Part II  Resource information for assessing potential development opportunities

Chapters 2 and 3 provide baseline information that readers can use to understand what soils and water resources are present in the Mitchell catchment and the current living and built environment of the Mitchell catchment. This information covers:

- the physical environment (Chapter 2)
- the people, ecology and institutional context (Chapter 3).


Chapter 2 examines the physical environment of the Mitchell catchment and seeks to identify the available soil and water resources. It provides fundamental information about the geology, soil, climate and the river and groundwater systems of the catchment. These resources underpin the natural environment and existing industries, providing physical bounds to the potential scale of irrigation development. Key components and concepts are shown in Figure 2-1.

Based on the Australian Water Resources Council river basins (Geoscience Australia, 1997) the catchment area of the Mitchell catchment was calculated to be 71,529 km².

Figure 2-1 Schematic diagram of key natural components and concepts in the establishment of a greenfield irrigation development
2.1 Summary

This chapter provides a resource assessment of the geology, soil, climate, groundwater and surface water resources of the Mitchell catchment. No attempt is made in this chapter to calculate physically plausible areas of land or volumes of water that could potentially be used for agriculture or aquaculture developments. These analyses are reported in Chapters 4 and 5.

2.1.1 KEY FINDINGS

Soils

About 40% of the Mitchell catchment has soils that are at least moderately suitable for some form of irrigated agriculture. Below the confluence of Rosser Creek and the Mitchell River the river becomes divergent and broad-scale flooding commences, which without regulation (i.e. major dams) would limit wet-season cropping and access to markets. Nevertheless, there are still large areas of land with soils suitable for irrigated agriculture upstream, which are not subject to broad-scale flooding – most notably an area of cracking clay soils upstream of the confluence of the Mitchell and Walsh rivers. These soils have a large capacity for holding water and are suitable for a wide range of crops, although further investigation would be required to assess the likelihood of salinity issues developing under irrigated cropping.

Climate

The Mitchell catchment has a hot and dry semi-arid to sub-humid climate. The climate is highly seasonal with an extended dry season. It receives, on average, 996 mm of rain per year, 97% of which falls during the wet season. Mean daily temperatures and potential evaporation are high relative to other parts of Australia. Potential evaporation exceeds 1800 mm/year across most of the catchment, meaning potential evaporative water loss from open water storages is nearly twice the mean annual rainfall.

Overall, the climate of the Mitchell catchment generally suits the growing of a wide range of crops, though in most years rainfall would need to be supplemented with irrigation. The variation in rainfall from one year to the next is high compared to southern Australia and other parts of the world of similar mean annual rainfall. While the length of consecutive dry years in the Mitchell catchment is not unusual, the intensity of the dry years is slightly higher than many centres in the Murray–Darling Basin and east coast of Australia.

The agricultural soils more suited to irrigated agriculture near the confluence of the Mitchell and Walsh rivers are largely buffered from the most damaging cyclonic winds by their distance from the coast, but the rain depressions can bring flood risk to those areas downstream.

Approximately one-third of the global climate models (GCMs) project an increase in mean annual rainfall, a quarter project a decrease in mean annual rainfall and about two-fifths indicate ‘little change’.

Hydrology

The timing and event-driven nature of rainfall events and high potential evaporation rates across the Mitchell catchment have important consequences for the catchment’s hydrology. Approximately 90% of all runoff in the Mitchell catchment occurs during the 3-month period,
January to March, which is very high compared to rivers in southern Australia. The variability in rainfall is amplified in runoff.

The Mitchell catchment is estimated to have a mean annual discharge of 15,000 GL to the Gulf of Carpentaria, of which over half is generated below the lowermost gauge on the Mitchell River at Dunbar. At this location the Mitchell River has a modelled mean annual streamflow of 7107 GL, 26% higher than the median annual streamflow at the same location. The Bulimba aquifer within the Bulimba Formation, which underlies the lower half of the Mitchell catchment, is the most promising aquifer from which to source groundwater in the catchment. Large parts of the aquifer are artesian (water would flow to the surface through a bore) and therefore pumping costs are currently minimal during groundwater extraction. The steeply dipping Gilbert River Formation may offer opportunities for groundwater resource development, though few data exist on this formation and its depth makes exploratory drilling expensive. Elsewhere, groundwater is largely limited to stock and domestic supplies.

The Mitchell River is perennial, however, its major tributaries the Palmer, Walsh and Lynd all experience periods of no flow, and in some reaches these rivers are reduced to a series of waterholes – some of which persist throughout the dry season. Most of the waterholes are maintained by streamflow, rather than groundwater, and act as important refugia for aquatic biota (see Section 3.2).

2.1.2 INTRODUCTION

This chapter seeks to address the question ‘What soil and water resources are available for irrigated agriculture in the Mitchell catchment?’

The chapter is structured as follows:

• Section 2.2 examines the geology of the Mitchell catchment, which is important in understanding the distribution of valuable minerals, coal, groundwater, soil and areas of high and low relief, which influences flooding and the deposition of soil.

• Section 2.3 examines the distribution of soils in the Mitchell catchment, their attributes and discusses management considerations.

• Section 2.4 examines the climate of the Mitchell catchment, including historical and future projections of patterns in rainfall.

• Section 2.5 examines the groundwater and surface water hydrology of the Mitchell catchment, including groundwater recharge, streamflow and flooding.
2.2 Geology of the Mitchell catchment

Geological history is closely linked to resources such as valuable minerals, coal, groundwater and soil. Geology exercises an important control on topography, which in turn is a key factor in the location of potential dam sites, flooding and deposition of soil. These resources are all important considerations when identifying suitable locations for large water storages and understanding past and present ecological systems and patterns of human settlement.

The geology of the Mitchell catchment may be divided into five major provinces. From west to east (downstream to upstream) these are the Karumba Basin, Carpentaria Basin, Savannah Province, Etheridge Province and the Hodgkinson Province (Figure 2-2). The broad major rock types associated with each geological province include igneous and meta-sedimentary rocks (Savannah, Etheridge and Hodgkinson provinces), sedimentary rocks and unconsolidated to consolidated surficial sediments (or ‘loose’ to ‘compacted’ grains or aggregates) (Karumba and Carpentaria basins).

![Figure 2-2 Major geological provinces of the Mitchell catchment](image)

The Hodgkinson Province is in the north-eastern part of the catchment (Figure 2-3) and comprises mainly siliciclastic sediments of Paleozoic age that have been intruded by granite, folded, faulted...
and uplifted, and subject to long periods of erosion since they were formed. The best potential dam sites in the Mitchell catchment are found where rivers have eroded through the rocks of the Hodgkinson Province. Other potential dam sites in the area occur where rivers have cut through ridges of hard sedimentary or metamorphic rock (such as arenite or chert) of the Hodgkinson Formation. They can generally be characterised as high strength and resistant to erosion. Consequently, they tend to form areas of higher relief and are often generally suitable for siting large dams. The rocks in these locations have very low primary porosity (<2%), with pores that are very small and not interconnected. For this reason, they do not hold much groundwater and are essentially impermeable. However, the Hodgkinson Province also contains rocks with reasonable secondary porosity features (fractures, joints and faults) that form fractured rock aquifers (Hodgkinson Formation) over large areas, which supply an important source of stock and domestic groundwater. Because these rocks are resistant to erosion they tend to have shallow soils.

Other potential dam sites occur where rivers have eroded through the younger volcanic rocks (ignimbrites and lavas) of Carboniferous to Permian volcanics (Figure 2-3). The ignimbrites in this area are strong rocks formed by the welding of pyroclastic flows (hot mixtures of ash and gas that flow rapidly from a volcano during an eruption). They have formed thick deposits covering large areas, which have been preserved because they have been deposited in subsidence areas (volcanic cauldrons). As ignimbrite is resistant to weathering and erosion, river valleys tend to be relatively narrow with relatively little alluvium and they do not hold much groundwater.

While there are potential dam sites in the Chillagoe Formation (Figure 2-3), care would be needed to avoid potential problems with karstic limestone in the foundations or storage area. In addition, care would also have to be taken with potential dam sites in the south-east in the upper reaches of the Lynd River where high leakages could be associated with relatively young basalts and the unconformities at the base of the basalts (Figure 2-3).

The Etheridge Province occurs in the north-central and south-eastern parts of the Mitchell catchment (Figure 2-3) and is underlain by the oldest rocks in the catchment, metamorphic rocks and granite of the Paleoproterozoic age. Much of the Etheridge Province produces topography unfavourable for dam construction but there are some places where the topography is more favourable (e.g. on the Lynd River where the river has eroded through or down to the volcanic rocks). Most of these rocks have very low primary porosity (<2%), are essentially impermeable and do not hold much groundwater. Isolated areas of these rocks, however, are weathered and fractured, with secondary porosity features supporting small localised aquifers that provide a small volume of groundwater.

Major ore bodies in the Mitchell catchment are generally limited to the very old igneous and metamorphic rocks (i.e. older than Permian) of the Hodgkinson and Etheridge provinces, where hot fluids have been transported from great depths and minerals in the fluids precipitated in the faults and fractures of these rocks. The formation of hydrothermal ore bodies (found in this area) is facilitated by deformation of the crust; the older the rock the greater the chance that deformation and mineralisation will occur. For this reason, economically exploitable mineral resources, primarily tin, gold and copper, are mainly located in the eastern third of the catchment around the towns of Chillagoe and Mount Garnet. Tin mineralisation is concentrated around Mount Garnet, while copper and other base metals (e.g. zinc, lead) are mainly focused in the Chillagoe area.
Jurassic- to Cretaceous-age sedimentary rocks of ‘clastic’ origin occur in the geological Carpentaria Basin in the south-central part of the catchment (Figure 2-3). These sedimentary rocks comprise mostly quartzose sandstone, mudstone and siltstone. The nature of the rocks and gentle rolling topography of the geological Carpentaria Basin has negligible economic potential and presents few opportunities for instream dams. Embankments generally must be very long to provide adequate storage, construction and operation of a spillway to cope with the large flood events that can occur and could pose significant risks. The quartzose sandstone, however, forms a highly porous, high-yielding aquifer, though most of the aquifer west of the outcrop area is too deep to drill for groundwater extraction economically.

There are no active hydrocarbon exploration leases in the Mitchell catchment, and this is mainly because the geological Carpentaria Basin is relatively juvenile and has no suitable source rocks deposited in the basin (e.g. organic-rich shales). In general, the area is not prospective for coal resources though there is one coal exploration lease that straddles the edge of the north of the catchment. There are no geothermal leases, and this is most probably due to a lack of radiogenic rocks at depth, coupled with the remoteness of much of the catchment.

Tertiary-age sedimentary rocks of ‘clastic’ origin occur in the Karumba Basin, which overlies the geological Carpentaria Basin in the western third of the catchment (Figure 2-3). Rock types include mostly claystones and sandstones that are deeply weathered and of low strength. The terrain underlain by rock of the Karumba Basin is usually not suitable for large dams because of the low topographic relief. Soils developed over these rocks may be moderately suitable for irrigation for some crops, albeit with limitations. The sandstone unit forms a highly porous, high-yielding aquifer that occurs as a series of paleochannels (an inactive river or stream channel buried by younger sediments) at moderate depths (~150 m) beneath the Mitchell River Fan Aggregation.

Surficial sediments occur mostly in the west of the Mitchell catchment (Figure 2-3) and comprise a mixture of sand, silt, gravel and clay. Those that comprise mainly sand or gravel often form highly porous, high-yielding aquifers that supply localised sources of groundwater. Those that comprise mainly clay often have low porosity and low permeability, as well as low aquifer yield. Surficial alluvial sediments (i.e. deposited by rivers) form a large area downstream of the confluence between the Palmer and Mitchell rivers in the western part of the catchment and smaller areas along the middle reaches of the Palmer and Mitchell rivers. These alluvial areas may be moderately suitable for some crops with limitations. The more elevated parts of these Tertiary sediments above the delta in the north are mainly sandy, loamy and gravelly areas also moderately suitable for a range of crops.
2.3 Soils of the Mitchell catchment

2.3.1 INTRODUCTION

Soils in a landscape occur as complex patterns resulting from the interplay of five key factors: parent material, climate, organisms, topography and time (Fitzpatrick, 1986). Consequently, soils can be highly variable across a landscape, with different soils having different attributes that determine their suitability for growing different crops and guide how they need to be managed. The distribution of these soils and their attributes closely reflects the geology and landform of the catchment. Hence data and maps of soil, and soil attributes, which provide a spatial representation of how soils vary across a landscape, are fundamental to regional-scale land use planning and nearly every aspect of farming.
This section briefly describes the spatial distribution of soil groups (Section 2.3.2) and soil attributes (Section 2.3.3) in the Mitchell catchment. The management considerations are also summarised. Maps showing the suitability of different crops under different irrigation types are presented in Section 5.5.

Unless otherwise stated, the material in Section 2.3 is based on findings described in the companion technical reports on digital soil mapping (Thomas et al., 2018a) and land suitability (Thomas et al., 2018b). Soils and their attributes were described adhering to Australian soil survey standards (National Committee on Soil and Terrain, 2009).

### 2.3.2 SOIL CHARACTERISTICS

The soils of the Mitchell catchment can be broadly classified into soil generic groups (SGGs) (Table 2-1 and Figure 2-4). These groupings provide a means of aggregating soils with broadly similar properties and management considerations. Seven SGGs occupy more than 5% of the Mitchell catchment; 5% of the Mitchell catchment is equivalent to 360,000 ha.

Table 2-1 Soil generic groups (SGG) for the Mitchell catchment

<table>
<thead>
<tr>
<th>SGG</th>
<th>SGG OVERVIEW AND % OF AREA</th>
<th>GENERAL DESCRIPTION</th>
<th>LANDFORM</th>
<th>MAJOR MANAGEMENT CONSIDERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Sand or loam over relatively friable red clay subsoils (&lt;1%)</td>
<td>Strong texture contrast between the A and B horizons, A horizons generally not bleached. B horizon not sodic and may be acid or alkaline. Moderately deep to deep well-drained red soils</td>
<td>Undulating plains to hilly areas on a wide variety of parent materials</td>
<td>The non-acid soils are widely used for agriculture; the strongly acid soils are generally used for native and improved pastures</td>
</tr>
<tr>
<td>1.2</td>
<td>Sand or loam over relatively friable brown, yellow and grey clay subsoils (&lt;1%)</td>
<td>As above, but moderately well-drained to imperfectly drained brown, yellow and grey soils</td>
<td>As above</td>
<td>As above, but may be restricted by drainage related issues</td>
</tr>
<tr>
<td>2</td>
<td>Friable non-cracking clay or clay loam soils (7%)</td>
<td>Moderate to strongly structured, neutral to strongly acid soils with little or only gradual increase in clay content with depth. Grey to red, moderately deep to very deep soils</td>
<td>Plains, plateaus and undulating plains to hilly areas on a wide variety of parent materials</td>
<td>Generally high agricultural potential because of their good structure, and their moderate to high chemical fertility and water-holding capacity. Ferrosols on young basalt and other basic landscapes may be shallow and rocky</td>
</tr>
<tr>
<td>3</td>
<td>Seasonally or permanently wet soils (17%)</td>
<td>A wide variety of soils grouped together because of their seasonal or permanent inundation. No discrimination between saline and freshwater</td>
<td>Coastal areas to inland wetlands, swamps and drainage depressions. Mostly unconsolidated sediments, usually alluvium</td>
<td>Require drainage works before development can proceed. Acid sulfate soils and salinity are associated problems in some areas</td>
</tr>
</tbody>
</table>

1 Note that a common set of soil generic groups (SGGs) was developed for the three study areas, but not all groups are found in all areas. In the Mitchell catchment, SGG 5 and SGG 10 soils are not found.
<table>
<thead>
<tr>
<th>SGG</th>
<th>SGG OVERVIEW AND % OF AREA</th>
<th>GENERAL DESCRIPTION</th>
<th>LANDFORM</th>
<th>MAJOR MANAGEMENT CONSIDERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Red loamy soils (8%)</td>
<td>Well-drained, neutral to acid red soils with little or only gradual increase in clay content at depth. Moderately deep to very deep red soils</td>
<td>Level to gently undulating plains and plateaus, and some unconsolidated sediments, usually alluvium</td>
<td>Moderate to high agricultural potential with spray or trickle irrigation due to their good drainage. Low to moderate water-holding capacity, often hard-setting surfaces</td>
</tr>
<tr>
<td>4.2</td>
<td>Brown, yellow and grey loamy soils (10%)</td>
<td>As above, but moderately well-drained to imperfectly drained brown, yellow and grey soils</td>
<td>As above, but more common in lower parts of the landscape</td>
<td>As above, but may be restricted by drainage related issues</td>
</tr>
<tr>
<td>5</td>
<td>Peaty soils (0%)</td>
<td>Soils high in organic matter</td>
<td>Predominantly swamps</td>
<td>Low agricultural potential due to very poor drainage</td>
</tr>
<tr>
<td>6.1</td>
<td>Red sandy soils (&lt;1%)</td>
<td>Moderately deep to very deep red sands, may be gravelly</td>
<td>Sandplains and dunes; Aeolian, fluvial and siliceous parent material</td>
<td>Low agricultural potential due to excessive drainage and poor water-holding capacity. Potential for irrigated agriculture</td>
</tr>
<tr>
<td>6.2</td>
<td>Brown, yellow and grey sandy soils (6%)</td>
<td>Moderately deep to very deep brown, yellow and grey sands, may be gravelly</td>
<td>As above, but more common in lower parts of the landscape</td>
<td>Low agricultural potential due to poor water-holding capacity combined with seasonal drainage restrictions. May have potential for irrigated agriculture</td>
</tr>
<tr>
<td>7</td>
<td>Shallow and/or rocky soils (37%)</td>
<td>Very shallow to shallow (&lt;0.5 m). Usually sandy or loamy, but may be clayey. Generally weakly developed soils that may contain gravel</td>
<td>Crests and slopes of hilly and dissected plateaus in a wide variety of landscapes</td>
<td>Negligible agricultural potential due to lack of soil depth, poor water-holding capacity and presence of rock</td>
</tr>
<tr>
<td>8</td>
<td>Sand or loam over sodic clay subsoils (12%)</td>
<td>Strong texture contrast between the A and B horizons; A horizons usually bleached. Usually alkaline but occasionally neutral to acid subsoils. Moderately deep to deep</td>
<td>Lower slopes and plains in a wide variety of landscapes</td>
<td>Generally low to moderate agricultural potential due to restricted drainage, poor root penetration and susceptibility to gully and tunnel erosion. Those with thick to very thick A horizons are favoured</td>
</tr>
<tr>
<td>9</td>
<td>Cracking clay soils (1.5%)</td>
<td>Clay soils with shrink-swell properties that cause cracking when dry. Usually alkaline and moderately deep to very deep</td>
<td>Floodplains and other alluvial plains. Level to gently undulating plains and rises (formed on labile sedimentary rock). Minor occurrences in basalt landscapes</td>
<td>Generally moderate to high agricultural potential. The flooding limitation will need to be assessed locally. Many soils are high in salt (particularly those associated with the treeless plains). Gilgai and coarse structured surfaces may occur</td>
</tr>
<tr>
<td>10</td>
<td>Highly calcareous soils (0%)</td>
<td>Moderately deep to deep soils that are calcareous throughout the profile</td>
<td>Plains to hilly areas</td>
<td>Generally moderate to low agricultural potential depending on soil depth and presence of rock</td>
</tr>
</tbody>
</table>

Cracking clay soils (SGG 9) occur to a limited extent in the Mitchell catchment. They are found on the gently undulating plains and rises at Wrotham Park, upstream of the confluence of the Mitchell and Walsh rivers. These self-mulching black Vertosols have high water-holding capacity, but may have restricted rooting depth due to high salt levels in the subsoil. These soils are suited to a variety of dry-season grain, forage and pulse crops, although require further investigation, especially at local scale, to assess the likelihood of salinity issues developing under irrigated cropping (see Section 7.6). Cracking clay soils are also found on the alluvial plains of the Mitchell
delta. These clay soils are suited to a variety of grain, forage and pulse crops, but are susceptible to seasonal wetness in many places across the delta.

Figure 2-4 Soil generic groups (SGG) of the Mitchell catchment produced by digital soil mapping
The inset map shows the data reliability, which for SGG mapping is based on the confusion index as described in Thomas et al. (2018a).

Although often suitable for cropping, the sands or loams over friable clay (SGG 1.1 and SGG 1.2) are found in relatively small areas in the upper eastern part of the catchment. These soils are well suited to intensive horticulture and are found in places that are highly fragmented by creeks resulting in few areas suitable for large-scale development. Where found on the alluvial plains their narrow irregular nature makes large-scale development difficult.

Sand or loam over sodic clay subsoils (SGG 8) occurs extensively throughout the Mitchell catchment. These soils are characterised by sodic subsoils with either sandy or loamy surface soil. The most extensive areas of these soils are on the regularly flooded broad delta with numerous flood channels that become more numerous and meandering closer to the coast. On all alluvial
plains upstream of the confluence of the Palmer and Mitchell rivers, the occasionally flooded ‘narrow’ alluvial plains are generally deeply incised by the main channel resulting in relatively narrow usable areas. Soils are dominated by hard-setting clay loam to silty clay loam surfaced soils with strongly sodic, dispersive structured clay subsoil. These slowly permeable moderately well-drained to imperfectly drained soils predominantly have moderate soil water storage. They are subject to regular flooding across the delta and to erosion on slopes – particularly gully erosion adjacent to stream channels. The soils have potential for agricultural development if their limitations can be managed.

The friable non-cracking clays and clay loam soils (SGG 2) occur to a very limited extent in the south-east, east and north-east of the upper catchment. Along the upper Lynd River large boulders on the surface and throughout the profile make agricultural development difficult and expensive. Although these soils are typically suited to irrigated agriculture, their narrow, ribbon-like form in many parts of the landscape where they are found may limit infrastructure layout. Soils that are found in the upper catchment near Mareeba are used extensively for cropping. Other areas include the moderately permeable soils in the high-rainfall Julatten area, and the plains on the Mitchell River delta. The Julatten area is largely steep hills and mountains with the deep soils on the gentler slopes used for cropping and grazing. The imperfectly drained friable non-cracking clays on prior streams and plains of the delta (associated with SGG 8 and SGG 9) are suited to a variety of grain, forage and pulse crops. Friable clays and loams are also associated with the Chillagoe Formation (i.e. limestone rocks) where shallow to deep red soils occur on gently undulating to undulating lower slopes of limestone hills. Although these soils on limestone are suited to irrigated agriculture their narrow, ribbon-like form may limit infrastructure layout.

Red, yellow and grey loamy soils (SGG 4.1 and SGG 4.2) occur on a variety of geologies and landforms across the catchment. Elevated flood-free areas occur on sandplains derived from ‘old’ alluvium generally adjacent to the major river channels in the catchment, including deep, well-drained red soils, which are restricted to the upper slopes of landforms in the south-east of the Lynd catchment and tend to be restricted in area to less than 100 ha. Soils in these two SGGs are also found on narrow levees adjacent to the major rivers and tributaries across the catchment and on prior streams across the delta. They also occur as very deep well-drained red soils in the quartz sandstone plateaus in the northern parts of the catchment. They are moderately permeable, deep to very deep soils, but have low to moderate soil water storage. Irrigation is limited to spray and trickle irrigation. These soils are typically nutrient deficient, hence require high fertiliser inputs when initially developed.

Seasonally wet and permanently wet soils (SGG 3) occur extensively on a range of low-lying landscapes. The Mitchell River alluvial plains and delta frequently have swamps with poorly drained clay soils, especially in the lower delta area around Kowanyama. Very poorly drained saline coastal marine plains, which were deposited during previous sea-level rises along the Gulf coast and now occur above tidal inundation, have very deep, non-cracking and cracking clays with frequent gilgais. The marine plains are also subject to storm surge from cyclones. The coastal salt pans and mangroves subject to regular tidal inundation near the coast often have acid sulfate deposits in the soil profile, which when disturbed and exposed to the atmosphere create sulfuric acid and other contaminants. The extensive level alluvial plains and alluvial fans to the north and south of the Mitchell River alluvium/delta and the plains on Tertiary sedimentary rocks to the north and south of the Mitchell River in the centre of the catchment frequently have seasonally
wet sands and loams over intractable grey sodic clay subsoils. All these soils have limited potential for agricultural development.

Deep sandy soils (SGG 6.1 and SGG 6.2) occur to a limited extent on the beach ridges along the coast and occur as very deep well-drained red sands on the quartz sandstone plateaus in the central part of the catchment. These highly permeable soils have very low soil water storage but have potential for irrigated horticulture (tree and small crops); otherwise, the potential for agriculture is low.

The eastern parts of the catchment are dominated by shallow sandy and stony soils (SGG 7). These shallow and gravelly soils with abundant rock outcrop have very limited potential for agricultural development due to low water storage, predominantly steep slopes subject to erosion, and their location within a fragmented landscape with intense drainage patterns.

Moderately deep to deep highly calcareous soils (SGG 10) and peaty soils (SGG 5) do not occur in the catchment.

2.3.3 SOIL ATTRIBUTE MAPPING

Using a combination of field sampling and digital soil mapping techniques, the Assessment mapped 16 attributes affecting the agricultural suitability of soil for the Mitchell catchment as described in the companion technical report on digital soil mapping (Thomas et al., 2018a). Descriptions and maps for six key attributes are presented below:

- surface soil pH
- minimum soil depth
- soil surface texture
- permeability
- plant available water capacity (PAWC) in the upper 100 cm of the soil profile – referred to as PAWC 100
- rockiness.

An important feature of the predicted attributes map is the companion reliability map indicating the relative confidence in the accuracy of the attribute predictions, noting that mapping is only provided here for regional-scale assessment. Areas of high reliability allow users to be more confident in the quality of mapping, whereas areas of low reliability show where users should be cautious.

Soil salinity and the potential for secondary salinisation are discussed in Section 7.6.
Surface soil pH

The pH value of a soil reflects the extent to which the soil is alkaline or acidic. This is important because pH affects the extent to which nutrients are available to the plant and, hence, plant growth. Most plant nutrients have highest availability in the soil pH range 5.5 to 6.5. Nutrient imbalances are common for soils with pH greater than 8.5 and less than 5.5. Surface pH, measured in the top 10 cm, is consistently 5.5 to 6.0 throughout the catchment (Figure 2-5a) with the highly weathered brown, yellow and grey loamy soils (SGG 4.2); brown, yellow and grey deep sands (SGG 6.2); and sandy surfaced wet soils and marine clays (SGG 3) at the lower end of this range. The self-mulching cracking clay soils at Wrotham Park have a surface pH consistently 6.5 to 7.0. The friable loams (SGG 2) in the high-rainfall Julatten area in the north-east of the catchment are strongly acidic (pH <5.5) in the surface. The reliability associated with pH predictions is highly variable across the Mitchell catchment (Figure 2-5b). Consequently, farm- and paddock-scale planning of agriculture development should rely on local soil testing and use these maps only as a regional guide to soil pH.

Figure 2-5 Surface soil pH of the Mitchell catchment
(a) Surface soil pH as predicted by digital soil mapping and (b) reliability of the prediction. Surface soil pH is the pH in the top 10 cm.
**Minimum soil depth**

Soil depth defines the potential root space and the extent of soil from which plants obtain their water and nutrients. The minimum soil depth is used here (Figure 2-6a) as some soils may be deeper than predicted as the length of the drill rig corers used in the Assessment was 1.5 m. Soils developed on the ‘old’ alluvial plains, alluvial plains and the delta of the catchment of the Mitchell River are very deep (>1.5 m). Minimum soil depths in Figure 2-6 are underestimated on the sand or loam over sodic clay subsoils (SGG 8) due to the very firm intractable clay subsoils, which limited soil auguring during field survey. Soils on the hillslopes and crests of the metamorphic and intrusive mountains, hills and rises of the elevated eastern catchment and the edges of the deeply weathered plateaus in the centre of the catchment are predominantly very shallow to shallow (<0.5 m). The soils on basalt in the upper Lynd catchment to the south-east are also shallow. The remaining soils on the gently sloping lower slopes of the hills and rises, including the self-mulching clays at Wrotham Park, are predominantly moderately deep to deep (0.5 to 1.5 m). The reliability associated with mapping of soil depth is generally high, and is highest in the central and western parts of the catchment (Figure 2-6b).

![Figure 2-6 Minimum soil depth of the Mitchell catchment](image)
(a) Minimum soil depth as predicted by digital soil mapping and (b) reliability of the prediction.
Soil surface texture

Soil texture refers to the proportion of sand, silt and clay-sized particles that make up the mineral fraction of a soil. Surface texture influences soil water-holding capacity, soil permeability, soil drainage, water and wind erosion, workability and soil nutrient levels. Light soils are generally those high in sand and heavy soils are dominated by clay. Sandy surface textures dominate the catchment (Figure 2-7a), particularly the metamorphic and intrusive geologies of the upper catchment, the deeply weathered sandstone geologies of the central and northern parts of the catchment, the ‘old’ alluvial plains and rises, the levees and prior steams of the alluvial plains, and the alluvial plains to the north and south of the delta, which are derived from sandy parent material. The complex metamorphic and intrusive geologies of the northern part of the catchment have a high proportion of loamy surfaced soils, particularly in the Julatten area in the north-east of the Mitchell catchment. Silty surface textures are dominant in the extensive delta of the Mitchell River, often grading to clay surface textures associated with the cracking clay soils. Clay surface textures are restricted to the coastal marine plains, the cracking clay soils of the delta, the gently undulating plains and rises at Wrotham Park upstream of the confluence of the Mitchell and Walsh rivers, and to a very limited extent on the basalts of the upper Lynd River to the south-east. Soil surface texture is mapped with most reliability in the northern part of the Mitchell catchment (Figure 2-7b).

Figure 2-7 Soil surface texture of the Mitchell catchment
(a) Surface texture of soils as predicted by digital soil mapping and (b) reliability of the prediction.
Permeability

The permeability of the profile is a measure of how easily water moves through a soil. Flood and furrow irrigation is most successful on soils with low and very low permeability, to reduce root zone drainage (i.e. water that passes below the root zone of a plant), rising watertables and nutrient leaching. Spray or trickle irrigation is more efficient on soils with moderate to high permeability. The Mitchell catchment is dominated by moderately permeable soils (Figure 2-8a), particularly the sands or loams over friable clay (SGG 1.1 and SGG 1.2), the friable clays and clay loam soils (SGG 2), the red, yellow and grey loamy soils (SGG 4.1 and SGG 4.2), and most of the shallow sandy and stony soils (SGG 7). The highly permeable soils are restricted to the sands (SGG 6.1 and SGG 6.2) on the beach ridges along the coast; the red, yellow and grey sands developed on the sandplains to the north of the delta; the quartz sandstones in the centre of the catchment; and the shallow sandy soils, mainly of granite origin, on the hills in the upper northern part of the catchment. The slowly permeable soils are associated with the cracking clay soils (SGG 9), the soils with sand or loam over sodic subsoils (SGG 8), and the wet and permanently wet soils (SGG 3). Permeability mapping reliability is highest in the old delta of the catchment (Figure 2-8b).

Figure 2-8 Soil permeability of the Mitchell catchment
(a) Soil permeability as predicted by digital soil mapping and (b) reliability of the prediction.
Plant available water capacity to 100 cm

Plant available water capacity (PAWC) is the maximum amount of water the soil can store and make available for plant use. PAWC 100 is the maximum amount of water that the top 100 cm of soil can hold for plant use; the higher the PAWC 100 value, the greater the capacity of the soil to store and supply plants with water. For irrigated agriculture, it is one factor that determines irrigation frequency and volume of water required to wet up the soil profile; low PAWC 100 soils require more frequent watering and lower volumes of water per irrigation. For dryland agriculture, PAWC 100 determines the capacity of crops to grow and prosper during dry spells. The PAWC 100 is highest in the central part of the catchment, where soils are dominated by deep clays (SGG 9) with little or no rockiness in the soil profile (Figure 2-9a). Other areas of high PAWC 100 (100 to 125 mm) are associated with alluvium on the delta and coastal plain, for example, soils with sand or loam over sodic subsoils (SGG 8). The deep sands (SGG 6.1 and SGG 6.2) and shallow coarser grained or stony soils (SGG 7) of the eastern uplands and western sand plains predominantly have very low (<50 mm) PAWC 100. Most of the soils developed on basalt in the upper Lynd catchment have abundant rock throughout the profile, resulting in low PAWC 100. The remaining soils, particularly the sands or loams over friable clay (SGG 1.1 and SGG 1.2); many of the hard-setting clay loam to silty clay loam surfaced soils with strongly sodic, dispersive structured clay subsoil (SGG 8); the friable clays and clay loam soils (SGG 2); and the red, yellow and grey loamy soils (SGG 4.1 and SGG 4.2) on alluvium and sand plains have moderate (50 to 100 mm) PAWC 100 values. Figure 2-9b indicates that reliability is reduced in the inaccessible central-north and south-east and is highest in the western and north-eastern parts of the catchment.

![Figure 2-9](image)

**Figure 2-9 Plant available water capacity (PAWC) in the Mitchell catchment**

(a) PAWC in the upper 100 cm of the soil profile (PAWC 100) as predicted by digital soil mapping and (b) reliability of the prediction.
Rockiness

The rockiness of soil impacts on agricultural management and on the growth of some crops, particularly root crops. Coarse fragments (e.g. pebbles, gravel, cobbles, stones and boulders), hard segregations and rock outcrop in the plough zone can damage and/or interfere with the efficient use of agricultural machinery. Surface gravel, stone and rock are particularly important and can interfere significantly with planting, cultivation and harvesting machinery used for root crops, small crops, annual forage crops and sugarcane.

The distribution of the rocky soils strongly reflects the patterns of some previous attributes (Figure 2-10a). For example, the uplands are dominated by rocky soils associated with the shallow soils of SGG 7, and are associated with the occurrence of residual stones after incomplete weathering, and outcropping on steep slopes. They are also associated with more recent parent material such as basalt that has had little time to weather. Alternatively, the non-rocky soils are found in the extensive lower lying areas of the central or alluvial plains, which feature alluvial deposits, marine plains or deeply weathered material, leaving no residual rockiness. The reliability of the rockiness predictions is higher in the western and central parts of the catchment and variable throughout the more complex landscapes (Figure 2-10b).

![Figure 2-10 Rockiness in soils of the Mitchell catchment](image)

(a) Rockiness represented by presence or absence as predicted by digital soil mapping and (b) reliability of the prediction.
2.4 Climate of the Mitchell catchment

2.4.1 INTRODUCTION

Weather is the key source of uncertainty affecting crop yield. It influences the rate and vigour of crop growth, while catastrophic weather events can result in extensive crop losses. Key climate parameters controlling plant growth and crop productivity include rainfall, temperature, radiation, humidity and wind speed and direction. These parameters are interrelated so they impact synergistically.

Of all the climate parameters affecting hydrology and agriculture in water-limited environments, rainfall is usually the most important. Rainfall is the main determinant of runoff and recharge and is a fundamental requirement for plant growth. For these reasons, reporting of climate parameters is heavily biased towards rainfall data. Other climate variables affecting crop yield are discussed in the companion technical reports on climate (Charles et al., 2016) and agricultural viability (Ash et al., 2018).

Unless otherwise stated, the material in Section 2.4 is based on findings described in the companion technical report on climate (Charles et al., 2016).

2.4.2 WEATHER PATTERNS OVER THE MITCHELL CATCHMENT

The Mitchell catchment is characterised by a distinctive wet and dry season due to its location in the northern Australia tropics. The mean annual rainfall, averaged over the Mitchell catchment for the 125-year historical period (1 September 1890 to 31 August 2015), is 996 mm. Rainfall totals are highest near the coast and decline in a south-easterly direction. An exception is a small area along the western side of the ranges in the east of the catchment, north of Mareeba, which experiences higher rainfall induced by topography. Rainfall in this area occurs when there is an easterly wind flow, which extends through a considerable depth, or during the passage of a tropical cyclone or low. In these situations, the depth of moisture is large enough to overcome the inhibiting orographic barrier.

Below the junction of the Palmer and Mitchell rivers about 97% of rain falls during the wet-season months (1 November to 30 April), while above this location about 94% falls during the wet-season months. The spatial distribution of rainfall during the wet and dry seasons is shown in Figure 2-11. Median wet-season rainfall exhibits a similar spatial pattern to median annual rainfall; median dry-season rainfall is highest in the eastern uplands of the Mitchell catchment and lowest near the coast. Mean and median annual rainfall is highest near the coast primarily due to the monsoonal westerly (onshore) flow, which generates significant rainfall during the wet season. The highest monthly rainfall totals typically occur during January and February (Figure 2-12).

The bulk of wet-season rainfall comes from active monsoon bursts, which bring significant shower and thunderstorm activity into the catchment from the west. Other major rainfall contributions come from thunderstorm activity during the transition months of October, November and April (often associated with Gulf Lines), and during monsoon break periods. Some parts of the far upper Mitchell catchment (around Mount Molloy or Atherton) receive rainfall right through the dry season (approximately 20 to 50 mm/month) due to less rain shadow influence from the Great
Dividing Ranges, whereas the rest of the catchment receives very little rainfall between May and October.

Tropical cyclones and lows contribute large quantities of rainfall over the Mitchell catchment in some years and can result in high daily rainfall values. Tropical cyclones that occur in the Gulf of Carpentaria and move east towards the west coast of northern Queensland will most greatly
affect the western parts of the Mitchell catchment and likely result in major flooding. Increased rainfall as well as storm surge and increased wind speeds are associated with tropical cyclones. The cyclone season in the Mitchell catchment falls between November and April, and for the 47 tropical cyclone seasons from 1969–70 to 2015–16, 26% of seasons experienced no tropical cyclones, 49% one tropical cyclone, 23% two and 2% (one season) three. Overall, a greater proportion of tropical cyclones impacting the area originate from the Coral Sea (54%) compared to the Gulf of Carpentaria (46%). Of those, 38% originating in the Coral Sea reach severe tropical cyclone categories whereas only 14% of those originating in the Gulf reach severe status.

There are several smaller scale processes that can affect localised rainfall over different parts of the Mitchell catchment. These processes include diurnal and localised storm activity, sea breeze convergence, Gulf Line activity, topography-induced and coastline orientation. These processes are discussed in more detail in the companion technical report on climate (Charles et al., 2016).

2.4.3 POTENTIAL EVAPORATION AND POTENTIAL EVAPOTRANSPIRATION

Evaporation is the process by which water is lost from open water, plants and soils to the atmosphere; it is a ‘drying’ process. It has become common usage to also refer to this as evapotranspiration.

There are three major ways in which evaporation affects the potential for irrigation:

1. losses that reduce runoff and deep drainage and, hence, the ability to fill water storages (Section 2.5)
2. influence on crop water requirements (Section 4.4)
3. losses from water storages (Section 5.3).

Potential evaporation (PE) or potential evapotranspiration (PET) is defined as the amount of evaporation that would occur if an unlimited source of water was available. Potential evaporation decreases with distance inland from the Gulf of Carpentaria (Figure 2-11). Kowanyama and Chillagoe in the Mitchell catchment have a mean annual potential evaporation of 1919 and 1799 mm (1965 to 2015), respectively.

Preliminary estimates of mean annual irrigation demand and net evaporation from water storages are sometimes calculated by subtracting the mean annual (seasonal) potential evaporation from the mean annual (seasonal) rainfall. This is commonly referred to as the mean annual (seasonal) rainfall deficit (Figure 2-11). The rainfall deficit or mean annual net evaporative water loss from open storages in the Mitchell catchment ranges from about 660 mm at Kowanyama to over 1000 mm in the mid-reaches of the catchment.

Two common methods for characterising climates are the United Nations Environment Programme (UNEP) aridity index and the Köppen-Geiger classification (Köppen, 1936; Peel et al., 2007). Under the aridity index the southern half of the Mitchell catchment is classified as ‘Semi-arid’ and northern half ‘Dry humid’, with small areas of ‘Humid’ near the coast. The Köppen-Geiger classification classifies the Mitchell catchment as predominantly ‘Tropical savanna’, with an area of ‘Temperate dry winter, hot summer’ in the upper catchment and small areas of ‘Arid hot steppe’ and ‘Tropical monsoon’ (see companion technical report on climate (Charles et al., 2016)).
2.4.4 VARIABILITY AND LONG-TERM TRENDS IN RAINFALL AND POTENTIAL EVAPORATION

The Mitchell catchment experiences a highly seasonal climate with an extended dry season. In the absence of groundwater, year-round cropping would require the construction of surface water storages. The Mitchell catchment also exhibits high variability in rainfall from one year to the next. The implication of this is that dryland farming in the Mitchell catchment is likely to be riskier than in many parts of southern Australia with the same mean annual rainfall (see Section 4.4) and the rest of the world with the same climate type as northern Australia (Petheram et al., 2008). The highly variable rainfall and high PE amplify the variability of streamflow. As discussed in Section 2.5, higher variability in streamflow means that, all other factors being equal, water supply from a large reservoir can be less reliable.

Climate variability is a natural phenomenon that can be seen in many ways, for example, warmer than average winters, and low- and high-rainfall wet seasons. Climate variability can also operate over long-term cycles of decades or more. Climate trends represent long-term, consistent directional changes such as warming or increasingly higher average rainfall. Separating climate variability from climate change is very difficult, especially when comparing climate on a year-to-year basis.

The highest monthly rainfall in the Mitchell catchment typically occurs during January and February (Figure 2-12). The months with the lowest rainfall are June through to September. In Figure 2-12, the blue shading represents the range under Scenario A (A range). The upper limit of the A range is the value at which rainfall (or PE) is exceeded 1 year in 5 and is known as the 20% exceedance. The lower limit of the A range is the value at which rainfall (or PE) is exceeded 4 years in 5 and is known as the 80% exceedance. The difference between the upper and lower limits of the A range indicates the variation in monthly values from one year to the next.

PE also exhibits a seasonal pattern. During the months of October to December PE exceeds 190 mm/month in most years (Figure 2-13). It is at its lowest during June. Months where PE is high correspond to those months where the demand for water by plants is also high. Mean wet-season and dry-season PE in the Mitchell catchment are approximately 200 mm and 100 mm,
respectively, depending on location (Figure 2-11). Compared to rainfall, the variation in monthly potential evaporation from one year to the next is small (Figure 2-13).

![Figure 2-13 Monthly potential evaporation in the Mitchell catchment at Kowanyama and Chillagoe under Scenario A](image)

(a) Monthly potential evaporation at Kowanyama and (b) monthly potential evaporation at Chillagoe. Scenario A is the historical climate (1890 to 2015). A range is the 20th and 80th percentile monthly potential evaporation.

Relative to locations with the same mean annual rainfall in southern Australia the Mitchell catchment has a high variability in rainfall from one year to the next and is comparable to other locations in northern Australia with a similar mean annual rainfall. The highest annual rainfall at Chillagoe (1946 mm) occurred in the 1973 to 1974 wet season, which was 5.6 times the lowest annual rainfall (350 mm) in the 1925 to 1926 wet season, and 2.3 times higher than the median annual rainfall value (i.e. 849 mm). The 10-year running mean provides an indication of the sequences of wet or dry years (i.e. variability at decadal time scales). For an annual time series, the 10-year running mean is the average of the 5 years of data either side of every annual data point. The 10-year running mean rainfall varied at Chillagoe from 698 mm to 1096 mm and from 1009 mm to 1541 mm at Kowanyama. Under Scenario A, PE exhibits much less inter-annual variability than rainfall (not shown, see companion technical report on climate (Charles et al., 2016)).

![Figure 2-14 Annual rainfall at Kowanyama and Chillagoe under Scenario A](image)

(a) Monthly rainfall at Kowanyama and (b) monthly rainfall at Chillagoe. Scenario A is the historical climate (1890 to 2015). The blue line represents the 10-year running mean.

The variation in rainfall from one year to the next (inter-annual variation) in the Mitchell catchment is higher than most other rainfall stations around Australia with the same mean annual
rainfall. The coefficient of variation (CV) provides a measure of the variability of rainfall from one year to the next, where the larger the CV value, the larger the variation in annual rainfall relative to a location’s mean annual rainfall – it is calculated as the standard deviation of mean annual rainfall divided by the mean annual rainfall. In Figure 2-15, the CV of annual rainfall is shown for rainfall stations with a long-term record around Australia. The figure shows that the inter-annual variation in rainfall in the Mitchell catchment is high compared to stations in southern Australia with a similar mean annual rainfall. The implications of these results are that dryland farming in the Mitchell catchment is likely to be riskier than in many parts of southern Australia with the same mean annual rainfall (see Section 4.4 about dryland farming in the Mitchell catchment). The high variability in rainfall means that streamflow is also highly variable. As discussed in Section 5.3, this has implications for the reliability with which irrigators can access water.

Furthermore, Petheram et al. (2008) observed that the inter-annual variability of rainfall in northern Australia is about 30% higher than that observed at rainfall stations from the rest of the world for the same type of climate as northern Australia. Hence, caution should be exercised before drawing comparisons between the agricultural potential of the Mitchell catchment and other parts of the world with a similar climate.

There are several factors driving this high inter-annual variation in Australia’s climate, including the El Niño – Southern Oscillation (ENSO), the Indian Ocean Dipole, the Southern Annular Mode, the Madden–Julian Oscillation and the Inter-decadal Pacific Oscillation.

Of these influences, the ENSO is a phenomenon that is considered to be the primary source of global climate variability over the 2- to 6-year timescale (Rasmusson and Arkin, 1993) and is reported as being a significant cause of climate variability for much of eastern and northern Australia. One of the modes of ENSO, El Niño, has come to be a term synonymous with drought in the western Pacific and eastern and northern Australia. Rainfall stations along eastern and northern Australia have been observed to have a strong correlation (0.5 to 0.6) with the Southern

Figure 2-15 (a) Coefficient of variation of annual rainfall and (b) the coefficient of variation of annual rainfall plotted against mean annual rainfall for 96 rainfall stations from around Australia

(a) The grey polygons indicate the extent of the Mitchell catchment. (b) Rainfall stations in the Mitchell catchment are represented by yellow symbols. The light blue diamonds indicate rainfall stations from the rest of northern Australia (RoNA) and hollow squares indicate rainfall stations from southern Australia (SA).
Oscillation Index (SOI), a measure of the strength of ENSO, during spring suggesting that ENSO plays a key role in between-year rainfall variability (McBride and Nicholls, 1983).

Another known impact of ENSO in northern Australia is the tendency for the onset of useful rains after the dry season to be earlier than normal in La Niña years and later than normal in El Niño years. For all years between 1960 and 2009 the mean rainfall onset date (defined as being the accumulation of 50 mm of rain after the dry season) for the Mitchell catchment is the last 10 days of October (see Charles et al., 2016). In SOI neutral, negative (El Niño) and positive (La Niña) years the mean rainfall onset dates for the Mitchell catchment is the last 10 days of October, first 10 days of November, and middle 10 days in October, respectively.

**Trends**

Over the north-east of northern Australia most studies do not report a statistically significant trend in annual or summer rainfall over the Cape York Peninsula (CSIRO, 2009; Klingaman et al., 2013; Lavender and Abbs, 2013; Li et al., 2009), though the literature is inconclusive. A decrease in rainfall over north-east Australia has been attributed to a weakening in the tropical Australian summer monsoon, possibly related to increased sea surface temperature (SST) trends experienced across the north-east Indian Ocean (Li et al., 2009).

**Runs of wet and dry years**

The Mitchell catchment is likely to experience dry periods of similar severity to many centres in the Murray–Darling Basin and east coast of Australia.

The Mitchell catchment is characterised by irregular periods of consistently low rainfall when successive wet seasons fail, as well as the typical annual dry season. Runs of wet and dry years occur when there are consecutive years of rainfall that are above or below the median, respectively. These are shown in Figure 2-16 at Kowanyama and Chillagoe as annual differences from the median annual rainfall. A run of consistently dry years may be associated with drought (though an agreed definition of drought continues to be elusive). Analysis of annual rainfall at stations in the Mitchell catchment indicate equally long runs of dry and wet years and nothing unusual about the length of the runs of dry years. However, the magnitude of dry years in the Mitchell catchment is slightly larger than that of stations in the Murray–Darling Basin and the east coast of Australia.
Paleo-climate records for northern Australia

The instrument record is very short in a geological sense, particularly in northern Australia, so a brief review of paleo-climate data is provided. The literature indicates that atmospheric patterns approximating the present climate conditions in northern Australia (e.g. Pacific circulation responsible for ENSO) are thought to have been in place from about 3 to 2.5 million years ago, which would suggest many ecosystems in northern Australia have experienced monsoonal conditions for many millions of years. However, past climates have been both wetter and drier than the instrument record for northern Australia, and the influence of ENSO has varied considerably over recent geological time. Several authors have found that present low levels of tropical cyclone activity in northern Australia (i.e. over the instrumental record) are possibly unprecedented over the past 550 to 1500 years and that the recurrence frequencies of high-intensity tropical cyclones (Category 4 to 5 events) may have been an order of magnitude higher than that inferred from the current short instrumental records. See companion technical report on climate (Charles et al., 2016) for more information.

2.4.5 CHANGES IN RAINFALL AND EVAPORATION UNDER A FUTURE CLIMATE

The effects of projected climate change on rainfall and PE are presented in Figure 2-17, Figure 2-18 and Figure 2-19. This analysis used 21 GCMs to represent a world where the global mean surface air temperatures are 2.2 °C higher relative to approximately 1990 global temperatures. Because the scale of GCM outputs is too coarse for use in catchment- and point-scale hydrological and
agricultural computer models, they were transformed to catchment-scale variables using a simple scaling technique (PS) and referred to as GCM-PSs. See companion technical report on climate (Charles et al., 2016) for further details.

In Figure 2-17 the rainfall and PE projections for the 21 GCM-PSs are spatially averaged across the Mitchell catchment and the GCM-PSs are ranked in order of increasing mean annual rainfall. This figure shows that about one-third of the projections for GCM-PSs indicate an increase in mean annual rainfall and two-thirds indicate either little change (43%) or a decrease (24%) in mean annual rainfall.

The spatial distribution of mean annual rainfall under Scenario C is shown in Figure 2-18. In this figure only the third ‘wettest’ GCM-PS (i.e. Scenario Cwet), the middle or 11th wettest GCM-PS (i.e. Scenario Cmid) and the third ‘driest’ (i.e. Scenario Cdry) GCM-PSs are shown.

Figure 2-19a shows mean monthly rainfall under scenarios A and C. The data suggest that under Scenario Cmid, mean monthly rainfall will be similar to the mean monthly rainfall under Scenario A. Under scenarios Cwet, Cmid and Cdry, the seasonality of rainfall in northern Australia is similar to that under Scenario A.

Figure 2-17 Percentage change in mean annual rainfall and potential evaporation under Scenario C relative to under Scenario A
Simple scaling of rainfall and potential evaporation have been applied to global climate model output (GCM-PS). GCM-PSs are ranked by increasing rainfall.
Potential evaporation

The mean annual change in GCM-PS PE shows projected PE increases of about 2 to 10%. Under scenarios Cwet, Cmid and Cdry, PE exhibits a similar seasonality to that under Scenario A. However, different methods of calculating PE give different results. Consequently, there is considerable uncertainty on how PE may change under a warmer climate. See Petheram et al. (2012) and Petheram and Yang (2013) for a more detailed discussion.

Sea-level rise and sea surface temperature projections

Global mean sea levels rose at a rate of 1.7 ± 0.2 mm/year between 1900 and 2010, a rate in the order of ten times faster than the preceding century. Australian tide gauge trends are similar to the global trends (CSIRO and Bureau of Meteorology, 2015). Sea-level projections for the Mitchell catchment are summarised in Table 2-2. This information may be considered in coastal aquaculture developments and flood inundation of coastal areas.
### Table 2-2 Projected sea-level rise for the coast of the Mitchell catchment

Values are median of Coupled Model Intercomparison Project (CMIP) Phase 5 GCMs. Numbers in parentheses are the 5 to 95% range of same. Projected sea-level rise values are relative to a mean calculated between 1986 and 2005.

<table>
<thead>
<tr>
<th>DATE (UNIT)</th>
<th>RCP 4.5</th>
<th>RCP 8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>2030 (m)</td>
<td>0.12 (0.07–0.15)</td>
<td>0.11 (0.07–0.16)</td>
</tr>
<tr>
<td>2050 (m)</td>
<td>0.22 (0.13–0.29)</td>
<td>0.23 (0.15–0.32)</td>
</tr>
<tr>
<td>2070 (m)</td>
<td>0.31 (0.19–0.44)</td>
<td>0.39 (0.26–0.54)</td>
</tr>
<tr>
<td>2090 (m)</td>
<td>0.43 (0.26–0.62)</td>
<td>0.60 (0.39–0.83)</td>
</tr>
</tbody>
</table>

**Rate of change at 2100 (mm/y)**

<table>
<thead>
<tr>
<th></th>
<th>RCP 4.5</th>
<th>RCP 8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.9 (3.1–8.8)</td>
<td>10.9 (6.8–15.7)</td>
</tr>
</tbody>
</table>

RCP = Representative Concentration Pathway

Source: CoastAdapt (2017)

Sea surface temperature (SST) increases around Australia are projected with very high confidence for all emissions scenarios, with warming of around 0.4 to 1.0 °C in 2030 under Representative Concentration Pathway (RCP) 4.5 and 2 to 4 °C in 2090 under RCP 8.5, relative to a 1986 to 2005 baseline (CSIRO and Bureau of Meteorology, 2015). There will be regional differences in SST warming due to variations in local responses, however, there is only medium confidence in coastal projections as climate models do not resolve local processes (CSIRO and Bureau of Meteorology, 2015). For Karumba, on the coast south of the Mitchell catchment, the corresponding projected SST increases are 0.8 °C (range across climate models is 0.6 to 1.1 °C) for 2030 and 2.9 °C (2.4 to 3.9 °C) for 2090. These changes are relative to a 1986 to 2005 baseline (CSIRO and Bureau of Meteorology, 2015).

#### 2.4.6 ESTABLISHMENT OF AN APPROPRIATE HYDROCLIMATE BASELINE

The allocation of water and the design and planning of water resources infrastructure and systems require great care and consideration and must have a genuine long-term view. A hydroclimate baseline from 1890 to 2015 (i.e. current) was deemed the most suitable baseline for the Mitchell catchment.

A poorly considered design can result in an unsustainable system or preclude the development of a more suitable and possibly larger system, thus adversely impacting existing and future users, industries and the environment. Once water is overallocated it is economically, financially, socially and politically difficult to reduce allocations in the future, unless water allocations are only assigned over short time frames (e.g. <15 years) and then reassessed. However, many water resource investments, particularly agricultural investments, require time frames longer than 30 years as there are often large initial infrastructure costs and a long learning period before full production potential is realised. Consequently, investors require certainty that over their investment time frame (and potentially beyond), their access to water will remain at the level of reliability initially allocated. A key consideration in the development of a water resource plan, or in the assessment of the water resources of a catchment, is the time period over which the water resources will be analysed, also referred to as the hydroclimate ‘baseline’ (e.g. Chiew et al., 2009).

If the hydroclimate baseline is too short it can introduce biases in a water resource assessment, for various reasons. Firstly, the transformation of rainfall to runoff and rainfall to groundwater recharge is non-linear. For example, averaged across the Flinders catchment in northern Australia...
the mean annual rainfall is only 8% higher than the median annual rainfall, yet the mean annual runoff is 59% higher than the median annual runoff (Charles et al. 2016). Similarly, between 1895 and 1945 the median annual rainfall was the same as the median annual rainfall between 1948 and 1987 (less than 0.5% difference), yet there was a 21% difference in the median annual runoff between these two time periods (and a 40% difference in the mean annual runoff) (Charles et al. 2016). Consequently, great care is required if using rainfall data alone to justify the use of short periods over which to analyse the water resources of a catchment.

In developing a water resource plan the volume of water allocated for consumptive purposes is usually constrained by the drier years (referred to as spells where consecutive dry years occur) in the historical record (see Section 2.4.4). This is because it is usually during dry spells that water extraction most adversely affects existing industries and the environment. All other factors being equal (e.g. market demand, interest rates), consecutive dry years are usually also the most limiting time periods for new water resource developments/investments, such as irrigated agriculture enterprises, particularly if the dry spells coincide with the start of an investment cycle. Consequently, it is important to ensure a representative range of dry spells (i.e. of different durations, magnitudes and sequencing) are captured over the assessment time period. For example, it is possible that two time periods may have very similar median annual runoff, but the duration, magnitude and sequencing of the dry spells may be sufficiently different that they pose different risks to investors and result in different modelled ecological outcomes.

In those instances where there is the potential for a long memory, such as in intermediate- and regional-scale groundwater systems or in river systems with large reservoirs, long periods of record are preferable to minimise the influence of initial starting conditions (e.g. assumptions regarding initial reservoir storage volume), to properly assess the reliability of water supply from large storages and to encapsulate the range of likely conditions (McMahon and Adeloye, 2005).

All these arguments favour using as long a time period as practicably possible. However, there may be some circumstances in which a shorter period may be preferable on the basis that it is a more conservative option. For example, in south-western Australia, water resource assessments to support water resource planning are typically assessed from 1975 onwards (Chiew et al., 2012; McFarlane et al., 2012). This is because since the mid-1970s there has been a marked reduction in runoff in south-western Australia, and this declining trend in rainfall is consistent with most GCM projections, which project reductions of rainfall into the future (Charles et al., 2010).

Although there were few rainfall stations in the three study areas at the turn of the 20th century (Section 1.3 and figures therein) relative to 2106, an exploratory analysis of rainfall statistics of the early period of instrument record does not appear to be anomalous when compared to the longer-term instrument record.

In deciding on an appropriate time period over which to analyse the water resources of the Mitchell catchment, consideration was given to the above arguments, as well as paleo-climate records, observed trends in the historical instrumental rainfall data and future climate projections.

For the Mitchell catchment, the literature is inconclusive as to whether there is an increasing trend in rainfall in the recent instrumental record, and two-thirds of the GCM-PSs project either no change or a decrease in mean annual rainfall for a 2.2 °C warming scenario. Furthermore, paleo-climate records indicate multiple wetter and drier periods have occurred in the recent geological past (see the companion technical report on climate (Charles et al., 2016)). For these reasons, the
entire instrument record (i.e. 1890 to 2015) available through the data drill Scientific Information for Land Owners (SILO) database (Jeffery et al., 2001), was adopted as the baseline for the Assessment.

It should be noted, however, that as climate is changing on a variety of time scales, detailed scenario modelling and planning (i.e. the design of major water infrastructure) should be broader than just comparing a single hydroclimate baseline to an alternative future.

2.5 Hydrology of the Mitchell catchment

2.5.1 INTRODUCTION

The timing and event-driven nature of rainfall events and high PE rates across the Mitchell catchment have important consequences for the catchment’s hydrology. The spatial and temporal patterns of rainfall and PE across the Mitchell catchment are discussed in Section 2.4. Rainfall can be broadly broken into evaporated and non-evaporated components (also referred to as ‘excess water’). The non-evaporated component can be broadly broken into overland flow and recharge (Figure 2-20). Recharge replenishes groundwater systems, which in turn discharge into rivers and the ocean. Overland flow and groundwater discharge into rivers combine to become streamflow. Streamflow in the Assessment is defined as a volume per unit of time. Runoff is defined as the millimetre depth equivalent of streamflow. Flooding is a phenomenon that occurs when the flow in a river exceeds the river channel’s capacity to carry the water, resulting in water spilling onto the land adjacent to the river.

Figure 2-20 Schematic diagram of terrestrial water balance in the Mitchell catchment
Runoff is the mm depth equivalent of streamflow. Overland flow includes shallow subsurface flow. Numbers indicate mean annual values spatially averaged across the catchment under Scenario A. Numbers will vary locally.
Section 2.5 covers the remaining terms of the terrestrial water balance (accounting for water inputs and outputs) of the Mitchell catchment, with particular reference to those processes and terms that are relevant to irrigation at the catchment scale. Information is firstly provided on groundwater, groundwater recharge and surface water – groundwater connectivity. Runoff, streamflow, flooding and persistent waterholes in the Mitchell catchment are then discussed.

Figure 2-20 shows a schematic diagram of the water balance of the Mitchell catchment, along with estimates of the mean annual value spatially averaged across the catchment and an estimate of the uncertainty for each term. The ‘water balance’ comprises all the water inflows and outflows to and from a particular catchment over a given time period.

2.5.2 GROUNDWATER

Within the Mitchell catchment the distribution, availability and quality of groundwater resources are heavily influenced by the physical characteristics of rocks of the major geological provinces (see Section 2.2). In general, several aquifer types exist:

- fractured rock
- sedimentary sandstones and limestones in the geological Carpentaria Basin of the Great Artesian Basin and the Karumba Basin
- surficial sediments including alluvium, colluvium, sand plains, regolith and beach ridge deposits.

The sedimentary aquifers of the Carpentaria and Karumba basins host regional-scale groundwater systems (Figure 2-21). That is, the distance between the recharge and discharge areas can be tens of kilometres to hundreds of kilometres, and the time taken for groundwater to discharge following recharge can be in the order of thousands to hundreds of thousands of years. The fractured rock aquifers of the Hodgkinson and Etheridge provinces (Figure 2-21) and the surficial sediments host local-scale groundwater systems. That is, the distance between the recharge and discharge areas is in the order of 1 to 10 km. The surficial aquifer systems in the Mitchell catchment are poorly characterised and are not well understood.

Hydrogeological units

Hydrogeological units of the Mitchell catchment are shown in Figure 2-21, these rock and sediment units host aquifers and aquitards (less permeable layers/aquifers) of various sizes. Major aquifer systems in the Mitchell catchment are found in the geological Carpentaria Basin (one of the four sub-basins of the Great Artesian Basin) and the Karumba Basin. Figure 2-24 shows a groundwater bore in the Bulimba Formation under artesian conditions.

For the Assessment, major aquifer systems are considered to be aquifers that contain regional-scale groundwater systems, with adequate storage volumes (i.e. gigalitres) that could potentially yield water at a sufficient rate (i.e. >10 L/second) and sufficient water quality (i.e. <1000 µS/cm) for irrigated cropping. Minor aquifers are considered to be aquifers that contain local-scale groundwater systems with lower storage (i.e. megalitres), with variable but often low yields (i.e. <5 L/second) and variable but often poor-quality water (i.e. >3000 µS/cm). The distribution and characteristics of these rocks are covered in Section 2.2.

Unless otherwise stated, the material in Section 2.5.3 is based on findings described in the companion technical report on hydrogeological assessment (Taylor et al., 2018). Only the major
Aquifers relevant to opportunities for future groundwater resource development are discussed in detail.

**Figure 2-21 Hydrogeological units in the Mitchell catchment**

Figure shows units that host aquifers and aquitards. Data source (DNRM, 2016a).

**Fractured rock aquifers**

The Hodgkinson Formation (Figure 2-21) within the Hodgkinson Province in the north-east of the catchment hosts a fractured rock aquifer system that supplies reasonable quantities of groundwater for stock and domestic use. The aquifer is highly variable in composition and hosts local-scale flow systems with most groundwater storage and flow resulting from the size and connectivity of secondary porosity features such as joints, fractures or faults. Individual bore yields range from 0.5 to 30 L/second (Figure 2-22), though yields are more commonly in the range of 2 to 5 L/second and water quality is highly variable. Recharge occurs as infiltration of rainfall and some streamflow (where rivers traverse the formation) through the soil to vertical fractures and joints. The main discharge mechanisms are from bores extracting groundwater for stock and domestic
use and from evaporation from shallow watertables. Minor fractured rock aquifers are also hosted by the igneous and meta-sedimentary rocks of the Etheridge Province, where bore yields are low and water quality is variable, limiting groundwater extraction to stock and domestic use only.

**Figure 2-22** Groundwater bore yields for different aquifers in the Mitchell catchment
Data source (DNRM, 2016b)

**Sedimentary aquifers of the geological Carpentaria Basin**

The main sedimentary aquifer of the geological Carpentaria Basin is the Gilbert River Formation aquifer (Figure 2-21), a regionally extensive (occurs in the subsurface north and south of the catchment and extends under the Gulf of Carpentaria) sandstone aquifer that overlies the basement rock of the Etheridge Province (Figure 2-23). The aquifer is unconfined (water can infiltrate from the land surface into the aquifer) in and just west (a few km) of the outcrop zone (the light blue unit occurring at the land surface in Figure 2-21), where it receives recharge via infiltration from intense wet-season rainfall and streamflow where rivers traverse the outcrop zone. West of the outcrop zone, the aquifer becomes confined (sealed by overlying rock so that
water cannot infiltrate from the land surface into the aquifer) as it dips steeply in the subsurface (Figure 2-23) (Horn et al., 1995; Smerdon et al., 2012). Outcropping units of the geological Carpentaria Basin can be seen in Figure 2-24.

![Figure 2-23 Two-dimensional hydrogeological cross-section of the Carpentaria and Karumba basins](image1)

Source: Figure 5.14 in Smerdon et al. (2012).

![Figure 2-24 Outcropping units of the geological Carpentaria Basin](image2)

Photo: CSIRO

Groundwater flow is generally from east to west based on groundwater level data for the entire geological Carpentaria Basin of the Great Artesian Basin (Smerdon et al., 2012), though in the Mitchell catchment only a few bores exist in this aquifer. Bore yields range from 0.04 to 12 L/second (Figure 2-22) and water quality is fresh, ranging from 370 to 900 μS/cm (Figure 2-25).
Some opportunities for future groundwater development exist for the Gilbert River Formation aquifer, though the scale of opportunities is unclear. Only a few bores and accompanying data exist and it is (for most of the catchment) prohibitively deep to warrant investigation by drilling.

**Figure 2-25** Groundwater salinity for different aquifers in the Mitchell catchment
EC = electrical conductivity. Data source (DNRM, 2016b).

**Sedimentary aquifers of the Karumba Basin**

The Karumba Basin aquifers in the Mitchell catchment include the sedimentary aquifers of the Bulimba Formation and the overlying Wyaaba Beds. The Bulimba aquifer currently offers the greatest opportunity for groundwater resource development in the Mitchell catchment. The aquifer is regionally extensive, occurring east from the outcrop of the formation (Figure 2-21) and extending in the subsurface west towards the coast and out under the Gulf of Carpentaria, north into the Coleman catchment and south into the Staaten catchment. It underlies the Bulimba Formation aquitard, the Wyaaba aquifer (only within 50 km of the coast) and Wyaaba Beds.
aquitard and overlying surficial sediments including the Mitchell River Fan Aggregation (Figure 2-21 and Figure 2-26).

The entire Bulimba aquifer from approximately 40 to 60 km west of the outcrop is confined and artesian (water under sufficient pressure that it would flow to the surface if a bore were sited here); therefore, pumping costs are currently minimal for extracting groundwater. If sufficiently large quantities of groundwater were extracted, then this formation may cease being artesian (Section 5.2). Indicative yields from existing stock bores are high, with bore yields ranging up to 50 L/second (Figure 2-22). Groundwater is fresh (Figure 2-25), with low salinity (>1000 μS/cm) and low ionic composition, making the water suitable for a variety of uses. However, groundwater does have a consistently low pH (5.7 to 6.5); therefore, bore construction needs to be carefully considered as the groundwater can be corrosive to bore infrastructure. Based on existing drilling information, the aquifer is located at potentially economical depths at most locations, with the depth below land surface ranging from approximately 20 m in the outcrop area to 150 m in towards the coast.

Groundwater flow is from the aquifer outcrop in the east, west towards the coast. Recharge to the aquifer occurs as infiltration at and near the outcrop zone during and following intense wet-season rainfall events and from some streamflow where rivers traverse the outcrop zone (Figure 2-21 and Figure 2-26). Discharge occurs as a combination of upward leakage through the aquitards, leakage from unsealed bores and spring discharge in the outcrop zone. Discharge also occurs as extraction of groundwater, as well as ‘submarine’ groundwater discharge to the ocean (Figure 2-26).

Figure 2-26 Two-dimensional conceptual schematic of key groundwater flow processes in the Bulimba aquifer
Arrows indicate directions and magnitude of flow. Horizontal axis is eastings.
The sedimentary aquifer of the Wyaaba Beds occurs as a clayey to sandy, poorly consolidated limestone formation restricted to within approximately 50 km of the coast (Herbert, 2000; Hillier, 1977). The Wyaaba aquifer is confined everywhere by the Wyaaba aquitard (Figure 2-26) and is close to artesian in most areas and occasionally artesian in areas of low elevations. Bores yields range between 0.5 to 16 L/second (Figure 2-22) and water quality varies spatially from fresh to saline (Figure 2-25). There is no mapped outcrop for the aquifer (DNRM, 2016; Herbert, 2000) and groundwater levels show little variation over time, suggesting very low recharge. Discharge occurs as a combination of upward leakage through overlying sediments as well as submarine groundwater discharge, though both mechanisms are poorly understood (Herbert, 2000). Discharge also occurs from extraction of groundwater. Due to limited inflows to the aquifer, there is little further potential for groundwater resource development of the Wyaaba aquifer beyond stock water requirements because of the likelihood of seawater intrusion into the aquifer.

**Surficial aquifers**

A thin veneer of surficial Tertiary to Quaternary alluvium, colluvium and regolith sediments are present predominantly in the western part of the catchment as sand plains and alluvial sediments associated with the numerous rivers, tributaries and their floodplains (Figure 2-21). These aquifers are poorly characterised, though existing groundwater levels, bore yields and salinities indicate they only host local-scale flow systems and therefore only offer potential as a localised or conjunctive water resource.

### 2.5.3 GROUNDWATER RECHARGE

Groundwater recharge is an important component of the water balance of an aquifer (i.e. the sum of the inflow and outflow components of an aquifer). It can inform how much an aquifer is replenished on an annual basis and therefore how sustainable a groundwater resource may be in the long term, particularly for aquifers with either low storage or that discharge to rivers, streams, lakes and the ocean, or via transpiration from groundwater-dependent vegetation. Recharge is influenced to varying degrees by many factors including spatial changes in soil type (and their physical properties), the amount of rainfall and evaporation, vegetation type, topography and depth to the watertable. Recharge can also be influenced by changes in land use, such as land clearing and irrigation. Directly measuring recharge can be very difficult as it usually represents only a small component of the water balance, can be highly variable spatially and temporally, and it can vary depending on the type of measurement or estimate technique used (Petheram et al., 2002).

Several approaches were used to estimate annual recharge for all aquifers in the catchment. Some areas surrounding the Mitchell catchment were included in the estimation where aquifers are continuous across the surface water catchment boundaries. Figure 2-27 provides an example of recharge estimates for the defined model extent used in the Assessment.

For more detail on how these estimates were derived, see the companion technical report on hydrogeological assessment (Taylor et al., 2018).
Figure 2-27 Annual recharge estimates for aquifers of the Mitchell catchment

Estimates based on up-scaled chloride mass balance method for the (a) 50th (b) 5th and (c) 95th percentiles. Note, the additional areas included in the recharge model extent were defined based on surface geology (DNRM 2016a); the white areas are excluded.

Figure 2-28 provides a summary of the range in mean annual recharge estimates related to the outcropping area of five key hydrogeological units in the Mitchell catchment and the surrounding areas included in the defined recharge model extent. The ranges in recharge estimates are based on the 5th and 95th percentiles and range from approximately 30 to 120, 30 to 135 and 25 to 90 mm/year, respectively, for formations in the west (Tertiary alluvium, Wyaaba Beds and Bulimba Formation). For formations in the east (Gilbert River Formation and Hodgkinson Formation), estimates of recharge range from approximately 20 to 75 and 10 to 50 mm/year for the 5th and 95th percentiles, respectively.

The estimates of groundwater recharge in the Assessment represent the spatial variability in mean annual recharge across the land surface and are a good starting point for estimating a water balance arithmetically or using a groundwater model. However, none of the methods account for aquifer storage (available space in the aquifer), so it is unclear whether the aquifers can accept these rates of recharge on an annual basis. The methods also do not account for preferential recharge from streamflow or flooding in the landscape, or through sandy palaeochannel features in the outcrop area – as is the case with the Bulimba Formation. Furthermore, in some cases aquifers may not outcrop anywhere at land surface as is the case with the Wyaaba Beds. Therefore, the key features of an aquifer must be carefully conceptualised before simply deriving a recharge volume based on the surface area of an aquifer outcrop and an estimated recharge rate.
Surface water – groundwater interactions occur at various locations in the Mitchell catchment and via a variety of processes. These processes are currently poorly quantified across the catchment due to a lack of groundwater monitoring infrastructure. However, where information does exist, this has been used to classify some river reaches into a likelihood of groundwater inflow (Figure 2-29), based on previous studies described below.

In the east of the catchment, the fractured rock aquifers of the Etheridge and Hodgkinson provinces receive some recharge from streamflow where rivers traverse the formations and their alluvium is in direct contact with faults, fractures and fissures of the underlying units. Discharge from these aquifers to overlying rivers is believed to be low based on previous work, highlighting that groundwater levels for these aquifers are well below streambed elevations (DNRMW, 2006).

There is known connectivity between the geological Carpentaria Basin aquifers and aquitards where the Mitchell, Walsh and Lynd rivers and their tributaries traverse the outcrop zones of the Gilbert River Formation and the Rolling Downs Group (Figure 2-21). A component of recharge to the Gilbert River Formation aquifer occurs where water from ephemeral rivers recharge the underlying aquifer where they are in direct contact with the overlying alluvium. Groundwater discharge also occurs through springs in and near the outcrop zone and is associated with outcropping aquifers that become full during the wet season, as well as upward flow through faults or thin parts of the overlying Rolling Downs Group (Smerdon et al., 2012). Very little is known about discharge from the Rolling Downs Group other than recent work by Batlle-Aguilar et al. (2014), which estimated that the Rolling Downs Group contributed approximately 40% of the total groundwater discharge to a 15-km reach of the Mitchell River. Here the river traverses the formation outcrop, though no indication was provided as to the discharge mechanism.

Surface water – groundwater interactions also occur between the Bulimba aquifer where the Alice, Palmer, Mitchell, Walsh and Lynd rivers and their tributaries traverse the outcropping zone. A component of recharge to the Bulimba aquifer occurs where some of the water in the rivers recharge the underlying aquifer where it is in direct contact with the overlying alluvium. A component of discharge from the Bulimba aquifer occurs as spring discharge (Figure 2-26) in the outcrop zone where the outcropping aquifer becomes full in the wet season (Herbert, 2000).
As discussed above, the alluvium of the major rivers and their tributaries are a common feature connecting groundwater and surface water. The alluvium receives a component of recharge via bank infiltration (river water infiltrating through the riverbank) from streamflow, as well as vertical recharge from overbank flooding. A component of discharge from the alluvium is via bank discharge (groundwater flowing out of the river bank) to rivers when wet-season streamflows reside in the dry season. These processes remain poorly quantified in the Mitchell catchment where bores in the alluvium are almost non-existent.

**Figure 2-29 Likelihood of groundwater inflow for reaches of the Mitchell and Lynd rivers**

### 2.5.5 SURFACE WATER

**Streamflow**

Approximately 60% of Australia’s runoff is generated in northern Australia (Petheram et al., 2010). Unlike the large internally draining Murray–Darling Basin, however, northern Australia’s runoff is distributed across many hundreds of smaller externally draining catchments (Figure 2-30). Figure 2-30 shows the magnitude of median annual streamflow of major rivers across Australia under ‘natural conditions’ (i.e. prior to water resource development). In terms of median annual
discharge under ‘natural’ conditions, the Mitchell River has the largest discharge of all rivers in northern Australia (Petheram et al. 2014) and is second to the Murray River across all of Australia.

Figure 2-30 Modelled streamflow under natural conditions
Streamflow under natural conditions is indicative of median annual streamflow prior to European settlement (i.e. without any large-scale water resource development/extractions) assuming the historical climate (i.e. 1890 to 2015). Source: Petheram et al. (2017).

The Mitchell catchment comprises five main river systems: the Alice, Palmer, Mitchell, Walsh and Lynd (Figure 2-31). The rivers carve rugged gorges through the eastern sedimentary and metamorphic highlands of the Great Dividing Range and flow 500 km to the west and discharge into the Gulf of Carpentaria. Below the confluence of the Mitchell and Palmer rivers near Dunbar (919009) is the current delta apex of the Mitchell River Fan Aggregation, at which point the Mitchell River diverges. This results in numerous outlets to the ocean (Figure 2-31) and features a complex system of deeply incised stream lines with many permanent waterholes, levees and seasonally flooded back plains, shallow incised valleys with waterholes and numerous circular depressions – some with permanent water.

At Dunbar (919009) on the Mitchell River the mean annual streamflow is about 7107 GL. Due to several very wet years ‘biasing’ the mean, this volume of water is more than 26% higher than the median annual streamflow (5659 GL). The Mitchell River, just before the confluence with the Walsh River, has the highest median annual streamflow (1731 GL), followed by the Palmer River.
(1591 GL at 919204), Walsh River (1166 GL at 919309) and Lynd River (1107 GL). The Alice River is ungauged and is estimated to discharge at least 5000 GL into the Gulf of Carpentaria in at least 50% of years. Below Dunbar it is estimated that the median annual discharge from the Mitchell River, its distributary channels and the channels draining the alluvial plains and fans south of the Mitchell River, is 8327 GL. The nature of the connection of the main river with the distributary streams is unknown, and no streamflow gauge data are available downstream of the Dunbar gauge (919009). As shown in Table 2-3, the upper sections of the Mitchell, Lynd, Palmer and Walsh rivers are perennial most years. Mid-catchment (upstream of gauge 919009), the Palmer and Mitchell rivers remain perennial most years, while the Walsh and Lynd rivers cease to flow for between 20 and 50% of days each year. Below Gamboola (919011) the Mitchell River is perennial.

Figure 2-31 Streamflow observation data availability in the Mitchell catchment

Table 2-3 provides a key summary of metrics for all gauging stations in the Mitchell catchment. The cease-to-flow column in Table 2-3 indicates the percentage of time that no streamflow was
observed at each of the streamflow gauging stations in the Mitchell catchment. The baseflow index provides a measure of the proportion of ‘slow’ or delayed streamflow as a proportion of total streamflow. The baseflow index at 95% of streamflow gauging stations in the Mitchell catchment ranges from 0.17 to 0.35. Low baseflow indices are indicative of rivers that rise and fall relatively quickly, and typically occur in smaller and more arid catchments. However, in the Mitchell catchment many of the smaller gauged catchments are in the humid headwater catchments. Consequently, the baseflow indices are higher than most similarly sized catchments elsewhere in northern Australia. In river reaches with a low baseflow index the time over which water can be extracted is limited and a large water pumping capacity may be required to maximise the reliability of extracting a full allocation of water. This is discussed in more detail in Section 5.3.

Table 2-3 Streamflow metrics at gauging stations in the Mitchell catchment
Annual streamflow data are calculated under Scenario A. These data are shown schematically in Figure 2-33 and Figure 2-34. 20th, 50th and 80th refer to the 20%, 50% and 80% exceedances, respectively. Cease-to-flow determined using observed data, where streamflow less than 0.1 ML/day was assumed to be equal to zero. Baseflow index was calculated using observed data and the Lyne and Hollick method (1979) (using alpha value equal to 0.925).

<table>
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<th>STATION ID</th>
<th>STATION NAME</th>
<th>CATCHMENT AREA (km²)</th>
<th>ANNUAL STREAMFLOW (GL)</th>
<th>CEASE-TO-FLOW (%)</th>
<th>BASEFLOW INDEX</th>
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The Mitchell River during the dry season is pictured Figure 2-32.

![Image of Mitchell River during the dry season](image-url)

**Figure 2-32 Mitchell River during the dry season**

Photo: CSIRO
Figure 2-33 shows how median annual streamflow increases towards the coast in the Mitchell catchment. As an indication of variability, Figure 2-34 shows the 20% and 80% annual exceedance flow in the Mitchell catchment.

Figure 2-33 Median annual streamflow (50% exceedance) in the Mitchell catchment under Scenario A
Figure 2-34 20% and 80% exceedances of annual streamflow in the Mitchell catchment under Scenario A

Figure 2-35 illustrates the decrease in catchment area and increase in elevation along the Mitchell River from the mouth of the river to its source. The large ‘step’ changes in catchment area are locations where major tributaries join the Mitchell River.

Figure 2-35 Catchment area and elevation profile along the Mitchell River from its mouth to its source

**Catchment runoff**

The simulated mean annual runoff averaged over the Mitchell catchment under Scenario A is 246 mm. There is reasonable uncertainty associated with this estimate as approximately half the runoff in the Mitchell catchment is generated below the lowermost gauge (9191009). The estimated mean annual runoff above gauge 919009 is 167 mm.

Figure 2-36 shows the spatial distribution of mean annual rainfall and runoff under Scenario A (1890 to 2015) across the Mitchell catchment. Mean annual runoff broadly follows the same
spatial patterns as mean annual rainfall; runoff is highest near the coast and in the north-east of the catchment adjoining the Great Dividing Range, and lowest in the central to upper part of the catchment. The certainty of runoff is lowest below the confluence of the Mitchell and Palmer rivers, where there are no streamflow gauging stations below Dunbar (919009). The Walsh and Palmer rivers during the dry season are pictured in Figure 2-37 and Figure 2-38 respectively.

Mean monthly and annual runoff data in the Mitchell catchment are highly skewed. Consequently, it is more appropriate to report median values for runoff and streamflow than mean values, which can be highly misleading. The median can also be referred to as the 50% exceedance. Other exceedance numbers provide further insights into the reliability of runoff. Figure 2-39 shows the spatial distribution of the annual runoff at 20%, 50% and 80% exceedance under Scenario A. The annual runoff at 20%, 50% and 80% exceedance averaged across the Mitchell catchment was 370, 229 and 96 mm, respectively (Figure 2-39). That is, runoff spatially averaged across the Mitchell catchment will exceed 370 mm 1 year in 5, 229 mm half the time and 96 mm 4 years in 5.

Figure 2-36 Mean annual rainfall and runoff across the Mitchell catchment under Scenario A
Pixel scale variation in mean annual runoff plot is due to modelled variation due to soil type.

Figure 2-37 Walsh River upstream of the junction with the Mitchell River during the dry season
Intra- and inter-annual variability in runoff

Rainfall, runoff and streamflow in the Mitchell catchment are variable between years but also within years. Approximately 90% of all runoff in the Mitchell catchment occurs in the 3 months from January to March, which is very high compared to rivers in southern Australia (Petheram et al., 2008). As a result, many of the tributaries to the Alice, Palmer, Mitchell, Walsh and Lynd rivers are ephemeral. Figure 2-40a illustrates that during the wet season there is a high variation in...
monthly runoff from one year to the next. For example, during the month of February, in 20% of years mean runoff exceeded 177 mm and in 20% of years it was less than 28 mm. It is important to consider the reliability of monthly inflows to farm dams in conjunction with crop growing seasons when assessing the suitability of an area for irrigation. The largest average annual runoff under Scenario A for the Mitchell catchment was 1028 mm in 1973–74. The smallest average annual runoff under Scenario A was 21 mm in 1901–02 (Figure 2-40). The CV of annual runoff in the Mitchell catchment is 0.65. Based on data from Petheram et al. (2008), the variability in runoff in the Mitchell catchment is comparable to the annual variability in runoff of other rivers in northern and southern Australia with a comparable mean annual runoff. It is, however, two to three times more variable than rivers from the rest of the world of the same climate type as northern Australia (Petheram et al., 2008). One implication of this is that, all other factors being equal, water storages need to be larger in northern Australia than elsewhere in the world to consistently meet a given demand.

(Figure 2-40 Runoff in the Mitchell catchment under Scenario A
(a) Monthly runoff averaged across the Mitchell catchment. (b) Time series of annual runoff averaged across the Mitchell catchment.

Flooding

The coastal floodplains of the Mitchell catchment regularly flood over large areas of land, and flooding may extend many hundreds of kilometres inland (Figure 2-41). Characterising these flood events is important for a range of reasons. Flooding can be catastrophic to agricultural production in terms of loss of stock, fodder and topsoil, and damage to crops and infrastructure; it can isolate properties and disrupt vehicle traffic. However, flood events also provide opportunity for offstream wetlands to be connected to the main river channel. The high biodiversity found in many unregulated floodplain systems in northern Australia is thought to largely depend on flood events, which allow for biophysical exchanges to occur between the main river channel and wetlands.

Unless otherwise stated, the material in this section is based on findings described in the companion technical report on flood mapping and modelling (Karim et al., 2018).

In the Mitchell catchment broad-scale flooding commences near the junction of Rosser Creek and the Mitchell River. Below the current/delta apex of the Mitchell River Fan Aggregation (an ‘aggregation’ of alluvial plains of varying geological age) located below the confluence of the Mitchell and Palmer rivers, flood flows spread extensively across several distributary channels.
before reaching the coastal plains and ultimately the sea. During large events some water spills out of the Mitchell catchment and enters the catchment of the Staaten River to the south. Above the confluence of Rosser Creek and the Mitchell River, however, satellite imagery indicates that the major rivers rarely break their banks.

Figure 2-41 Flood inundation map of the Mitchell catchment
Data captured using MODIS satellite imagery. This figure illustrates the maximum percentage of MODIS pixel inundated between 2000 and 2015.

Figure 2-42 indicates the spatial extent and temporal variation in inundation on the coastal floodplains of the Mitchell catchment for selected flood events, based on computer model simulations (see Karim et al., 2018). Where introduced pastures are inundated with stagnant water for a period greater than 5 consecutive days, the above-ground biomass may die; this may extend to 2 weeks if the water is aerated. Where the period of inundation is greater than 20 consecutive days, the entire plant may die. This does, however, vary between pasture species. The largest flood event recorded at streamflow gauging station 919009, the most downstream station in the Mitchell catchment, was in 2011.
Figure 2-42 Spatial extent and temporal variation of inundation during simulated flood events of (a) 2001 (AEP 1 in 10), (b) 2006 (AEP 1 in 2) and (c) 2009 (AEP 1 in 26)
AEP refers to annual exceedance probability.
Further observations of flooding under the historical climate in the Mitchell catchment are as follows:

- Flood peaks typically take about 2.5 days to travel from Dunbar to Kowanyama, near the mouth of the Mitchell River, at a mean speed of 1.7 km/hour.
- For flood events of annual exceedance probability (AEP) 1 in 5, 1 in 10 and 1 in 20 the peak discharge (discharge) at Gamboola on the Mitchell River is 2815, 4435 and 6560 m³/second, respectively.
- Between 1981 and 2015 (35 years) events with a discharge greater than or equal to AEP 1 in 1 occurred during all months between November and April, with about 80% of events occurring between January and March. Of the 10 events with the largest flood peak discharge at Gamboola on the Mitchell River, 1 event occurred during January, 6 in February and 3 in March.
- The maximum areas inundated for events of AEP 1 in 2 (2006), AEP 1 in 10 (2001), AEP 1 in 26 (2009) were 950, 1815 and 2620 km², respectively. Duration of flooding varies spatially and increases with flood magnitude. Floodplains in the lower reaches of the Mitchell River were inundated for more than 20 days during an event of AEP 1 in 38 (2011). Larger floods had longer periods of connectivity between the main river channel and offstream wetlands. However, variation in local runoff and the shape of the inflow hydrograph (e.g. single or multiple peaks) had a strong influence on the duration of connectivity.

Relationship between streamflow, inundation area and flood frequency in the Mitchell floodplain

A strong relationship is observed between peak flood discharge at gauge 919009 and maximum inundated area of the Mitchell River floodplain. This relationship enables maximum inundated area to be estimated from streamflow data (Figure 2-43a). Figure 2-43b shows the relationship between peak flood discharge and annual exceedance probability (AEP). These two figures can be used together to estimate the AEP of maximum inundated areas. For example, Figure 2-43a shows the maximum inundated area of 2500 km² corresponds to a peak flood discharge of about 4800 m³/second, which in turn corresponds to an AEP of 20% (or 1 in 5 years) (Figure 2-43). Hence a maximum inundated area of 2500 km² is exceeded in 20% of years.

![Figure 2-43 Relationships between peak flood discharge, maximum inundated area and annual exceedance probability](image-url)

(a) Peak flood discharge at gauge 919009 (Dunbar) and maximum inundation area of Mitchell River floodplain and (b) peak flood discharge and annual exceedance probability at gauge 919009.
Streamflow forecasting

The Bureau of Meteorology offers seasonal streamflow forecasting service in the Mitchell catchment at Drumduff (919204) on the Palmer River. The skill of streamflow forecasting largely depends on knowledge of antecedent catchment conditions and skill of forecast rainfall and/or climate indicators. During January there is a high level of skill at forecasting total streamflow volume at Drumduff on the Palmer River for the February to April period. During December there is a very low level of skill at forecasting total streamflow volume at the same location for the January to March period (see companion technical report on climate (Charles et al., 2016)). While annual rainfall is not always reliable and seasonal forecasting moderate, important information about water availability (i.e. soil water and water in dams at the end of the wet season) is often available when it is most important agriculturally – before planting time for most crops.

Instream waterholes during the dry season

The Mitchell River experiences very few no-flow days. However, its major tributaries the Palmer, Walsh and Lynd and their tributaries do experience cease-to-flow periods (Table 2-3). Once streamflow has ceased the rivers break up into a series of waterholes during the dry season. Waterholes that ‘persist’ from one year to the next are key aquatic ‘refugia’ and are likely to be sustaining ecosystems in the Mitchell catchment (Section 3.2). Waterholes in the Mitchell catchment are pictured in Figure 2-44 and Figure 2-45.
In some reaches waterholes may be partly or wholly sustained by groundwater discharge (Section 2.5.4). However, in other reaches there is little evidence that ‘persistent’ waterholes receive water from groundwater discharge and are likely to be replenished following wet-season flows.

The ecological importance and functioning of key aquatic refugia are discussed in more detail in the companion technical report on ecology (Pollino et al., 2018).

For illustrative purposes the formations of waterholes following a cease-to-flow event were captured using satellite imagery for a river reach in the Flinders catchment, northern Australia (Figure 2-46). Figure 2-47 maps 1-km river reaches/segments where water is recorded in greater than 90% of dry-season satellite imagery. It provides an indication of those river reaches containing permanent water.

![Figure 2-46 Instream waterhole evolution](image)

This figure shows the area of waterholes at a given time after flow ceased and the ability of the water index threshold to track the change in waterhole area and distribution.

As shown in Figure 2-44 and Figure 2-45 persistent waterholes can have variable characteristics, e.g. levels of turbidity and adjacent riparian vegetation. These differences can result in waterholes having varying degrees of ecological importance and different ecological responses arising from a development (Section 3.2).
Persistent river reaches are defined as 1-km river reaches where water was identified in greater than 90% of the dry-season LandSat imagery between 1990 and 2016.

**Surface water quality**

Water quality samples were taken at sites located on the Palmer, Mitchell, Walsh and Lynd rivers during low- and high-flow conditions (Figure 2-47) during 2017 and 2018. Samples were analysed for nitrogen, phosphorus and heavy metals content. Heavy metals were targeted since legacy mines exist across the upper half of the catchment, particularly in the catchment of the Palmer River. The results indicate that measured levels of all heavy metals are below drinking water guideline levels for human health (NHMRC, 2011). Figure 2-48 shows the measured heavy metal concentrations at the sample locations. For more details see companion technical report on river model simulation (Hughes et al., 2018).
2.6 References


