Water in the South-West Gulf region of the Gulf of Carpentaria Drainage Division
A report to the Australian Government from the CSIRO Northern Australia Sustainable Yields Project

August 2009
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
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National Research Flagships
CSIRO
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<th>Abbreviation or acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHD</td>
<td>Australian Height Datum</td>
</tr>
<tr>
<td>AMTD</td>
<td>Adopted Middle Thread Distance (the distance along a river upstream from its outlet)</td>
</tr>
<tr>
<td>APET</td>
<td>Areal potential evapotranspiration</td>
</tr>
<tr>
<td>AR4</td>
<td>The fourth assessment report of the Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>ARI</td>
<td>Average recurrence interval – the statistical length of time that might be expected to pass before a similar condition is repeated</td>
</tr>
<tr>
<td>AWRC</td>
<td>Australian Water Resources Council</td>
</tr>
<tr>
<td>BFI</td>
<td>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</td>
</tr>
<tr>
<td>BRS</td>
<td>Bureau of Rural Sciences, Department of Agriculture, Fisheries and Forestry</td>
</tr>
<tr>
<td>CLW</td>
<td>CSIRO Division of Land and Water</td>
</tr>
<tr>
<td>CMAR</td>
<td>CSIRO Division of Marine and Atmospheric Research</td>
</tr>
<tr>
<td>CMB</td>
<td>Chloride mass balance</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>COAG</td>
<td>Council of Australian Governments</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Scientific and Industrial Research Organisation</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital elevation model</td>
</tr>
<tr>
<td>DERM</td>
<td>(Queensland) Department of Environment and Resource Management</td>
</tr>
<tr>
<td>DEWHA</td>
<td>Department of the Environment, Water, Heritage and the Arts, Australian Government</td>
</tr>
<tr>
<td>DNRM</td>
<td>Previous incantation of DERM</td>
</tr>
<tr>
<td>DNRW</td>
<td>Previous incantation of DERM</td>
</tr>
<tr>
<td>DTW</td>
<td>Depth to watertable</td>
</tr>
<tr>
<td>E</td>
<td>Extraction</td>
</tr>
<tr>
<td>E/B</td>
<td>Extraction to baseflow ratio</td>
</tr>
<tr>
<td>E/R</td>
<td>Extraction to recharge ratio</td>
</tr>
<tr>
<td>Eᵢ</td>
<td>Future groundwater extraction</td>
</tr>
<tr>
<td>EC</td>
<td>Electrical conductivity, a measure of salinity. 1 EC (µS/cm) ≈ 0.6 mg/L TDS</td>
</tr>
<tr>
<td>ET</td>
<td>Evapotranspiration</td>
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<tr>
<td>FDC</td>
<td>Flow duration curve</td>
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<tr>
<td>GAB</td>
<td>Great Artesian Basin</td>
</tr>
<tr>
<td>GCM</td>
<td>Global climate model, also known as general circulation model</td>
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<tr>
<td>GDA</td>
<td>Geographic datum of Australia</td>
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<tr>
<td>GDE</td>
<td>Groundwater-dependent ecosystem</td>
</tr>
<tr>
<td>GRCI</td>
<td>Groundwater resource condition indicator</td>
</tr>
<tr>
<td>IQQM</td>
<td>Integrated Quantity and Quality Model – a river systems model</td>
</tr>
<tr>
<td>MAR</td>
<td>Managed aquifer recharge</td>
</tr>
<tr>
<td>MDB</td>
<td>Murray-Darling Basin</td>
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<tr>
<td>MGSH</td>
<td>Maximum gauged stage height</td>
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<tr>
<td>MSLP</td>
<td>Mean sea level pressure</td>
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<td>NAILSMA</td>
<td>Northern Australia Indigenous Land and Sea Management Alliance</td>
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<tr>
<td>NAS</td>
<td>Network attached storage</td>
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<tr>
<td>NRETA</td>
<td>Previous incantation of NRETAS</td>
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<tr>
<td>NRETAS</td>
<td>Northern Territory Department of Natural Resources, Environment, the Arts and Sport</td>
</tr>
<tr>
<td>NSE</td>
<td>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 R² coefficient of determination</td>
</tr>
<tr>
<td>PET</td>
<td>Potential evapotranspiration</td>
</tr>
<tr>
<td>R</td>
<td>Recharge</td>
</tr>
<tr>
<td>RAM</td>
<td>Random access memory</td>
</tr>
<tr>
<td>RSF</td>
<td>Recharge scaling factor</td>
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<tr>
<td>SAN</td>
<td>Storage area network</td>
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### Abbreviation or acronym

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<th>Abbreviation or acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>SRN</td>
<td>Streamflow reporting node</td>
</tr>
<tr>
<td>TDS</td>
<td>Total Dissolved Solids (mg/L ≈ 1.7 EC)</td>
</tr>
<tr>
<td>TRaCK</td>
<td>Tropical Rivers and Coastal Knowledge Research Hub</td>
</tr>
<tr>
<td>WRON</td>
<td>Water Resources Observation Network</td>
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### Units of measurement

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<th>Measurement units</th>
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<tbody>
<tr>
<td>ML</td>
<td>Megalitres, 1,000,000 litres</td>
</tr>
<tr>
<td>GL</td>
<td>Gigalitres, 1,000,000,000 litres</td>
</tr>
<tr>
<td>TL</td>
<td>Teralitres, 1,000,000,000,000 litres</td>
</tr>
<tr>
<td>Cumecs</td>
<td>Cubic metres per second; m³/sec; equivalent to 1,000 litres per second</td>
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<tr>
<td>1 Sydney Harbour</td>
<td>~500 GL</td>
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<tr>
<td>1 Lake Argyle</td>
<td>10,380 GL</td>
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### Glossary of terms

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<tr>
<th>Term</th>
<th>Description</th>
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<tr>
<td>Scenarios</td>
<td>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, 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.</td>
</tr>
<tr>
<td>Historical</td>
<td>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)</td>
</tr>
<tr>
<td>Recent</td>
<td>Scenario B: 1st September, 1996 to 31st August, 2007</td>
</tr>
<tr>
<td>Future</td>
<td>Scenario C: Climate conditions estimated for ~2030 compared to ~1990 conditions</td>
</tr>
<tr>
<td>Development</td>
<td>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</td>
</tr>
<tr>
<td>Without development</td>
<td>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.</td>
</tr>
<tr>
<td>Water Resource Assessment</td>
<td>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</td>
</tr>
<tr>
<td>Water Availability Assessment</td>
<td>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</td>
</tr>
<tr>
<td>Water Sustainable Yield Assessment</td>
<td>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</td>
</tr>
<tr>
<td>IHACRES Classic</td>
<td>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</td>
</tr>
<tr>
<td>WAVES</td>
<td>An analytical recharge model developed by Zhang and Dawes (1998) used to estimate groundwater recharge under different soils, vegetation and climate scenarios</td>
</tr>
<tr>
<td>SRES 1B</td>
<td>A future (2100) greenhouse gas emissions scenario used to compare climate model forecasts</td>
</tr>
<tr>
<td>Unallocated water</td>
<td>Water that is identified as water potentially available for future allocation</td>
</tr>
<tr>
<td>General Reserve</td>
<td>Unallocated water which may be granted for any purpose</td>
</tr>
<tr>
<td>Strategic Reserve</td>
<td>Unallocated water which may only be granted for a state purpose</td>
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</tbody>
</table>
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

SW-1.2.1 Under historical climate and current development

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

<table>
<thead>
<tr>
<th>Station</th>
<th>River</th>
<th>Station name</th>
<th>Annual BFI *</th>
<th>Dry season BFI *</th>
<th>Dry season baseflow *</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>912101A</td>
<td>Gregory</td>
<td>Gregory Downs</td>
<td>0.26</td>
<td>0.86</td>
<td>58.3</td>
</tr>
<tr>
<td>912103A</td>
<td>Lawn Hill Ck</td>
<td>Lawn Hill No 2</td>
<td>0.17</td>
<td>0.74</td>
<td>8.3</td>
</tr>
<tr>
<td>912104A</td>
<td>Widdallion Ck</td>
<td>Lawn Hill</td>
<td>0.25</td>
<td>0.80</td>
<td>12.7</td>
</tr>
<tr>
<td>912105A</td>
<td>Gregory</td>
<td>Riversleigh No.2</td>
<td>0.30</td>
<td>0.86</td>
<td>57.9</td>
</tr>
<tr>
<td>912106A</td>
<td>Musselbrook Ck</td>
<td>Stockyard Ck</td>
<td>0.07</td>
<td>0.08</td>
<td>0.2</td>
</tr>
<tr>
<td>G9070132</td>
<td>McArthur</td>
<td>M. I. M. Pump</td>
<td>0.09</td>
<td>0.52</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Historical recharge ** | Estimated groundwater extraction

| GL/y | 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

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

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 indicate 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

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

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**

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**

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 km²) 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)
SW-1.6 Water storage options

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

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

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 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.

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**


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.
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 annual 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.
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.

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 km² 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**

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

* 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).

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).

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](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 derived from ACRES, 2000. Clouds may be visible in image](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).

![False colour satellite image of the Thorntonia Aggregation](image)

Forest 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 km². 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 km². 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 km².
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)](image)

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.
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.

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](image)

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).

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 negligible 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

*Groundwater salinity reflects all bores completed in shallow and deep aquifers*
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.
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>
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<th>Indigenous</th>
<th>TOTAL</th>
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<td>4400</td>
<td>-</td>
<td>8800</td>
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<tr>
<td>Gregory</td>
<td>2500</td>
<td>5000</td>
<td>-</td>
<td>7500</td>
</tr>
</tbody>
</table>

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

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.
SW-3. Water balance results for 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.
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

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)
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>
<thead>
<tr>
<th>Water year*</th>
<th>Wet season</th>
<th>Dry season</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm/y</td>
<td>mm/season</td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical</td>
<td>670</td>
<td>631</td>
</tr>
<tr>
<td>Cwet</td>
<td>732</td>
<td>683</td>
</tr>
<tr>
<td>Cmid</td>
<td>668</td>
<td>624</td>
</tr>
<tr>
<td>Cdry</td>
<td>632</td>
<td>593</td>
</tr>
<tr>
<td>Areal potential evapotranspiration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Historical</td>
<td>1961</td>
<td>1103</td>
</tr>
<tr>
<td>Cwet</td>
<td>2022</td>
<td>1134</td>
</tr>
<tr>
<td>Cmid</td>
<td>2009</td>
<td>1125</td>
</tr>
<tr>
<td>Cdry</td>
<td>2041</td>
<td>1143</td>
</tr>
</tbody>
</table>

* 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 CO₂, 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>
<thead>
<tr>
<th>Region</th>
<th>Awet</th>
<th>Amid</th>
<th>Adry</th>
<th>B</th>
<th>Cwet</th>
<th>Cmid</th>
<th>Cdry</th>
</tr>
</thead>
<tbody>
<tr>
<td>South-West Gulf</td>
<td>1.12</td>
<td>0.97</td>
<td>0.86</td>
<td>1.60</td>
<td>1.39</td>
<td>1.09</td>
<td>0.99</td>
</tr>
</tbody>
</table>
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 CO₂ 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)](image-url)
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)

<table>
<thead>
<tr>
<th></th>
<th>High global warming</th>
<th>Medium global warming</th>
<th>Low global warming</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GCM</td>
<td>Rainfall</td>
<td>Recharge</td>
</tr>
<tr>
<td>csiro</td>
<td>-20%</td>
<td>-20% csiro</td>
<td>-15%</td>
</tr>
<tr>
<td>mri</td>
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<td>-1% mri</td>
<td>-4%</td>
</tr>
<tr>
<td>iap</td>
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<td>1% iap</td>
<td>-3%</td>
</tr>
<tr>
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<td>-1%</td>
<td>4% inmcm</td>
<td>0%</td>
</tr>
<tr>
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<td>9% cnrm</td>
<td>-3%</td>
</tr>
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<td>11% giss_aom</td>
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<td>12% ipsl</td>
<td>0%</td>
</tr>
<tr>
<td>ncar_ccsm</td>
<td>1%</td>
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<td>1%</td>
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<tr>
<td>mpi</td>
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<td>17% mpi</td>
<td>0%</td>
</tr>
<tr>
<td>cccma_t47</td>
<td>1%</td>
<td>22% cccma_t47</td>
<td>1%</td>
</tr>
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<td>ncar_pcm</td>
<td>7%</td>
<td>27% ncar_pcm</td>
<td>5%</td>
</tr>
<tr>
<td>gfdl</td>
<td>0%</td>
<td>27% gfdl</td>
<td>0%</td>
</tr>
<tr>
<td>miroc</td>
<td>10%</td>
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<td>7%</td>
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<td>miub</td>
<td>8%</td>
<td>39% miub</td>
<td>6%</td>
</tr>
<tr>
<td>cccma_t63</td>
<td>10%</td>
<td>52% cccma_t63</td>
<td>8%</td>
</tr>
</tbody>
</table>

Under Scenario C wet recharge increases 39 percent; this is less than under Scenario B. Under Scenario C mid recharge increases 9 percent. Under Scenario C dry 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](image-url)
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.

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.

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**Figure SW-31. Schematic of conceptual model for groundwater discharge to the Gregory River and Lawn Hill Creek of the South-West Gulf region**

**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-3.4  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.
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 exceedance 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 catchments 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 10th percentile, median and 90th 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 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 (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 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 (1.00) 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)

<table>
<thead>
<tr>
<th>GCM</th>
<th>High global warming</th>
<th>Medium global warming</th>
<th>Low global warming</th>
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<td></td>
<td>Rainfall %</td>
<td>Runoff %</td>
<td>Rainfall %</td>
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<tr>
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<td>-20%</td>
<td>-34%</td>
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</table>
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>
<thead>
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<th>Evapotranspiration</th>
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<td>A</td>
<td>666</td>
<td>89</td>
<td>576</td>
</tr>
<tr>
<td>B</td>
<td>27%</td>
<td>78%</td>
<td>19%</td>
</tr>
<tr>
<td>Cwet</td>
<td>7%</td>
<td>19%</td>
<td>5%</td>
</tr>
<tr>
<td>Cmid</td>
<td>-1%</td>
<td>-3%</td>
<td>-1%</td>
</tr>
<tr>
<td>Cdry</td>
<td>-6%</td>
<td>-18%</td>
<td>-4%</td>
</tr>
</tbody>
</table>

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)
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 km². 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>
<thead>
<tr>
<th>Standard metrics</th>
<th>Units</th>
<th>A</th>
<th>B</th>
<th>Cwet</th>
<th>Cmid</th>
<th>Cdry</th>
<th>Dwet</th>
<th>Dmid</th>
<th>Ddry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gregory River - Node 1 (confidence level: low flow = 5, high flow = 1)</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Annual flow (mean)</td>
<td>GL</td>
<td>455</td>
<td>+19%</td>
<td>+24%</td>
<td>-3%</td>
<td>-18%</td>
<td>nm</td>
<td>nm</td>
<td>nm</td>
</tr>
<tr>
<td>Wet season flow (mean)*</td>
<td>GL</td>
<td>387</td>
<td>+21%</td>
<td>+24%</td>
<td>-3%</td>
<td>-18%</td>
<td>nm</td>
<td>nm</td>
<td>nm</td>
</tr>
<tr>
<td>Dry season flow (mean)**</td>
<td>GL</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Low flow threshold (discharge exceeded 90% of the time under Scenario A)</td>
<td>GL/d</td>
<td>NR</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Number of days below low flow threshold (mean)</td>
<td>d/y</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of days of zero flow (mean)</td>
<td>d/y</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>High flow threshold (discharge exceeded 5% of the time under Scenario A)</td>
<td>GL/d</td>
<td>3.1</td>
<td></td>
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<tr>
<td>Number of days above high flow threshold (mean)</td>
<td>d/y</td>
<td>18.3</td>
<td>+5.3</td>
<td>+3.8</td>
<td>-0.4</td>
<td>-3.1</td>
<td>nm</td>
<td>nm</td>
<td>nm</td>
</tr>
<tr>
<td><strong>Port McArthur Tidal Wetlands System - Node 3 (confidence level: low flow = 5, high flow = 3)</strong></td>
<td></td>
<td></td>
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<tr>
<td>Annual flow (mean)</td>
<td>GL</td>
<td>401</td>
<td>+71%</td>
<td>+4%</td>
<td>-10%</td>
<td>-19%</td>
<td>nm</td>
<td>nm</td>
<td>nm</td>
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<td>Wet season flow (mean)*</td>
<td>GL</td>
<td>390</td>
<td>+72%</td>
<td>+3%</td>
<td>-9%</td>
<td>-19%</td>
<td>nm</td>
<td>nm</td>
<td>nm</td>
</tr>
<tr>
<td>Dry season flow (mean)**</td>
<td>GL</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Low flow threshold (discharge exceeded 90% of the time under Scenario A)</td>
<td>GL/d</td>
<td>NR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of days below low flow threshold (mean)</td>
<td>d/y</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of days of zero flow (mean)</td>
<td>d/y</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>High flow threshold (discharge exceeded 5% of the time under Scenario A)</td>
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<td>5.97</td>
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</tr>
<tr>
<td>Number of days above high flow threshold (mean)</td>
<td>d/y</td>
<td>18.3</td>
<td>+10.5</td>
<td>+0.3</td>
<td>-1.8</td>
<td>-3.4</td>
<td>nm</td>
<td>nm</td>
<td>nm</td>
</tr>
<tr>
<td><strong>Thorntonia Aggregation - Node 3 (confidence level: low flow = 5, high flow = 2)</strong></td>
<td></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Annual flow (mean)</td>
<td>GL</td>
<td>232</td>
<td>+23%</td>
<td>+26%</td>
<td>-2%</td>
<td>-20%</td>
<td>nm</td>
<td>nm</td>
<td>nm</td>
</tr>
<tr>
<td>Wet season flow (mean)*</td>
<td>GL</td>
<td>195</td>
<td>+25%</td>
<td>+26%</td>
<td>-3%</td>
<td>-20%</td>
<td>nm</td>
<td>nm</td>
<td>nm</td>
</tr>
<tr>
<td>Dry season flow (mean)**</td>
<td>GL</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Low flow threshold (discharge exceeded 90% of the time under Scenario A)</td>
<td>GL/d</td>
<td>NR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of days below low flow threshold (mean)</td>
<td>d/y</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of days of zero flow (mean)</td>
<td>d/y</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>High flow threshold (discharge exceeded 5% of the time under Scenario A)</td>
<td>GL/d</td>
<td>1.57</td>
<td></td>
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</tr>
<tr>
<td>Number of days above high flow threshold (mean)</td>
<td>d/y</td>
<td>18.3</td>
<td>+6.2</td>
<td>+3.9</td>
<td>-0.4</td>
<td>-3.4</td>
<td>nm</td>
<td>nm</td>
<td>nm</td>
</tr>
</tbody>
</table>

* 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 Cmd 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 Cmd 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 Cmd 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 Cmd 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


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:

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Phone: 02 6274 1111
Email: northern.assessment@environment.gov.au

CSIRO and the Flagships program

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills. CSIRO initiated the National Research Flagships to address Australia’s major research challenges and opportunities. They apply large scale, long term, multidisciplinary science and aim for widespread adoption of solutions.