October. Scenarios Cwet, Cmid and Cdry are selected on the basis of the ranked mean annual rainfall for the modelled subcatchments in Section MI-3.5.1

River system models can be used to assess the implications of the changes in inflows on the reliability of water supply to users. They may also be used to support water management planning by assessing the trade-offs between supplies to various competing categories of users. These models describe infrastructure, water demands, and water management and sharing rules. Given the time constraints of the project, and the need to link the assessments to state water planning processes, it is necessary to use the river system models currently used by state agencies.

The Mitchell region is described by the Mitchell river system model using the IQQM program (version 6.42.2). The Mitchell model was setup by the Department of Environment and Resource Management (DERM) to support the Queensland Water Resource Planning Process. Results from this model for the period from January 1913 to December 1995 were used to establish the water sharing rules in the *Gulf (draft) Resource Operations Plan* (DNRW, 2008). The level of development represented by the model is based on the full use of existing entitlements.

As part of the Northern Australia Sustainable Yields Project input data for the model were extended so that they covered the period 1 January 1890 to 30 June 2008. Results for the Northern Australia Sustainable Yields Project are presented over 77-year time sequences for the common modelling period 1 September 2007 to 31 August 2084. The results presented in DNRW reports (e.g. Water Assessment Group, 2004; DNRW, 2008) may differ from numbers published in this report due to the different modelling period and different initial conditions.

In the Northern Australia Sustainable Yields Project the river system modelling for the Mitchell region consists of ten scenarios:

 

- Scenario A – historical climate and full use of existing entitlements
  This scenario assumes a full use of existing entitlements. Full use of existing entitlements refers to the total entitlements within a plan area including existing water authorisations and unallocated reserves. This refers to the water accounted for in the resource operations plan, but the licences are interim or not allocated as yet. The period of analysis commences on 1 September 2007 and streamflow metrics are produced by modelling the 77-year historical climate sequence between 1 September 2007 and 31 August 2084. This scenario is used as a baseline for comparison with all other scenarios.
- Scenario AN – historical climate and without-development
  Current levels of development such as public storages and demand nodes are removed from the model to represent without-development conditions. Inflows were not modified for groundwater extraction, major land use change or farm dam development because the impact of these factors on catchment yield are currently considered to be negligible. This scenario uses the historical flow and climate inputs used for Scenario A.
- Scenario BN – recent climate and without-development
  Current levels of development such as public storages and demand nodes are removed from the model to represent without-development conditions. Inflows were not modified for groundwater extraction, major land use change or farm dam development because the impact of these factors on catchment yield are currently considered to be negligible. This scenario uses seven consecutive 11-year climate sequences between 1 September 1996 and 31 August 2007 to generate a 77-year climate sequence representative of the 'recent climate' (see Section 2.1.2 of the division-level Chapter 2 for more detail).
- Scenario CN – future climate and without-development
  Current levels of development such as public storages and demand nodes are removed from the model to represent without-development conditions. Inflows were not modified for groundwater extraction, major land use change or farm dam development because the impact of these factors on catchment yield are currently considered to be negligible. Scenarios CNwet, CNmid and CNdry represent a range of future climate conditions that are derived by adjusting the historical climate and flow inputs used in Scenario A.
- Scenario B – recent climate and full use of existing developments
  This scenario incorporates the effects of current land use and uses seven consecutive climate sequences between 1 September 1996 and 31 August 2007 to generate a 77-year climate sequence representative of the 'recent climate' (see Section 2.1.2 of the division-level Chapter 2 for more detail).
- Scenario C – future climate and full use of existing entitlements
  Scenarios Cwet, Cmid and Cdry represent a range of future climate conditions that are derived by adjusting the historical climate and flow inputs used in Scenario A. The level of development for Scenario C assumes the full use of existing entitlements, i.e. the same as for Scenario A.

The changes in inflows between scenarios reported in this chapter differ from the changes in runoff reported in Chapter MI-3.5. These differences are due to difference in the methods by which the GCMs were ranked and difference in areas that are considered to contribute runoff to the surface water model. The scenarios presented in this project may not eventuate but they encompass consequences that might arise if no management changes are made. Consequently results from this assessment are designed to highlight pressure points in the system, both now and in the future. This assessment does not elaborate on what management actions might be taken to address any of these pressure points. Where management changes to mitigate the effects of climate change have recently been implemented, the impacts of the changes predicted in this section may be an overestimate.

## MI-3.6.1 River model configuration

### Mitchell model description

The Mitchell region is described by the Mitchell systems model (Water Assessment Group, 2004). The system is represented in the model by 27 river sections and 124 nodes. Figure MI-36 is a schematic of the Mitchell IQQM simulation model, showing the approximate location of main stream gauges and key demand and storage nodes.

The model does not extend over the whole Mitchell River basin, but excludes the upper catchment areas of the Mitchell and Walsh rivers which are included in the *Barron Water Resources Plan* area, and these catchments are modelled in the Barron River IQQM. The upstream limits of the model are the Walsh River at Flatrock streamflow recorder and the Mitchell River at AMTD 601.2 km. The simulated outflows from the Barron River IQQM at these locations become the inflows to the Mitchell River IQQM. Inflows include inter-valley transfer from the Barron River for irrigation diversions in the upper reaches of the Walsh and Mitchell rivers. The net average annual diversion from the Barron system is 6.2 GL/year (diversions less transfers).

The downstream limit of the model is the mouth of the Mitchell River. The stream gauging station at Koolatah (919009) is the most downstream location at which flow records are available. This station monitors flow from approximately two-thirds of the river basin. The Mitchell River is the principal stream and major tributaries of the Mitchell River are the Palmer, Walsh, Lynd and Tate rivers. The river basin boundary and the subdivision of the river basin into subcatchments for modelling purposes are shown in Figure MI-25.

Grazing is the predominant land use over the basin. Some irrigated agriculture is practised in the upper reaches of the Walsh and Mitchell rivers, where irrigation supplies are obtained from the Mareeba-Dimbulah Water Supply Scheme. Within the area modelled the main consumptive water uses are small-scale irrigation and small mines. Communities and towns, including Chillagoe and Mount Molloy, add to the overall consumption of water in the area.

There are no state-owned storages or water supply schemes in the modelled area. One major storage, Southedge Dam, and five smaller instream storages, are represented by the model. Details for Southedge Dam and the five smaller instream storages are provided in Table MI-12. There are no passing flow requirements for storages. The degree of regulation metric presented in Table MI-12 is the sum of the net evaporation and controlled releases from the dam divided by the total inflows. Controlled releases exclude spillage. Storages with radial gates and without spillways are not reported in this table (there is only one known storage of this type in the project area, which is the Kununurra Diversion Dam in the Ord-Bonaparte region). The degree of regulation of Southedge Dam for the full use of existing entitlements (0.53) would be relatively high.

Table MI-12. Storages in the river system model

| Major reservoirs | Active storage | Average annual Inflow | Average annual release | Average annual net evaporation | Degree of regulation |
|---|---|---|---|---|---|
| | GL | GL/y | | | |
| Southedge Dam | 122.6 | 88.7 | 20.0 | 26.9 | 0.53 |
| Other storages * | 11.7 | 2077.0 | | 1.8 | 0.00 |
| **Region total** | **134.26** | **2165.65** | **20.00** | **28.72** | **0.02** |

The level of development represented by the model is based on the full use of existing entitlements. A consequence of this is that the model does not simulate current levels of development. Water use is modelled by 27 nodes that are categorised into different users in Table MI-13. Diversions are modelled from:

- one node that is for a regulated supply from a private storage
- 21 nodes for unregulated supplies from run-of-river flows
- five nodes for high flow diversion (water harvesting).

 

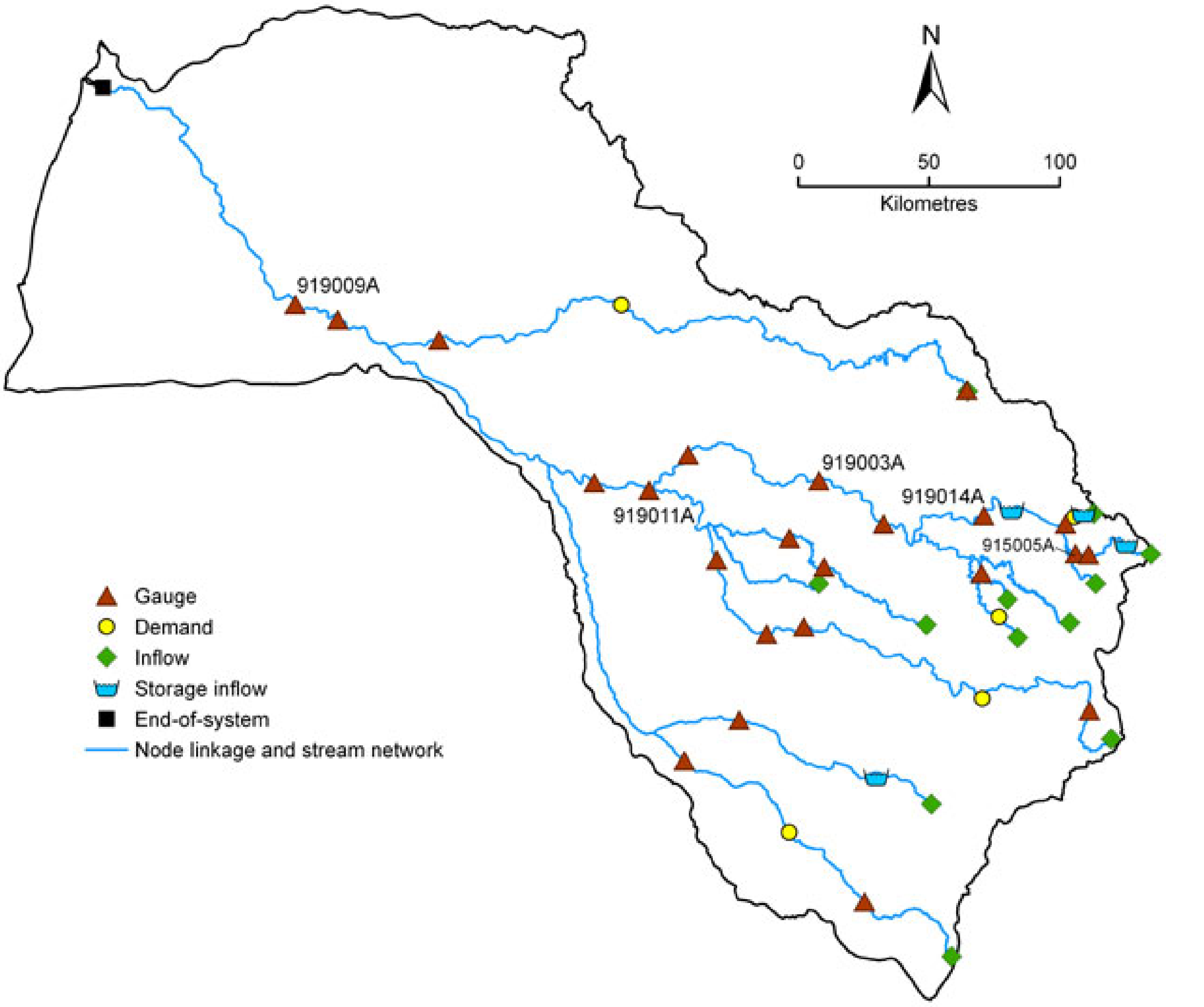


Figure MI-36. Schematic of the approximate location of gauging stations, main demand nodes and storages for the Mitchell river system model

In Table MI-13 and the sections that follow, 'volumetric limit' is defined as the maximum volume of water that can be extracted from a river system within this region under the resources operation plan. Unsupplemented water is defined as surface water that is not sourced from a water storage that is able to regulate or control supply to users.

Table MI-13. Modelled water use configuration

| Water users | Number of nodes | Volumetric limit | Planted area | Model notes |
|---|---|---|---|---|
| | | GL/y | ha | |
| Unsupplemented Agriculture | 12 | 31.056 | 3,084 | |
| Unsupplemented (Town Water Supply) | 2 | 0.192 | | Fixed demand |
| Unsupplemented (Mining) | 4 | 10.368 | | Fixed demand |
| High Security (Other Uses) | 1 | 20 | | Fixed demand |
| Unsupplemented (Other Uses) | 8 | 15.374 | | Fixed demand |
| **Sub-total** | **27** | **76.99** | **3084** | |

### Model setup

The original Mitchell river model and associated IQQM V6.42.2 executable code were obtained from DERM. The time series rainfall, evaporation and flow inputs to this model for the historical climate time series were set to cover the reporting period 1 September 1930 to 31 August 2007. The model was run for the reporting period and the results were validated against results from the original model over the same period.

For the scenarios that assume the full use of existing entitlements, the initial state of storages can influence the results obtained so the same initial storage levels need to be used for all scenarios. In this project all scenarios are reported for the 77-year period commencing on 1 September 2007. However, the demand simulated by an IQQM model for month *n* is dependent upon the simulation results for month *n-1*. For this reason the initial conditions (i.e. storage levels) are set to the levels simulated on the 1 August 2007 for all scenarios. The models are then run for 77 years and one month.

A without-development version of the Mitchell model was created by removing all instream storages, all irrigators and fixed demands. Flow and climate input files to the Barron IQQM model were not modified for climate change scenarios. Hence, inflows to the Mitchell IQQM from the Barron IQQM were only sourced for Scenario A. However, inflows to the Mitchell IQQM from the Barron IQQM were modified for scenarios B and C during the process of applying the Mitchell subcatchment constant monthly scaling factors to all inflows.

Table MI-14. Mitchell system river model setup information

| Model setup information | | Version | Start date | End date |
|---|---|---|---|---|
| Mitchell | IQQM | 6.42.2 | 01/01/1890 | 20/08/2008 |
| Connection | | | | |
| Barron IQQM | Inflows from model to Walsh River at Flatrock gauge | | | |
| | Inflows from model to Mitchell River at AMTD 601.2 | | | |
| Baseline models | | | | |
| Warm up period | | | 1/08/2007 | 31/08/2007 |
| Mitchell | IQQM | 6.42.2 | 1/09/2007 | 31/08/2084 |
| Connection | | | | |
| | | | | |
| Modifications | | | | |
| Data | Data extended by DNRW | | | |
| Inflows | No adjustment | | | |
| Initial storage volume Southedge | 109.3GL | | | |
| Initial storage volume for other storages | set to level at 01/08/2007 | | | |

## MI-3.6.2 River system water balance

The mass balance table (Table MI-15) shows volumetric components for Scenario A as GL/year, with all other scenarios presented as a percentage change from Scenario A. Mass balance includes the change in storage that is averaged over the 77-year period and is shown as GL/year.

The directly gauged inflows represent the inflows into the model that are based on data from a river gauge. The indirectly gauged inflows include flows from the Barron IQQM and other inflows that are derived to achieve a mass balance between mainstream gauges. Diversions are listed based on the different water products in the region. End-of-system flows are shown for the Mitchell River at modelled end-of-system which includes inflows from other creeks below the gauge at Koolatah.

The mass balance tables for the 17 subcatchments in the model are reported in Petheram et al. (2009b). The mass balance of each of these river reaches and the overall mass balance were checked by taking the difference between inflows, diversions, outflows of the system and change in storage volume. In all cases the mass balance error was zero. Unattributed fluxes in Table MI-15 are the modelled river losses. River losses are estimated from loss relationships that are determined during calibration of the IQQM model such that flow is conserved between upstream and downstream gauging stations.

 

Results in Table MI-15 show that under scenarios Cwet and Cdry inflows in the Mitchell valley increase by 49 percent and decrease by 26 percent respectively. End-of-system flows increase by 51 percent and decrease by 26 percent under scenarios Cwet and Cdry respectively. However, there is minimal impact to total diversions (<2 percent) as demands in the valley are much smaller than the total inflows. Results for consumptive use are discussed further in Section MI-3.6.5.

Under Scenario B (Table MI-15), inflows increase by 3 percent (relative to Scenario A) for gauged subcatchments while inflows increase by 18 percent (relative to Scenario A) for ungauged subcatchments. This large difference is due to the larger increase in rainfall under Scenario B on the (largely ungauged) lower reaches of the Mitchell catchment compared to the upper reaches, where the majority of the gauging stations are located.

Table MI-15. Mitchell system river model average annual water balance under scenarios A, B and C

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | | | | |
| Storage volume | | | | | |
| Change over period | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | | | | | |
| | GL/y | percent change from Scenario A | | | |
| Inflows | | | | | |
| Subcatchments | | | | | |
| Gauged | 2878.7 | 3% | 44% | -5% | -26% |
| Ungauged | 10675.8 | 18% | 51% | -6% | -26% |
| | | | | | |
| **Sub-total** | **13554.6** | **15%** | **49%** | **-6%** | **-26%** |
| Diversions | | | | | |
| Agriculture | | | | | |
| Unsupplemented | 29.8 | 0% | 1% | -3% | -1% |
| Mining | | | | | |
| Unsupplemented | 10.1 | 0% | 1% | -2% | 0% |
| Town Water Supply | | | | | |
| Unsupplemented | 0.2 | 0% | 0% | 0% | -1% |
| Other Uses | | | | | |
| High Security | 20.0 | 0% | 0% | 0% | 0% |
| Unsupplemented | 14.9 | 0% | 2% | 0% | -2% |
| **Sub-total** | **75.0** | **0%** | **1%** | **-1%** | **-1%** |
| Outflows | | | | | |
| End of system flow | 12023.2 | 16% | 51% | -6% | -26% |
| **Sub-total** | **12023.2** | **16%** | **51%** | **-6%** | **-26%** |
| Net evaporation | | | | | |
| Southedge | 26.9 | -5% | -9% | 4% | -2% |
| Other Storages | 1.8 | -4% | -10% | 11% | 5% |
| **Sub-total** | **28.7** | **-5%** | **-9%** | **5%** | **-1%** |
| Unattributed fluxes | | | | | |
| | **1427.6** | **7%** | **35%** | **-3%** | **-23%** |

## MI-3.6.3 Inflows

### Inflows

There are several ways that the total inflows into the river system can be calculated. The obvious way would be to sum all of the inflows in the model. This is 13,555 GL/year for the Mitchell IQQM (Table MI-15). The table also shows that a large proportion of the inflow is indirectly gauged and therefore estimated as part of model calibration. The approach used to calibrate these inflows varies considerably between reaches and model implementations. In some cases inflows are inflated and subsequently compensated for by loss relationships. In other cases the losses are inherent in the inflows. Totalling inflows does not provide a consistent assessment of total river system inflows across different models because of the different approaches to calibration.

An alternative to simply totalling modelled inflows is to locate the point of maximum average annual flow in the river system under without-development conditions. The gauge with maximum average annual flow is a common reference across all models irrespective of how mass balance is calibrated. This is because all river models are calibrated to achieve mass balance at mainstream gauges. The without-development scenarios remove the influences of upstream extractions and regulation and gives a reasonable indication of total inflows. For the IQQM catchments in northern Australia, where there have been minimal modifications to subcatchment inflows due to farm dams, commercial forestry plantations and groundwater use, Scenario AN can be considered to be broadly representative of pre-European settlement conditions.

A comparison between scenarios for reaches along the Mitchell River is presented in Figure MI-37. This shows that the maximum average annual mainstream gauged flow occurs at the last gauge 919009 (Mitchell River at Koolatah) with a value of 6786 GL/year under Scenario AN. This is typical of the Gulf catchments as the rivers are continually gaining to the regions outlet during the wet season. Figure MI-37 shows that about half of the mean annual inflows occur between the last gauge (919009) and the end-of-system.

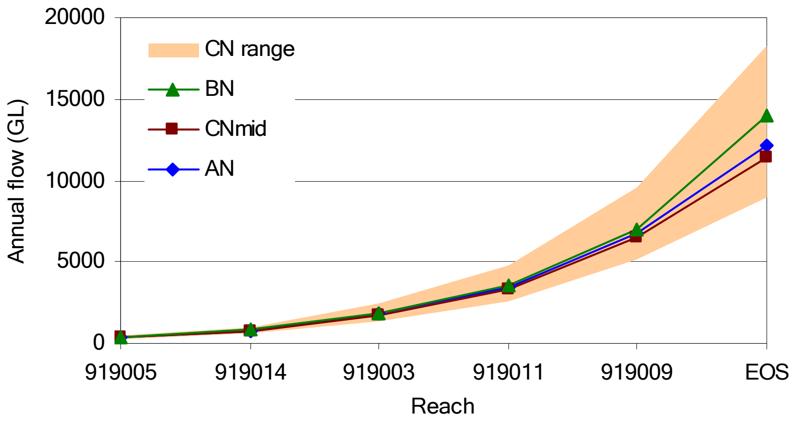


Figure MI-37. Transect of total mean annual river flow under scenarios AN, BN and CN

## Water availability

In the Murray-Darling Basin Sustainable Yields Project, water availability was defined as the volume of water under the without-development scenario which occurs at the point of maximum mean annual flow along a river system. This occurred where a river system turned from a gaining reach to a losing reach. The major rivers in the Gulf of Carpentaria drainage division are, however, gaining systems. In other words, their highest mean annual flow occurs at their end-of-system. However end-of-system flow volumes are uncertain due to considerable ungauged flow contribution to these points. For this reason water availability is defined in this project as the volume of water under the without-development scenario which occurs at the mainstream gauge with the maximum mean annual flow along a river system. In the river systems of the Gulf of Carpentaria this point is at the most downstream gauge. When computing water availability for this project ecological, social, cultural and economic values are not considered.

It must also be noted, however, that not all the water at the most downstream gauge is accessible for consumptive use. In the Gulf of Carpentaria the majority of suitable locations for large carry over storages are in the headwater catchments that are not typically near the last gauge in the system. Further, during large out-of-bank flows (flood flows) water harvesting operations are constrained by the rapid rise and fall in stage height (Petheram et al., 2008) and insufficient on-farm storage capacity. The Mitchell is perhaps better positioned than other rivers, as there are relatively long flow recessions which might provide opportunities for water harvesting.

Annual diversions from the Barron system (6.2 GL/year) are included in the inflow time series for the without-development scenario for the Mitchell IQQM. Therefore consideration was given to adjusting water availability for this use. The relative contribution of this flow at the point of maximum flow was determined by considering flow at the gaining reach with and without the Barron inflows. The resultant impact without the flow at the last gauge was less than 0.5 GL/year, and was not considered significant to adjust the water availability value (Table MI-16). The point of maximum water availability is assessed as 6786 GL/year (Table MI-16 and Figure MI-37).

 

A time series of total annual surface water availability under Scenario AN is shown in Figure MI-38. The lowest annual water availability is 567 GL in Year 22 while the greatest annual water availability is 32,175 GL in Year 44. Figure MI-39 shows the difference in annual total surface water availability under Scenario CN relative to Scenario AN.

Table MI-16. Annual water availability at station 919009 under scenarios AN, BN and CN

| Water availability | AN | BN | CNwet | CNmid | CNdry |
|---|---|---|---|---|---|
| | | | GL/y | | |
| Modelled without-development maximum average mainstream flow | 6786.1 | 7050.2 | 9558.9 | 6489.8 | 5092.3 |
| Net Subcatchment Use (Barron IQQM) | | | | | |
| transferred flow | 105.7 | | | | |
| usage within the Mitchell catchment modelled in Barron IQQM | 111.9 | | | | |
| net diversions | 6.2 | | | | |
| Adjusted to flow at EOS | 0.3 | | | | |
| | | | | | |
| Total surface water availability with adjustment | 6786.4 | 7050.5 | 9559.2 | 6490.1 | 5092.6 |

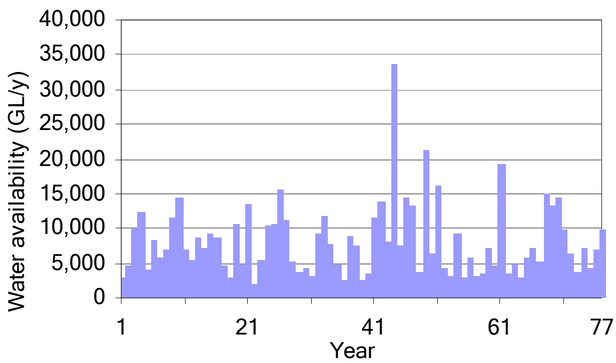


Figure MI-38. Annual water availability at gauging station 919009 under Scenario AN

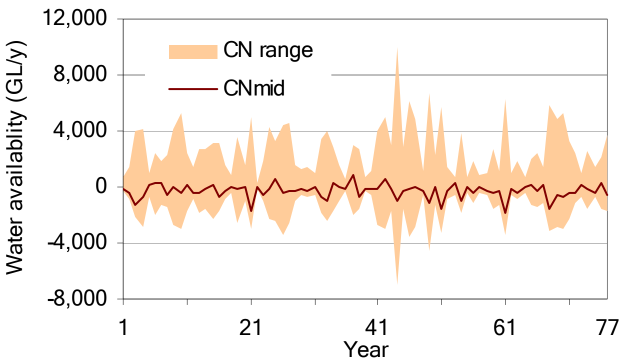


Figure MI-39. Change in total surface water availability at gauging station 919009 under Scenario CN relative to Scenario AN

## MI-3.6.4 Storage behaviour

The modelled behaviour of major storages indicates how reliable the storage is during extended periods of low or no inflows. Table MI-17 provides indicators that show for each of the scenarios the lowest recorded storage volume and the corresponding date for Southedge Dam. The average and maximum years between spills is also provided. A spill commences when the storage exceeds full supply volume and ends when the storage falls below 90 percent of full supply volume. The end condition is applied to remove the periods when the dam is close to full and oscillates between spilling and just below full which would otherwise distort the analysis. The period between spills is the length of time from when one spill ends (i.e. the storage falls below 90 percent of the full supply volume) until the next spill commences (i.e. when the storage exceeds the fully supply volume).

Under all scenarios apart from Scenario Cdry, the storage does not reach the dead storage level (6450 ML). The storage behaviour under Scenario Cmid is similar to that under Scenario A with the average years between spills of 1.2 and maximum of 4.7 years. Under Scenario Cdry the average years between spills is more than twice that of Scenario A.

The maximum period between spills is longer under Scenario B than under Scenario A. This is because although the entire Mitchell region is wetter under Scenario B than under Scenario A, the area upstream of Southedge Dam is drier under Scenario B than under Scenario A.

Table MI-17. Details of dam behaviour

| Southedge Dam | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| Minimum storage volume (GL) | 21 | 19 | 27 | 17 | 6 |
| Minimum storage date | 18 Jan, Year 65 | 18 Jan, Year 65 | 29 Jan, Year 37 | 18 Jan Year 65 | 17 Jan, Year 66 |
| Average years between spills | 1.2 | 1.2 | 1.0 | 1.2 | 2.8 |
| Maximum years between spills | 4.7 | 5.8 | 4.7 | 4.7 | 9.6 |

The time series of storage behaviour for Southedge Dam for the maximum period between spills under each of the scenarios is shown in Figure MI-40.

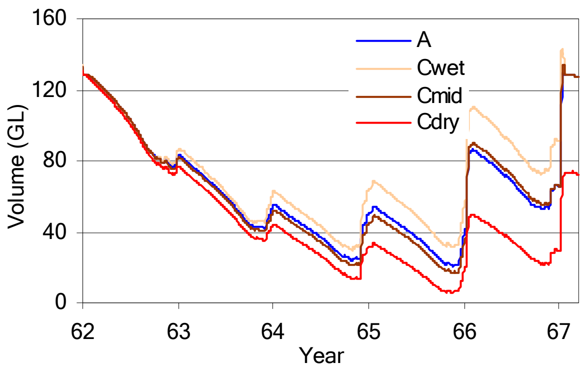


Figure MI-40. Southedge Dam behaviour for the maximum period between spills under Scenario A with change in storage behaviour under Scenario C

## MI-3.6.5 Consumptive water use

### Diversions

Table MI-18 shows the total average annual diversions for each subcatchment (Figure MI-36) under Scenario A and the percentage change under scenarios B and C relative to Scenario A. Water harvesting of high river flows accounts for about 65 percent of total diversions (48.8 GL/year) under the full use of existing entitlements case for Scenario A. The change in total diversions decreases under Scenario Cdry because demands do not vary with change in climate, but less water is accessible to divert.

 

Table MI-18. Total mean annual diversions in each subcatchment in the Mitchell system under Scenario A and under scenarios B and C relative to Scenario A

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| Reach | GL/y | percent change from Scenario A | | | |
| 9190051 | 22.3 | 0% | 0% | 0% | 0% |
| 9190011 | 1.9 | 0% | 0% | 0% | -1% |
| 9190131 | 0.1 | 0% | 0% | 0% | 0% |
| 9190141 | 0.6 | 2% | 1% | -1% | -11% |
| 9190031 | 4.8 | 1% | 3% | -1% | -6% |
| 9193101 | 5.0 | 0% | 2% | 0% | -3% |
| 9190111 | 19.8 | 0% | 1% | 0% | -2% |
| 9190061 | 5.1 | -1% | 1% | 0% | -1% |
| 9192041 | 15.4 | 0% | 1% | 0% | -2% |
| **Total** | **75.0** | **0%** | **1%** | **0%** | **-2%** |

Figure MI-41 shows total mean annual diversions under scenarios A and C for subcatchment reaches. The subcatchments with the largest diversions in the Mitchell region are from Southedge Dam (919005) and extractions from Palmer River (919204).

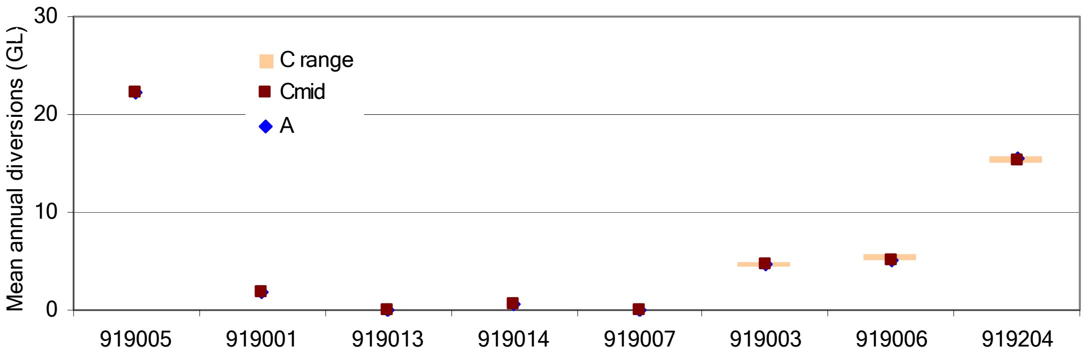


Figure MI-41. Total mean annual diversions for each subcatchment in the Mitchell system under scenarios A and C

Figure MI-42 shows the annual time series of total diversions under Scenario A and the difference from Scenario A under Scenario C. The maximum and minimum diversions under Scenario A are 85.2 GL in Year 17 and 57.1 GL in Year 22 respectively. This figure indicates that there is little change in diversions within the 77-year period modelled. This is primarily due to diversions being a small proportion of the available water demands. Demands in the Mitchell are also modelled using constant demand patterns and hence the demand patterns do not vary with climate. The change in diversions is within 10 GL/year under scenarios Cwet, Cmid and Cdry.

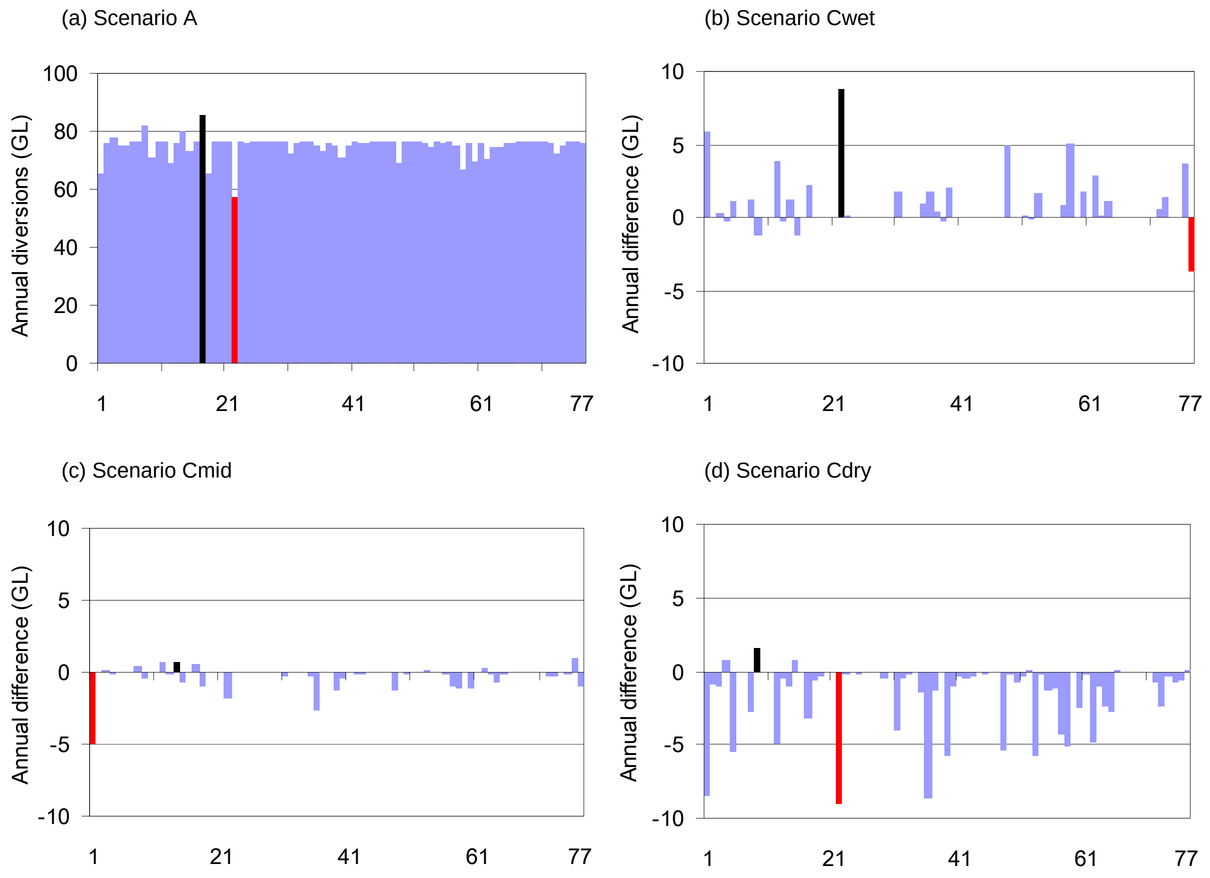


Figure MI-42. Total annual diversions in the Mitchell system under (a) Scenario A; and difference from Scenario A under (b) Scenario Cwet, (d) Scenario Cmid and (d) Scenario Cdry

## Level of use

The level of use metric used in this project is indicated by the ratio of total use to surface water availability. Total use comprises subcatchment and streamflow use. Subcatchment use includes the net usage from the Barron water resource plan area, which is defined as diversions in the upper reaches of the Mitchell and Walsh rivers less transfers from the Barron River catchment. Streamflow use includes total net diversions, which are defined as the net water diverted for the full range of water products. Net diversion is the sum of the diversions minus the return flows. It should be noted, however, there are no return flows in the Mitchell IQQM. Net diversions are used to reflect the change in mass balance of the system. They do not consider the difference in water quality that may exist between diversions and returns.

Level of use is presented in two ways for this region. The first approach is the same as presented in the Murray-Darling Basin Sustainable Yields Project: the ratio of total use to total surface water availability (Table MI-19). The second is to present a transect of level of use at each main river gauge, which compares the cumulative diversions up to the gauge (including diversions on effluents and tributaries) with the average annual river flow at the gauge. This approach shows the spatial variation of use (Figure MI-43).

Overall the level of use for the Mitchell region is low with 1 percent of the total available surface water resource diverted for use. Level of use is, however, highest in the upper reaches of the Mitchell region (approximately 6 percent) due to smaller inflows and higher water consumption. As use is low in the region, demands are able to be met under various climate scenarios. In Table MI-19 the total use is lowest under Scenario Cdry for the reasons outlined in the above section on diversions.

Current utilisation of licences is estimated by considering the unallocated water reserves from the *Mitchell Draft Resource Operations Plan* (DNRW, 2008) and the modelled volumetric limits. For the Mitchell region, the volumetric limits are 77 GL/year and the unallocated reserves are reported to be 70 GL/year. Based on these values it is estimated that current usage is approximately 7 GL/year. Allowable usage or total average diversions from IQQM are for the reporting period (1930 to 2007) and therefore may differ to the volumes used to develop the resource operations plan.

 

Table MI-19. Relative level of surface water use under scenarios A, B and C

| | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | | | | |
| Total surface water availability | 6786 | 7050 | 9559 | 6490 | 5093 |
| Subcatchment use | | | | | |
| Net usage (diversion less transfers from Barron River) | 6 | 6 | 6 | 6 | 6 |
| Streamflow use | 75 | 75 | 76 | 75 | 74 |
| **Total use** | **81** | **81** | **82** | **81** | **80** |
| | percent | | | | |
| Relative level of use | 1% | 1% | 1% | 1% | 2% |
| **Level of use** | | | | | |

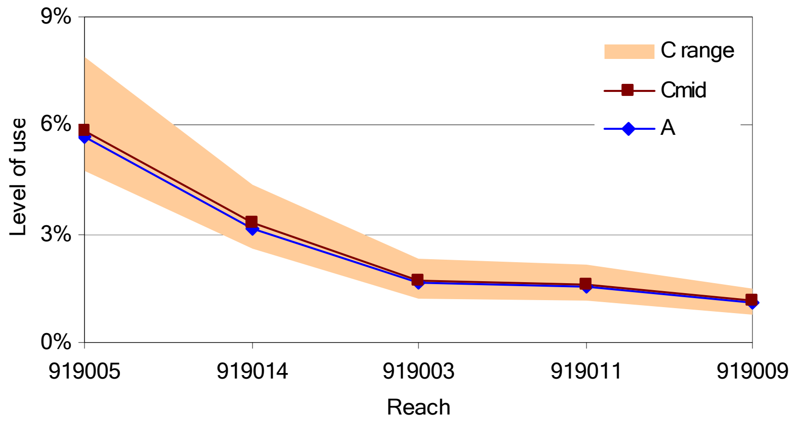


Figure MI-43. Transect of relative level of surface water use in the Mitchell system under scenarios A and C

## Use during dry periods

Table MI-20 shows the average annual diversions, as well as the annual diversions for the lowest 1-, 3- and 5-year periods under Scenario A and the percentage change from Scenario A under each other scenario. These figures indicate the relative impact on surface water use during dry periods is greatest for a 1-year period. For longer periods the change is less than 4 percent for all scenarios.

Table MI-20. Indicators of surface water diversions in the Mitchell system during dry periods under Scenario A and under scenarios B and C relative to Scenario A

| Annual diversion | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| | GL/y | percent change from Scenario A | | | |
| Lowest 1-year period | 57 | 1% | 14% | -3% | -16% |
| Lowest 3-year period | 70 | 0% | 4% | -1% | -4% |
| Lowest 5-year period | 70 | 1% | 3% | -1% | -3% |
| Average | 75 | 0% | 1% | 0% | -2% |

### Reliability

The average reliability of water products can be indicated by the ratio of total diversions to the total volumetric limit. For the Mitchell region, unsupplemented agricultural usage is compared against the maximum area planted by an application rate or a specified capacity for each licence; high security use is compared against the licence volume; and unsupplemented demands for town water supply, mining and other uses are compared against the reference demand that is associated with a fixed demand pattern. Table MI-21 shows the average reliability under Scenario A and the percent change under scenarios B and C relative to Scenario A. Results indicate that generally reliability is good for all water products.

Table MI-21. Average reliability of water products under Scenario A and under scenarios B and C relative to Scenario A

| | | A | | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| | Volumetric limit | Mean annual diversions | Fraction diverted per 1ML | | | | |
| | GL/y | | | percent change from Scenario A | | | |
| Licensed private usage | | | | | | | |
| Unsupplemented Access | 31.06 | 29.78 | 0.96 | 0% | 1% | -1% | -3% |
| Unsupplemented (TWS) | 0.19 | 0.16 | 0.86 | 0% | 0% | 0% | -1% |
| Unsupplemented (Mining) | 10.37 | 10.13 | 0.98 | 0% | 1% | 0% | -2% |
| High Security (Other Uses) | 20.00 | 20.00 | 1.00 | 0% | 0% | 0% | 0% |
| Unsupplemented (Other Uses) | 15.37 | 14.92 | 0.97 | 0% | 0% | 0% | 0% |

There is a difference in most systems between the water that is available for use, as modelled in the Mitchell IQQM, and water that is actually diverted for use. These differences may be due to a range of factors including unallocated water reserves, under-utilisation of existing licences and water being provided from other sources such as rainfall. The difference between available and diverted water will vary considerably across water products and time.

## MI-3.6.6 River flow behaviour

There are many ways of considering the flow characteristics in river systems. For this report three different indicators are provided: daily flow exceedance, seasonal plot and daily event frequency. These are considered at the end-of-system. Figure MI-44 shows the flow exceedance curves.

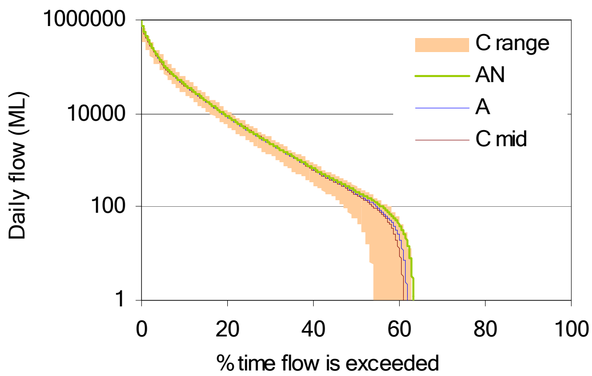


Figure MI-44. Daily flow exceedance curves for the Mitchell end-of-system under scenarios AN, A and C

 

Figure MI-45 gives the mean monthly flow under scenarios AN, A, B and C at the end-of-system. There is a strong seasonality at the end-of-system gauges reflecting the wet and dry seasons. This figure also shows minimal change in the seasonality of end-of-system flows under all scenarios relative to Scenario AN.

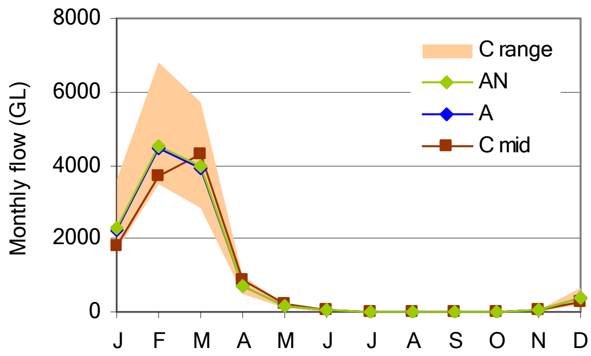


Figure MI-45. Mean monthly flow at the Mitchell end-of-system under scenarios AN, A and C

Table MI-22 presents the percentage of time flow is greater than 1 ML/day under all scenarios at the end of the system. Under scenario Cdry there is an 8 percent decrease to low flows at the end-of-system.

Table MI-22. Percentage of time modelled flow at the Mitchell end-of-system is greater than 1 ML/day under scenarios AN, A, B and C

| Catchment | AN | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|
| Mitchell | 63% | 62% | 64% | 64% | 61% | 55% |

## MI-3.6.7 Share of water resource

### Non-diverted water shares

There are several ways of considering the relative level of impact on non-diverted water. Table MI-23 presents two indicators:

- the average annual non-diverted water as a proportion of the available water
- average annual non-diverted water under each scenario compared with average annual non-diverted under Scenario A.

Table MI-23. Relative level of non-diverted water in the Mitchell system under scenarios A, B and C

| Mitchell | A | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|
| Non-diverted water as a percentage of total available water | 99% | 99% | 99% | 99% | 99% |
| Non-diverted share relative to Scenario A non-diverted share | 100% | 104% | 141% | 96% | 75% |

Most water in the Mitchell region is not diverted (99 percent) there fore the change in non-diverted water predominantly reflects changes due to climate. However, non-diverted water under scenarios B and C vary relative to Scenario A reflecting the changes in water availability.

### Combined water shares

Figure MI-46 combines the results from the water availability and non-diverted water. The size of the bars indicates water availability and the subdivision of the bars indicates the diverted and non-diverted fractions. It should be noted, however, that water availability is based on the mean annual volume of water at the last gauge in the system. For the reasons discussed in Section MI-3.6.3 it is unlikely that this volume of water is accessible for consumptive use.

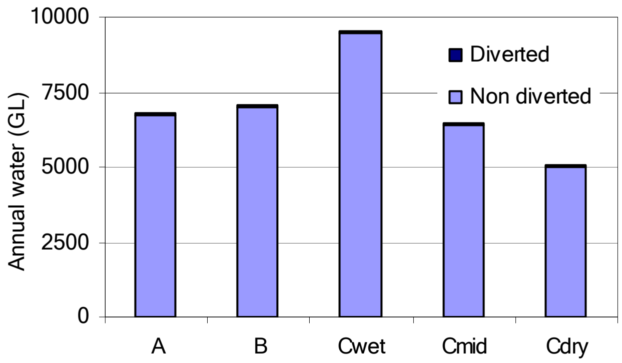


Figure MI-46. Comparison of diverted and non-diverted shares of water in the Mitchell system under scenarios A, B and C

## MI-3.7 Changes to flow regimes at environmental assets

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. One environmental asset has been shortlisted in the Mitchell region: Mitchell River Fan Aggregation. The location of this asset is shown in Figure MI-1 and the asset is characterised in Chapter MI-2.

This section presents the assessment of shortlisted assets and reports metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis. Confidence in results for low flows and high flows was calculated separately on a scale of 1 to 5, with 1 indicating results with the highest confidence (as described in Section 2.2.6 of the division-level Chapter 2). Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are 1, 2 or 3. If confidence levels in the low flows or high flows are ranked 4 or 5, results are not reported and are labelled NR (not reported).

In the absence of site-specific metrics for the Mitchell region a set of standard metrics related to high and low flows have been utilised. However the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and ecology.

 

### MI-3.7.1 Standard metrics

Table MI-24. Standard metrics for changes to flow regime at environmental assets in the Mitchell region under Scenario AN and under scenarios B, C and D relative to Scenario AN

| Standard metrics | Units | AN | B | Cwet | Cmid | Cdry | Dwet | Dmid | Ddry |
|---|---|---|---|---|---|---|---|---|---|
| | | | change from Scenario A | | | | | | |
| Mitchell River Fan Aggregation - Node 1 (confidence level: low flow = <3, high flow = <3) | | | | | | | | | |
| Annual flow (mean) | GL | 6790 | +3% | +40% | -6% | -26% | nm | nm | nm |
| Wet season flow (mean)* | GL | 6620 | +3% | +40% | -6% | -26% | nm | nm | nm |
| Dry season flow (mean)** | GL | 164 | +2% | +29% | +12% | -37% | nm | nm | nm |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | 0.0454 | | | | | | | |
| Number of days below low flow threshold (mean) | d/y | 36.5 | -2.7 | -3.7 | +13.5 | +44.7 | nm | nm | nm |
| Number of days of zero flow (mean) | d/y | 6.13 | -0.7 | -0.2 | +6.2 | +21.3 | nm | nm | nm |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | 105 | | | | | | | |
| Number of days above high flow threshold (mean) | d/y | 18.3 | +0.6 | +7.2 | -1.2 | -4.9 | nm | nm | nm |

*Wet season covers the six months from November to April.
** Dry season covers the six months from May to October.
NR – metrics not reported because streamflow confidence level is ranked 4 or 5.
nm – not modelled.

Note that the results for the above asset node come from an IQQM model therefore Scenario AN results represent predevelopment conditions. Scenario B represents the last 11 years of climate with full allocation of existing water entitlements and Scenario C represents climate change scenarios with full allocation of existing water entitlements (see Section MI-3.6 for details).

#### Mitchell River Fan Aggregation

The surface water flow confidence level for the selected reporting node for the Mitchell River Fan Aggregation (see location on Figure MI-5) is at least moderately reliable (<3) for both wet season and dry season flows (Table MI-24). Under Scenario AN annual flow into this asset is highly dominated by wet season flows (97 percent) which have only been 3 percent higher under Scenario B. Dry season flows have also been marginally higher (2 percent) under Scenario B when compared to Scenario AN. Annual and seasonal flows do not change much under Scenario Cmid (6 to12 percent) compared to Scenario AN, but there are large increases under Scenario Cwet (29 to 40 percent). Under Scenario Cdry there are moderate decreases in wet season flow (26 percent) compared to Scenario AN and larger decrease in dry season flow (37 percent). No separate Scenario D modelling was undertaken.

Under Scenario Cdry, there is more than twice the number of days with flow that is below the low flow threshold as defined by Scenario AN (Table MI-24). There is also a large increase in low flow days under Scenario Cmid when compared to Scenario AN and little change under Scenario Cwet. A similar pattern is seen in the number of days of zero flow days, although these only occur about 2 percent of the time. Under Scenario B the exceedance of the high flow threshold is similar to that under Scenario AN. In contrast, compared to Scenario AN, there are large increases and decreases in the high flow threshold exceedance under scenarios Cwet and Cdry respectively, with little change under Scenario Cmid.

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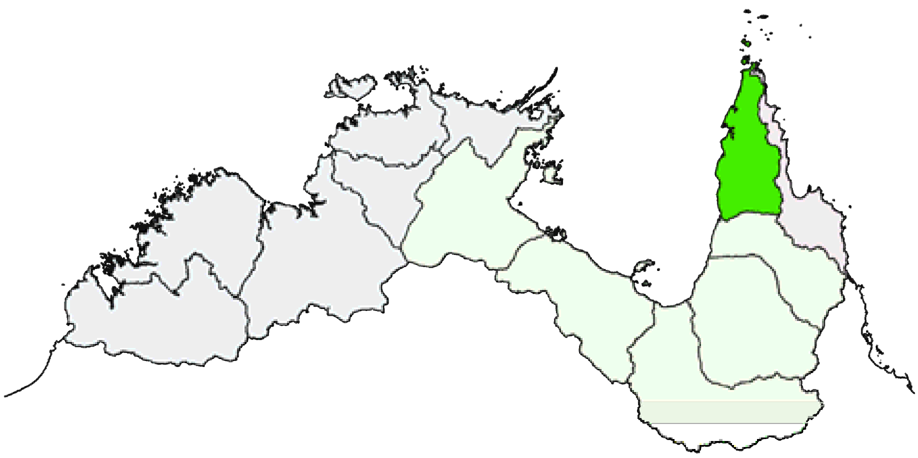
# Water in the Western Cape region



# WC-1 Water availability and demand in the Western Cape region

The first part of this report (the Preamble, Chapter 1 and Chapter 2) reports at the division level, including division-wide descriptions of climate and geology and methods which apply to all regions. Subsequent chapters report at the region level. In particular, Chapters WC-1, WC-2 and WC-3 focus on the Western Cape region (Figure WC-1).

This chapter summarises the water resources of the Western Cape region, using information from Chapter WC-2 and Chapter WC-3, and directly addresses the Terms of Reference, specifically terms 3, 4 and 5 as listed in the Preamble. Essentially, this chapter provides a synoptic view of the region and covers:

- regional observations
- water resource assessment
- changes to flow regime at environmental assets
- seasonality of water resources
- surface–groundwater interaction
- water storage options
- data and knowledge gaps.

For further details on the context of the region (physical and climate descriptions, hydrogeology and legislation) see Chapter WC-2. Region-specific methods and results are provided in Chapter WC-3. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2.

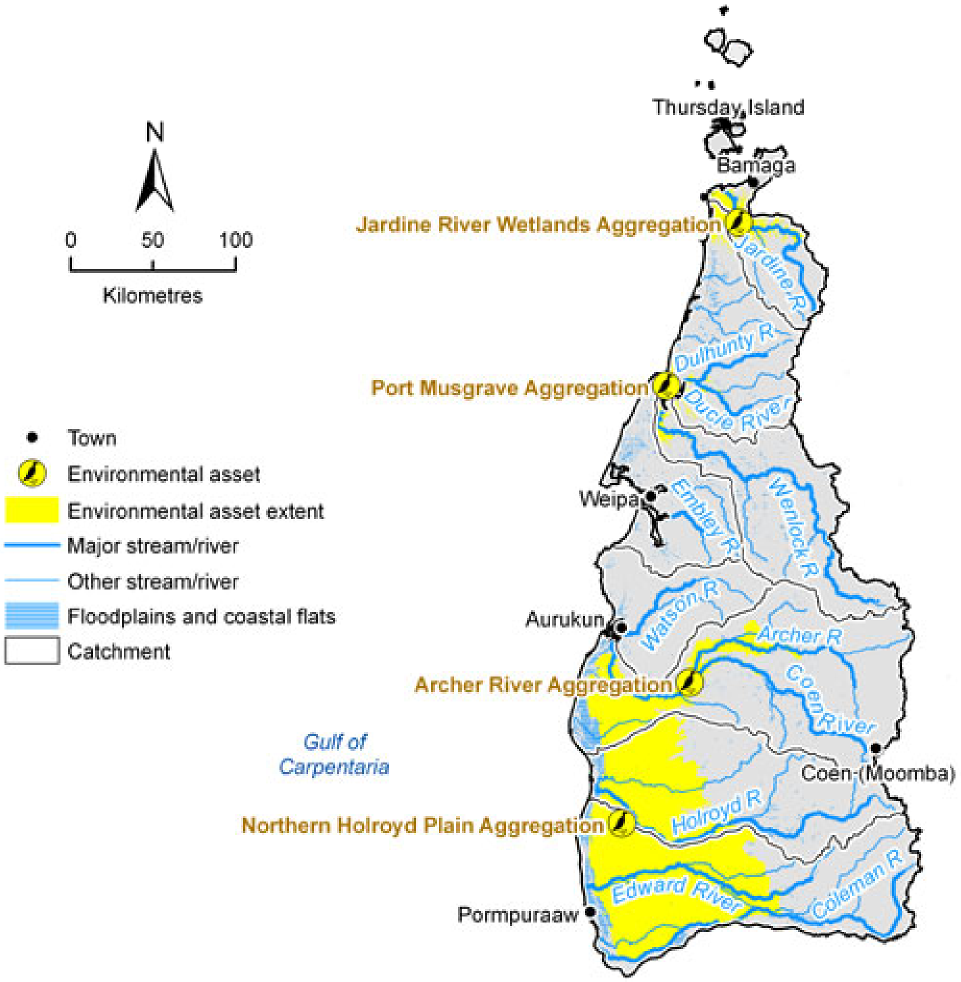



Figure WC-1. Major rivers, towns and location of environmental assets selected for assessment of changes to hydrological regime in the Western Cape region

# WC-1.1 Regional summary

These regional observations summarise key modelling results and other relevant water resource information about the Western Cape region.

The Western Cape region has a moderate inter-annual variability in rainfall and hence runoff and recharge. Coefficients of variation are relatively low compared to the other regions across northern Australia and reflect the combined climatic influence of the northern monsoon and the influence of the orographic rain driven by the south-east trade winds rising over the Great Dividing Range to the east. The region may, however, experience multiple years of below average or above average rainfall. Typically, three to four months of the year are without rain.

The mean annual rainfall for the region is 1417 mm. Mean annual areal potential evapotranspiration (APET) is 2033 mm. The mean annual runoff averaged over the modelled area of the Western Cape region is 479 mm, 34 percent of rainfall. Compared to other regions, average rainfall is highest of all regions and APET is amongst the highest. Under the historical climate the mean annual streamflow over the Western Cape region is estimated to be 31,981 GL.

There is a strong seasonality in rainfall patterns, with 97 percent of rainfall falling between November and May, and a very high dry season potential evapotranspiration. The region has a relatively high rainfall intensity, and short lag between rainfall and runoff, with a slightly increasing amount and intensity of rainfall over the historical (1930 to 2007) period. Under the historical climate, the mean annual stream flow for the Western Cape region is modelled to be 32 GL.

The Gilbert River Formation and Eulo Queen Group aquifers of the Great Artesian Basin (GAB) provide groundwater discharge to streams, allowing surface water flows in many rivers to be maintained well into the dry season. The Gilbert River Formation is the main groundwater resource in the region. This formation is predominantly a confined aquifer, but is found in rock outcrop to the south and east where it is known to provide groundwater baseflow to a number of rivers. The most significant perennial river in the region is the Jardine, which receives an estimated 15,000 L/second or 485 GL/year baseflow from the GAB (GABCC, 1998).

There is a strong north-west to south-east rainfall gradient. With decreasing rainfall, runoff decreases from 50 to 15 percent of rainfall.

The region is annually water-limited; there is more energy available to remove water than there is water available to be removed.

Under the recent (1996 to 2007) climate the Western Cape region has been similar to the historical (1930 to 2007) record. Modelling suggests that future (~2030) conditions may be slightly drier than historical conditions. Future runoff is likely to be similar to historical levels, but potential diffuse recharge may be higher, as modelling suggests future rainfall intensity may be higher than historical levels.

The major groundwater use from the Gilbert River Formation aquifer is for industrial and mining processes associated with the Comalco bauxite mines near Weipa. The water resource planning process has allowed for potentially up to 10.1 GL/year (10 GL from the total GAB allocation; 0.1 GL from the Cape management area) to be set aside for projects of state or regional significance (to encourage sustainable development opportunities) or for town water supply purposes. Currently applications for groundwater extraction have been submitted for more than 9 GL/year of State Reserve from the Cape Management Area.

The Great Artesian Basin springs discharging in the region provide an important source of water for maintaining surface water flow during the dry season.

The Archer River has been declared as a wild river under the *Wild Rivers Act 2005*. The Coleman, Holroyd, Watson, Wenlock, Ducie and Jardine river basins have been identified as potential wild river areas.

At environmental assets, total flow volumes are highly dominated by wet season flows (in November to April) with dry season flows (in May to October) only a small fraction of total annual flow. However, environmental assets depend on this strong seasonality and any significant changes in the frequency and duration of floods and dry season flows are likely to have an environmental impact. In the recent past there has been more flow, resulting in fewer low flow days and more high flow days relative to the historical record.

Under the median future climate, future flows are expected to be similar to historical levels. However, under the wet and dry extreme future climates, large changes to the high flow threshold exceedance occur which could have negative environmental impact. At asset nodes associated with perennial reaches, there is little change, but at sites where zero flow is frequent, there are moderate changes in the number of zero flow days which may have environmental impacts.

The region is generally datapoor.

## WC-1.2 Water resource assessment

Term of Reference 3a

### WC-1.2.1 Under historical climate and current development

Term of Reference 3a (i)

Mean annual rainfall over the Western Cape region is 1417 mm, with a standard deviation of 200 mm. Maximum recorded rainfall fell in 1999 with 2033 mm; the lowest was in 1961 with 735 mm. Rainfall is high relative to other regions across northern Australia. Mean annual areal potential evapotranspiration (APET) is 1874 mm, with a small annual variation (standard deviation of 47 mm). Highest APET occurred in 1992 (2003 mm); lowest in 1944 (1696 mm). The mean annual runoff averaged over the modelled area of the Western Cape region is 479 mm, 34 percent of rainfall. Rainfall and runoff both decline with distance from the coast. While rainfall shows little spatial variation, spatial variation in runoff is high ranging from over 800 mm/year in the Jardine River basin and amidst the coastal lowlands in the middle of the Western Cape region, to less than 130 mm/year for the south-eastern corner of region.

Rainfall is very seasonal, with 97 percent falling during the wet season, and runoff is highest in February and March.

Current groundwater entitlements in the Western Cape region amount to about 30.6 GL/year, of which about two-thirds is allocated from Cainozoic sediments and one-third from Great Artesian Basin (GAB) aquifers. The level of utilisation of these entitlements is largely unknown, although Rio Tinto uses in the order of 6 to 7 GL/year out of an allocation of 9 GL/year from the GAB at Weipa. Unlicensed stock and domestic use is estimated to be about 0.5 GL/year. Natural groundwater discharge from the Gilbert River Formation of the GAB plays an important role in providing dry season flows in several major perennial rivers including the Archer, Coen, Delhunty, Holroyd, Jardine and Wenlock rivers (Table WC-1 and Figure WC-2). It should be noted that Table WC-1 does not include the Jardine River as the gauging stations for this river failed to satisfy the selection criteria for baseflow analysis (see Section 2.4.1 in the division-level Chapter 2).

Table WC-1. Estimated groundwater contribution (baseflow) to streamflow, modelled diffuse recharge and groundwater extraction for the Western Cape region under historical climate

| Station | River | Station name | Annual BFI * | Dry season BFI * | Dry season baseflow * |
| --- | --- | --- | --- | --- | --- |
| | | | | | GL |
| 920002A | Coleman | King Junction | 0.22 | 0.46 | 3.2 |
| 922001A | Archer | Telegraph Crossing | 0.23 | 0.47 | 32.5 |
| 922101A | Coen | Coen | 0.26 | 0.62 | 4.1 |
| 925001A | Wenlock | Moreton | 0.35 | 0.65 | 60.8 |
| 925002A | Wenlock | Wenlock | 0.26 | 0.51 | 10.5 |
| 926001A | Ducie | Bertiehaugh | 0.32 | 0.52 | 7.4 |
| 926002A | Dulhunty | Dougs Pad | 0.53 | 0.75 | 37.2 |
| | | Historical recharge ** | Estimated groundwater extraction | | |
| | | GL/y | | | |
| Entire Western Cape region | | 22,390 | 31 | | |

* BFI (baseflow index) and baseflow volume derived from gauged data.
** Aggregated recharge using Zhang and Dawes (1998).

Under a continued historical climate, mean annual groundwater recharge to the unconfined aquifers of the Western Cape region is likely to be similar to the historical (1930 to 2007) average. Given that the majority of existing groundwater use is for mining and industrial purposes around Weipa, it is likely that continued extraction at current levels will cause localised drawdown in groundwater levels. Whilst this cannot be quantified without a detailed groundwater model, the greatest potential impacts are likely to be through reduced discharge to springs and, in turn, perennial watercourses.

### WC-1.2.2 Under recent climate and current development

Term of Reference 3b

The mean annual rainfall and runoff under the recent (1996 to 2007) climate are 9 percent and 27 percent higher, respectively, than the historical (1930 to 2007) mean values, but there is spatial variability across the region, with the north and south-east being statistically significantly wetter.

Under a continued recent climate, mean annual groundwater recharge to the unconfined aquifers of the Western Cape region is likely to be similar to the historical average rate.

### WC-1.2.3 Under future climate and current development

Term of Reference 3a (ii)

Future rainfall is expected to be similar to the historical climate. Under the wet extreme future climate, mean annual rainfall is 1570 mm; under the median future climate, 1435 mm; and under the dry extreme future climate, 1320 mm (or a range of 7 percent lower to 11 percent higher than historically). Corresponding mean annual APET under these scenarios is 1902, 1897 and 1944 mm, respectively (or a range of 4 to 1 percent higher than historically).

Rainfall-runoff modelling indicates that mean annual runoff in the future in the Western Cape region is equally likely to increase as decrease. For the high global warming scenario, rainfall-runoff modelling with climate change projections from four of the GCMs indicates a decrease in mean annual runoff greater than 10 percent while two of the GCMs indicate an increase in mean annual runoff greater than 10 percent. Under the wet extreme, median and dry extreme future climates, mean annual runoff changes by 30, 1 and -19 percent relative to historical levels. By comparison, the range based on the low global warming scenario is a -11 to 16 percent change in mean annual runoff.

Under the future climate, mean annual groundwater recharge to the unconfined aquifers of the Western Cape region is likely to be higher than the historical average rate. Without a detailed model for the main aquifers in the region, it is not possible to quantify the impacts of increased recharge rates on the groundwater balance, either under current or future development scenarios.

### WC-1.2.4 Under future climate and future development

Term of Reference 3a (iii)

The majority of catchments in this region are either under wild river declaration or a moratorium pending decision, hence future development is likely to have minimal consequence to water resources. Future development is most likely to be related to mining and will be subject to environmental impact assessments.

The Embley River basin contains a number of world-class bauxite mines. Development controls are in place to preserve the local environment and absolute water use is low.

## WC-1.3 Changes to flow regime at environmental assets

Term of Reference 3a (iv)

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Four environmental assets were shortlisted for the Western Cape region: the Archer River Aggregation, Jardine River Wetlands Aggregation, Northern Holroyd Plain Aggregation and Port Musgrave Aggregation. These assets are characterised in Chapter WC-2.

In deciding whether it is feasible to report hydrological regime metrics for these shortlisted assets, it is important to consider the confidence levels in modelled streamflow (as described in Section 2.2.6 of the division-level Chapter 2). Confidence in results for low flows and high flows was calculated separately. Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are sufficiently high. If confidence in the low flow or high flow is too low, metrics are not reported, and hence an important gap in our knowledge is identified.

Some of the assets in this region have multiple nodes at which streamflow modelling results are available. When reporting hydrological regime metrics for such assets a single node was selected. The selected node was that with the highest streamflow confidence level and the largest proportion of streamflow to the asset. The location of nodes for each asset are shown on satellite images in section WC-2.1.3. Results for all nodes are presented in McJannet et al. (2009).

The confidence levels in modelled streamflow are sufficiently high to report hydrological regime metrics at all assets in this region with one exception. The surface water flow confidence level for the Jardine River Wetlands Aggregation is considered unreliable for high flows so metrics relating to such flows will not be reported. In contrast, the confidence level for low flows at this asset is considered moderately reliable and thus low flow metrics are reported.

Annual flow into all assets is dominated by wet season flow, which has been 16 percent higher under the recent climate. Dry season flows have been significantly (>40 percent) higher under the recent climate.

Under the future climate, stream flows are expected to be similar to the historical record, though the wet extreme future climate may see increases, while the extreme dry future climate may see moderate decreases.

The number of days when flow is below the low flow threshold is projected to be similar under both the historical and future climates. Zero flow days are generally rare, and this is unlikely to change. Where we have confidence in the data (Archer River Aggregation, Northern Holroyd Plain Aggregation) there is similarly little change expected from historical levels.

## WC-1.4 Seasonality of water resources

Term of Reference 4

The rivers have a marked seasonal flow regime of high water levels during the wet season (November to April) and minimal flow during the dry season. Approximately 97 percent of rainfall, and 96 percent of runoff, occurs during the wet season months under both the historical and recent climate. Very similar seasonal percentages (±1 percent) of rainfall and runoff are projected for 2030.

Approximately 4 percent of runoff occurs in the dry season. This is high relative to other regions across northern Australia and perennial streamflow occurs in a number of rivers within the region, most notably the Jardine River.

## WC-1.5 Surface–groundwater interaction

Term of Reference 4

The Great Dividing Range trends north-northwest along the eastern margin of the Western Cape region. The country west of the divide slopes gently westward towards the Gulf of Carpentaria and is drained by eight major rivers; the Coleman, Holroyd, Archer, Watson, Embley, Wenlock, Ducie and Jardine rivers.

The presence of highly permeable surficial bauxite, sands and clays means that infiltration rates are high and hence there is minimal runoff following even high rainfall events across much of the region. Subsequently creek flows during the wet season are high, mainly due to interflow (i.e. rainfall that infiltrates the surface and moves laterally through the unsaturated zone).

Analysis of gauged streamflow data indicates that dry season baseflow (the low portion of streamflow mostly contributed from regional groundwater discharge) is particularly high in this region compared with other regions in the Gulf of Carpentaria Division, with the Jardine, Archer, Dulhunty and Wenlock rivers having the highest dry season baseflow in the region (Table WC-1 and Figure WC-2). DNRM (2005) identified a number of rivers that receive groundwater discharge from the Gilbert River Formation aquifer (and its equivalents) including the Jardine, Wenlock, Archer, Coen, Holroyd and Delhunty rivers (Figure WC-3).

The Jardine River flows all year round, with the continual flow of water attributed to baseflow derived from the shallow sandstones of the Gilbert River Formation and to high annual rainfall (over 1500 mm). Unlike other northern tropical rivers which are subject to seasonal rainfall patterns, the Jardine River catchment experiences rain all year around, even during the dry season (EPA, 2009). The Wenlock, Archer and Holroyd rivers are also known to flow through the dry season. Figure WC-3 shows the river reaches potentially receiving baseflow as well as the location of GAB springs.

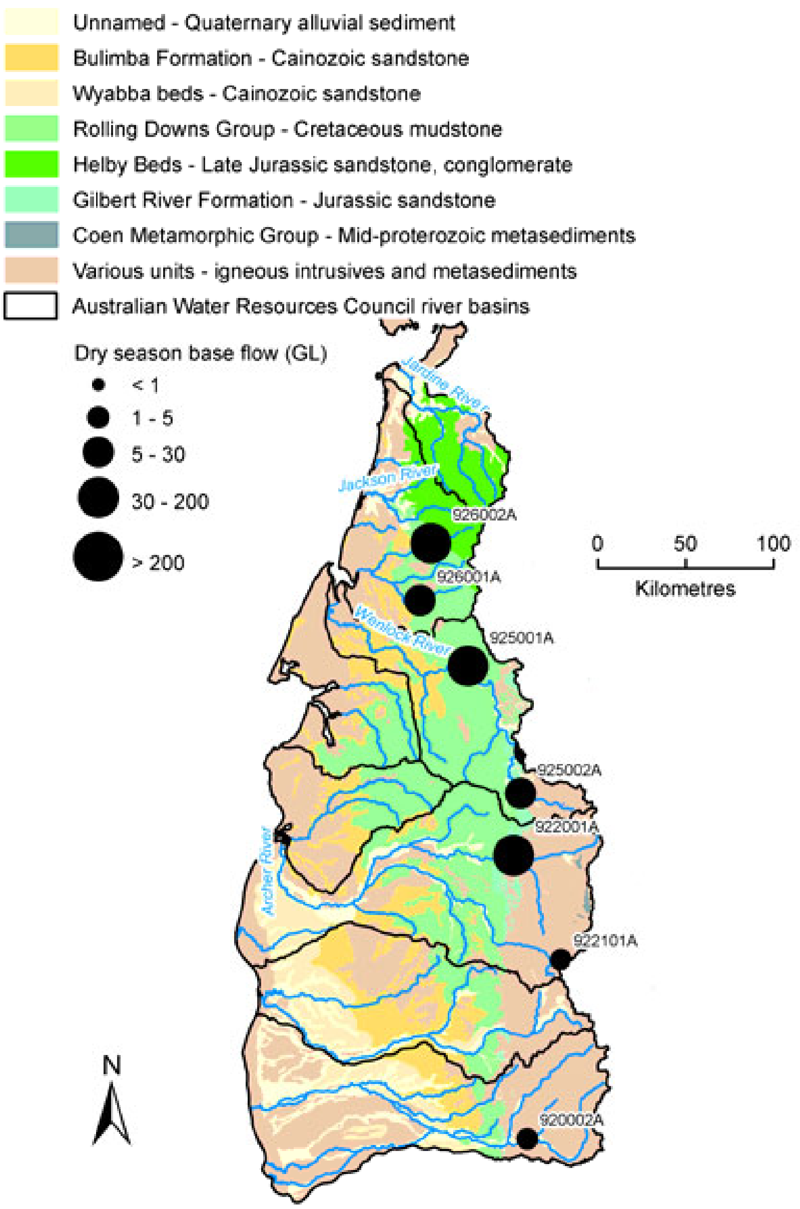



Figure WC-2. Surface geology and modelled mean dry season baseflow of the Western Cape region

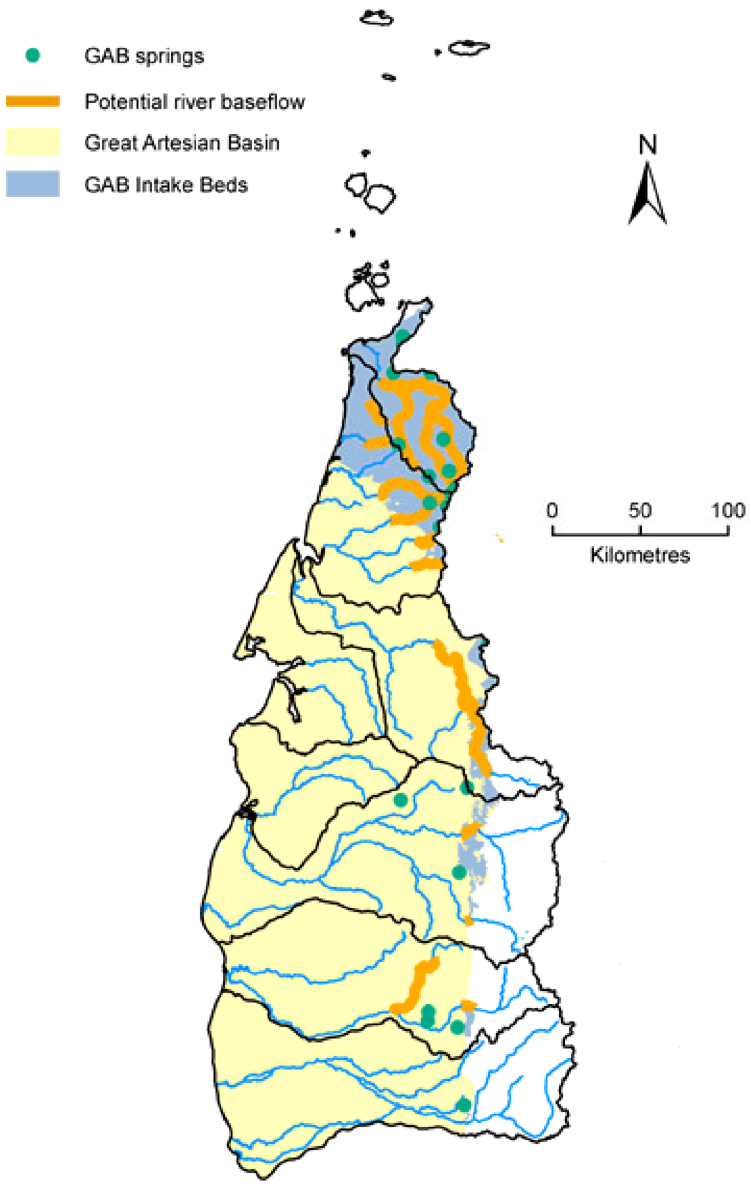



Figure WC-3. Locations of spring groups and potential river baseflow in the Western Cape region

## WC-1.6 Water storage options

Term of Reference 5

### WC-1.6.1 Surface water storages

Under current and planned development, no major water storages are reported, or are expected, in the region.

### WC-1.6.2 Groundwater storages

The high annual rainfall in this region contributes to very high estimated groundwater recharge rates – and significantly higher than all other regions within the Northern Australia Sustainable Yields project area. Accordingly, most near-surface aquifers, including outcropping areas of the Gilbert River Formation, are completely replenished each wet season. Managed aquifer recharge (MAR) has limited prospects in this region, simply because there is no additional storage capacity within the aquifers at the end of each wet season.

## WC-1.7 Data gaps

Term of Reference 1e

Time series groundwater level and salinity data is required for each of the main aquifer types in the Western Cape region to provide greater understanding of recharge processes and inter-aquifer leakage, particularly for the Great Artesian Basin aquifers. Water quality information, including chemical and isotopic data, from the eight large perennial rivers in the region (Coleman, Holroyd, Archer, Watson, Embley, Wenlock, Ducie and Jardine rivers) would provide insight to the source of dry season flows – that is, whether the baseflow is derived from shallow Cainozoic sediments or the Great Artesian Basin aquifers.

## WC-1.8 Knowledge gaps

Term of Reference 1e

The potential for diffuse upward leakage of water out of the Great Artesian Basin aquifers and into overlying Tertiary sediments is unknown. Further research is required to estimate these discharge fluxes so that a detailed groundwater balance can be developed for the aquifers to guide future management in the region.

Research is also required to ascertain the sources of water for dry season flows in the eight large perennial rivers in the region. Obtaining this knowledge is crucial for ensuring future groundwater developments in the region do not adversely impact the ecosystems that depend on the perennial rivers.

None of the environmental assets in this region have any site-specific metrics by which to gauge the potential impacts of changes in future climate and development. In the absence of site-specific metrics a set of standard metrics related to high and low flows have been utilised. However the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and specific ecological entities (for example, macrophyte populations, fish passage, faunal and floral habitats, etc.).

Many environmental assets depend not simply on duration above or below certain flow levels, but on triggers (e.g. for reproduction or migration) set by the rate of change of flow. In addition, some environmental assets depend on the frequency and duration of events that occur less than annually (i.e. once every 5, 10 or 20 years or more). Further analysis is therefore required to look at how the timing, duration and rate of rise and fall in flow rates at critical times of the season will vary under the various scenarios.

Flooding is an important factor that sustains many environmental assets and this occurs when the stream breaks out of its banks (a level known as bankfull stage or discharge). However, bankfull discharge is not known for many streams, nor is the dependence of area flooded on increasing stream depth, so it is difficult to predict when assets are inundated. Further information about bankfull stage and discharge are needed for most environmental assets.

Dry season flows are poorly understood in this region therefore the ability to predict the potential impacts of the various scenarios on low flows at environmental assets is very limited. Improved monitoring of low streamflow conditions is needed along with the development of hydrological models that combine surface and groundwater regimes. Further monitoring of groundwater levels is also required so that the potential impacts of climate and development change on groundwater-dependent ecosystems can be better understood.

## WC-1.9 References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# WC-2 Contextual information for the Western Cape region

This chapter summarises the background information for the region, outlining existing knowledge of water resources and prior and current investigations relevant to the water resources of the region. This chapter also outlines the current and potential future legislation, water plans and other water resource management arrangements. This chapter is arranged into four sections:

- physical and climate descriptions
- data availability
- hydrogeology
- legislation, water plans and other arrangements.

# WC-2.1 Overview of the region

## WC-2.1.1 Geography and geology

The Western Cape region covers a total of 66,766 $km^2$ and comprises nine Australian Water Resource Council (AWRC) river basins: Coleman (13,130 $km^2$), Holroyd (10,542 $km^2$), Archer (14,227 $km^2$), Watson (4832 $km^2$), Embley (4796 $km^2$), Wenlock (7807 $km^2$), Ducie (7050 $km^2$), Jardine (3447 $km^2$) and the Torres Strait Islands (the largest being Home Island (56 $km^2$) and Thursday Island (4 $km^2$).

The Coleman River rises near the Musgrave Roadhouse on the Peninsula Development Road and ends its journey between Pormpuraaw to the north and Kowanyama to the south where it drains into the Gulf of Carpentaria.

The Holroyd and Archer rivers rise in the rainforests of the McIlwraith Range and traverse the vast savannah landscape and enormous wetlands of western Cape York.

The Watson River just south of Weipa on the west coast of Cape York tumbles into Archer Bay in the Gulf of Carpentaria from its journey through the Cape’s distinct savannah forest landscape and plentiful wetlands.

The region consists of a complex geology dominated by the Torres Strait Volcanics in the north (Figure WC-4). The metamorphic rocks and acid intrusive rocks of various ages of the Coen-Yambo Inlier run north to south along the eastern margin of the region and encompass the high-altitude/high-rainfall areas of Iron Range and McIlwraith Range. The deeply dissected sandstone plateaus and ranges of the Battle Camp Sandstones lie in the south of the region adjacent to the undulating Laura Lowlands composed of residual weathered sands and flat plains of colluvial and alluvial clays, silts and sands. The west of the region is dominated in the south by the extensive Tertiary sand sheets dissected by the intricate drainage systems of the Holroyd Plain, the Tertiary laterite of the undulating Weipa Plateau and the low rises of Mesozoic sandstones. The northern extension of the Weipa Plateau and extensive coastal plains adjoin the Gulf of Carpentaria. Extensive aeolian dunefields lie in the east associated with Cape Bedford/Cape Flattery in the south and the Olive and Jardine rivers.

 

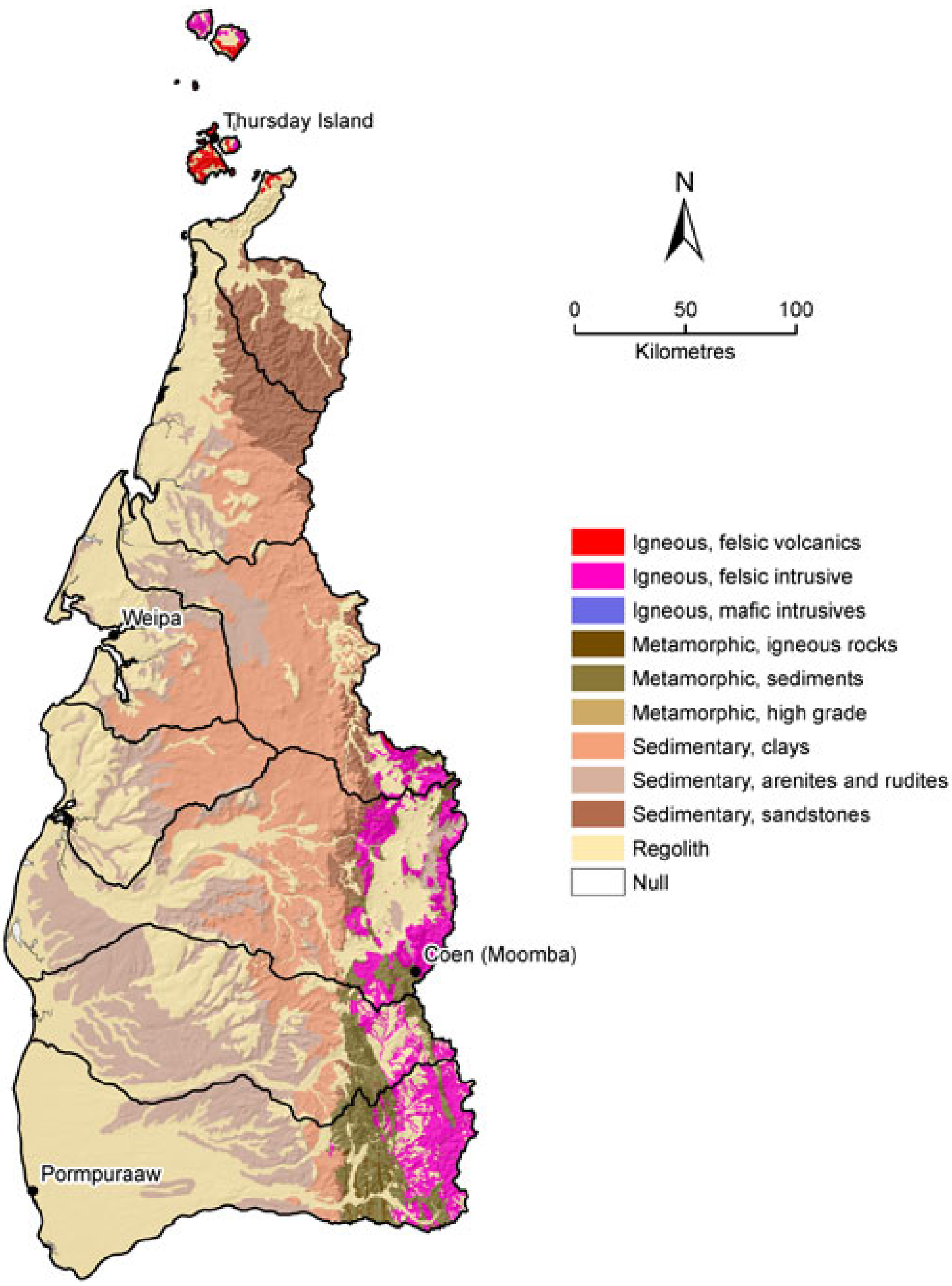


Figure WC-4. Surface geology of the Western Cape region overlaid on a relative relief surface

### WC-2.1.2 Climate, vegetation and land use

The Western Cape region receives an average of 1417 mm of rainfall over the September to August water year, most of which (1370 mm) falls in the November to April wet season (Figure WC-5). Across the region there is a strong east–west gradient in annual rainfall, ranging from 1054 mm in the east to 1809 mm in the west. Over the 1930 to 2007 period, annual rainfall has been gradually increasing from an initial average of around 1300 mm to approximately 1500 mm later in the period. The highest regionally averaged yearly rainfall received was 2033 mm which fell in 1974, and the lowest was 735 mm in 1961.

Areal potential evapotranspiration (APET) is very high across the region, averaging 1874 mm over a water year, and varies moderately across the seasons. APET generally remains higher than rainfall from April until November resulting in water-limited conditions over these months. Between December and March conditions are energy-limited meaning more rain falls than can potentially be evaporated.

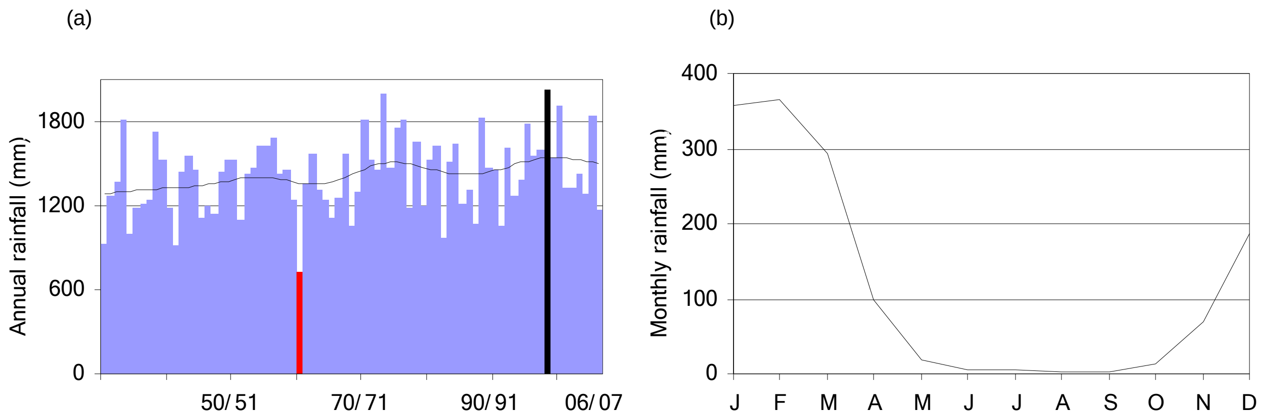


Figure WC-5. Historical (a) annual and (b) mean monthly rainfall averaged over the Western Cape region. The low-frequency smoothed line in (a) indicates longer term variability

The most extensive vegetation types are predominantly *Eucalyptus tetrodonta* woodlands, usually in association with bloodwoods *Corymbia nesophila, C. hylandii* or *C. clarksoniana*, and *Melaleuca viridiflora* low open-woodlands (Figure WC-6) Other extensive vegetation types include *Corymbia clarksoniana, Eucalyptus chlorophylla* and *E. cullenii* woodlands; grasslands and grassy open-woodlands; heathlands; sedgelands; and notophyll vine forests, with semi-deciduous mesophyll vine forests on the eastern ranges and deciduous vine thickets on drier western slopes. Extensive mangrove forests are found in Kennedy Inlet in the north-east of the region and estuaries on both the west and east coasts.

 

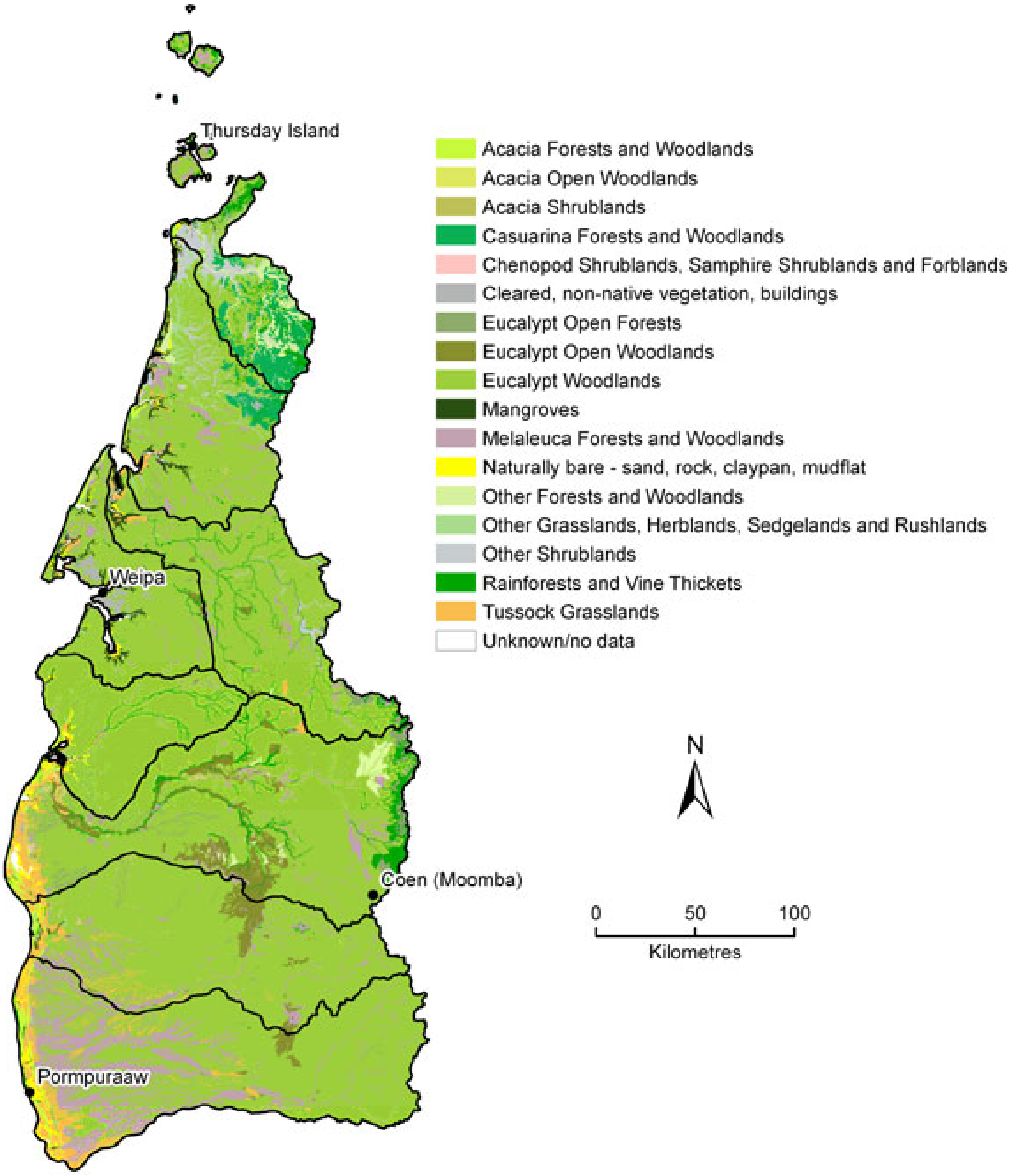


Figure WC-6. Map of current vegetation types across the Western Cape region (source DEWR, 2005)

Pastoralism is the dominant land use throughout the region (Figure WC-7). There are also large areas of nature conservation, Indigenous land use and forestry.

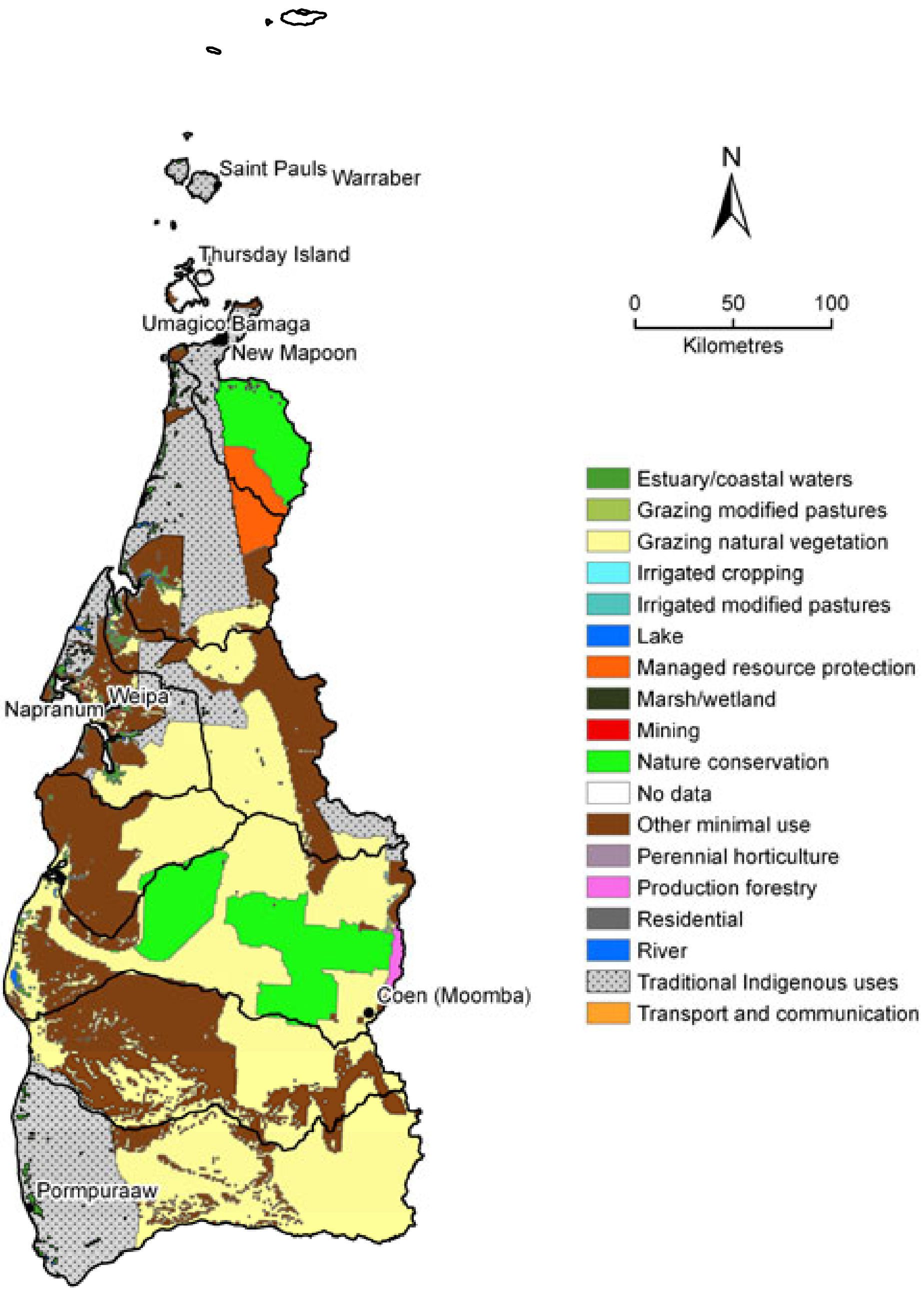


Figure WC-7. Map of dominant land uses of the Western Cape region (after BRS, 2002)

### WC-2.1.3 Regional environmental asset description

Environmental assets were chosen from wetlands which are listed in the Directory of Important Wetlands in Australia (Environment Australia, 2001). From this directory, environmental assets were shortlisted for assessing changes to the hydrological regime under the climate and development scenarios. The selection of this shortlist was undertaken in consultation with state governments and the Australian Government through direct discussions and through internal reviews (see Section 1.3 in the division-level Chapter 1 for further detail).

All nationally, or internationally, important wetlands listed for the Western Cape region in the Directory of Important Wetlands in Australia (Environment Australia, 2001) are detailed in Table WC-2, with asterisks identifying the four shortlisted assets: Archer River Aggregation, Jardine River Wetlands Aggregation, Northern Holroyd Plain Aggregation, and Port Musgrave Aggregation. The location of these shortlisted wetlands is shown in Figure WC-1. There are no wetlands classified as Ramsar sites in this region. Wetlands may be nationally or regionally significant depending on more locally specific criteria. All wetlands are important for a variety of ecological reasons or because they bear historical significance or have high cultural value, particularly to Indigenous people.

 

The following section characterises these shortlisted wetlands and is based largely on the description of these assets as outlined by Environment Australia (2001). Chapter ID-3 presents the assessment of those shortlisted assets, and reports hydrological regime metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis.

Table WC-2. List of Wetlands of National Significance located within the Western Cape region

| Site code | Name | Area | Ramsar site |
|---|---|---|---|
| | | ha | |
| QLD056 | Archer Bay Aggregation | 29,900 | No |
| QLD057 * | Archer River Aggregation | 150,000 | No |
| QLD058 | Bull Lake | 27 | No |
| QLD063 * | Jardine River Wetlands Aggregation | 81,800 | No |
| QLD067 | Northeast Karumba Plain Aggregation | 183,000 | No |
| QLD068 * | Northern Holroyd Plain Aggregation | 1,110,000 | No |
| QLD071 * | Port Musgrave Aggregation | 52,700 | No |
| QLD074 | Skardon River - Cotterell River Aggregation | 63,200 | No |
| QLD075 | Somerset Dunefield Aggregation | 7,940 | No |
| QLD113 | Southeast Karumba Plain Aggregation | 336,000 | No |

* Asterisk against the site code identifies those assets which are shortlisted for assessment of changes to flow regime.

## Archer River Aggregation

The Archer River Aggregation (Figure WC-8) is probably the best example of a large, relatively pristine system of riverine and associated wetland types characteristic of the western Cape York Peninsula. The site has an area of 150,000 ha and an elevation between 2 m and 139 m above sea level (Environment Australia, 2001).


Figure WC-8. False colour satellite image of the Archer River Aggregation (derived from ACRES, 2000). Clouds may be visible in image

This site has very high wilderness value and contains many vegetation communities that are either rare or are amongst the best examples of their class on Cape York Peninsula. The riparian forest is an important corridor for the dispersal of many species between the extensive rainforests on the east coast and the smaller sand-ridge rainforests on the west coast. It is also an important dry season corridor for woodland species. The coastal extents are important habitat for seasonal waterfowl and the Archer system has a significant hydrological role in maintaining the extensive permanent and semi-permanent Aurukun coastal wetlands (Environment Australia, 2001).

### Jardine River Wetlands Aggregation

The Jardine River Wetlands Aggregation (Figure WC-9) contain the largest area and amongst the best examples of sedgeland on Cape York Peninsula (Abrahams et al., 1995). The wetland vegetation of the area is very diverse, reflecting differences in development and hydrology. The site is centred on the large floodplain of the Jardine River and the alluvial plains of its major tributaries. This area contains the largest and most widely spaced series of beach ridges on Cape York Peninsula. The site has an area of 81,800 ha and an elevation between zero and 40 m above sea level (Environment Australia, 2001). The area contains well-developed and representative examples of the landforms associated with an aggrading coastline.

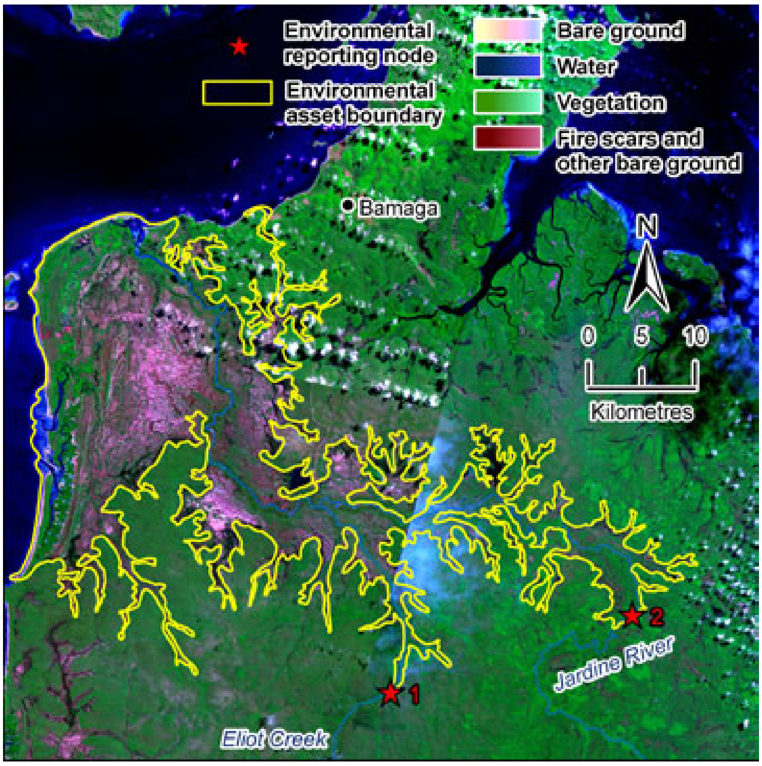


Figure WC-9. False colour satellite image of the Jardine River Wetlands Aggregation (derived from ACRES, 2000). Clouds may be visible in image

Most of the site is of high to very high wilderness value. The site supports mangrove communities, swampy woodland, pure stands of northern paperbark forest and palm forests. The shoreline of the site is important habitat for numerous bird species while terrestrial areas support populations of bats, frogs, snakes and turtles.



 

## Northern Holroyd Plain Aggregation

The Northern Holroyd Plain Aggregation (Figure WC-10) contains the best examples of a characteristic suite of wetlands occurring on one of the most striking land surfaces of the Cape York Peninsula. Certain areas have never been grazed and contain some of the most pristine inland wetlands in western Cape York (Environment Australia, 2001). The aggregation comprises a huge area of wetland totally within an area of uniformly very high wilderness quality (Abrahams et al., 1995). It contains significant drought and seasonal habitat refuge for waterbird species which disperse in relatively small flocks over the hundreds of individual wetlands which make up the aggregation. The area contains large tracts of the highest quality wilderness recognised for the Cape York Peninsula. The site has an area of 1,110,000 ha and an elevation between 10 m and 90 m above sea level (Environment Australia, 2001).

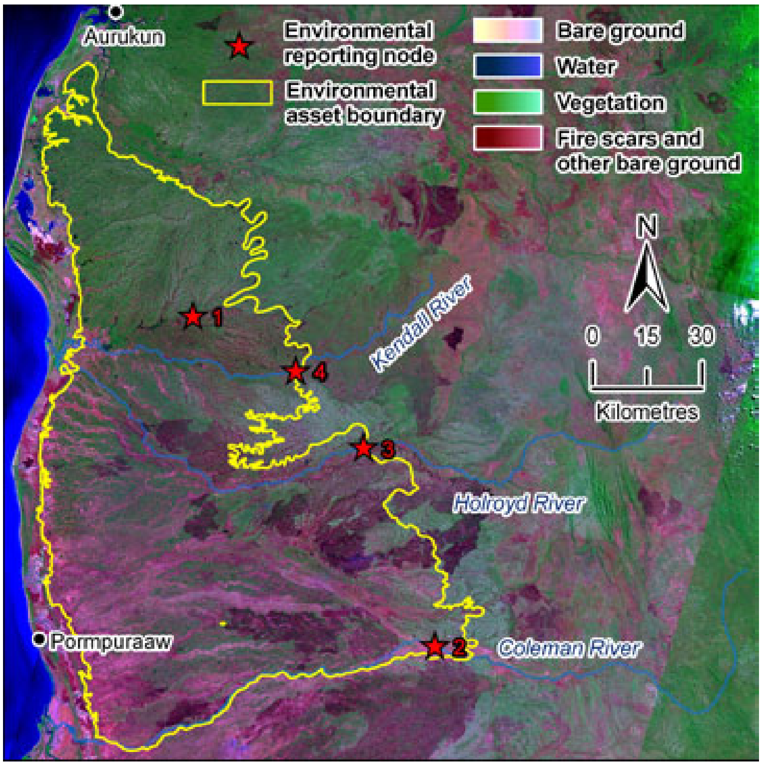


Figure WC-10. False colour satellite image of the Northern Holroyd Plain Aggregation (derived from ACRES, 2000). Clouds may be visible in image

The vegetation of ephemeral lakes and ponds is dominated by grasses and sedges. There is a seasonal variation reflecting the waxing and waning of the water bodies; grasses tend to dominate during the dry season and sedges during the wet (Environment Australia, 2001). The site contains areas of high cultural significance to Indigenous people associated with the Kowanyama, Pormpuraaw and Aurukun communities.

## Port Musgrave Aggregation

The Port Musgrave Aggregation (Figure WC-11) has been identified as one of the most important areas of crocodile habitat on the Cape York Peninsula (Taplin, 1987; Magnusson et al., 1980). The number of crocodiles recorded in the area was nearly double that recorded at any of the other surveyed sites on Cape York Peninsula. The large numbers recorded are considered to be related to the large extent of good nesting habitat present. The mangrove forests of the Wenlock and Ducie rivers are outstanding representative examples of their type. The site has an area of 52,700 ha and an elevation between zero and 5 m above sea level (Environment Australia, 2001).

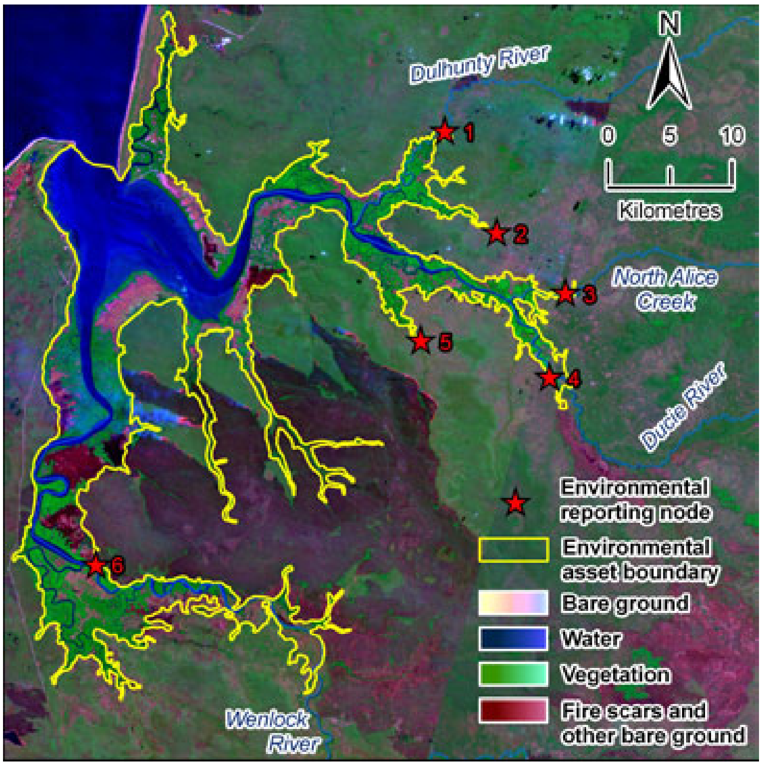


Figure WC-11. False colour satellite image of the Port Musgrave Aggregation (derived from ACRES, 2000). Clouds may be visible in image

There are approximately 4800 ha of seagrass beds in shallow water at the mouth of Port Musgrave. A little over half of the area of these beds is located within the site (Environment Australia, 2001). There are numerous mangrove communities and small but significant areas of evergreen notophyll riparian vine forest.



 

## WC-2.2 Data availability

### WC-2.2.1 Climate

The rainfall-runoff modelling uses historical daily climate data (Scenario A) from the SILO database for the period 1 September 1930 to 31 August 2007 at 0.05 x 0.05 degree (~ 5 x 5 km) grid cells. Full details and characterisation of the SILO database are provided at the division level in Section 2.1 of Chapter 2. Scenario B and Scenario C climate data are rescaled versions of the Scenario A data; this is also discussed in Section 2.1 of Chapter 2.

### WC-2.2.2 Surface water

Streamflow gauging stations are or have been located at 20 locations within the Western Cape region. Six of these gauging stations either: (i) are flood warning stations and measure stage height only; or (ii) have less than ten years of measured data. Of the remaining 14 stations, five recorded more than half of their total volume of flow during events that exceed the maximum gauged stage height. Figure WC-12 shows the spatial distribution of good quality data (duration) for flows above maximum gauged stage height (MGSH). There are six gauging stations currently operating in the Western Cape region at density of one gauge for every 11,100 km$^2$. For the 13 regions the median number of gauging stations per region is 12 and the median density of gauging stations per region is one gauge for every 9,700 km$^2$. The Western Cape region has a slightly lower density of current gauging stations than the median of the 13 regions across northern Australia. The density of stations in the Western Cape region is considerably lower than the Murray-Darling Basin average. The mean density of current stream gauging stations across the entire Murray-Darling Basin is one gauge for every 1,300 km$^2$.

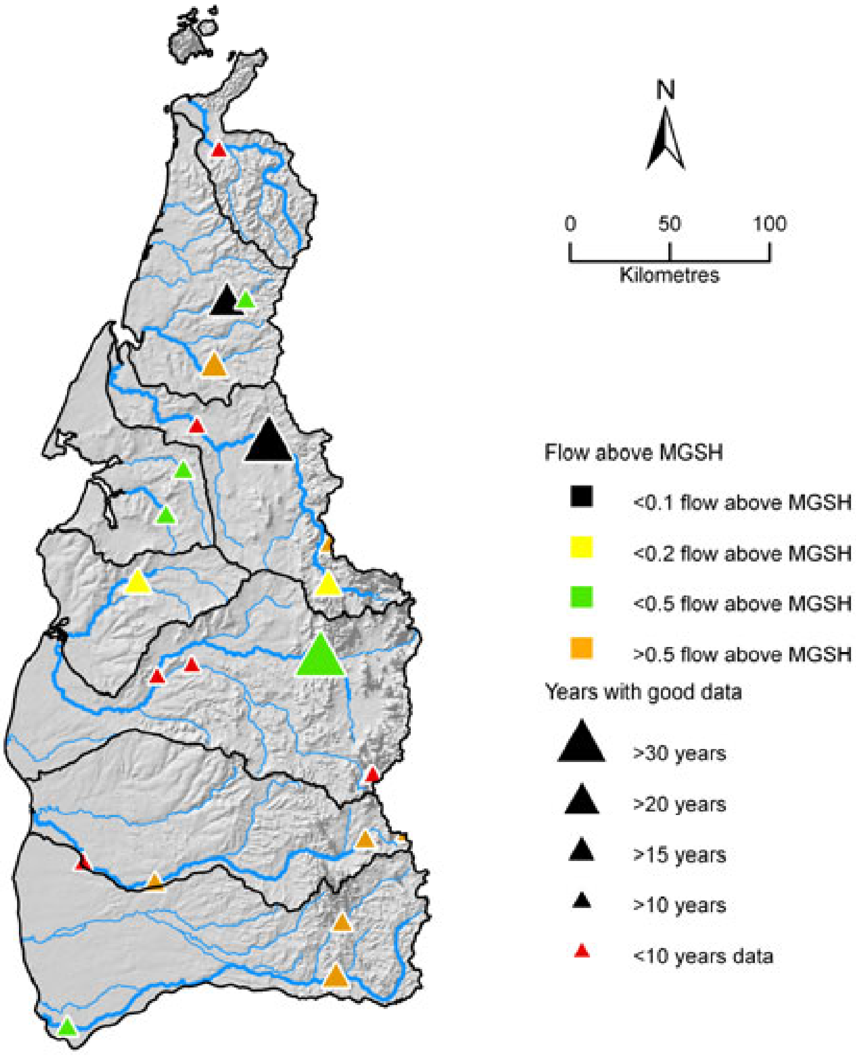


Figure WC-12. Location of streamflow gauging stations overlaid on a relative relief surface showing the proportion of gauges with flow above maximum gauged stage height across the Western Cape region

 

## WC-2.2.3 Groundwater

The Western Cape region contains a total of 585 registered groundwater bores. Of these, 245 bores have surveyed elevations that could enable watertable surfaces to be constructed for the main aquifers. However these bores are not necessarily monitored on a regular basis. There are 13 water level monitoring bores in the region; four are historical and nine are current (Figure WC-13). Of the nine current monitoring bores, one is for the Great Artesian Basin (GAB) aquifer and eight are for sub-artesian aquifers.

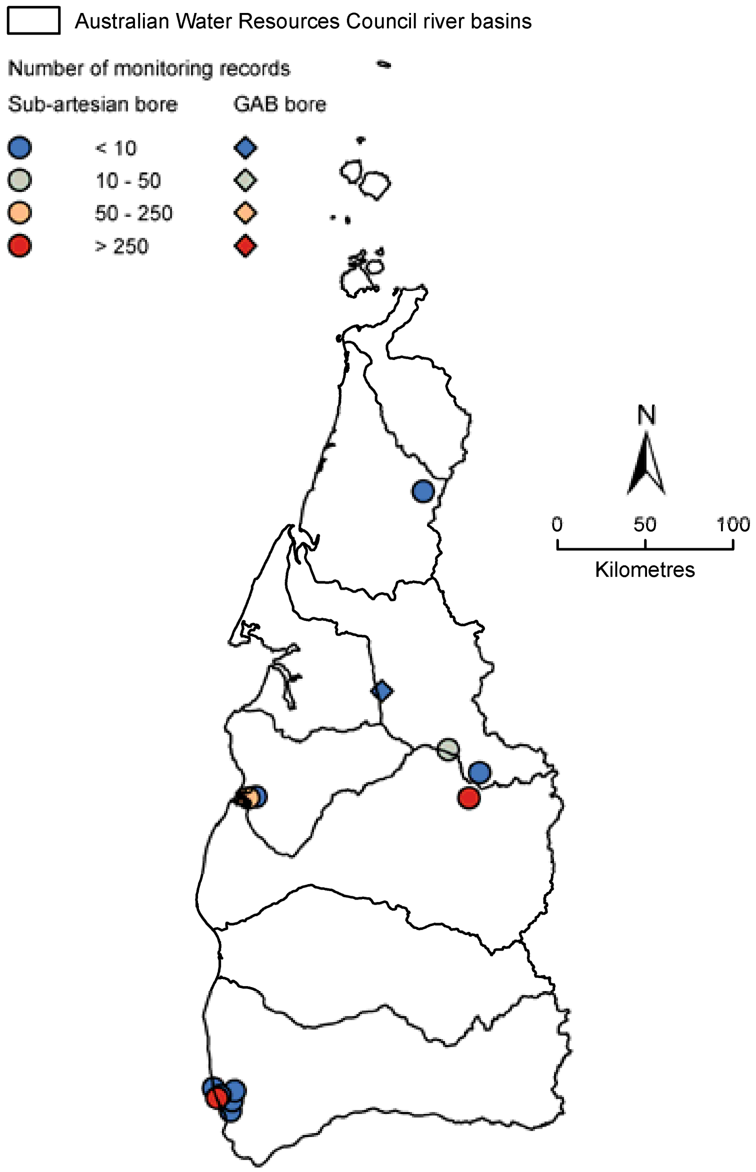


Figure WC-13. Current groundwater monitoring bores in the Western Cape region

## WC-2.2.4 Data gaps

Time series groundwater level and salinity data are required for each of the main aquifer types in the Western Cape region to provide greater understanding of recharge processes and inter-aquifer leakage, particularly for the Great Artesian Basin aquifers.

# WC-2.3 Hydrogeology

This section describes the key sources of groundwater in the Western Cape region.

## WC-2.3.1 Aquifer types

The majority of the Western Cape region is underlain by aquifers of the GAB. The exception is the Coen Inlier which occurs in the east of the region (Figure WC-2). A veneer of Tertiary and Quaternary sediments also provides shallow, localised aquifers.

### Fractured rock aquifers of the Coen Inlier

The Coen Inlier resides along the eastern margin of the Western Cape region. It comprises Precambrian age metamorphics and predominantly Carboniferous to Permian age intrusive rocks that have experienced tectonic compression and metamorphism (Horn et al., 1995). The fractured rock aquifers derive groundwater storage capability from secondary porosity features such as joints, faults and voids. Aquifer yields are generally low, but are also highly variable depending on the character of fractures intersected when drilling.

The primary source of groundwater is contained within the weathered zones of the granite of the Coen Inlier, with water bores typically constructed to depths of less than 25 m (Horn et al., 1995). Below this depth the granite becomes massive, with negligible groundwater storage capacity.

### Great Artesian Basin aquifers

The Great Artesian Basin comprises a multi-layered confined aquifer system, with aquifers occurring in Triassic, Jurassic and Cretaceous continental quartzose sandstones, predominantly confined by low permeability mudstones and siltstones.

The Gilbert River Formation occurs across the entire region, west of the Great Dividing Range. It comprises fine- to coarse-grained quartzose sandstone with pebble conglomerate and siltstone. The Gilbert River Formation is confined in the south of the region, by the mudstones of the overlying Rolling Downs Group. Large supplies (>60 L/second) of medium quality groundwater can be obtained from the Gilbert River Formation aquifer from bores that intersect the entire sandstone sequence (Figure WC-2). The Helby Beds are considered an equivalent of the Gilbert River Formation, the main difference being that they are unconfined. Shallow bores that intersect the unconfined Gilbert River Formation typically provide yields of 1 to 5 L/second of good quality groundwater (DNRM, 2005).

The Garraway Beds underlie the Gilbert River Formation in the Aurukun and Holroyd areas. The Garraway Beds are similar to the Gilbert River Formation in lithology and the combined thickness of these two units is 200 to 300 m in the area around the Edward River (McEniery, 1979).

### Cainozoic aquifers

The Bulimba Formation occurs across the entire Western Cape region, west of the Great Dividing Range, with significant areas of outcrop occurring north of the Holroyd River. The Bulimba Formation comprises fluvial sediments derived mainly from the weathering of the Gilbert River Formation outcrop in the eastern part of the region. Aquifers are typically constrained to old stream channels which trend easterly and meander through a matrix of clayey, less transmissive sediments and hence are not continuous and not always in hydraulic connection with one another. In the Aurukun area, the easterly trending sand bodies are in the order of 100 m wide and are utilised for stock and domestic purposes (Pettifer et al., 1976). South of approximately the Archer River, the Bulimba Formation is overlain by the Wyaaba Beds and contains locally artesian aquifers (Pettifer et al., 1976).

The Bulimba Formation has been affected by several episodes of lateritic weathering which has formed a highly permeable, pisolitic, bauxite cap. The bauxite is typically 20 m thick and underlain by approximately 80 m of Bulimba Formation (Coffey & Hollingsworth, 1975). The bauxite is usually unsaturated, with the watertable residing in the underlying Bulimba Formation.

The Upper Tertiary Wyaaba Beds are typically 80 m thick (Grimes, 1977) and have a similar lithology to the Bulimba Formation. The marine facies of the Wyaaba Beds is characterised by muddy, coralline limestone and forms the main aquifer of this formation. The limestone aquifer of the Wyaaba Beds is found near the base of the formation and is up to 50 m thick (DNRMW, 2006). The Wyaaba Beds limestone aquifer is limited to the present day coastline and only supplies artesian water up to 50 km inland from the coast (Horn et al., 1995). The Wyaaba Beds are not considered a significant groundwater resource outside of the area where the limestone occurs.

There is negligible information available for either the Quaternary alluvial or coastal deposits. Overall they do not provide a viable groundwater resource, as extraction is difficult due to the fine-grained nature of the sediments. Furthermore, the saline conditions and risk of saltwater intrusion are key factors against development of the coastal aquifers. Shallow groundwater may be obtained from the valley alluvium associated with the larger rivers.

### WC-2.3.2 Inter-aquifer connection and leakage

There is potential for inter-connection and leakage via upward vertical flow from the Gilbert River and the Bulimba Formations, to the overlying alluvial sediments. Typical positive head pressures of bores tapping the confined Gilbert River Formation aquifers are 25 m in the western onshore margins (DNRM, 2005). Upward leakage is likely to occur where the confining beds are thin and hydraulic gradients are high, conditions typical of marginal areas of the basin. It will also occur where faults act as conduits for the upward migration of groundwater. Despite the low permeability and percolation rates, this leakage probably accounts for considerable volumes of discharge (DNRM, 2005). The presence of springs along the eastern margin of the region (in the recharge area) predominantly results from the rejection of aquifer recharge.

During the wet season this process is essentially reversed, as stream leakage recharges the unconfined aquifers through which they are incised.

Tidal influences have been recognised in bores constructed in the Wyaaba Beds, which was interpreted by Horn et al. (1995) to indicate aquifer outcrop on the seabed to the west. The aquifer is hydraulically connected to seawater under the Gulf of Carpentaria and thus is at risk of saltwater intrusion if the groundwater levels of the aquifer decline.

### WC-2.3.3 Recharge, discharge and groundwater storage

#### Fractured rock aquifers of the Coen Inlier

Fractured rock aquifers of the Coen Inlier are recharged via the vertical infiltration of rainfall where the basement outcrops. Recharge to fracture zones will be rapid in areas where fractures persist to great depths. Where fractures are exposed to ephemeral streams, a significant volume of groundwater recharge is likely to occur during the wet season.

#### Great Artesian Basin aquifers

Groundwater moves in a westerly direction from what are known as ‘recharge beds’ or ‘intake beds’ (Figure WC-3) to the Gulf of Carpentaria, along an estimated gradient of 1 in 1000 (Coffey and Hollingsworth, 1975).

The primary recharge mechanisms to the GAB aquifers include diffuse rainfall, preferred pathway flow, and localised recharge beneath rivers, creeks and alluvial groundwater systems overlying the intake beds (Kellett et al., 2003). Preferred pathway flow involves the movement of water through conduits such as fissures, joints, remnant tree roots or highly permeable beds and is considered the dominant recharge process for the intake beds. Diffuse rainfall recharge and localised recharge occurs where the GAB sandstone aquifers outcrop along the elevated western slopes of the Great Dividing Range.

Discharge from the GAB occurs in a number of ways, including:

- natural discharge from springs. Springs are quite common in the recharge areas to the north-east of the region where the GAB aquifers are recharged. The location of springs can be seen in Figure WC-3. They are mainly associated with ‘overflow’ or the ‘rejection’ of recharge into aquifers, or from the interaction between the local topography and aquifers.
- upward vertical leakage through the confining beds towards the regional watertable. This occurs throughout the basin and, despite the slow percolation rates, may constitute a significant volume of water
- subsurface outflow from the GAB into the Gulf of Carpentaria (although little is known about the volume or significance of this form of discharge)

- artificial discharge, via artesian flow and pumped extraction from wells drilled into aquifers.

### Cainozoic aquifers

The Bulimba Formation is predominantly recharged via the vertical infiltration of rainfall. The watertable tends to rise and fall simultaneously over the whole Bulimba Formation aquifer without any lag, which indicates that recharge does not occur at a distant source, but via direct rainfall infiltration (Coffey and Hollingsworth, 1971). The watertable rises each wet season by an amount which is dependent upon, but not directly proportional to, rainfall. A rise in watertable level is typically not observed until wet season rainfall has exceeded approximately 1 m. Prior to this, rainfall is accounted for by evapotranspiration, surface runoff and wetting of the upper strata (Coffey and Hollingsworth, 1975).

Discharge from the Bulimba Formation occurs as discharge to creeks. Drainage from the aquifer helps maintain flow in a number of creeks during the dry season.

The Wyaaba Beds limestone aquifer is completely confined and has no known onshore outcrop. The primary recharge mechanism is suspected to be via lateral groundwater inflow from the east (NRMW, 2006). Given that the water levels of the aquifer have remained relatively stable throughout the 1980s and early 1990s, it is unlikely that the aquifer receives no recharge (WRC, 1993).

## WC-2.3.4 Groundwater quality

Figure WC-14 shows groundwater salinity at approximately 100 bores in the Western Cape region. The majority of the bores have groundwater salinity of less than 5000 µS/cm. These bores have measurement dates ranging from 1967 to 1997, and represent total depths of between 3 m and more than 1000 m below ground surface. Hence there are no apparent trends in the spatial distribution of groundwater salinity in this map because the data represents groundwater from multiple aquifers (shallow and deep).

Groundwater salinity within the fractured rock aquifers of the Coen Inlier is typically higher when derived from the granites as opposed to the metamorphic rocks (Horn et al., 1995). The Department of Natural Resources and Water (DNRW) records groundwater quality information for 17 bores constructed in the fractured rock aquifers. These bores have groundwater salinity observations ranging from 255 to 4760 µS/cm EC. The median salinity observation is 1700 µS/cm.

Groundwater from deeper sections of the Gilbert River Formation is not suitable for human consumption, due to the high fluoride concentration of between 2 and 10 mg/L (Horn et al., 1995). In the Western Cape region, the DNRW has groundwater quality information for three bores constructed in the Gilbert River Formation and equivalents. These three bores have depths of 54, 101 and 121 m and latest salinity measurements of 158, 210 and 691 µS/cm EC, respectively.

The DNRW has groundwater quality information for 42 bores constructed in the Bulimba Formation. Salinity observations range from 24 to 3750 µS/cm, with a mean value from all records of 53 µS/cm.

Groundwater quality for the Pormpuraaw Town bore, constructed in the Wyaaba Beds, averages 790 mg/L TDS (WRC, 1993). The salt/fresh water interface for the Wyaaba Beds aquifer occurs approximately 2 km offshore and hence seawater intrusion is not currently an issue. Successions of poor wet seasons, however, are likely to have caused the landward movement of the saltwater interface.



 

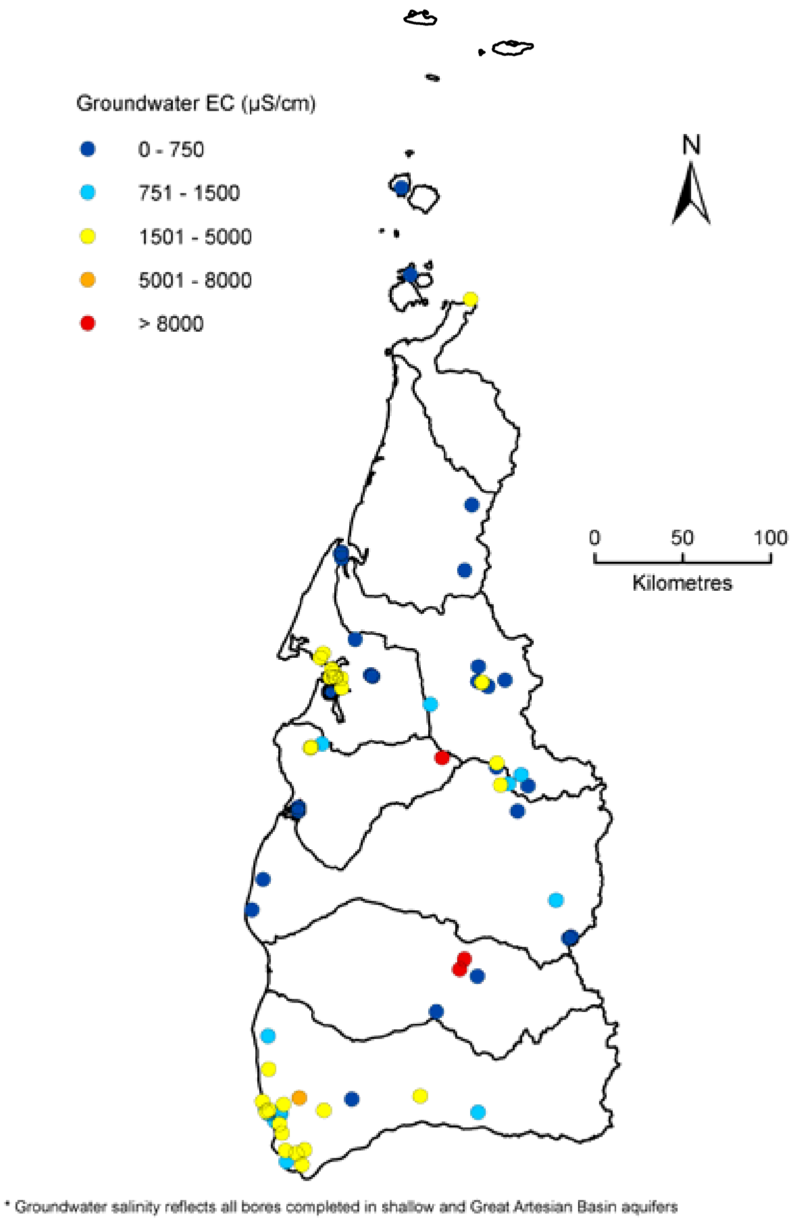


Figure WC-14. Groundwater salinity (as electricalconductivity – EC) distribution for all bores drilled in the Western Cape region

# WC-2.4 Legislation, water plans and other arrangements

## WC-2.4.1 Legislated water use, entitlements and purpose

Seven river basins in the Western Cape region are either declared or potential wild river areas. The *Wild Rivers Act 2005* includes a process for the Minister for Natural Resources to declare wild river areas. The intent of the legislation it preserve the natural values of rivers that have all or almost all of their natural values intact - wild rivers. It does this by regulating most future development activities and resource allocations within a declared wild river and its catchment - the wild river area. A wild river declaration will include water allocation limits by including unallocated water held in reserves for specific purposes. New development activities will be regulated through existing development assessment process with wild river requirements applied through a wild river declaration or the wild rivers code. Development and authorisations in place at the time a declaration is made are not affected and continue.

## WC-2.4.2 Groundwater use and entitlements

Groundwater entitlement volumes and estimated stock and domestic use volumes were reported as part of the *Water Resource (Great Artesian Basin) Plan 2006* (listed under the *Water Act 2000*). This information was collated in terms of the management areas defined for the GAB in Queensland (Table WC-3) and has been reconfigured by DNRW to estimate volumes for the Northern Australia Sustainable Yields Project reporting regions.

Groundwater sourced from the GAB aquifers is vital to the outback regions of Queensland, as it is often the only reliable water supply for towns, stock and domestic purposes. The GAB aquifers also provide water for industrial purposes such as mining, power generation, aquaculture, feedlots and piggeries. In the Western Cape region groundwater extraction from the GAB aquifers is dominated by mining use at Weipa.

For the Western Cape region the estimated volume of stock and domestic use is less than 1 GL/year and the volume of licensed entitlements is approximately 30 GL/year (Table WC-3). This table shows that the Cainozoic sediments of the Karumba Basin are the most extensively utilised groundwater source, with approximately 21 GL/year of entitlements assigned to this aquifer, whilst a relatively smaller portion (i.e. approximately 10 GL/year) is assigned to the GAB aquifers.

Table WC-3. Estimated stock and domestic groundwater use and sum of groundwater entitlements for the Western Cape region

| Formation | Stock & domestic use | Entitlement |
|---|---|---|
| | GL/y | |
| Quaternary alluvium | 0.00 | 0.055 |
| Cainozoic sediments (including Karumba Basin) | 0.24 | 21.461 |
| Cretaceous sedimentary rocks | 0.05 | 0.000 |
| Jurassic – Early Cretaceous Great Artesian Basin aquifers | 0.20 | 9.007 |
| Paleozoic rocks | 0.01 | 0.100 |
| Proterozoic rocks | 0.00 | 0.000 |
| **Total volume** | **0.51** | **30.623** |

### Fractured rock aquifers of the Coen Inlier

Groundwater occurs in both the granites and metamorphic rocks of the Coen Inlier. There are three bores in the town of Coen that extract water from the metamorphic rocks and although they provide small groundwater yields (approximately 1 L/second) they are used from September to December in most years when surface water supplies diminish (Horn et al., 1995). Groundwater use is limited in the fractured rock aquifers of the Coen Inlier, due to the variability of groundwater yields.

 

## Great Artesian Basin aquifers

The majority of the Western Cape region is represented by the Cape Management Area (Figure WC-15). This management area serves to protect the groundwater resources of the GAB sediments in the Carpentaria Basin north of the Holroyd River.

The southern portion of the Cape Management Area includes the Gilbert River Formation and the underlying Garraway Beds (which are considered equivalents and hence managed as one resource) which occur between Dulhunty and Holroyd rivers. The major water use from the Gilbert River Formation in this area is for industrial and mining purposes associated with the Comalco bauxite mines near Weipa. The small number of stock and domestic bores that exist in the area are restricted to areas of outcrop to the east, where only shallow bores are required (DNRM, 2005).

The northern third of the Cape Management Area comprises the Helby Beds (equivalent to unconfined Gilbert River Formation). Water use is restricted to stock and domestic purposes in this area.

The springs, streams and associated riparian environments have significant environmental, cultural and economic value. Environmental tourism is the second most important industry after mining in this area.

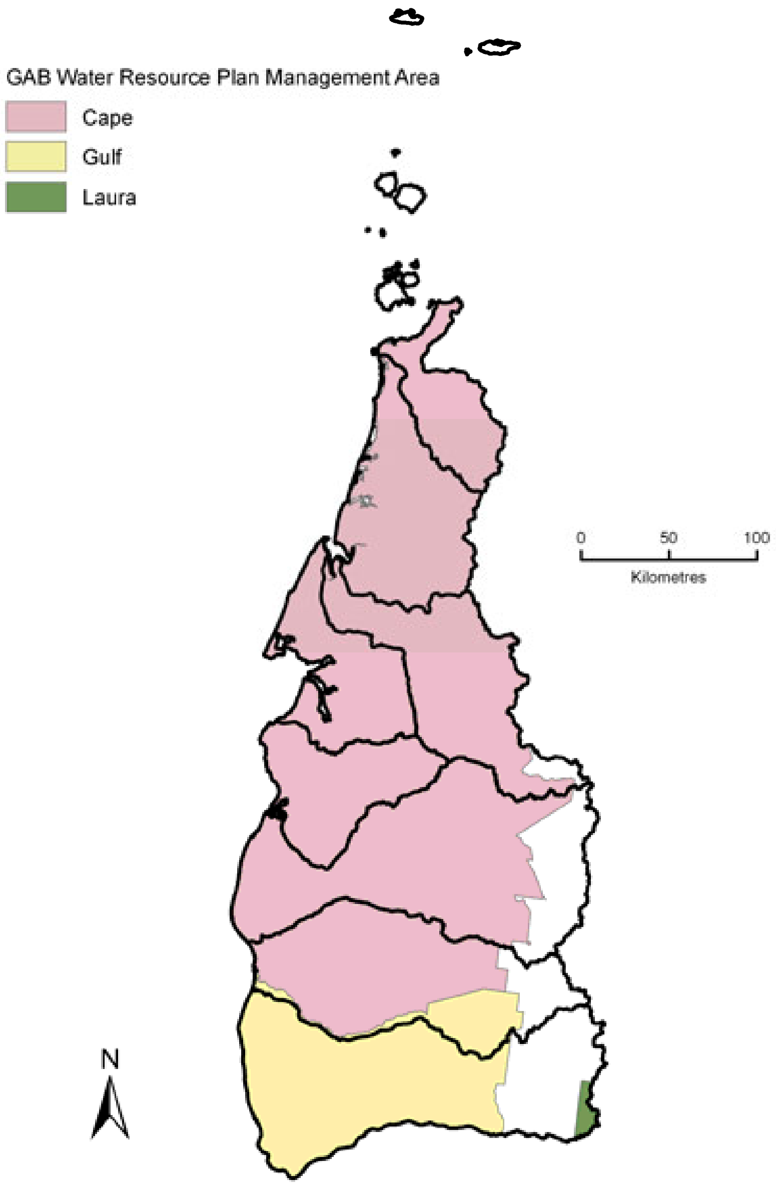


Figure WC-15. Groundwater management areas of the Great Artesian Basin in the Western Cape region

DNRM (2005) concluded that there was no capacity for further allocation of water from the GAB aquifers in the Cape Management Area. This was based on the following issues related to current and future extraction from the Cape area:

- management of current groundwater use
- potential future groundwater use under the existing agreement acts
- potential future groundwater use as part of the Aurukun Project mining proposal
- interaction between the two existing Agreement Acts and the *Water Act 2000*
- preservation of spring discharge and river baseflows and the ecosystems that they maintain.

The current situation is that unallocated water has been made available under the *Water Resource (Great Artesian Basin) Plan 2006* - 100ML in the Gilbert River Equivalents in the Cape area and 10000ML in a State reserve (across the whole GAB). Unallocated water may be granted from the State reserve for a project of State significance, project of regional significance or for water granted to a local government - town water supply purposes. There are applications for 9000ML for State Reserve in the Cape area.

#### Cainozoic aquifers

Good supplies of water can be obtained from small easterly-trending permeable bodies of sand within the Bulimba Formation. These intermittent aquifers occupy approximately 10 percent of the formation and around half of these aquifers reside below the watertable (Pettifer et al., 1976).

The Pormpuraaw community is centred on the alluvial plains dissected by the Edward River. The Wyaaba Beds provide stock and town water supplies in this area. Bores are constructed in the sandy limestone aquifer, at depths of 45 to 65 m below ground surface. The town supply bore provides groundwater yields of 7 L/second.

Underlying the bauxite deposits at Weipa, a sandy aquifer of the Bulimba Formation contains groundwater suitable for industrial and domestic use. It occurs between 5 to 10 m below the surface and is typically 3 to 12 m thick. In excess of 15 bores are constructed in this aquifer.

### WC-2.4.3 Rivers and storages

There are no storages on any rivers in the Western Cape region.

### WC-2.4.4 Unallocated water

Under the *Cape York Peninsula Heritage Act 2007 (Qld)* a wild river declaration must ‘provide for a reserve of water in the area to which the declaration or plan relates for the purpose of helping indigenous communities in the area achieve their economic and social aspirations’. This allocation is known as the Indigenous reserve.

The Archer basin wild river declaration provides for 6000 ML/year as the Indigenous reserve. Additional unallocated water reserves include a Strategic Reserve of 6000 ML/year and a General Reserve of 2000 ML/year.

Table WC-4. Current unallocated waterreserves for the Western Cape region

| Reserve type | Location | Total volume |
|---|---|---|
| | | ML/y |
| Archer River Basin | | |
| General reserve | Undefined | 2,000 |
| Strategic reserve (state purpose) | Undefined | 6,000 |
| Indigenous reserve | Undefined | 6,000 |
| **Total volume** | | **14,000** |

 

### WC-2.4.5 Social and cultural considerations

The Western Cape region is typified by a low mobility of population, low employment in agriculture, manufacturing or mining and high reemployment by government, and low incomes. Most people rent from community organisations. A high percentage, however, have ten years or more of schooling, though there are relatively few vehicles and little Internet access. There is a medium to high percentage of Indigenous people in the region. Indigenous owners are represented by 24 language groups (Thaayorre, Bakanh, Yir Yoront, Kunjen, Wik, Thaayorre, Kaanju, Mungkan, Southern Kaanju, Ayapathu, Winda Winda, Mbeiwum, Kaanju, Yinwum, Luthig, Teppathiggi, Yupangathi, Tjungandi, Thanakwithi, Anggamudi, Mpalitjahn, Teppathiggi, Wuthahti and Yadhaigana).

The exception to these statistics is the Embley River basin, which contains the Weipa bauxite mines and hence has a high percentage of people working in the mining and manufacturing industries.

### WC-2.4.6 Changed diversion and extraction regimes

Only minor diversions and extractions will be permitted across the Western Cape region.

### WC-2.4.7 Changed land use

There is unlikely to be any substantial land use change in the near future.

### WC-2.4.8 Environmental and legislative constraints and implications of future development

Major threats to the wild river values of this region include encroaching invasive weeds, growing numbers of feral pigs, and under-investment in land management. Wild river protection, as well as the Indigenous Wild River Ranger program, will help address these impacts and resourcing issues.

The Queensland Parliament passed the *Wild Rivers Act 2005* in October 2005. The purpose of this Act is to preserve the natural values of rivers that have not been significantly affected by development and thus have all, or almost all, of their natural values intact. It does this by regulating development within a declared wild river and its catchment area, and by regulating the taking of natural resources from the area. The Act establishes a framework that includes the declaration of wild river areas that may include:

- high preservation areas
- preservation areas
- floodplain management areas
- subartesian management areas.

The *Wild Rivers and Other Legislation Amendment Act 2006* was assented to on 7 December 2006. This Act amended the *Wild Rivers Act* (and a number of associated Acts) as well as other unrelated legislation.

The amendments removed a number of unintended consequences and constraints on low-impact economic development, while retaining the original intent of the wild rivers policy. These included allowing low-impact development for mining, transport, agricultural and other industries, and removing many wild river requirements for development in urban areas.

# WC-2.5 References


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# WC-3 Water balance results for the Western Cape region

This chapter describes modelling results and the assessment of the water resources undertaken by this project for the Western Cape region. Detailed, quantified assessments are made where possible, and relevant, and confidence is estimated. Modelling results are reported under climate and development scenarios as defined at the division level in Section 2.1 of Chapter 2. This chapter is sub-divided into:

- climate
- recharge estimation
- conceptual groundwater models
- groundwater modelling results
- rainfall-runoff modelling results
- river system water balance
- changes to flow regimes at environmental assets.



## WC-3.1 Climate

### WC-3.1.1 Historical climate

The Western Cape region receives an average of 1417 mm of rainfall over the September to August water year (Figure WC-16), most of which (1370 mm) falls in the November to April wet season (Figure WC-17). Across the region there is a strong east–west gradient in annual rainfall (Figure WC-18), ranging from 1054 mm in the east to 1809 mm in the west. During the historical (1930 to 2007) period, annual rainfall has been gradually increasing from an initial average of around 1300 mm to approximately 1500 mm later in the period. The highest yearly rainfall received was 2033 mm which fell in 1999, and the lowest was 735 mm in 1961.

Areal potential evapotranspiration (APET) under the historical climate is very high across the region, averaging 1874 mm over a water year (Figure WC-16), and varies moderately across the seasons (Figure WC-17). APET generally remains higher than rainfall from April until November resulting in water-limited conditions over these months. Between December and March conditions are energy-limited meaning more rain falls than can potentially be evaporated.

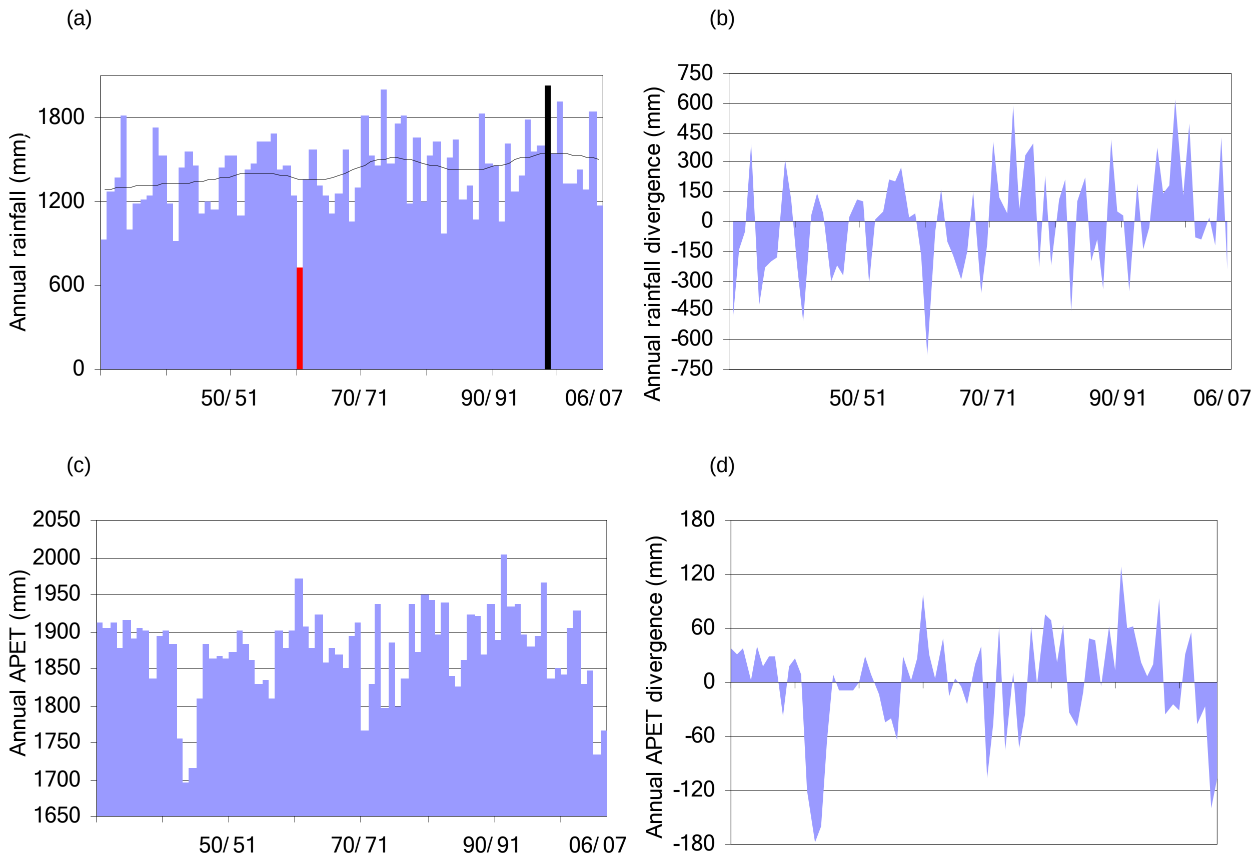



Figure WC-16. (a) Historical annual rainfall and (b) its divergence from the long-term mean; and (c) historical annual areal potential evapotranspiration and (d) its deviation from the long-term mean averaged over the Western Cape region. The low-frequency smoothed line in (a) indicates longer term variability

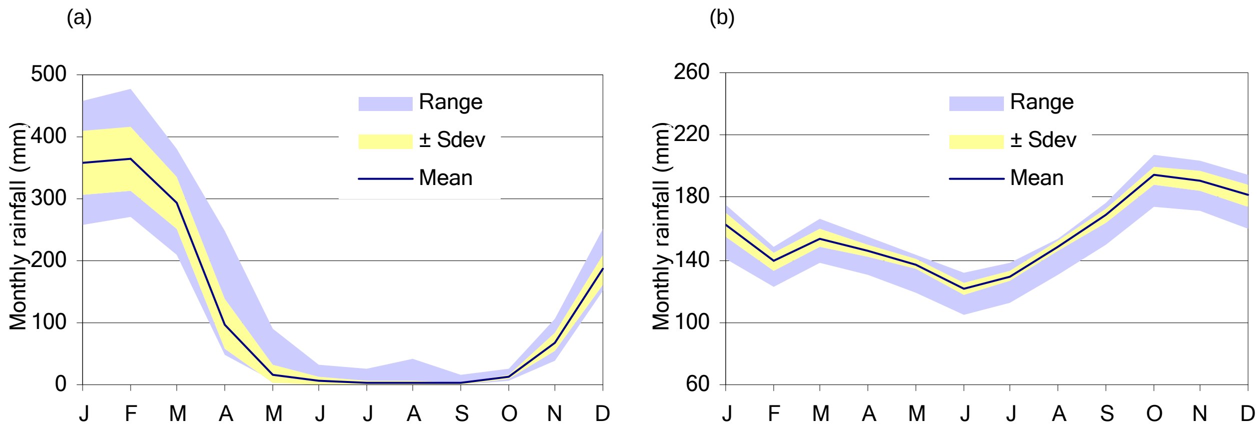



Figure WC-17. Historical mean monthly (a) rainfall and (b) areal potential evapotranspiration and their temporal variation (range and ± one standard deviation) averaged over the Western Cape region

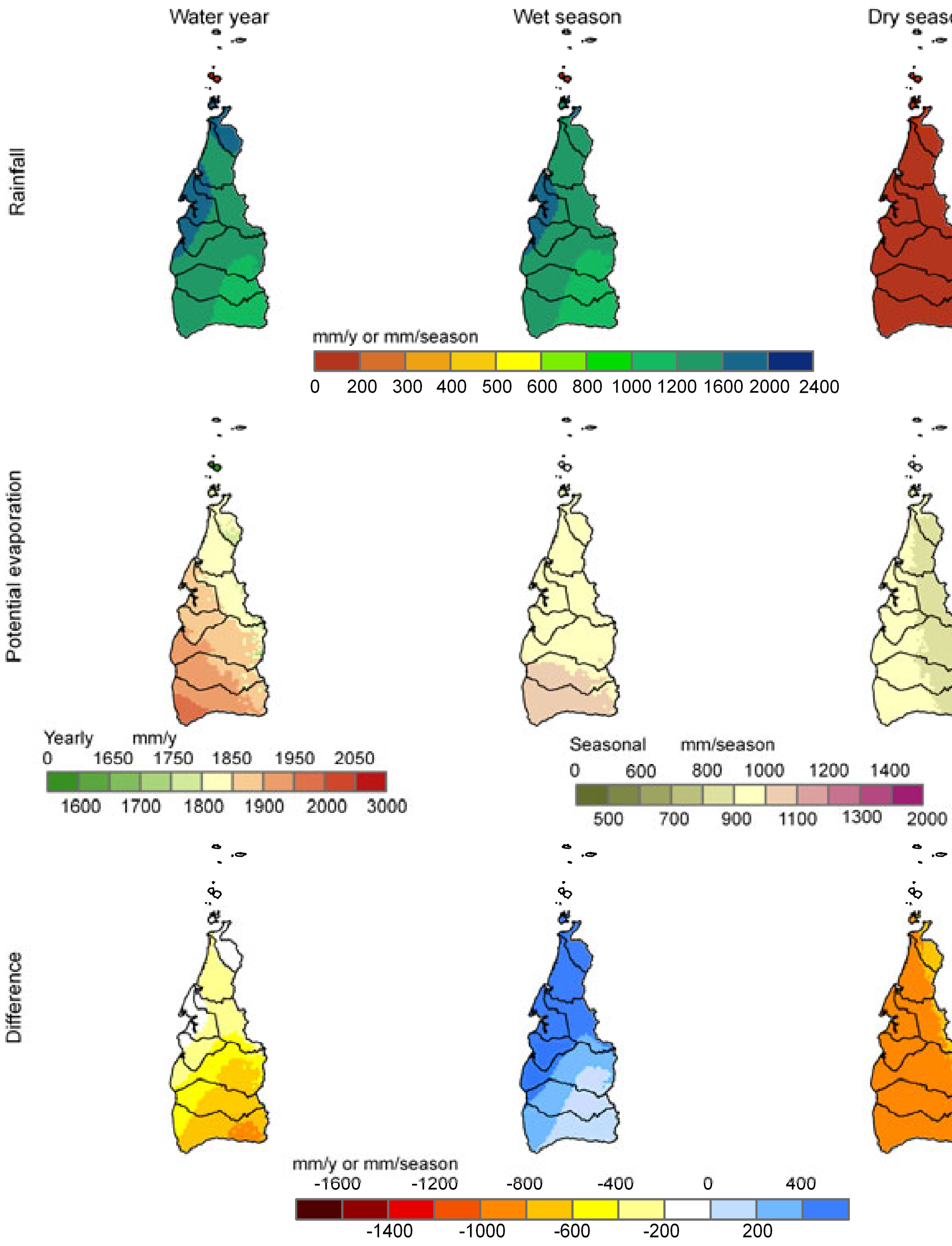



Figure WC-18. Spatial distribution of historical mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration (potential evaporation) and their difference (rainfall less areal potential evapotranspiration) across the Western Cape region

## WC-3.1.2 Recent climate

Figure WC-19 compares recent (1996 to 2007) to historical (in this case the 66-year period 1930 to 1996) mean annual rainfall for the Western Cape region. Across the whole region, recent rainfall is between zero and 30 percent higher than historical rainfall. In the north and south-west of the region there have been statistically significant increases in rainfall.

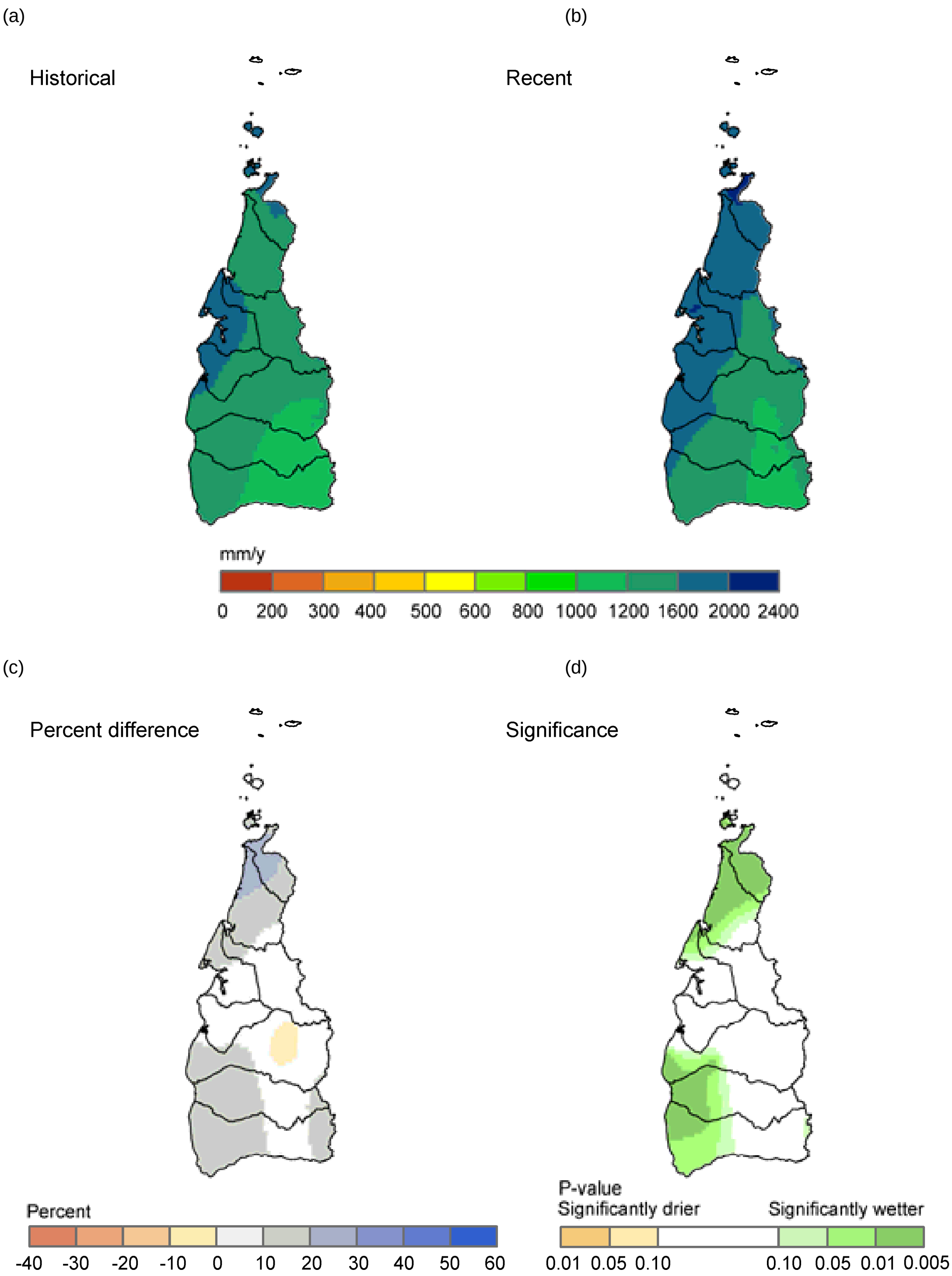



Figure WC-19. Spatial distribution of (a) historical and (b) recent mean annual rainfall; and (c) their relative percent difference and (d) the statistical significance of these differences across the Western Cape region. (Note that historical in this case is the 66-year period 1930 to 1996)

### WC-3.1.3 Future climate

Under Scenario C rainfall varies between 1320 and 1570 mm/year (Table WC-5) compared to the historical mean of 1417 mm/year. Similarly, APET ranges between 1897 and 1944 mm/year compared to the historical mean of 1874 mm/year.

A total of 45 variants of Scenario C were modelled (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). Subsequently, results from an extreme ‘wet’, median and extreme ‘dry’ variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet annual rainfall and APET increase by 11 percent and 2 percent, respectively. Under Scenario Cmid both annual rainfall and APET increase by 1 percent. Under Scenario Cdry annual rainfall decreases by 7 percent and APET increases by 4 percent.

Under Scenario Cmid monthly averages of rainfall and APET do not differ much from historical values (Figure WC-20). Under Scenario Cmid rainfall lies well within the range in values from all 45 future climate variants. The seasonality of rainfall is expected to change in that wet season rainfall decreases slightly. In contrast the seasonality of APET remains the same as any changes occur uniformly across the year. Under Cmid (and the majority of all Scenario C variants) APET is lower than historical values for every month of the year.

The spatial distributions of rainfall and APET under Scenario C are compared to the historical distribution in Figure WC-21 and Figure WC-22. Under Scenario C the strong east–west gradient in rainfall is retained in the wet season, with greatest changes in rainfall in the north. The spatial distribution of APET under Scenario C is similar to the highly regionalised historical distribution. The greatest changes to APET occur in the south of the region.

Table WC-5. Mean annual (water year), wet season and dry season rainfall and areal potential evapotranspiration in the Western Cape region under historical climate and Scenario C

| | Water year* | Wet season | Dry season |
|---|---|---|---|
| | mm/y | mm/season | |
| Rainfall | | | |
| Historical | 1417 | 1370 | 47 |
| Cwet | 1570 | 1502 | 48 |
| Cmid | 1435 | 1369 | 48 |
| Cdry | 1320 | 1265 | 39 |
| Areal potential evapotranspiration | | | |
| Historical | 1874 | 974 | 900 |
| Cwet | 1902 | 979 | 921 |
| Cmid | 1897 | 982 | 913 |
| Cdry | 1944 | 1013 | 929 |

* Note that the sum of the wet season and dry season values does not always equal the water year values because the combined wet season and dry season period (November to October) is different to the water year period (September to August).

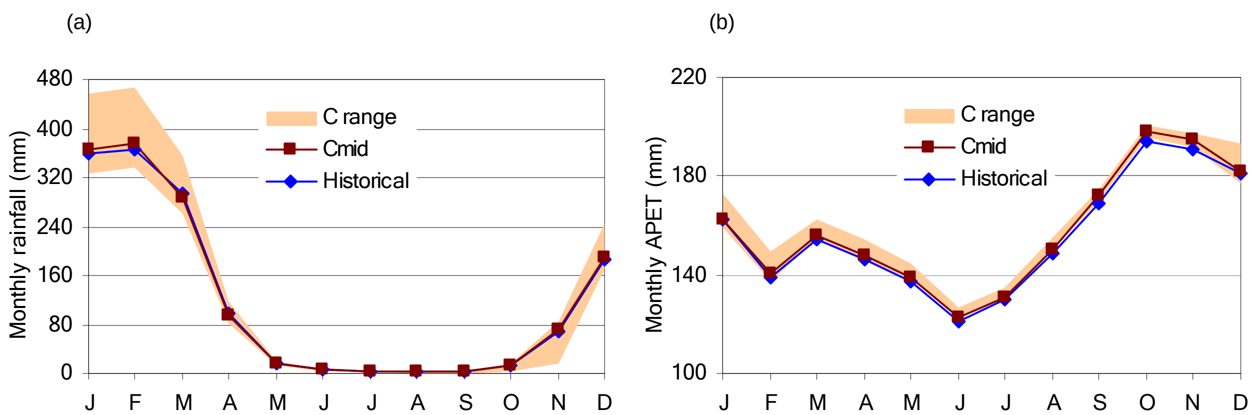



Figure WC-20. Mean monthly (a) rainfall and (b) areal potential evapotranspiration averaged over the Western Cape region under historical climate and Scenario C. (C range is the range under the 45 Scenario C simulations – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

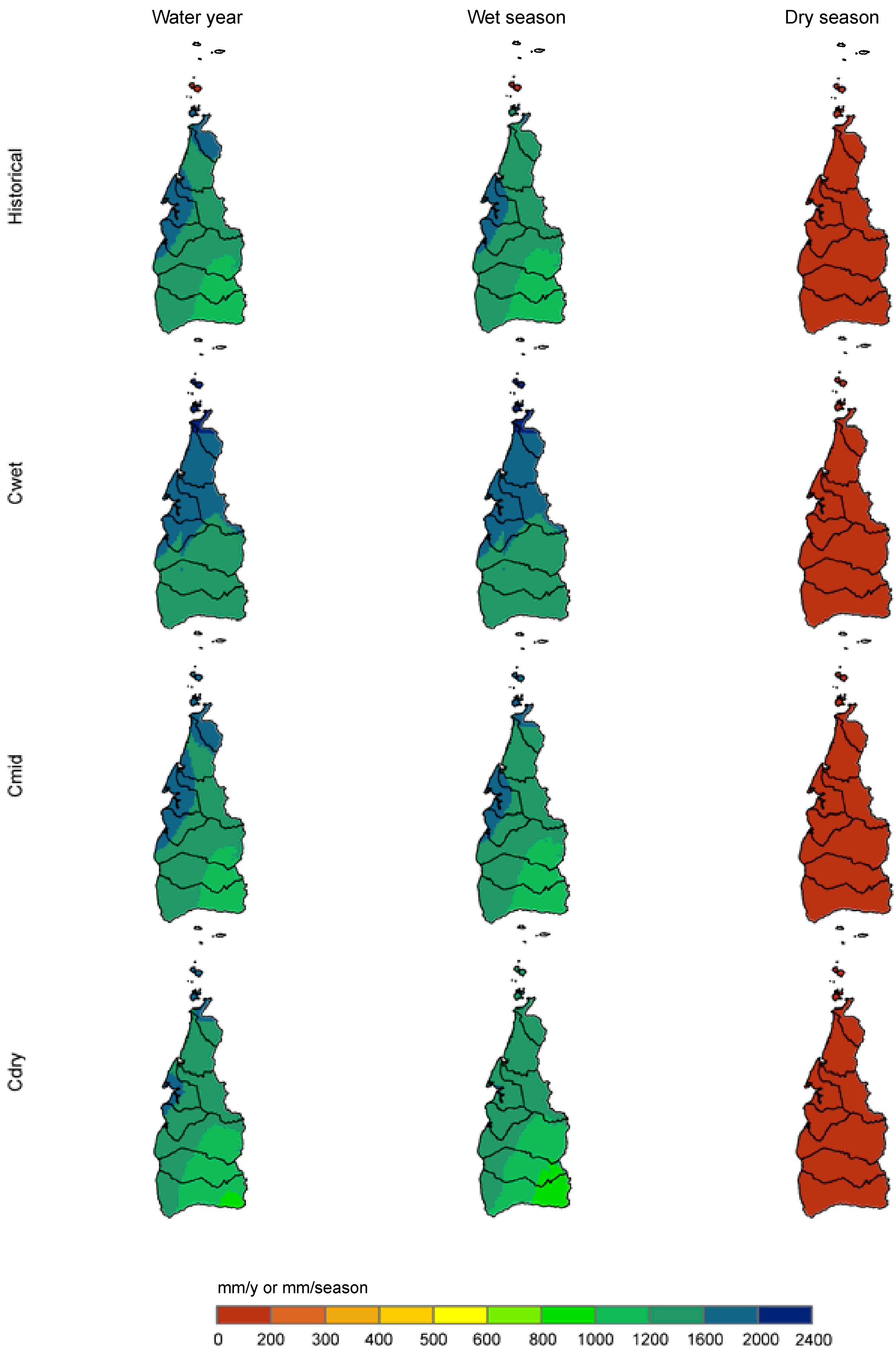



Figure WC-21. Spatial distribution of mean annual (water year), wet season and dry season rainfall across the Western Cape region under historical climate and Scenario C

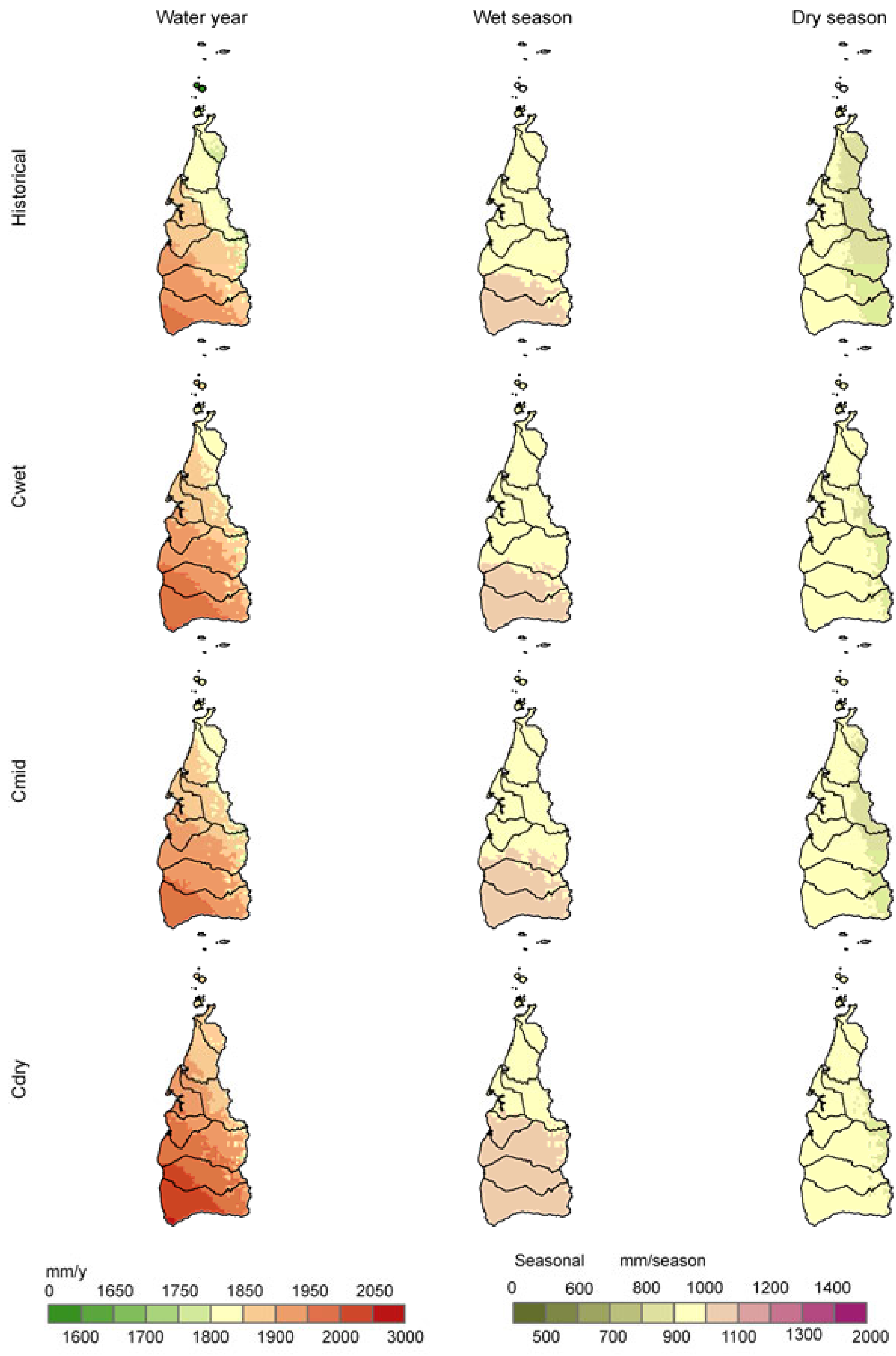



Figure WC-22. Spatial distribution of mean annual (water year), wet season and dry season areal potential evapotranspiration across the Western Cape region under historical climate and Scenario C

### WC-3.1.4 Confidence levels

Analysis of confidence of the climate data is presented at the division level and is reported in Section 2.1.4 in Chapter 2.

## WC-3.2 WAVES potential diffuse recharge estimations

The WAVES model (Zhang and Dawes, 1998) was used to estimate the change in groundwater recharge across the Western Cape region under a range of different climate scenarios. WAVES is a vertical recharge flux model that can model plant physiological feedbacks in response to increased $CO_2$, as well as modelling the water balance of different soil, vegetation and climate regimes. It was chosen for its balance in complexity between plant physiology and soil physics. It was also used to assess recharge for the Murray-Darling Basin Sustainable Yields Project (Crosbie et al., 2008).

### WC-3.2.1 Under historical climate

The calculated historical recharge for the Western Cape region shows that recharge is greatest in the north and decreases progressively to the south following the rainfall gradient. The historical record was assessed to establish any difference between wet and dry periods of recharge. A 23-year period was used, which allows the projection of recharge estimates to 2030 – in other words, to estimate recharge in 2030 assuming future climate is similar to historical climate (Scenario A). Under a wet historical climate (Scenario Awet) recharge increases 13 percent. Under the median estimate of historical climate (Scenario Amid) recharge decreases 3 percent. Under a dry historical climate (Scenario Adry) recharge decreases 15 percent.

Table WC-6. Recharge scaling factors in the Western Cape region for scenarios A, B and C

| Region | Awet | Amid | Adry | B | Cwet | Cmid | Cdry |
|---|---|---|---|---|---|---|---|
| Western Cape | 1.13 | 0.97 | 0.85 | 1.04 | 1.49 | 1.12 | 1.01 |

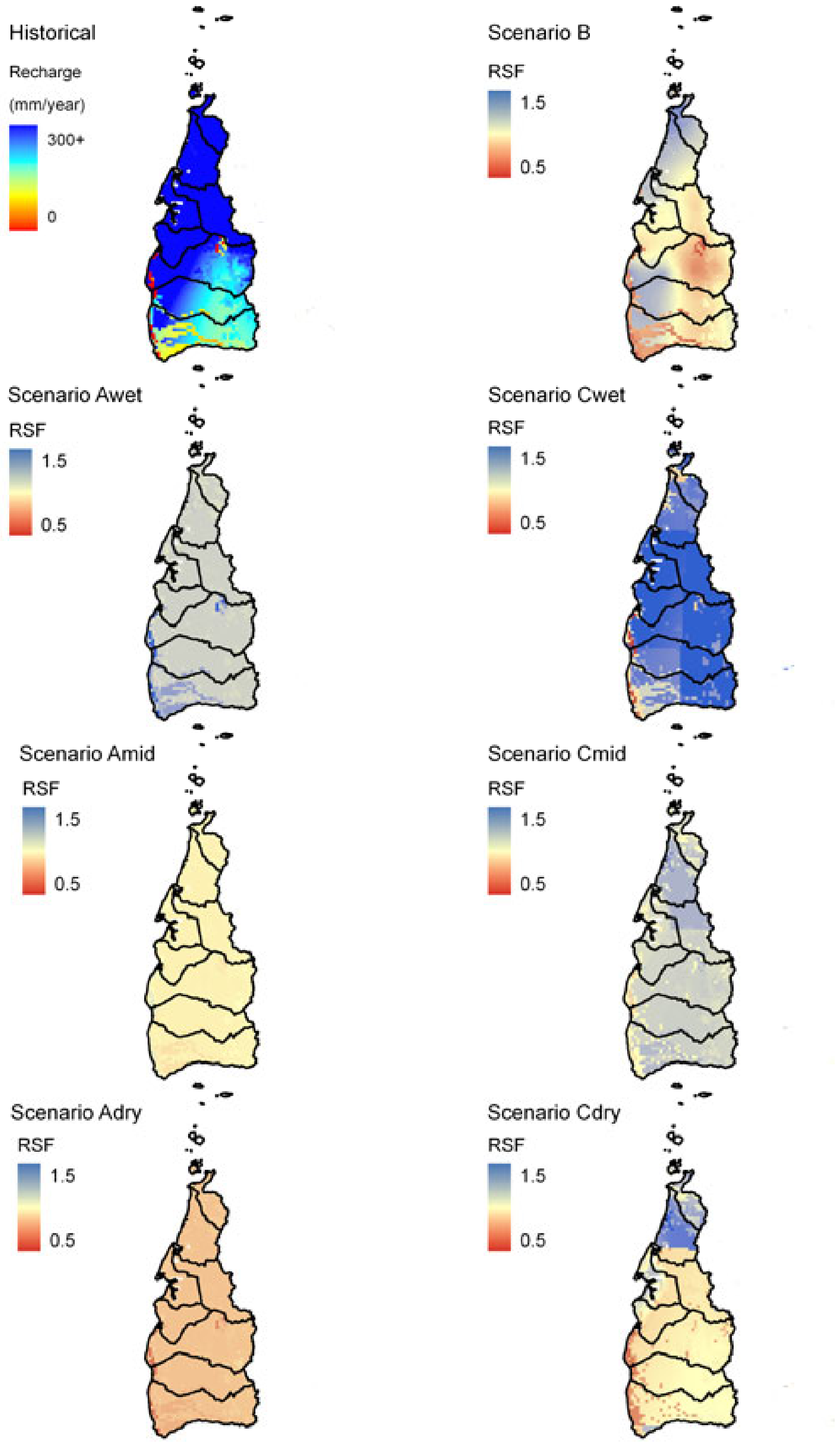



Figure WC-23. Spatial distribution of historical mean recharge rate; and recharge scaling factors across the Western Cape region for scenarios A, B and C. Recharge scaling factors are the ratio of the projected recharge in a scenario to that under Scenario A

### WC-3.2.2 Under recent climate

The recent (1996 to 2007) climate in the Western Cape region has been wetter than the historical (1930 to 2007) average and consequently the calculated recharge increases by 4 percent under Scenario B relative to Scenario A (Table WC-6). This increase has not been spatially uniform with some areas in the east and south showing a decrease in recharge (Figure WC-23).

### WC-3.2.3 Under future climate

Figure WC-24 shows the percentage change in modelled mean annual recharge averaged over the Western Cape region for Scenario C relative to Scenario A for the 45 scenarios (15 GCMs for each of the high, medium and low global warming scenarios). The percentage change in the mean annual rainfall and recharge from the corresponding GCMs are also tabulated in Table WC-7. Under some scenarios the recharge is projected to increase despite a decrease in rainfall. This is because total rainfall is not the only climate variable that has an influence over recharge. Daily rainfall intensity, temperature and $CO_2$ concentration are also important drivers (see Section 2.3.3 in the division-level Chapter 2), and specific situations can result in this counter-intuitive result. In particular, rainfall intensity is seen as a significant factor in this relationship.

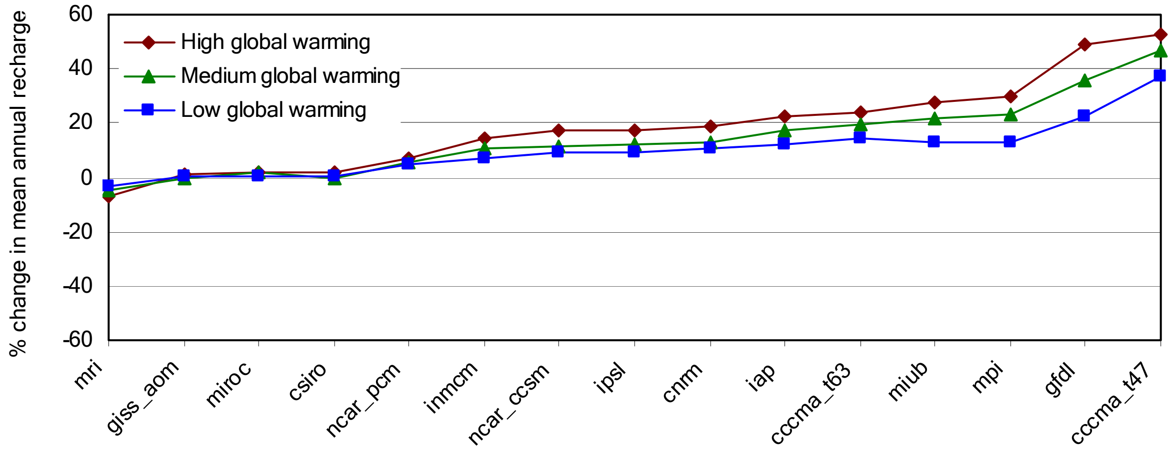



Figure WC-24. Percentage change in mean annual recharge under the 45 Scenario C simulations (15 global climate models and three global warming scenarios) relative to Scenario A recharge

Table WC-7. Summary results under 45 Scenario C simulations (numbers show percentage change in mean annual rainfall and recharge under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Recharge | GCM | Rainfall | Recharge | GCM | Rainfall | Recharge |
| mri | -7% | -7% | mri | -5% | -5% | mri | -3% | -3% |
| **giss_aom** | **-5%** | **1%** | giss_aom | -3% | -1% | giss_aom | -2% | 0% |
| miroc | -2% | 2% | miroc | -2% | 2% | miroc | -1% | 0% |
| csiro | -9% | 2% | csiro | -8% | 0% | csiro | -5% | 1% |
| ncar_pcm | 2% | 7% | ncar_pcm | 1% | 6% | ncar_pcm | 1% | 5% |
| inmcm | 1% | 15% | inmcm | 1% | 11% | inmcm | 1% | 7% |
| ncar_ccsm | 5% | 17% | ncar_ccsm | 4% | 12% | ncar_ccsm | 3% | 9% |
| ipsl | 2% | 17% | **ipsl** | **2%** | **12%** | ipsl | 1% | 9% |
| cnrm | 2% | 19% | cnrm | 2% | 13% | cnrm | 1% | 11% |
| iap | 2% | 22% | iap | 2% | 17% | iap | 1% | 12% |
| cccma_t63 | 11% | 24% | cccma_t63 | 8% | 20% | cccma_t63 | 6% | 15% |
| miub | 3% | 28% | miub | 2% | 22% | miub | 2% | 13% |
| mpi | 0% | 30% | mpi | 0% | 23% | mpi | 0% | 13% |
| **gfdl** | **-3%** | **49%** | gfdl | -3% | 36% | gfdl | -2% | 22% |
| cccma_t47 | 26% | 53% | cccma_t47 | 20% | 47% | cccma_t47 | 14% | 37% |

Under Scenario Cwet recharge increases 49 percent. Under Scenario Cmid recharge increases 12 percent. Under Scenario Cdry recharge increases 1 percent. Due to the way the GCMs were selected for scenario Cwet and Cdry, an area near the tip of Cape York is calculated to have a decrease in recharge under Scenario Cwet and an increase in recharge under Scenario Cdry.

### WC-3.2.4 Confidence levels

The estimation of recharge from WAVES is only indicative of the actual recharge and has not been validated with field measurements. A steady state groundwater chloride mass balance has been conducted as an independent measure of recharge (Crosbie et al., 2009). The results for the Western Cape region show that the historical estimate of recharge using WAVES (mean 346 mm/year) is much greater than the best estimate using the chloride mass balance (124 mm/year) and is outside of the confidence limits of the chloride mass balance (34 to 246 mm/year). These inconsistencies between methods are in part due to the different scales of each method, and they demonstrate the difficulty associated with deriving an accurate estimate of recharge in data poor areas.

## WC-3.3 Conceptual groundwater models

The fractured rock aquifers in the east of the region are recharged via the direct infiltration of rainfall and via leakage from incised streams. Discharge occurs predominantly as throughflow and as baseflow where rivers incise the fractured rock. Evapotranspiration is not considered a significant process in the fractured rock aquifer in the Western Cape region. Only small groundwater supplies are obtained from this aquifer, as groundwater from these fractured rock aquifers contains relatively poor quality groundwater and the yields obtained are low.

The Gilbert River Formation aquifer is present across the entire Western Cape region, to the west of the Great Dividing Range. It is confined and artesian to the south of the region where it is overlain by the Rolling Downs Group. Here it capable of supplying large groundwater supplies. To the north of the region, the Gilbert River Formation is unconfined and typical bore yields are much lower.

The groundwater salinity of the Gilbert River Formation aquifer is typically low (i.e. less than 700 µS/cm EC). However the high fluoride concentration of groundwater from deeper parts of the aquifer precludes its use for human consumption or stock watering purposes.

Upward vertical leakage from the Gilbert River Formation to the overlying units is likely to occur; given that typical positive head pressures are about 25 m. Groundwater springs exist along the flanks of the Great Dividing Range, providing groundwater baseflow to many streams. The Jardine, Wenlock, Archer, Coen, Holroyd and the Dulhunty rivers all receive groundwater baseflow from the Gilbert River Formation aquifer. The Jardine River flows all year and is considered Queensland's largest perennial river. The continual flow of water is attributed to baseflow derived from the shallow sandstones of the Gilbert River Formation and to high annual rainfall which (unlike other northern tropical rivers which are subject to seasonal rainfall patterns) occurs all year around, even during the dry season.

During the wet season the process of groundwater discharge to rivers is essentially reversed, such that stream leakage recharges the unconfined aquifers through which they are incised. The primary recharge mechanism for GAB aquifers however, is the direct infiltration of rainfall where the GAB sandstone outcrops.

The Bulimba Formation overlies the GAB aquifers and occurs across the entire Western Cape region, west of the Great Dividing Range. It outcrops significantly north of the Holroyd River and is overlain by the Wyaaba Beds to the south, where it contains locally artesian aquifers. Aquifers are typically constrained to old stream channels and hence are not always in hydraulic connection with each other. Recharge occurs where the Bulimba Formation is found in outcrop and also potentially from upward vertical leakage from underlying GAB aquifers. Discharge occurs as baseflow to creeks, which helps maintain flow into the dry season.

The marine facies of the Wyaaba Beds is completely confined with the primary recharge mechanism thought to be via lateral groundwater inflow from the east. It is not considered a significant groundwater resource outside of the area where the limestone occurs, which is within approximately 50 km of the coastline.

Groundwater use in the Western Cape region is predominantly sourced from the Gilbert River Formation aquifer. For much of this region, DNRM (2005) recommend that no further allocations should be made from the GAB aquifers. The basis for this recommendation is to preserve spring discharge and river baseflow, thereby maintaining groundwater dependent ecosystems in the Cape Managemenat Area.

### WC-3.3.1 Baseflow index analysis

The results of the baseflow analysis for suitable gauges in the Western Cape region are provided in Table WC-1 (in Chapter WC-1). The annual base flow index (BFI) values range from 0.221 to 0.532 (n=7, median = 0.261). Figure WC-2 (in Chapter WC-1) shows the surface geology of the Western Cape region and the average volume of dry season baseflow to rivers. A clear relationship is seen between higher dry season baseflow volumes and rivers that incise GAB aquifers. For these river reaches, the volume of groundwater derived stream flow ranges from 5 to 200 GL/year; whilst rivers that incise the older fractured rock aquifers have a much smaller volume of dry season baseflow, ranging from 1 to 5 GL/year.

# WC-3.4 Groundwater modelling results

The limited data for the region precluded the development of quantitative groundwater models.

# WC-3.5 Rainfall-runoff modelling results

In this section the term runoff is the sum of overland flow, interflow and baseflow. It is equivalent to streamflow expressed as a mm depth equivalent. All plots show data averaged over the modelled subcatchments of the Western Cape region. For this reason rainfall reported in this section may vary slightly from that reported elsewhere due to differences between the catchment boundaries (shown in Figure WC-1) and the DEM-derived catchment boundaries used here. In this section, where annual data are reported years are represented by numbers 1 through 77. Consistently throughout this report, annual data are based on the water year (1 September to 31 August) and the dry season is defined as 1 May to 31 October. Unless stated otherwise scenarios Cwet, Cmid and Cdry are selected on the basis of the ranked mean annual runoff. For more details on methods refer to Section 2.2 of the division-level Chapter 2.

## WC-3.5.1 Regional synopsis

The rainfall-runoff modelling estimates runoff in 0.05 degree grid cells in 47 subcatchments (Figure WC-25). Optimised parameter values from ten calibration catchments are used. Nine of these calibration catchments are in the Western Cape region, the remaining calibration catchment is to the east in the Northern Coral region. The calibration catchments are sparsely located throughout the region.

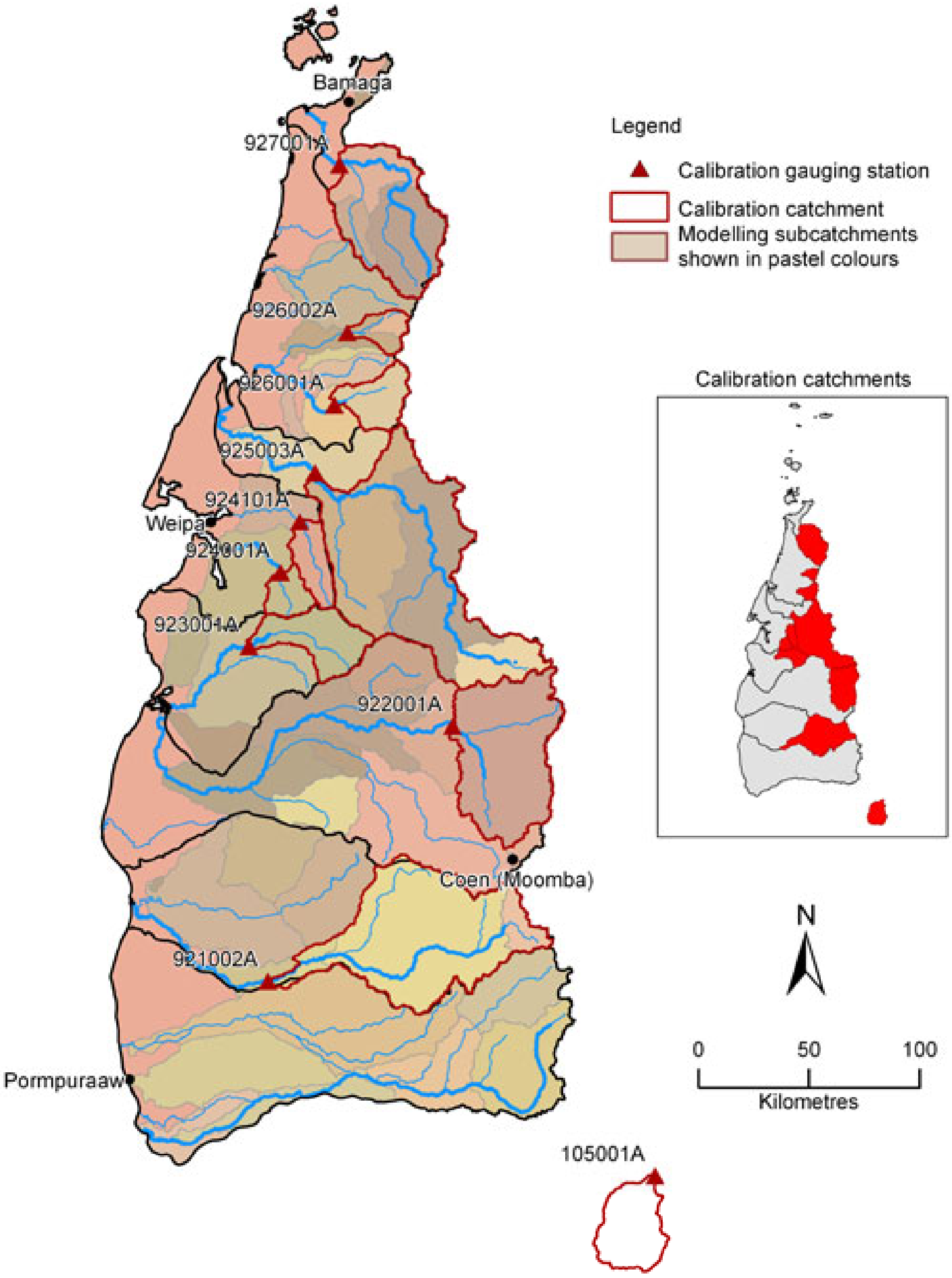



Figure WC-25. Map of the modelling subcatchments, calibration catchments and calibration gauging stations used for the Western Cape region with inset highlighting (in red) the extent of the calibration catchments

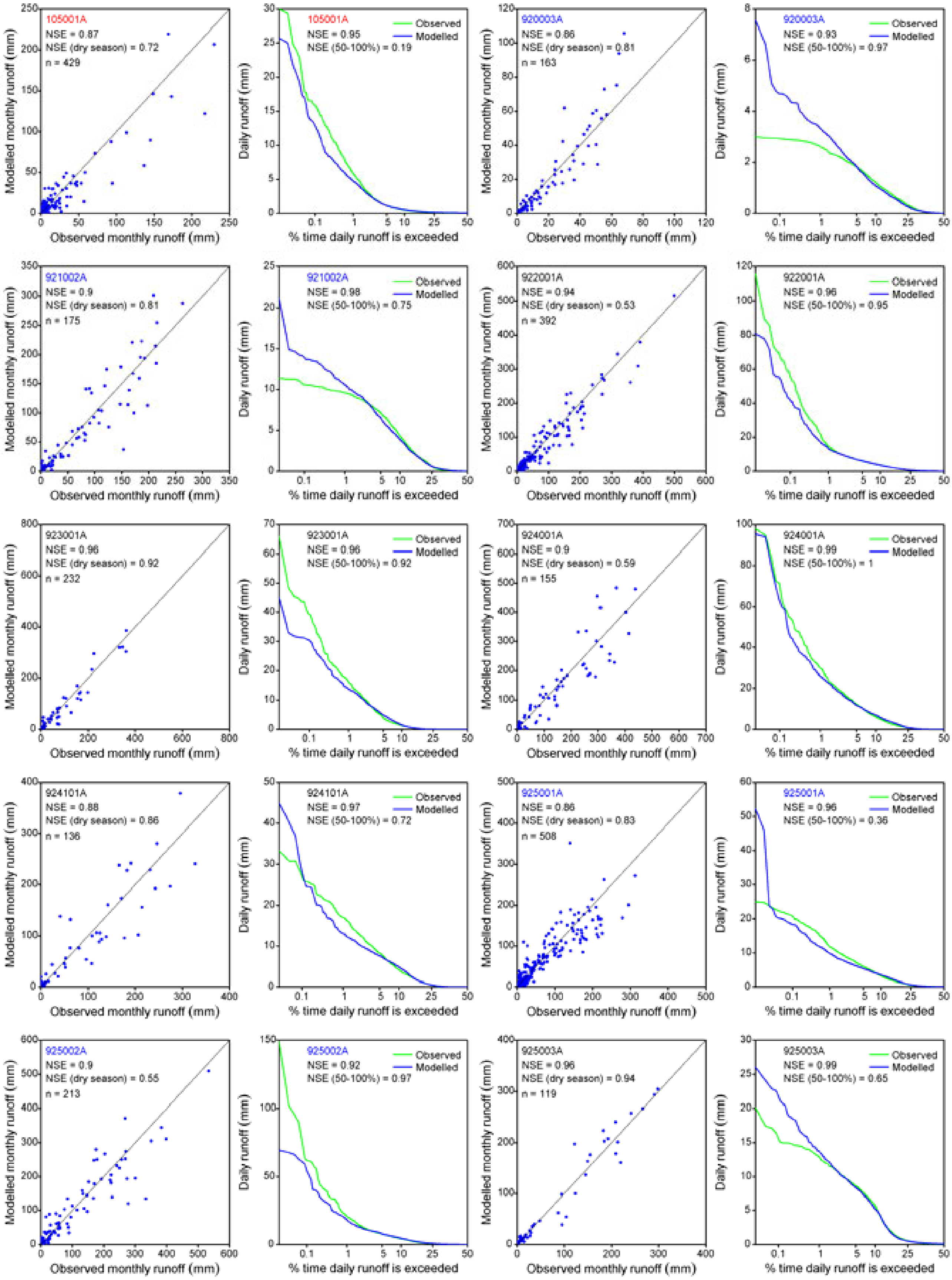
### WC-3.5.2 Model calibration

Figure WC-26 compares the modelled and observed monthly runoff and the modelled and observed daily flow exceedance curves for the 14 calibration catchments. Nash-Sutcliffe efficiency (NSE) values provide a quantitative measure of how well simulated values match observed values. NSE values are described in more detail in Section 2.2.3 of the division-level Chapter 2. On the monthly plots NSE is the monthly Nash-Sutcliffe efficiency value and NSE (dry season) is the dry season monthly Nash-Sutcliffe efficiency value. On the daily flow exceedance plots, NSE is the daily flow exceedance curve Nash-Sutcliffe efficiency value and NSE (50 to 100 percent) is the lower half of the daily flow exeedance curve Nash-Sutcliffe efficiency value.

The results indicate that the ensemble calibration of the rainfall-runoff models Sacramento and IhacresClassic can reasonably reproduce the observed monthly runoff series (NSE values generally greater than 0.8) and the daily flow exceedance curve (NSE values generally greater than 0.85). The volumetric constraint used in the model calibration also ensures that the total modelled runoff is within 5 percent of the total observed runoff.

The calibration method places more importance on the simulation of high runoff, and therefore rainfall-runoff modelling of the medium and high runoff is considerably better than the modelling of low runoff. It should be noted, however, that while the relative difference between the observed and simulated low flow values may be large, (which is what gives rise to the low monthly dry season NSE values for example) the absolute difference between the observed and simulated low flow values is generally small because both values are small. Nevertheless, an optimisation to reduce overall error variance can result in some underestimation of high runoff and overestimation of low runoff. This is evident in some of the scatter plots comparing the modelled and observed monthly runoff and many of the daily flow exceedance curves. For the majority of calibration catchments the disagreement between the modelled and observed daily runoff curves is discernable for runoff that is exceeded less than 5 percent of the time. This is accentuated in the plots because of the linear scale on the y-axis and normal probability scale on the x-axis. In any case, the volumetric constraint used in the model calibration ensures that the total modelled runoff is always within 5 percent of the total observed runoff. As indicated by the relatively low NSE values for the lower half of the daily flow exceedance curve and monthly dry season there may be considerable disagreement between observed and modelled low flow values (i.e. cease-to-flow). Overall the monthly NSE values are considered sufficient for the general purposes of estimating long-term mean annual runoff.


105001A
NSE = 0.87
NSE (dry season) = 0.72
n = 429
105001A
NSE = 0.95
NSE (50-100%) = 0.19
920003A
NSE = 0.86
NSE (dry season) = 0.81
n = 163
920003A
NSE = 0.93
NSE (50-100%) = 0.97
921002A
NSE = 0.9
NSE (dry season) = 0.81
n = 175
921002A
NSE = 0.98
NSE (50-100%) = 0.75
922001A
NSE = 0.94
NSE (dry season) = 0.53
n = 392
922001A
NSE = 0.96
NSE (50-100%) = 0.95
923001A
NSE = 0.96
NSE (dry season) = 0.92
n = 232
923001A
NSE = 0.96
NSE (50-100%) = 0.92
924001A
NSE = 0.9
NSE (dry season) = 0.59
n = 155
924001A
NSE = 0.99
NSE (50-100%) = 1
924101A
NSE = 0.88
NSE (dry season) = 0.86
n = 136
924101A
NSE = 0.97
NSE (50-100%) = 0.72
925001A
NSE = 0.86
NSE (dry season) = 0.83
n = 508
925001A
NSE = 0.96
NSE (50-100%) = 0.36
925002A
NSE = 0.9
NSE (dry season) = 0.55
n = 213
925002A
NSE = 0.92
NSE (50-100%) = 0.97
925003A
NSE = 0.96
NSE (dry season) = 0.94
n = 119
925003A
NSE = 0.99
NSE (50-100%) = 0.65
Observed
Modelled
Modelled monthly runoff (mm)
Observed monthly runoff (mm)
Daily runoff (mm)
% time daily runoff is exceeded

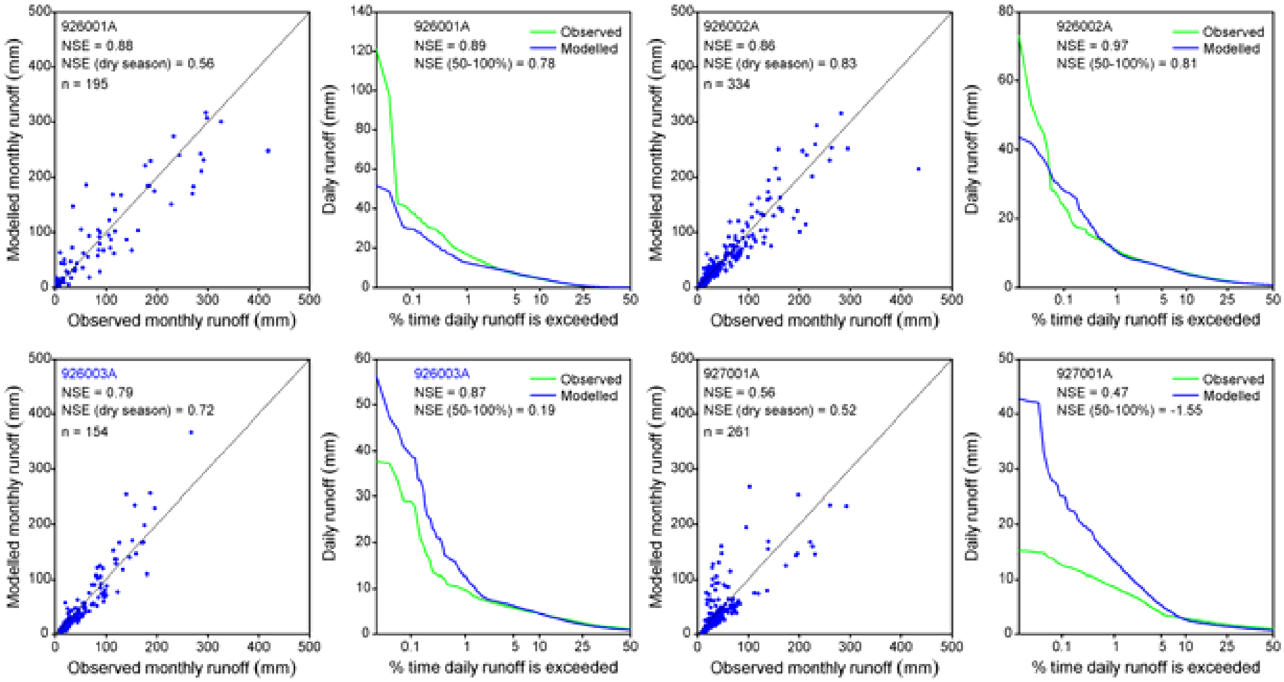



Figure WC-26. Modelled and observed monthly runoff and daily flow exceedance curve for each calibration catchment in the Western Cape region. (Red text denotes catchments located outside the region; blue text denotes catchments used for streamflow modelling only)

### WC-3.5.3 Under historical climate

Figure WC-27 shows the spatial distribution of mean annual rainfall and runoff under Scenario A (averaged over 1930 to 2007) across the Western Cape region. Figure WC-28 shows the mean annual rainfall and runoff averaged over the region.

The mean annual rainfall and runoff averaged over the Western Cape region are 1407 mm and 479 mm respectively. The mean wet season and dry season runoff averaged over the Western Cape region are 458 mm and 21 mm respectively.

In this project, all runoff grids are presented as long-term mean annual values. However the distributions of monthly and annual runoff data in northern Australia can be highly skewed, consequently the median and additional percentile values spatially averaged over the region are also reported. The 10$^{th}$ percentile, median and 90$^{th}$ percentile annual runoff values across the Western Cape region are 722, 471 and 221 mm respectively. The median wet season and dry season runoff averaged over the Western Cape region are 454 mm and 17 mm respectively.

The mean annual rainfall varies from about 1800 mm along parts of the west coast to 1000 mm in the south-east. The mean annual runoff varies from over 800 mm along parts of the west coast to less 160 mm in the south-west (Figure WC-27) and runoff coefficients vary from about 15 percent to nearly 50 percent. The majority of rainfall and runoff occurs during the wet season months December to April (Figure WC-29). Rainfall and runoff can vary considerably from year to year with long periods over several years or decades that are considerably wetter or drier than others (Figure WC-28). The coefficients of variation of annual rainfall and runoff averaged over the Western Cape region are 0.19 and 0.43 respectively.

The Western Cape is one of 13 regions which cover the three divisions studied in this project. Mean annual rainfall and runoff, as well as coefficients of variation, have been calculated for all of these 13 regions, and it is useful to compare the Western Cape results to results across all 13 regions. Across all 13 regions in this project 10$^{th}$ percentile, median and 90$^{th}$ percentile values are 1371, 936 and 595 mm respectively for mean annual rainfall and 374, 153 and 78 mm respectively for mean annual runoff. The mean annual rainfall (1407 mm) and runoff (479 mm) averaged over the Western Cape region are the highest of the 13 regions. Across all 13 regions in this project the 10$^{th}$ percentile, median and 90$^{th}$ percentile values are 0.34, 0.26 and 0.19 respectively for the coefficient of variation of annual rainfall and 1.39, 0.69 and 0.48 for the coefficient of variation of runoff. The coefficients of variation of annual rainfall (0.19) and runoff (0.43) averaged over the Western Cape region are among the lowest of the 13 reporting regions.

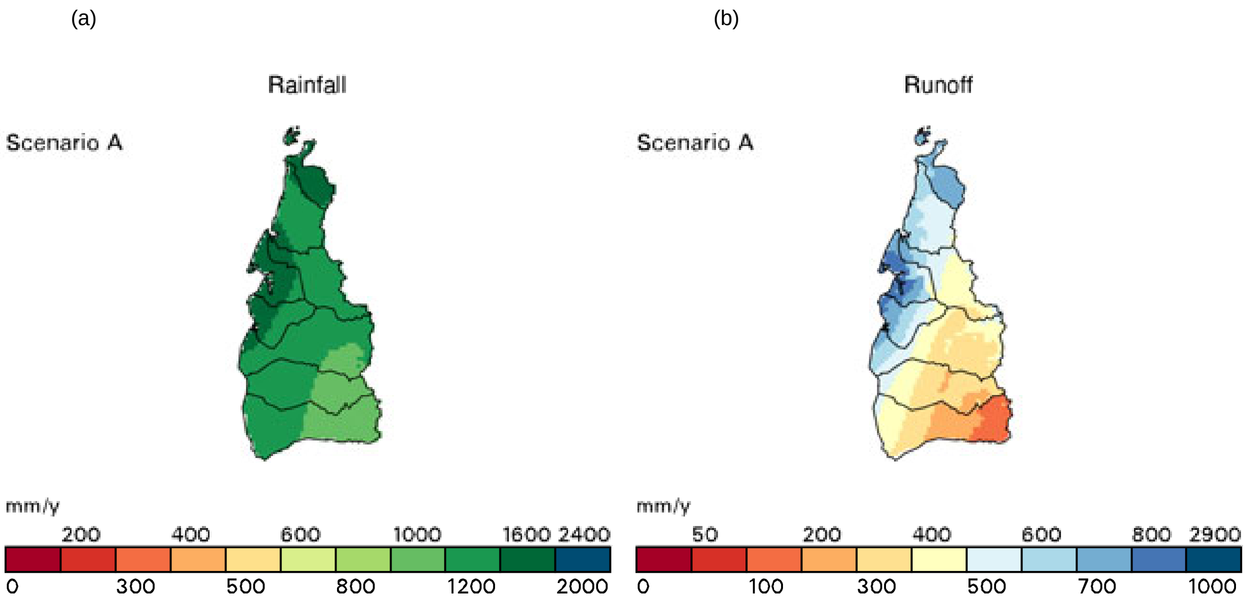



Figure WC-27. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the Western Cape region under Scenario A

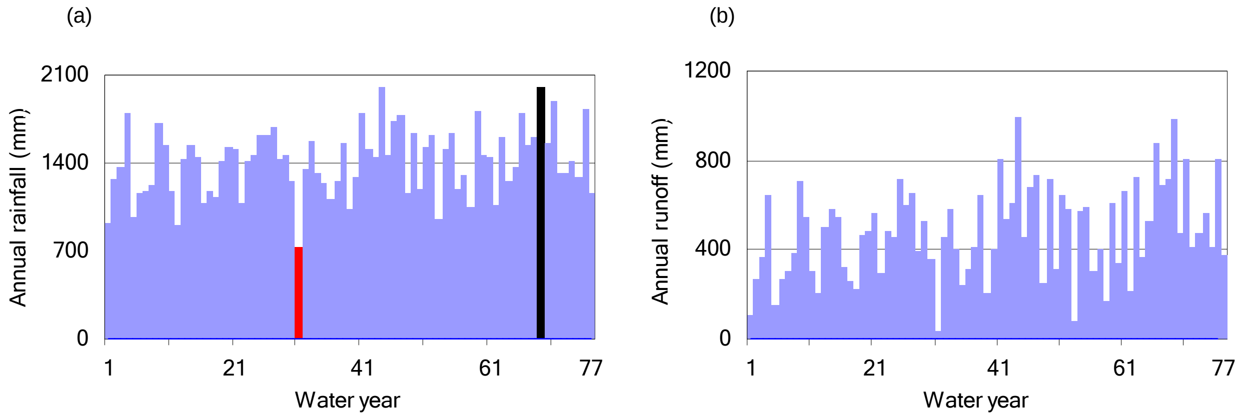



Figure WC-28. Annual (a) rainfall and (b) modelled runoff in the Western Cape region under Scenario A

Figure WC-29 (a,b) shows the minimum and maximum monthly rainfall and runoff and the range of values between the 25$^{th}$ and 75$^{th}$ percentile monthly rainfall and runoff. Figure WC-29(c,d) shows the mean and median monthly flows and the range of values between the 25$^{th}$ and 75$^{th}$ percentile monthly rainfall and runoff. In the Western Cape region the mean monthly runoff during the wet season is similar to the median monthly runoff during the wet season.

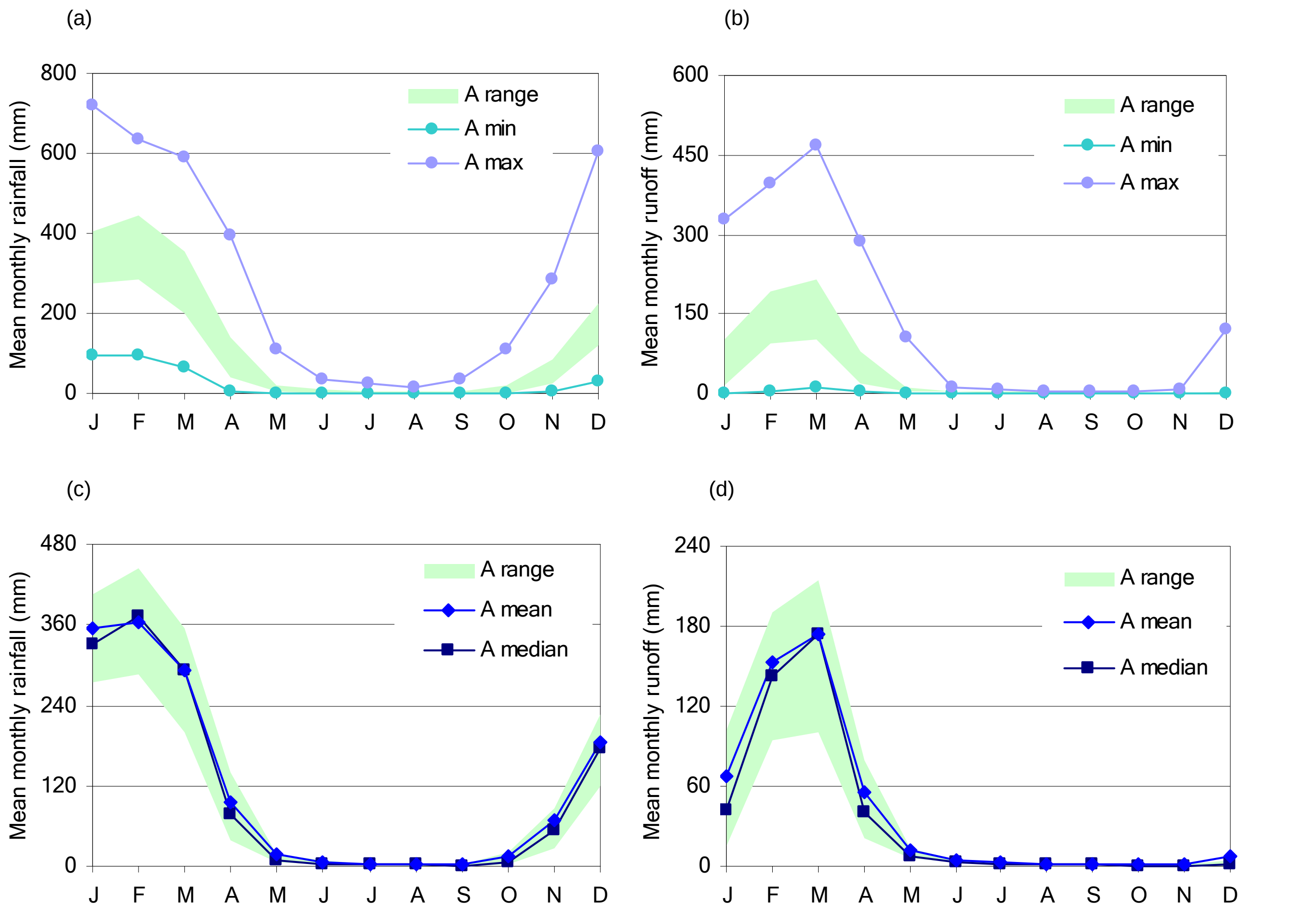



Figure WC-29. Minimum, maximum and A range monthly (a) rainfall and (b) modelled runoff; and mean, median and A range monthly (c) rainfall and (d) modelled runoff in the Western Cape region under Scenario A (A range is the 25th to 75th percentile monthly rainfall or runoff)

## WC-3.5.4 Under recent climate

The mean annual rainfall and runoff under Scenario B (1996 to 2007) are 9 percent and 27 percent higher respectively than the historical (1930 to 2007) mean values. The spatial distribution of rainfall and runoff across the Western Cape region under Scenario B is shown in Figure WC-30.

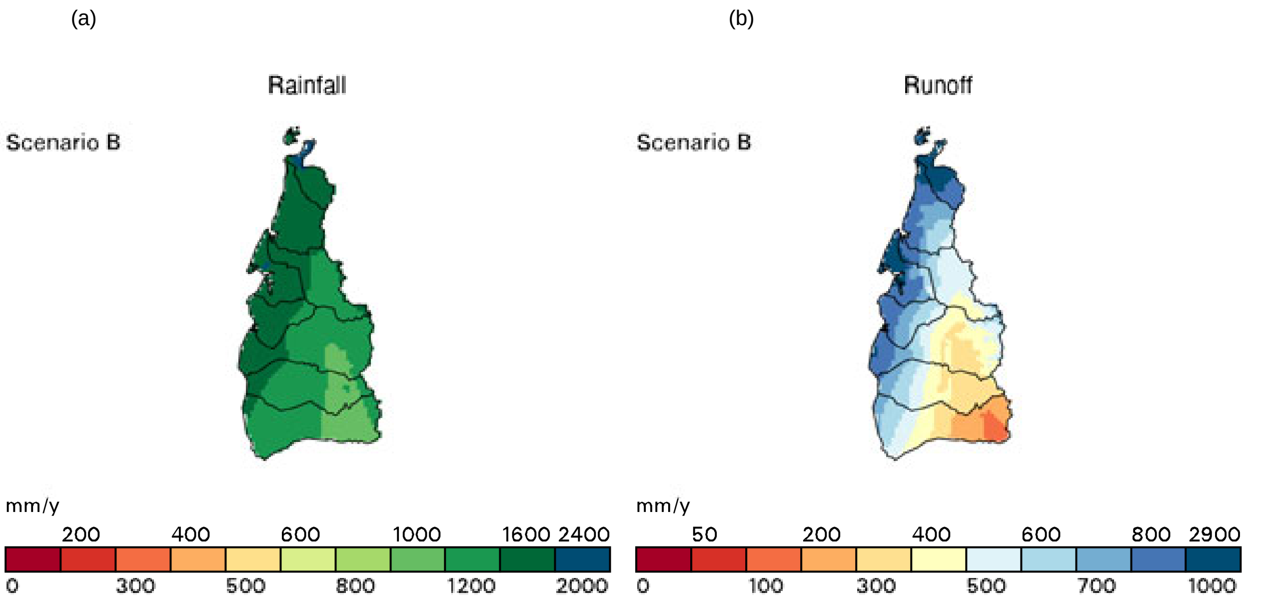



Figure WC-30. Spatial distribution of mean annual (a) rainfall and (b) modelled runoff across the Western Cape region under Scenario B

### WC-3.5.5 Under future climate

Figure WC-31 shows the percentage change in the mean annual runoff averaged over the Western Cape region under Scenario C relative to Scenario A for the 45 scenarios (15 global climate models (GCMs) for each of the high, medium and low global warming scenarios). The percentage change in the mean annual runoff and rainfall from the corresponding GCMs are also tabulated in Table WC-8.

The figure and table indicate that the potential impact of climate change on runoff can be very significant. Although there is considerable uncertainty in the estimates, the results indicate that runoff in ~2030 in the Western Cape region is as likely to increase as decrease. Rainfall-runoff modelling with climate change projections from half of the GCMs shows a reduction in mean annual runoff, while rainfall-runoff modelling with climate change projections from the other half of the GCMs shows an increase in mean annual runoff. The wide range of mean annual runoff values shown in Figure WC-31 and Table WC-8 is primarily due to the wide range of future projections of rainfall by the 15 GCMs.

Because of the large variation between GCM simulations and the method used to obtain the climate change scenarios, the biggest increase and biggest decrease in runoff come from the high global warming scenario. For the high global warming scenario, rainfall-runoff modelling with climate change projections from four of the GCMs indicates a decrease in mean annual runoff greater than 10 percent while rainfall-runoff modelling with climate change projections from two of the GCMs indicates an increase in mean annual runoff greater than 10 percent.

In subsequent reporting here and in other sections, only results from an extreme ‘wet’, ‘mid’ and extreme ‘dry’ variant are shown (referred to as scenarios Cwet, Cmid and Cdry). Under Scenario Cwet, results from the second highest increase in mean annual runoff from the high global warming scenario are used. Under Scenario Cdry, results from the second highest reduction in mean annual runoff from the high global warming scenario are used. Under Scenario Cmid, the median mean annual runoff results from the medium global warming scenario are used. These are shown in bold in Table WC-8.

Under scenarios Cwet, Cmid and Cdry, mean annual runoff increases by 30 and 1 percent and decreases by 19 percent relative to Scenario A. By comparison, the range based on the low global warming scenario is a 16 to -11 percent change in mean annual runoff. Figure WC-32 shows the mean annual runoff across the Western Cape region under scenarios A and C. The linear discontinuities that are evident in Figure WC-32 are due to GCM grid cell boundaries.

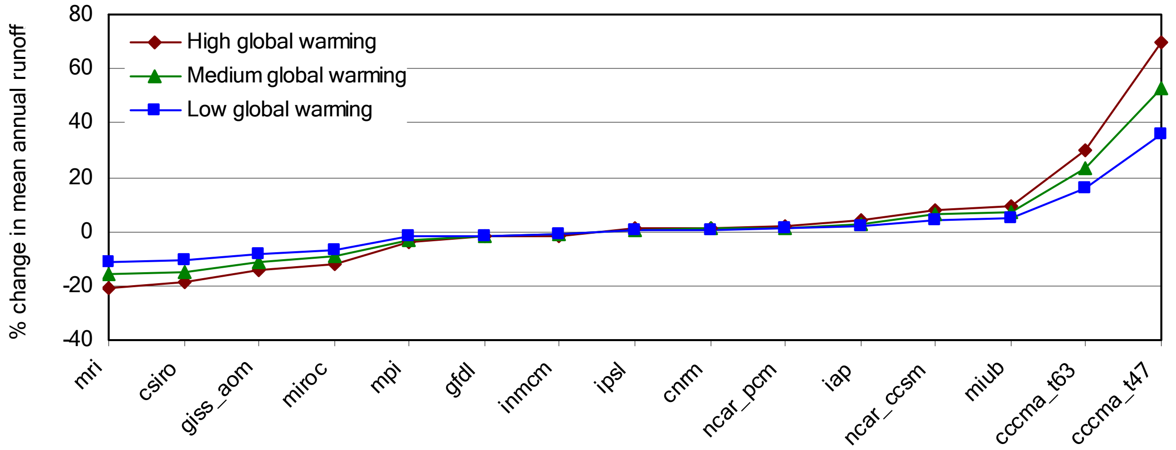



Figure WC-31. Percentage change in mean annual modelled runoff under the 45 Scenario C simulations (15 global climate models and three global warming scenarios) relative to Scenario A

Table WC-8. Summary results under the 45 Scenario C simulations for the modelling subcatchments in the Western Cape region (numbers show percentage change in mean annual rainfall and modelled runoff under Scenario C relative to Scenario A)

| High global warming | | | Medium global warming | | | Low global warming | | |
|---|---|---|---|---|---|---|---|---|
| GCM | Rainfall | Runoff | GCM | Rainfall | Runoff | GCM | Rainfall | Runoff |
| mri | -7% | -21% | mri | -6% | -16% | mri | -4% | -11% |
| **csiro** | **-10%** | **-19%** | csiro | -8% | -15% | csiro | -6% | -11% |
| giss_aom | -5% | -15% | giss_aom | -4% | -11% | giss_aom | -3% | -8% |
| miroc | -3% | -12% | miroc | -2% | -9% | miroc | -2% | -7% |
| mpi | 0% | -4% | mpi | 0% | -3% | mpi | 0% | -2% |
| gfdl | -4% | -2% | gfdl | -3% | -2% | gfdl | -2% | -1% |
| inmcm | 1% | -1% | inmcm | 1% | -1% | inmcm | 0% | -1% |
| ipsl | 1% | 1% | **ipsl** | **1%** | **1%** | ipsl | 1% | 1% |
| cnrm | 2% | 1% | cnrm | 1% | 1% | cnrm | 1% | 1% |
| ncar_pcm | 1% | 2% | ncar_pcm | 1% | 2% | ncar_pcm | 1% | 1% |
| iap | 2% | 4% | iap | 1% | 3% | iap | 1% | 2% |
| ncar_ccsm | 5% | 8% | ncar_ccsm | 4% | 6% | ncar_ccsm | 3% | 4% |
| miub | 2% | 9% | miub | 2% | 7% | miub | 1% | 5% |
| **cccma_t63** | **10%** | **30%** | cccma_t63 | 8% | 23% | cccma_t63 | 6% | 16% |
| cccma_t47 | 25% | 70% | cccma_t47 | 19% | 52% | cccma_t47 | 14% | 36% |

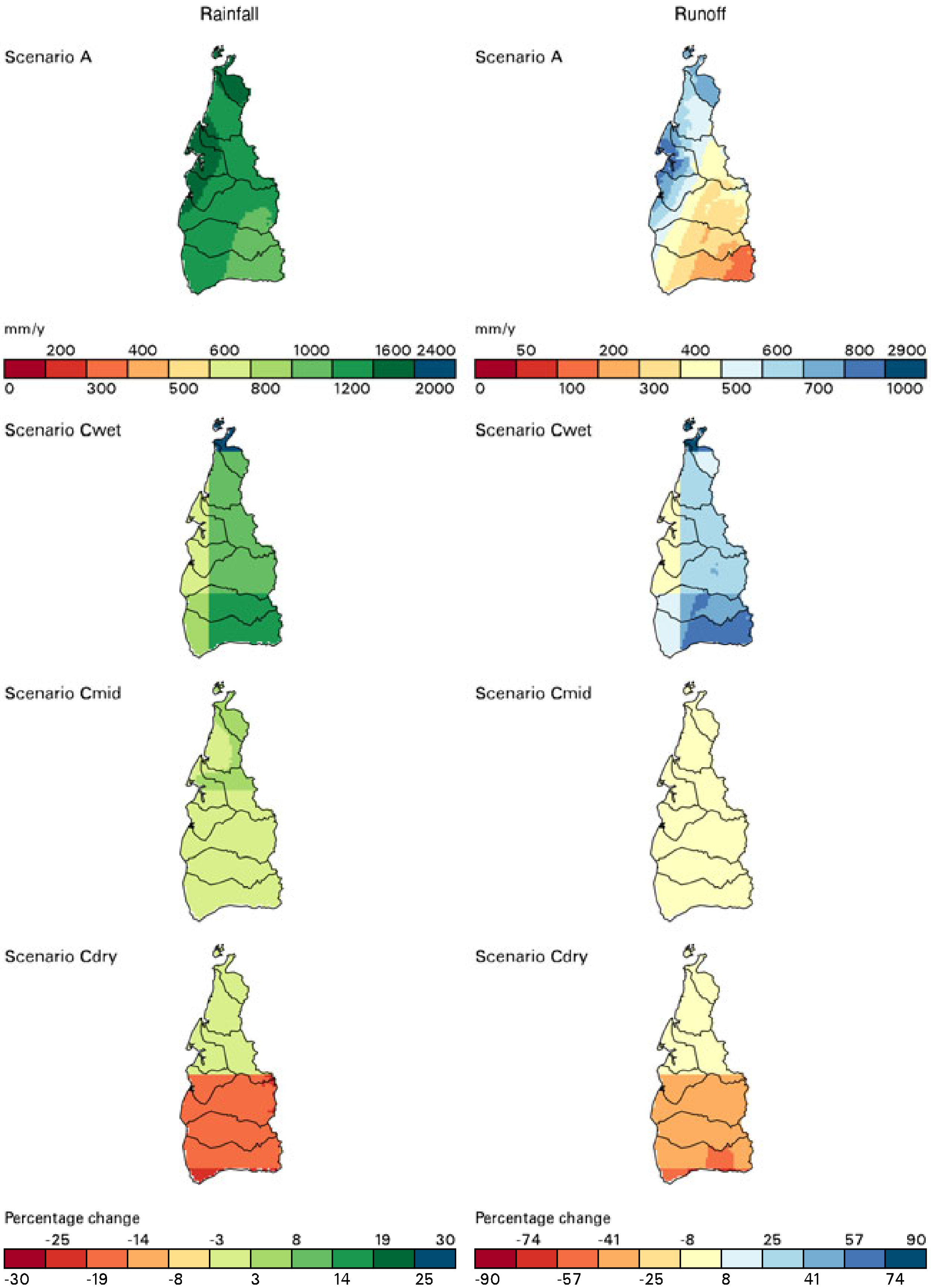



Figure WC-32. Spatial distribution of mean annual rainfall and modelled runoff across the Western Cape region under Scenario A and under Scenario C relative to Scenario A

## WC-3.5.6 Summary results for all scenarios

Table WC-9 shows the mean annual rainfall, runoff and actual evapotranspiration under Scenario A averaged over the Western Cape region, and the percentage changes in the rainfall, runoff and actual evapotranspiration under scenarios B and C relative to Scenario A. The Cwet, Cmid and Cdry results are based on the mean annual runoff, and the rainfall changes shown in Table WC-9 are the changes in the mean annual value of the rainfall series used to obtain the runoff under scenarios Cwet, Cmid and Cdry. The changes in mean annual rainfall do not necessarily translate directly to the changes in mean annual runoff because of changes in seasonal and daily rainfall distributions and the relationship between rainfall and runoff is non-linear. The latter factor usually results in small changes in rainfall to be amplified in runoff (Table WC-8).

Figure WC-33 shows the mean monthly rainfall and runoff under scenarios A and C averaged over 1930 to 2007 for the region. Figure WC-34 shows the daily rainfall and flow exceedance curves under scenarios A and C averaged over the region. In Figure WC-33 scenarios Cwet, Cmid and Cdry are selected on a month-by-month basis, while in Figure WC-34 scenarios Cwet, Cmid and Cdry are selected for every day of the daily flow exceedance curve.



Table WC-9. Water balance over the entire Western Cape region under Scenario A and under scenarios B and C relative to Scenario A

| Scenario | Rainfall | Runoff | Evapotranspiration |
|---|---|---|---|
| | | mm | |
| A | 1407 | 479 | 928 |
| | | percent change from Scenario A | |
| B | 9 | 27 | 0 |
| Cwet | 10 | 30 | 0 |
| Cmid | 1 | 1 | 1 |
| Cdry | -10 | -19 | -5 |

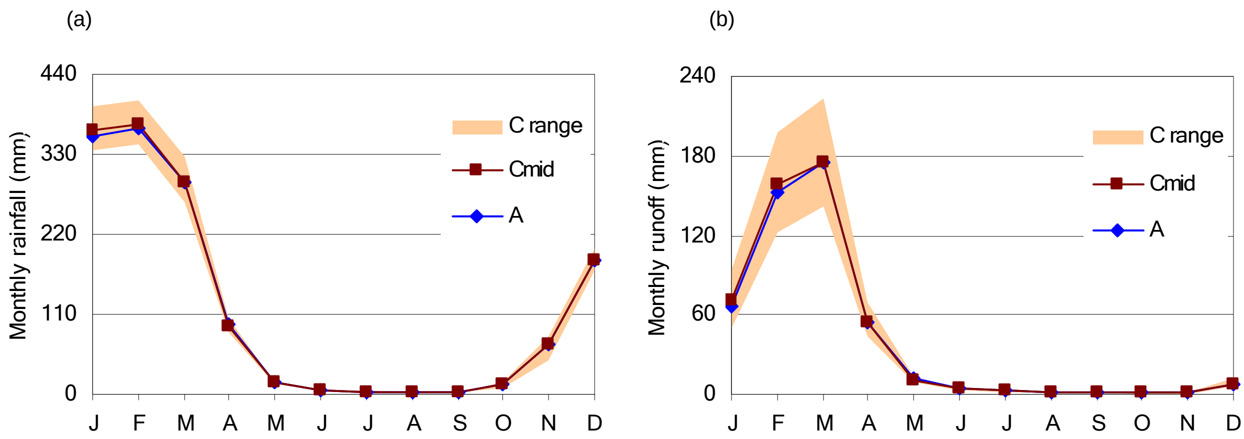



Figure WC-33. Mean monthly (a) rainfall and (b) modelled runoff in the Western Cape region under scenarios A and C (C range is based on the consideration of each month separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

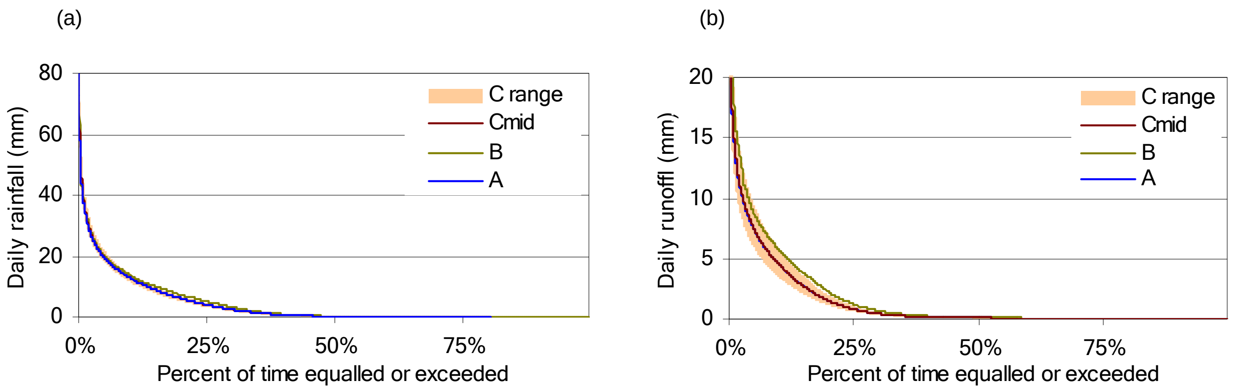



Figure WC-34. Daily flow exceedance curves for (a) rainfall and (b) modelled runoff in the Western Cape region under scenarios A, B and C (C range is based on the consideration of each rainfall and runoff percentile separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet)

### WC-3.5.7 Confidence levels

The rainfall-runoff model verification analysis with data from 123 catchments from across all of northern Australia indicates that the mean annual runoff for ungauged catchments are under estimated or over estimated, when using optimised parameter values from a nearby catchment, by less than 20 percent in 40 percent of catchments and by less than 50 percent in 80 percent of the catchments.

The runoff estimates for the Western Cape region are reasonable considering the remoteness of the area. The lowest levels of confidence in the runoff predictions are in the southern coastal parts of the region due to the long distances between donor calibration catchments and target ungauged subcatchments. Diagrams illustrating which calibration catchments donated rainfall-runoff model parameter sets to which ungauged subcatchments are shown in Petheram et al. (2009).

Figure WC-35 illustrate the level of confidence in the modelling of the mid to high runoff events (i.e. peak flows) and dry season runoff (respectively) for the subcatchments of the Western Cape region. It should be noted that these maps of level of confidence are not statistical confidence levels and are intended to only convey a broad reliability of prediction. Note the level of confidence in streamflow predictions will vary slightly from the level of confidence in runoff predictions shown below and as discussed in Section 2.2.6 of the division-level chapter.

There is a high degree of confidence that dry season runoff in the Western Cape region is low because it is known that rainfall and baseflow are low during the dry season. The map of level of confidence for dry season flow shown in Figure WC-35 provides a relative indication of how well dry season metrics, such as mean annual dry season flow and cease-to-flow criteria, are simulated.

Although there is uncertainty associated with annual runoff volumes for individual ungauged catchments in the Western Cape region, they are not all biased to one direction. The non-systematic errors therefore tend to cancel one another to some extent, and across the entire Western Cape region the long-term average monthly and annual results are reasonable. As shown in Figure WC-35, in many areas of the Western Cape region localised studies will require more detailed analysis than undertaken and reported here and would most likely require the site to be visited and additional field measurements made.

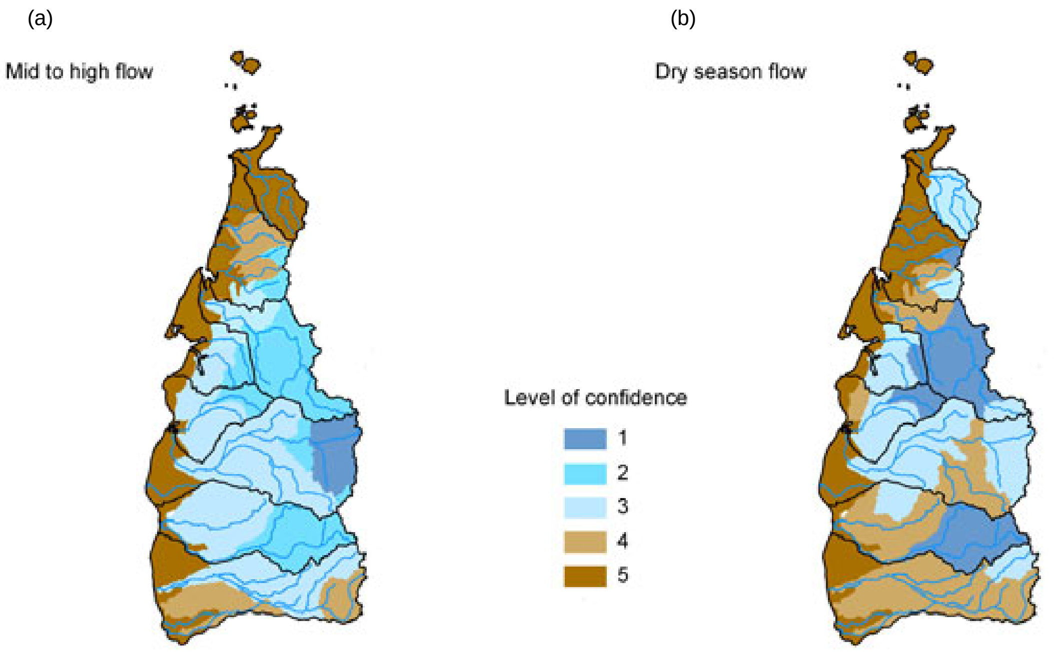



Figure WC-35. Level of confidence of the modelling of runoff for (a) mid- to high flow events and (b) monthly dry season flow events for the modelling subcatchments of the Western Cape region. 1 is the highest level of confidence and 5 is the lowest

## WC-3.6 River system water balance

The Western Cape region is comprised of eight AWRC river basins and has an area of 66,766 km$^2$. Under the historical climate the mean annual runoff across the region is 479 mm (Section WC-3.5.3), which equates to a mean annual streamflow across the region of 31,981 GL.

Across the region there is very little water use and future development is likely to be related to mine development, some ecotourism and indigenous enterprises. Hence, little information on infrastructure, water demand, water management, sharing rules or future development is currently available, and consequently there is no river modelling section to the Western Cape region report. Streamflow time series have been generated for each streamflow reporting node (SRN) based on the upstream grid cell rainfall-runoff simulations, as described in Section 2.2.5 of the division-level Chapter 2. The locations of these nodes are shown in Figure WC-36. Summary streamflow statistics for each SRN are reported in Petheram et al. (2009). In addition to the streamflow time series generated by the rainfall-runoff model ensemble, a range of hydrological metrics computed using regression analysis are also available for each SRN (as described in Section 2.2.7 of the division-level Chapter 2). The complete set of results for the multiple regression analysis is reported in SKM (2009). The merit of each approach is discussed in Section 2.2.7 of the division-level Chapter 2.

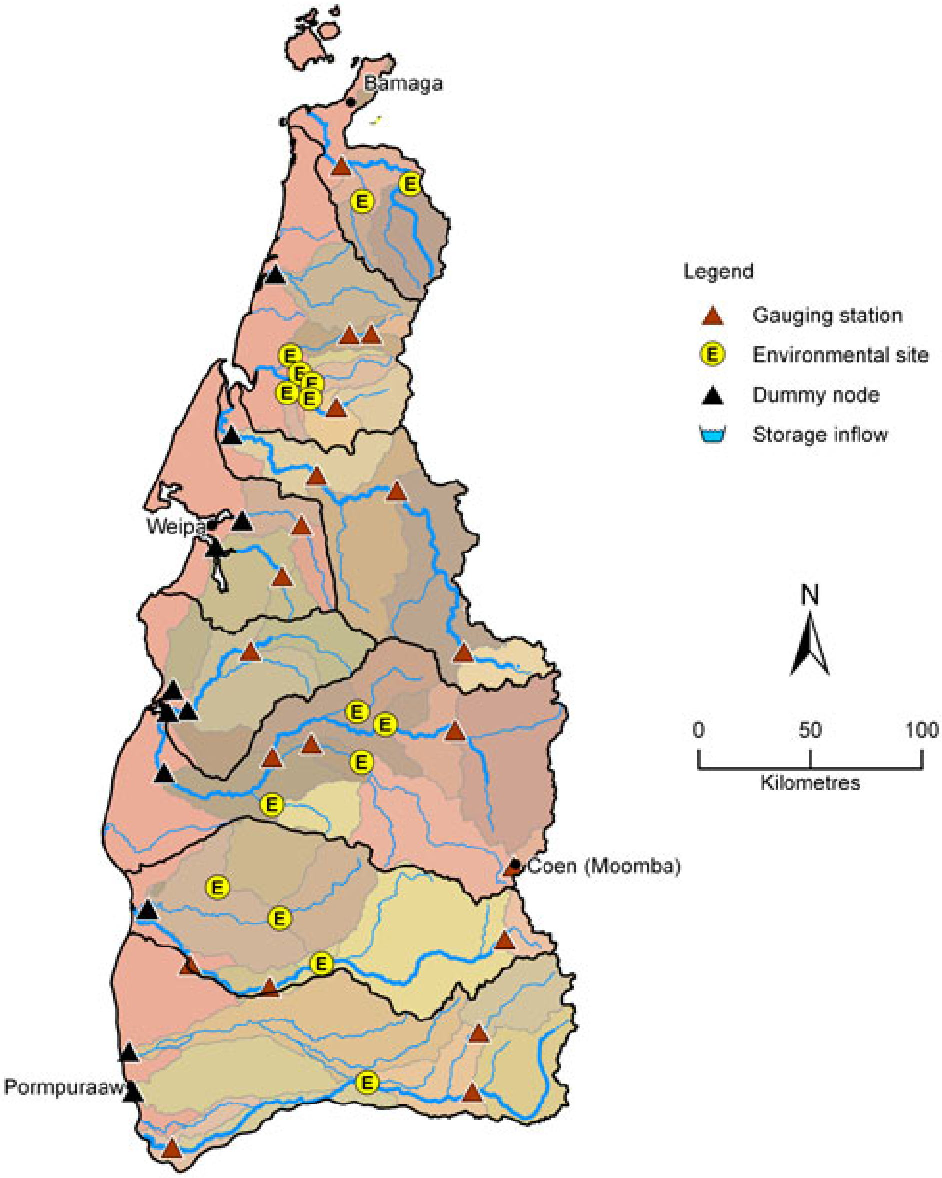



Figure WC-36. Location of streamflow reporting nodes (gauging stations, environmental sites, dummy nodes and storage inflows) in the Western Cape region. (Note no storage inflows are reported for this region)

## WC-3.7 Changes to flow regime at environmental assets

Section 1.3 of the division-level Chapter 1 describes how environmental assets were shortlisted for assessment by this project. Four environmental assets have been shortlisted in the Western Cape region: Archer River Aggregation, Jardine River Wetlands Aggregation, Northern Holroyd Plain Aggregation, and Port Musgrave Aggregation. The locations of these assets are shown in Figure WC-1 and the assets are characterised in Chapter WC-2.

This section presents the assessment of these shortlisted assets and reports metrics for those assets which have sufficient confidence in the modelled streamflow to enable analysis. Confidence in results for low flows and high flows was calculated separately on a scale of 1 to 5, with 1 indicating results with the highest confidence (as described in Section 2.2.6 of the division-level Chapter 2). Hydrological regime metrics (as defined in Section 2.5 of the division-level Chapter 2) for either low flows or high flows are reported only where confidence levels are 1, 2 or 3. If confidence levels in the low flows or high flows are ranked 4 or 5, results are not reported and are labelled NR (not reported).

Some of the assets in this region have multiple nodes at which streamflow modelling results are available. When reporting hydrological regime metrics for such assets a single node was selected. The selected node was that with the highest streamflow confidence level and the largest proportion of streamflow to the asset. Results for all nodes are presented in McJannet et al. (2009).

In the absence of site-specific metrics for the Western Cape region a set of standard metrics related to high and low flows have been utilised. However the conversion of these metrics into environmental impacts still requires development of quantitative relationships between flow and ecology.

### WC-3.7.1 Standard metrics

Table WC-10. Standard metrics for changes to surface water flow regime at environmental assets in the Western Cape region under scenarios A, B, C and D

| Standard metrics | Units | A | B | Cwet | Cmid | Cdry | Dwet | Dmid | Ddry |
|---|---|---|---|---|---|---|---|---|---|
| | | | change from Scenario A | | | | | | |
| Archer River Aggregation - Node 2 (confidence level: low flow = 3, high flow = 2) | | | | | | | | | |
| Annual flow (mean) | GL | 1550 | +18% | +33% | +1% | -21% | nm | nm | nm |
| Wet season flow (mean)* | GL | 1470 | +16% | +34% | +1% | -22% | nm | nm | nm |
| Dry season flow (mean)** | GL | 76.2 | +43% | +17% | -3% | -19% | nm | nm | nm |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | 0.0006 | | | | | | | |
| Number of days below low flow threshold (mean) | d/y | 36.5 | -3.3 | -4.9 | +0.6 | +17 | nm | nm | nm |
| Number of days of zero flow (mean) | d/y | 11.2 | -0.8 | -1.9 | +0.5 | +8.5 | nm | nm | nm |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | 22.5 | | | | | | | |
| Number of days above high flow threshold (mean) | d/y | 18.3 | +3.6 | +6.9 | +0.1 | -5.6 | nm | nm | nm |
| Jardine River Wetlands Aggregation - Node 2 (confidence level: low flow = 3, high flow = 4) | | | | | | | | | |
| Annual flow (mean) | GL | NR | NR | NR | NR | NR | nm | nm | nm |
| Wet season flow (mean)* | GL | NR | NR | NR | NR | NR | nm | nm | nm |
| Dry season flow (mean)** | GL | 193 | +31% | +22% | +0% | -14% | nm | nm | nm |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | 0.291 | | | | | | | |
| Number of days below low flow threshold (mean) | d/y | 36.5 | -26.3 | -14.7 | -0.8 | +16.1 | nm | nm | nm |
| Number of days of zero flow (mean) | d/y | 1.55 | -0.1 | 0 | 0 | 0 | nm | nm | nm |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | NR | | | | | | | |
| Number of days above high flow threshold (mean) | d/y | NR | NR | NR | NR | NR | nm | nm | nm |
| Northern Holroyd Plain Aggregation - Node 3 (confidence level: low flow = 2, high flow = 2) | | | | | | | | | |
| Annual flow (mean) | GL | 1230 | +20% | +52% | +2% | -23% | nm | nm | nm |
| Wet season flow (mean)* | GL | 1190 | +16% | +53% | +3% | -23% | nm | nm | nm |
| Dry season flow (mean)** | GL | 42.7 | +115 % | +38% | -6% | -25% | nm | nm | nm |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | 0 | | | | | | | |
| Number of days below low flow threshold (mean) | d/y | 88.2 | -14 | -12.5 | -2.1 | +11.1 | nm | nm | nm |
| Number of days of zero flow (mean) | d/y | 88.2 | -14 | -12.5 | -2.1 | +11.1 | nm | nm | nm |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | 20.7 | | | | | | | |
| Number of days above high flow threshold (mean) | d/y | 18.3 | +3.7 | +15 | +0.5 | -6.8 | nm | nm | nm |
| Port Musgrave Aggregation - Node 6 (confidence level: low flow = 3, high flow = 3) | | | | | | | | | |
| Annual flow (mean) | GL | 3330 | +17% | +34% | +1% | -22% | nm | nm | nm |
| Wet season flow (mean)* | GL | 3140 | +16% | +35% | +1% | -22% | nm | nm | nm |
| Dry season flow (mean)** | GL | 190 | +36% | +21% | -2% | -16% | nm | nm | nm |
| Low flow threshold (discharge exceeded 90% of the time under Scenario A) | GL/d | 0.0727 | | | | | | | |
| Number of days below low flow threshold (mean) | d/y | 36.5 | -12.6 | -11.9 | -0.1 | +15.3 | nm | nm | nm |
| Number of days of zero flow (mean) | d/y | 1.88 | -1.4 | 0 | 0 | 0 | nm | nm | nm |
| High flow threshold (discharge exceeded 5% of the time under Scenario A) | GL/d | 52.3 | | | | | | | |
| Number of days above high flow threshold (mean) | d/y | 18.3 | +3.3 | +11.9 | +0.6 | -6.7 | nm | nm | nm |

* Wet season covers the six months from November to April; ** Dry season covers the six months from May to October

NR – metrics not reported because streamflow confidence level is ranked 4 or 5
nm – not modelled

## Archer River Aggregation

The surface water flow confidence level for the selected reporting node for the Archer River Aggregation (see location on Figure WC-8) is considered fairly reliable (2) for wet season flows and moderately reliable (3) for dry season flows (Table WC-10). Under Scenario A annual flow into this asset is dominated by wet season flows (95 percent) which have been 16 percent higher under Scenario B. Dry season flows have also been (43 percent) higher under Scenario B when compared to Scenario A. Annual and seasonal flows do not change much under Scenario Cmid compared to Scenario A, but there are large increases under Scenario Cwet (17 to 34 percent) and more moderate decreases under Scenario Cdry (19 to 22 percent). There are no development scenarios for the area upstream of this asset.

Compared to Scenario A, the number of days when flow is less than the low flow threshold does not change very much under Scenario Cmid, but there is a large increase in low flow days under Scenario Cdry and a moderate decrease in low flow days under Scenario Cwet (Table WC-10). Zero flow days only occur 3 percent of the year on average under Scenario A, with little change in any of the scenarios except Scenario Cdry where the number of days without flow almost doubles. Under Scenario B high flows have been more frequent than under Scenario A. Compared to Scenario A there is little change in high flow threshold exceedance under Scenario Cmid. Under Scenario Cwet high flow exceedance increases considerably from Scenario A; conversely, there is a more moderate decrease in high flow days under Scenario Cdry.

## Jardine River Wetlands Aggregation

The surface water flow confidence level for the selected reporting node for the Jardine River Wetlands Aggregation (see location on Figure WC-9) is considered unreliable (4) for wet season flows and moderately reliable (3) for dry season flows (Table WC-10). Because of the low confidence in wet season flows, metrics relating to such flows will not be reported. Compared to Scenario A, dry season flows have been 31 percent higher under Scenario B. Dry season flows do not change much under Scenario Cmid compared to Scenario A, but there is a moderate increase under Scenario Cwet (22 percent) and a moderate decrease under Scenario Cdry (14 percent). There are no development scenarios for the area upstream of this asset.

Compared to Scenario A, the number of days when flow is less than the low flow threshold does not change very much under Scenario Cmid , but there is a large increase in low flow days under Scenario Cdry and also a large decrease in low flow days under Scenario Cwet (Table WC-10). Under Scenario B low flows have been much more frequent than under Scenario A. Zero flow days are rare at this point in this river under Scenario A (less than 2 days per year on average) and this does not change under any of the scenarios. There are no high flow metrics reported for this asset.

## Northern Holroyd Plain Aggregation

The surface water flow confidence level for the selected reporting node for the Northern Holroyd Plain Aggregation (see location on Figure WC-10) is considered fairly reliable (2) for both wet and dry season flows (Table WC-10). Under Scenario A annual flow into this asset is highly dominated by wet season flows (97 percent) which have been 16 percent higher under Scenario B. Dry season flows have also been a lot higher (115 percent) under Scenario B when compared to Scenario A. Annual and seasonal flows do not change much under Scenario Cmid compared to Scenario A, but there are large increases under Scenario Cwet (38 to 53 percent) and more moderate decreases under Scenario Cdry (23 to 25 percent). There are no development scenarios for the area upstream of this asset.

Under Scenario A the low flow threshold for this asset is zero with flow ceasing for 24 percent of the year on average (Table WC-10). The number of days when flow stops does not change very much under Scenario Cmid compared to Scenario A, but there is a moderate increase in low flow days under Scenario Cdry and a moderate decrease in low flow days under Scenario Cwet. Under Scenario B high flows have been more frequent than under Scenario A. There is little change in high flow threshold exceedance under Scenario Cmid. Under Scenario Cwet high flow exceedance increases very markedly from Scenario A; conversely, there is a large decrease in high flow days under Scenario Cdry.

## Port Musgrave Aggregation

The surface water flow confidence level for the selected reporting node for the Port Musgrave Aggregation (see location on Figure WC-11) is considered moderately reliable (3) for both wet and dry season flows (Table WC-10). Under Scenario A annual flow into this asset is highly dominated by wet season flows (94 percent) which have been 16 percent higher in Scenario B. Dry season flows have also been (36 percent) higher in Scenario B than under Scenario A. Annual and seasonal flows do not change much under Scenario Cmid when compared to Scenario A, but there are fairly large increases under Scenario Cwet (21 to 35 percent) and moderate decreases under Scenario Cdry (16 to 22 percent). There are no development scenarios for the area upstream of this asset.

Compared to Scenario A, the number of days when flow is less than the low flow threshold does not change under Scenario Cmid , but there is a large increase in low flow days under Scenario Cdry and a large decrease in low flow days under Scenario Cwet (Table WC-10). Zero flow days are rare at this point in this river and this does not change under any of the scenarios. Under Scenario B high flows have been more frequent than in Scenario A. There is little change in high flow threshold exceedance under Scenario Cmid when compared to Scenario A. Under Scenario Cwet high flow exceedance increases greatly from Scenario A; conversely, there is also a large decrease in high flow days under Scenario Cdry.

# WC-3.8 References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# About the project

The Northern Australia Sustainable Yields (NASY) Project has assessed the water resources of northern Australia. The project modelled and quantified, within the limits of available data, the changes to water resources under four scenarios: historical climate; recent climate; future climate considering current water use and future climate with potential future water demand. The project identified regions that may come under increased, or decreased, stress due to climate change and increased water use.

The assessments made in this project provide key information for further investigations carried out through the Australian Government's Northern Australia Water Futures Assessment. This initiative aims to develop a knowledge base so that any development proceeds in an ecologically, culturally and economically sustainable way.

The NASY project was commissioned by the National Water Commission in consultation with the Australian Government Department of the Environment, Water, Heritage and the Arts. This followed a March 2008 agreement by the Council of Australian Governments to undertake comprehensive scientific assessments of water yield in all major water systems across the country and provide a consistent analytical framework for water policy decisions across the nation. CSIRO is also undertaking assessments in south-west Western Australia and Tasmania.

The NASY project was reviewed by a Steering Committee and a Technical Reference Panel. Both include representation from federal and state governments, as well as independent experts.

For further information:


**Water for a Healthy Country Flagship**
Project Leader
Dr Richard Cresswell
Phone: 07 3214 2767
Email: Richard.Cresswell@csiro.au
Web: www.csiro.au/partnerships/NASY

**Northern Australia Water Futures Assessment**
Department of the Environment, Water, Heritage and the Arts
Phone: 02 6274 1111
Email: northern.assessment@environment.gov.au
Web: http://www.environment.gov.au/nawfa

**Contact Us**
Phone: 1300 363 400
+61 3 9545 2176
Email: enquiries@csiro.au
Web: www.csiro.au/flagships