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Water resource assessment for the Southern Gulf catchments

A report from the CSIRO Southern Gulf Water Resource Assessment for the National Water Grid

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Important disclaimer

CSIRO Southern Gulf Water Resource Assessment acknowledgements

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Aspects of the Assessment have been undertaken in conjunction with the Northern Territory (NT) and Queensland governments.

The Assessment was guided by two committees:

i. The Governance Committee: CRC for Northern Australia/James Cook University; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Agriculture and Fisheries; Queensland Department of Regional Development, Manufacturing and Water

ii. The Southern Gulf catchments Steering Committee: Amateur Fishermen's Association of the NT; Austral Fisheries; Burketown Shire; Carpentaria Land Council Aboriginal Corporation; Health and Wellbeing Queensland; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Prawn Fisheries; Queensland Department of Agriculture and Fisheries; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Regional Development, Manufacturing and Water; Southern Gulf NRM

Responsibility for the Assessment's content lies with CSIRO. The Assessment's committees did not have an opportunity to review the Assessment results or outputs prior to their release.

This report was reviewed by Mr Mike Grundy (Independent consultant). Individual chapters were reviewed by Dr Peter Wilson, CSIRO (Chapter 2); Dr Andrew Hoskins, CSIRO (Chapter 3); Dr Brendan Malone, CSIRO (Chapter 4); Dr James Bennett, CSIRO (Chapter 5); Dr Nikki Dumbrell, CSIRO (Chapter 6); Mr Darran King, CSIRO (Chapter 7). The material in this report draws largely from the companion technical reports, which were themselves internally and externally reviewed.

For further acknowledgements, see page xxviii.

Acknowledgement of Country

CSIRO acknowledges the Traditional Owners of the lands, seas and waters of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture and pay our respects to their Elders past and present.

Photo

Saltwater Arm, a tributary of the Albert River. This view typifies the tidal rivers and estuaries along the southern coast of the Gulf of Carpentaria. Source: Shutterstock

Director's foreword

Sustainable development and regional economic prosperity are priorities for the Australian, Queensland and Northern Territory (NT) governments. However, more comprehensive information on land and water resources across northern Australia is required to complement local information held by Indigenous Peoples and other landholders.

Knowledge of the scale, nature, location and distribution of likely environmental, social, cultural and economic opportunities and the risks of any proposed developments is critical to sustainable development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpin the resource security required to unlock investment, while at the same time protecting the environment and cultural values.

In 2021, the Australian Government commissioned CSIRO to complete the Southern Gulf Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to generate data and provide insight to support consideration of the use of land and water resources in the Southern Gulf catchments. The Assessment focuses mainly on the potential for agricultural development, and the opportunities and constraints that development could experience. It also considers climate change impacts and a range of future development pathways without being prescriptive of what they might be. The detailed information provided on land and water resources, their potential uses and the consequences of those uses are carefully designed to be relevant to a wide range of regional-scale planning considerations by Indigenous Peoples, landholders, citizens, investors, local government, and the Australian, Queensland and NT governments. By fostering shared understanding of the opportunities and the risks among this wide array of stakeholders and decision makers, better informed conversations about future options will be possible.

Importantly, the Assessment does not recommend one development over another, nor assume any particular development pathway, nor even assume that water resource development will occur. It provides a range of possibilities and the information required to interpret them (including risks that may attend any opportunities), consistent with regional values and aspirations.

All data and reports produced by the Assessment will be publicly available.

C. Chilcott

Chris Chilcott

Project Director

Key findings for the Southern Gulf catchments

The Southern Gulf catchments have an area of 108,200 km^2 across the Northern Territory (NT) and Queensland. They comprise the catchments of Settlement Creek (17,600 km^2), Nicholson River (52,200 km^2), Leichhardt River (33,400 km^2) and, Morning Inlet (3,700 km^2) and the Wellesley island groups (1,200 km^2). The rivers of these catchments flow into the lower Gulf of Carpentaria, an important part of northern Australia's marine environment with high ecological, cultural and economic values. Within the study area, 12% of the land is Aboriginal freehold tenure of which 33% is national park, including the UNESCO World Heritage-listed Australian Fossil Mammal Sites (Riversleigh, Queensland). The dominant land use by area is extensive grazing of beef cattle on native rangelands, constituting 77% of the study area. Mining occupies less than 0.05% of the land area and irrigated agriculture, occupies about 0.01% (~1,400 ha).

The population of the catchments in 2021 was approximately 22,500 people, of whom about 27% were Indigenous Australians. In comparison, Indigenous Australians make up 25% of the population of the NT, 4% of the population of Queensland and 3% of Australia as a whole. There is one significant urban area, Mount Isa (population 18,000) and Doomadgee (population 1,387) is the only other settlement with a population greater than 1,000. Distinct demographic and socio-economic differences exist within the Southern Gulf catchments based on the differences between Mount Isa and the remainder of the study area. The population density outside Mount Isa is one of the lowest in Australia, and some communities in the study area are ranked as being among the most disadvantaged in Australia.

Indigenous Peoples have continuously occupied and managed the Southern Gulf catchments for tens of thousands of years. They retain significant and growing rights and interests in land and water resources, including crucial roles in water and development planning and as co-investors in future development. Indigenous Peoples remain closely tied to their territory associations. The key language groups are Garawa, Gangalidda, Waanyi, Kukatj, Lardil, Yangkaal, Kaiadilt, Wakabunga, Nguburinji, Kalkadoon, Mitakoodi, Mayi-Kutuna, Mayi-Thakurti, Mayi-Yapi and Mayi-Yali. A number of related groups and subgroups occur within these regional ownership descriptors.

The creeks and rivers of the Southern Gulf catchments contribute about 6% of the mean annual discharge into the Gulf of Carpentaria, supporting many important ecological assets, some of national significance, and existing industries such as the Northern Prawn Fishery.

This fishery had a prawn catch across whole of northern Australia valued at $85 million in 2019–20. While the Leichhardt River is deeply incised over much of its length, high-flow distributary channels have formed where the Nicholson and Gregory rivers flow across the extensive Armraynald Plain.

The Nicholson and Leichhardt rivers are the two largest rivers in the Southern Gulf catchments and have median annual discharges of 1,873 and 1,211 GL, respectively. The Settlement Creek catchment encompasses numerous relatively short rivers, including Running, Settlement, Lagoon, Eight Mile, Cliffdale and Moonlight creeks. The median annual discharge from the creeks within the Settlement Creek catchment is 1,304 GL. The Gregory River, which flows into the Nicholson

River approximately 85 km from the coast, is the largest perennial river in semi-arid Queensland. The Gregory River and its major tributary, Lawn Hill Creek, receive groundwater discharge throughout the dry season from the Cambrian Limestone Aquifer (CLA), which is comprised mostly of the Camooweal Dolostone and Thorntonia Limestone in the south of the study area.

The concentration of mining and industrial activity around Mount Isa has resulted in sufficiently high water demand from high-value industries for the construction of five large, purpose-built reservoirs of at least 10 GL capacity in the Leichhardt catchment, including the Leichhardt Dam (Lake Moondarra) and Julius Dam (Lake Julius). Consequently, as a proportion of its median annual streamflow, the water in the Leichhardt River is more heavily regulated than most other rivers in northern Australia west of the Great Dividing Range. As a result of existing entitlements (105.7 GL/year) and licence conditions in the Leichhardt catchment, only limited quantities of water could be reliably available for irrigated agriculture from Julius Dam without affecting the reliability of water supply to existing water entitlement holders. The study area has numerous small dams (<10 GL) providing water to mines as well as farm-scale dams, several for irrigation, but the only other instream water structure of note is a low weir (<1 GL capacity) on the Nicholson River downstream of Doomadgee, which is used to supply water for the town.

With irrigation, the Southern Gulf catchments have a climate that is suitable for a wide range of annual and perennial horticulture, and broadacre crops and forages. However, the opportunities and risks of irrigation development adjacent to each of the major rivers are starkly different.

Adjacent to the east bank of the Gregory River downstream and slightly upstream of the township of Gregory, the grey cracking clay soils of the treeless Armraynald Plain are highly favourable for large-scale irrigation developments (based on instream dams) or small-scale irrigation developments (based on water harvesting). The large contiguous areas of soil suitable for broadacre irrigation and ringtanks (1.03 million ha) gently slope away from the Gregory River, enabling water to be efficiently distributed using gravity and natural distributary channels running away from the river. The most cost-effective potential site for a dam in the study area is located approximately 70 km upstream of the township of Gregory, but that potential dam's reservoir would be located within a part of the Gregory River that is a nationally significant wetland, the Thorntonia Aggregation. Being one of the few perennial rivers in the Southern Gulf and neighbouring Flinders catchment region, the Gregory River is particularly highly valued by local residents.

On the Nicholson River downstream of Doomadgee are contiguous areas of red sandy and loamy soils (totalling 23,000 ha) suitable for irrigated vegetables. However, in the absence of a dam upstream, on-farm storage of water for irrigated annual horticulture would be challenging due to the difficulty of constructing ringtanks on these sandy soils. These soils are unlikely to be suitable for perennial horticulture due to the risk of flooding.

The Leichhardt catchment has opportunities for irrigated horticulture on the friable soils (103,000 ha) on the narrow levees of the Leichhardt River downstream of Kajabbi. Adjacent to these soils, and up to 1 km from the river, are friable clay soils suitable for broadacre irrigation. While these heavier soils are suitable for constructing ringtanks, conveying water pumped from the Leichhardt River across the sandy levee soils to ringtanks may be costly and inefficient in some locations. The proximity of the eastern side of the mid-reaches of the Leichhardt River to the Burke Developmental Road and Mount Isa would be an advantage to new irrigation developments compared with more remote parts of northern Australia. For example, the more remote Nicholson and Settlement Creek catchments are often inaccessible for long periods due to flooding during the wet season.

It is physically possible that water harvesting could extract 150 GL of water in 75% of years, spread across the Nicholson and Leichhardt catchments, without affecting the reliability of supply of existing water entitlement holders. This extraction would reduce the median and mean annual discharge to the Gulf of Carpentaria from these catchments by 5% and 3%, respectively. It would be sufficient water to irrigate about 12,000 ha of mixed broadacre crops.

A hypothetical total of 10,000 ha of irrigated mixed broadacre (85%) and horticulture (15%) agriculture in the Southern Gulf catchments, would result in total annual increased economic activity (direct and indirect) of potentially as much as $190 million and support up to 360 full-time-equivalent jobs.

In reality, the nature and scale of future surface water development would depend heavily upon community and government values, acceptance of potential impacts to water-dependent ecosystems, and the likely beneficiaries. Economic data from the NT and north-western Queensland indicate that, like other industries such as mining, grazing and fishing, benefits arising from agriculture developments elsewhere in the NT and Queensland have been heavily skewed to non-Indigenous households relative to Indigenous households.

The most promising groundwater resources in the Southern Gulf catchments are the regional-scale CLA and Gilbert River Aquifer (GRA). The CLA coincides with large, contiguous areas of cracking clay soils suitable for irrigated broadacre cropping (308,000 ha) along the south-western margin of the study area. However, groundwater discharge from the CLA provides the dry-season flow in Lawn Hill Creek and the Gregory and O'Shannassy rivers and some of their tributaries. The major rivers of the Southern Gulf catchments are also characterised by relatively extensive alluvial aquifers, up to 5 km either side of the river. These systems are poorly characterised but likely to be highly heterogeneous and connected to the rivers, meaning the alluvial aquifers could be recharged by and discharge into 'connected' rivers at different times of the year. In addition to the 3.5 GL of existing groundwater entitlements in the study area, it is physically possible that groundwater systems across the Southern Gulf catchments could supply up to approximately 30 GL of water per year for irrigated agriculture, sufficient to irrigate about 4,000 ha of mixed broadacre cropping. Up to 10 GL of additional groundwater per year could potentially be extracted for other uses from areas of hard rock (i.e. poor soil) and poor water quality. The actual quantity of water extracted, however, would depend on community and government acceptance of impacts to groundwater-dependent ecosystems (GDEs) and existing groundwater users.

Irrigated agriculture and aquaculture in the Southern Gulf catchments is only likely to be financially viable where there is an alignment of good prices for high-value crops and market advantages. This makes achieving scale challenging. Other factors include availability of suitable markets for the products, investment in fundamental infrastructure such as all-weather roads and bridges and land tenure arrangements. New agricultural developments in the study area, if they were to eventuate, are likely to start irrigating broadacre crops on heavier clay soils before progressing to higher-value and higher-input enterprises, such as horticulture on sandy and loamy soils, as farmers build confidence in their skills and expertise in this largely greenfield region. Landholders could potentially transition from broadacre cropping to annual horticulture on the heavy clay soils and nearby sandy levees adjacent to the Leichhardt River. Along the lower coastal reaches, about 194,000 ha of land is suitable for prawn and barramundi aquaculture, using earthen ponds. For all of the area estimates noted above, the land is considered suitable but with minor to considerable limitations and would require careful soil management.

Growing irrigated forages or hay to feed young cattle to improve market access or to enable sale at younger ages is unlikely to be financially viable. Irrigation increases beef production but requires high capital outlay, and gross margins would be reasonably similar to, or less than, baseline cattle operations. Consistent rainfed cropping in the catchment is likely to be opportunistic (only possible in suitable years) and depend upon farmers' appetite for risk and future local demand. How land cultivated for rainfed agriculture is managed in the years when rainfall is insufficient for rainfed cropping will be crucial for sustainable farming operations and the industry's social licence to operate.

Changes to groundwater baseflow and streamflow under projected drier future climates are likely to be considerably greater than changes that would result from plausible groundwater and surface water developments. Of the global climate models examined, 44% projected a drier future climate over the Southern Gulf catchments and 40% projected 'little change'. Adopting a conservatively dry global climate model projection of a 13% reduction in long-term mean annual rainfall and a 9% increase in potential evaporation, the modelled reduction in median annual discharge to the Gulf of Carpentaria from the Nicholson and Leichhardt catchments was 30%.

The Southern Gulf catchments, although not pristine, have many unique characteristics and valuable ecological assets, which support existing industries such as grazing, tourism and commercial fishing. Whether based on groundwater or offstream storage, irrigated agricultural development has a wide range of potential benefits and risks that differentially intersect diverse stakeholder views on ecology, economy and culture. The detailed reports upon which this summary is based provide information that can be used to help consider the trade-offs from potential developments.

Leichhardt River flowing through the Isa Highlands
Photo: CSIRO – Nathan Dyer

Overview of the Southern Gulf catchments

The Southern Gulf catchments comprise four river basins defined by the Australian Water Resource Council, referred to here as catchments, that discharge into the Gulf of Carpentaria: Settlement Creek, Nicholson, Leichhardt and Morning Inlet. The study area also encompasses the Wellesley islands groups.

The Southern Gulf catchments have a highly variable climate

Northern Australia’s tropical climate is notable for the extremely high variability of rainfall between seasons and especially between years. This has major implications for evaluating and managing risks to development, infrastructure and industry.

The climate of the Southern Gulf catchments is hot and semi-arid to dry subhumid. Generally, these catchments are water-limited environments, so efficient and effective methods for capturing, storing and using water are critical.

- The mean and median annual rainfall – averaged across the Southern Gulf catchments – are 602 mm and 554 mm, respectively. A strong rainfall gradient runs from Mornington Island in the north (1,150 mm annual median) to the south of Mount Isa (400 mm annual median).
- Averaged across the catchments, 6% of the rainfall occurs in the dry season (May to October). Median annual dry-season rainfall ranges from 15 mm in the south-east to 60 mm along the western boundary.
- Annual rainfall totals in the Southern Gulf catchments are highly variable. Annual totals are approximately 1.3 times more variable than in comparable parts of the world.

The seasonality of rainfall presents opportunities and challenges for both wet- and dry-season cropping.

- Information about water availability (i.e. soil water and water in storages) helps minimise risk when it is known ahead of important agricultural decisions – before planting time for most dry-season planted crops. Such information allows farmers to manage risk by choosing crops that optimise use of the available water or by deciding to forego cropping for a season.

Rainfall is difficult to store.

- Mean annual potential evaporation is higher than rainfall, averaging about 1,850 mm over most of the study area, with the highest values near the mouth of the Leichhardt River and Morning Inlet.
- Large farm-scale ringtanks lose about 30% to 50% of their water to evaporation and seepage between April and October. Deeper farm-scale gully dams lose about 20% to 40% of their water over the same period. Using stored water early in the season is the most effective way to reduce these losses.

The more promising agricultural land in the Southern Gulf catchments is in the middle to lower reaches of the rivers, which are the parts of the study area most susceptible to destructive cyclonic winds.

- Of the 53 consecutive cyclone seasons prior to 2021–22, the Southern Gulf catchments had no tropical cyclones in 60% of those seasons, one cyclone in 36% of seasons and two cyclones in 4% of seasons.

More than twice as many global climate models project a drier future climate than a wetter future climate for the Southern Gulf catchments, thus it is prudent to plan for water scarcity.

- For the Southern Gulf catchments, 44% of climate models project a drier future, 16% project a wetter future and 40% project a future within ±5% of the historical mean, indicating 'little change'. Other studies indicate that tropical cyclones will be fewer but more intense in the future, although uncertainties remain.
- Palaeoclimate records indicate past climates have been both wetter and drier over the past several thousand years.
- Climate and hydrology data that support short- to medium-term water resource planning should capture the full range of likely or plausible conditions and variability at different timescales, and particularly for periods when water is scarce. These are the periods that most affect industry and the environment. When industries 'compete' with the environment for water when it is most scarce, it can have profound long-term consequences to both if the scarcity is poorly understood and not planned for.
- Future changes in temperature, vapour pressure deficit, solar radiation, wind speed and carbon dioxide concentrations will separately act to increase or decrease crop water demand and crop yield under irrigation in northern Australia. For example, during the cooler months of the dry season, cotton in the more southerly parts of the Southern Gulf catchments (e.g. Barkly Tableland) may be limited by minimum temperatures at key stages of cotton boll development. Higher temperatures may increase the irrigation water requirement, depending upon whether other climate variables such as wind speed increase or decrease in the future. However, for some crops, higher crop water demand, and hence smaller planted area, could be offset by higher yields and lower risk of crop failure.
- Changes under future climates to the amount of irrigation water required and crop yield are likely to be modest compared to improvements arising from new crop varieties and technology over the next 40 years. Historically, these types of improvements have been difficult to predict, but they are potentially large.

The Southern Gulf catchments are comprised of many different types of rivers and creeks

The rivers and creeks of the Southern Gulf catchments constitute about 6% of the mean annual flow into the Gulf of Carpentaria, an important part of northern Australia's marine environment with high ecological and economic values.

- The mean and median annual discharges from the Southern Gulf catchments into the Gulf of Carpentaria are 6,759 and 4,961 GL, respectively.
- The Nicholson and Leichhardt rivers are the two largest rivers in the Southern Gulf catchments. The Nicholson River has the 13th largest median annual discharge (1,873 GL) of all rivers that flow into the Gulf of Carpentaria, and the Leichhardt River has the 16th largest (1,211 GL).

- The Settlement Creek catchment encompasses numerous relatively short creeks and its median annual discharge to the Gulf of Carpentaria is 1,304 GL. The median annual discharges from the Morning Inlet catchments and the Wellesley Island groups are 195 and 173 GL, respectively.
- Annual variability in streamflow in the Southern Gulf catchments is comparable with other rivers in northern Australia with similar mean annual runoff, but the annual variability in runoff is two to three times greater than rivers in the rest of the world in similar climates.

Broad-scale flooding occurs along the lower reaches of the rivers of the Southern Gulf catchments, particularly adjacent to the distributary channels from the Nicholson and Gregory rivers to the Albert River.

- Between 1980 and 2023 (43 years), 51 streamflow events broke the banks of the Gregory River at Riversleigh Road crossing. All events occurred between November and April (inclusive), and about 84% of events occurred between January and March (inclusive).

Under a potential dry future climate (13% reduction in rainfall), median annual discharges from the Nicholson and Leichhardt rivers are projected to decrease by approximately 30%.

The Leichhardt catchment is one of the most regulated catchments in northern Australia, west of the Great Dividing Range, based on extractions as a proportion of its median annual flow.

- Current licensed surface water extractions in the Leichhardt catchment are about 105.7 GL/year (~7% of median annual discharge). However, actual mean annual water use is estimated to be less than half this amount.
- Discounting tailings dams, the Leichhardt catchment contains five dams listed in the Australia National Committee on Large Dams register: Julius Dam (107.5 GL capacity), Leichhardt River Dam / Lake Moondarra (103 GL capacity), Greenstone Creek / Waggaboonya Lake (Greenstone) (13.6 GL capacity), East Leichhardt Dam / Lake Mary Kathleen (12.1 GL capacity) and Rifle Creek Dam (9.5 GL capacity). With the exception of East Leichhardt Dam, which is now only used for recreation, the dams supply water for mining, industry and town uses.
- Water quality is variable across the Southern Gulf catchments. Studies in the late 2000s found the water quality of the upper Leichhardt River had been influenced by urban and mining activity and exceeded a number of heavy metal water quality guideline trigger values, however the drinking water source for Mount Isa (Lake Moondarra) was found to meet drinking water guidelines.

The Gregory River, which flows into the Nicholson River approximately 85 km from the coast, is the largest perennial river in semi-arid Queensland.

- Lawn Hill Creek and the Gregory and O’Shannassy rivers receive groundwater discharge throughout the dry season from the CLA, which is composed mostly of the Camooweal Dolostone and Thorntonia Limestone.
- On average, approximately 87% of the streamflow in the Southern Gulf catchments occurs between January and March. In the perennial Gregory River, however, approximately 78% of streamflow occurs over the same time period.

The Southern Gulf catchments contain a significant diversity of species and habitats, including freshwater, terrestrial and marine habitats of great cultural, conservation and commercial importance

The Southern Gulf catchments are largely intact, but they are not pristine.

- A range of economic enterprises, infrastructure and human-induced impacts occur in the Southern Gulf catchments, and the nature and extent to which these have modified the habitats and affected species of the Southern Gulf catchments vary.
- The near-coastal and estuary habitats of the Southern Gulf catchments support fishing industries, including a commercial barramundi fishery, prawns and mud crabs (mainly *Scylla serrata*).
- In the Leichhardt catchment, Lake Julius and Lake Moondarra are listed in the Directory of Important Wetlands in Australia (DIWA). While the water in these two storages predominantly supplies urban, mining and industrial demand around Mount Isa and Cloncurry, the permanent water provides important dry-season refuge for waterbirds and supports a variety of freshwater fish species.
- In the Southern Gulf catchments, feral horses, wild pigs and cane toads are among the introduced animals.
- Weed species of interest in and around the Southern Gulf catchments include prickly acacia, buffel grass, salvinia rubber vine and water hyacinth.

Floods have economic significance because they underpin the health of the recreational and commercial fisheries in the Gulf of Carpentaria, which include a barramundi fishery and the Northern Prawn Fishery, which had a catch of prawns worth $85 million in 2019–20.

- Wet-season flooding inundates significant parts of the lower reaches of the rivers in the catchments, connecting wetlands to river channels, inundating floodplains, and allowing the exchange of fauna, flora and nutrients, which drives an ecological productivity boom.
- The 13 DIWA-listed wetlands in the Southern Gulf catchments include a variety of wetland types, ranging from estuarine wetlands with salt flats and saltmarshes to artificial lakes and spring-fed creeks and rivers.
- Protected areas located in the Southern Gulf catchments include the UNESCO World Heritage-listed Australian Fossil Mammal Sites (Riversleigh, Queensland), which is in Boodjamulla National Park (Queensland), and Finucane Island National Park (Queensland). There are also three Indigenous Protected Areas: Ganalanga-Mindibirrina, NT; Nijinda Durlga, Queensland; and Thuwathu/Bujimulla, Queensland.
- The marine, near-shore and estuarine environments of the Southern Gulf catchments have extensive intertidal flats and estuarine communities, including mangroves, salt flats, coral reefs and seagrass habitats. These habitats are highly productive, have high cultural value and include many areas of national significance.
- Seagrass beds in the near-coastal Gulf of Carpentaria have high diversity and grow in vigorous stands. They provide important food and habitat for dugongs (*Dugong dugon*), green sea turtles (*Chelonia mydas*) and prawns (*Penaeus* spp.).

- The dominant vegetation types in the catchments are open eucalypt woodlands, Melaleuca forests and woodlands, and, on the cracking clay plains, tussock grasslands characterised by the Mitchell grasses (*Astrebla* spp.).
- The marine and near-shore marine areas of the catchments contain significant habitat for sea turtles, shorebirds and seabirds.
- Protected species include freshwater or largetooth sawfish (*Pristis pristis*; Vulnerable, EPBC Act) and the Gulf snapping turtle (*Elseya lavarackorum*).
- The Southern Gulf catchments provide important stopover habitat for migratory shorebird species listed under the EPBC Act, including the eastern curlew (*Numenius madagascariensis*; Critically Endangered) and the Australian painted snipe (*Rostratula australis*; Endangered).

Indigenous values, rights and development goals

Indigenous Peoples are a significant and increasing population of the Southern Gulf catchments.

- Traditional Owners have recognised native title and cultural heritage rights, have Aboriginal freehold land ownership and control, or are the custodians of, significant natural and cultural resources, including land, water, coastline and sea.
- Water-dependent fishing and hunting are key health, customary and economic roles for Indigenous Peoples in the Southern Gulf catchments. The rivers and underground water support food security and good nutrition, and are crucial to geographical and cultural relationships.
- The history of pre-colonial and colonial patterns of land and natural resource use and preservation in the Southern Gulf catchments is important to understanding present circumstances. This history has shaped residential patterns, including across the Queensland–NT border, and it also informs responses by the Indigenous Peoples to future development possibilities.
- The Indigenous population of the Southern Gulf catchments outside the Mount Isa urban centre is 60% of the total population.

From an Indigenous perspective, ancestral powers are still present in the landscape, including underground water, and they intimately connect Peoples, Country and culture.

- Those powers must be considered in any action that takes place on Country.
- Patterns of ownership and language affiliation follow features of the landscape and waterways and are reflected in the place names and songs of significant Dreamings and totemic figures.
- Water is central to the cultural landscape. Riverine and aquatic areas are known to be strongly correlated with cultural heritage sites.
- Some current cultural heritage considerations restrict Indigenous capacity to respond to development proposals because some knowledge is culturally sensitive and cannot be shared with those who do not have the cultural right and authority to know.

Catchment-wide deliberative processes will be vital to ensuring that Indigenous water rights and interests are actively engaged and included in future water-dependent development and planning.

- Indigenous Peoples, especially those in the downstream parts of the catchments, see environmental impact assessments as crucial tools to assist them to make decisions about water-dependent development.
- Indigenous Peoples have business and water development objectives designed to create opportunities for existing residential populations, including the supply of safe and secure community water to residents, and to aid the return of Peoples living elsewhere.
- Indigenous Peoples want to be owners, partners, investors and stakeholders in any future development. This reflects their status as the longest-term residents with deep inter-generational ties to the catchment. Indigenous custodians in the catchments are engaged in diverse collaboration and partnership models with the private, non-government, government and research sectors.

Opportunities for agriculture and aquaculture

There is about 1,400 ha of irrigated agriculture and 4,000 ha of rainfed agriculture in the Southern Gulf catchments.

Although an abundance of soil is suitable for irrigated agriculture in the Southern Gulf catchments, the area that can be irrigated is limited by water.

- Up to about 5.1 million ha of soils in the Southern Gulf catchments are classified as moderately suitable with considerable limitations (Class 3) or better (Class 1 or Class 2) for irrigated agriculture, depending on the crop and irrigation method chosen.
- Class 3 soils have considerable limitations that lower production potential or require more careful management than more suitable soils, such as Class 2 soils.
- About 4.7 million ha of soils in the Southern Gulf catchments are rated as Class 3 or better for irrigated pulses (i.e. food legumes) using spray irrigation in the dry season. Most of this area is rated as Class 2. In comparison, about 1.7 million ha of soils are rated Class 3 or better using furrow irrigation in the dry season for the same crops.
- About 4.7 million ha of soils in the Southern Gulf catchments are rated as Class 3 or better for cotton or grains crops using spray irrigation in the dry season. Under furrow irrigation in the dry season, there are about 1.8 million ha of soil suitable for cotton or grain crops, all of which are rated as Class 3.

Bushfoods are an emerging niche industry across northern Australia. Kakadu plum, though not recorded as occurring in the Southern Gulf catchments, is one of the best known and has one of the most well-developed supply chains. However, most bushfoods continue to be wild-harvested with very little grown commercially. Limited information on commercial bushfood operations is publicly available.

The soils in different parts of the study area are starkly different.

- The largest arable areas in the Southern Gulf catchments are the self-mulching cracking clay soils of the Armraynald Plain (1.03 million ha) and Barkly Tableland (308,000 ha). The cracking clay soils are likely to present severe trafficability constraints throughout much of the wet season. Irrigation of the Armraynald Plain and Barkly Tableland would be best suited to use of surface water and groundwater respectively.

- Downstream of Doomadgee are large contiguous areas of red sandy and loamy soils suitable for irrigated vegetables (23,000 ha) along the Nicholson River. However, in the absence of a dam upstream, on-farm storage of water for broad-scale irrigation would be challenging due to the difficulty of constructing ringtanks on these sandy soils. These soils are unlikely to be suitable for perennial horticulture due to the risk of flooding. It may be possible to slightly raise and enhance the existing weir on the Nicholson River near Doomadgee to provide some additional water to irrigate small-scale market gardens either on these sandy and loamy soils or on similar soils closer to Doomadgee.
- The Leichhardt catchment has opportunities for irrigated horticulture on the friable soils (103,000 ha) on the narrow levees of the Leichhardt River downstream of Kajabbi. Adjacent to these soils, and up to 1 km from the river, are friable clay soils suitable for broadacre irrigation. While these heavier soils are suitable for constructing ringtanks, conveying water pumped from the Leichhardt River across the sandy levee soils to ringtanks may be costly and inefficient in some locations.

Irrigation enables higher yields and more flexible and reliable production than rainfed crops

- Many annual crops can be grown at most times of the year with irrigation in the Southern Gulf catchments. Irrigation provides increased yields and flexibility in sowing date.
- Sowing dates must be selected to balance the need for the best growing environment (optimising solar radiation and temperature) with water availability, pest avoidance, trafficability, crop sequences, supply chain requirements, infrastructure requirements, market demand, seasonal commodity prices and, in the case of genetically modified cotton, planting windows specified within the cotton industry.
- Irrigated crops likely to be commercially viable with a dry-season planting (late March to August) include annual horticulture, cotton and mungbean. Irrigated crops likely to be commercially viable with a wet-season planting (December to early March) include cotton, forages and peanuts.
- Seasonal irrigation water applied to crops can vary enormously with crop type (e.g. due to variations in duration of growth, rooting depth), season of growth, soil type and rainfall received. For example, cotton planted in the wet season and dry season requires about 5 ML/ha and 6 ML/ha, respectively, of irrigation water in at least 50% of years. A high-yielding perennial forage such as Rhodes grass requires up to about 20 ML/ha each year, averaged across a full production cycle.
- Rainfed cropping is theoretically possible but most likely to be opportunistic in the Southern Gulf catchments based on rainfall received and stored soil water.How cultivated land is managed in the years when rainfall is insufficient for rainfed cropping will be crucial for sustainable farming operations and the industry’s social licence to operate.

Excess rainfall can also constrain crop production on some soils.

- High rainfall and possible inundation mean that wet-season cropping on the alluvial clay soils of the Armraynald Plain carries considerable risk due to potential difficulties with access to paddocks, trafficability, waterlogging of immature crops and deteriorating water quality where agricultural runoff is poorly managed.• Accumulation of soil salinity due to irrigation over time in these soils is currently unknown and would need to be monitored, especially in the imperfectly drained soils on the northern part of the Armraynald Plain.

Establishing irrigated cropping in a new region (i.e. greenfield development) is challenging. It has high input costs, high capital requirements and requires an experienced skills set.

- For broadacre crops, gross margins of the order of $4,000 per hectare per year are required to provide a sufficient return on investment where on-farm development capital costs are about $20,000/ha. Crops likely to achieve such a return include cotton and to a lesser extent Rhodes grass hay, noting that the gross margins of hay are highly sensitive to local demand, price and the transport costs.
- Horticultural gross margins would have to be higher (of the order of $7,000 to $11,000 per hectare per year) to provide an adequate return on the higher capital costs of developing this more intensive type of farming (relative to broadacre). Profitability of horticulture is extremely sensitive to prices received, so the locational advantage of supplying out-of-season (winter) produce to southern markets is critical to viability. Annual horticulture row crops would be the most likely to achieve these returns in the Southern Gulf catchments, but would be marginal.

Growing more than one crop per year may enhance the viability of greenfield irrigation development.

- There are proven benefits to sequentially cropping more than one crop per year in the same field in northern Australia, particularly where additional net revenue can be generated from the same initial investment in farm development.
- Numerous options for crop sequences could be considered, but these would need to be tested and adapted to the particular opportunities and constraints of the Southern Gulf catchments' soils and climates. While somewhat opportunistic, the most likely sequential farming systems could be those combining short-duration crops such as annual horticulture (e.g. melons), mungbean, chickpea and grass forages. Following a rainfed wet-season crop with an irrigated dry-season crop might also be possible.
- Trafficability constraints on the alluvial clay soils will limit the options for sequential cropping systems. The well-drained loamy soils on elevated plains near Doomadgee and the friable soils adjacent to the Leichhardt River pose fewer constraints for scheduling sowing times and the farm operations required for sequencing two crops in the same field each year. Even so, sequential cropping systems would be very tight operationally.
- Tight scheduling requirements mean that even viable crop sequences may be opportunistic. The challenges in developing locally appropriate sequential cropping systems, and the management packages and skills to support them, should not be under-estimated.

Irrigated cropping has the potential to produce off-site environmental impacts, although these can be mitigated by good management and new technology.

- The pesticide and fertiliser application rates required to sustain crop growth vary widely among crop types. Selecting crops and production systems that minimise the requirement for pesticides and fertilisers can simultaneously reduce costs and negative environmental impacts.

- Refining application rates of fertiliser to better match crop requirements, using controlled-release fertilisers and improving irrigation management, are effective ways to minimise nutrient additions to waterways and, hence, the risk of harmful microalgae blooms.
- Adherence to well-established best management practices can significantly reduce erosion where intense rainfall and slope would otherwise promote risk. This would also decrease the risk of herbicides, pesticides and excess nitrogen entering the natural environment.
- More than 99% of the cotton grown in Australia is genetically modified. The genetic modifications have allowed the cotton industry to substantially reduce insecticide (by greater than 85%) and herbicide application to much lower levels than previously used. In addition to reducing the likelihood and severity of off-site impacts, genetically modified crops offer health benefits to farm workers who handle fewer chemicals. This technology has considerable relevance to northern Australia.

Irrigated forages can increase the number of cattle sold and the income of cattle enterprises. However, the increased income is usually offset by the high initial capital costs and ongoing costs of irrigating a forage crop.

- The dominant beef production system in the Southern Gulf catchments is a cow–calf breeding enterprise, with several markets possible. There is limited fattening of cattle within the study area, and many cattle are moved to different parts of Queensland before their final destination.
- While native pastures are generally well adapted to harsh environments, they impose constraints on beef production through their low productivity and digestibility and their declining quality through the dry season. Growing irrigated forages and hay would allow higher-quality feed to be fed to specific classes of livestock to achieve higher production and/or different markets. These species could include perennial grasses, forage crops and legumes.
- Grazing of irrigated forages by young cattle, or feeding them hay, decreases the time they take to reach sale weight and, in particular, increases their daily weight gain through the dry season.
- While ostensibly simple, there are many unknowns regarding the best way to implement a system whereby irrigated forages and hay are grown on-farm to augment an existing cattle production system.
- Growing forages or hay to feed young cattle for the export market was not financially viable in the modelled scenarios tested when capital costs were considered.While beef production and total income increased, gross margins were reasonably similar to, or less than, baseline cattle operations.

Pond-based black tiger prawns or barramundi (in saltwater) or red claw crayfish (in fresh water) offer potentially high returns

Along the coastal reaches of the Southern Gulf catchments, approximately 194,000 ha of land is suitable for prawn and barramundi aquaculture, using earthen ponds.

- A large (i.e. 100 ha) pond-based marine culture aquaculture farm typically uses less than 4 GL/year of freshwater.

- Prawn and barramundi aquaculture elsewhere have proven land-based production practices and well-established markets for harvested products. These are not fully established for other aquaculture species being trialled in northern Australia.
- Prawns could potentially be farmed in either extensive (low-density, low-input) or intensive (higher-density, higher-input) pond-based systems. Land-based farming of barramundi would likely be intensive.
- The most suitable areas of land for pond-based marine aquaculture systems are restricted to the areas of the catchment under tidal influence and the river margins where cracking clay and seasonally or permanently wet soils dominate.
- Annual operating costs for intensive aquaculture are so high that they can exceed the initial cost of developing the enterprise. Operational efficiency is therefore the most important consideration for new enterprises, particularly the production efficiency in converting feed to saleable product.

Surface water storage potential

Indigenous customary, residential and economic sites are usually concentrated along major watercourses and drainage lines. Consequently, potential instream dams are more likely to have an impact on areas of high cultural significance than are most other infrastructure developments of comparable size.

- Complex changes in habitat resulting from inundation could create new habitat to benefit some species, while other species could experience a negative impact through loss of habitat.

Many of the upland regions of the Southern Gulf catchments are topographically and geologically favourable for large instream dams. However, the semi-arid climate and small catchment areas would result in most potential dam sites being relatively low yielding.

- The most cost-effective potential dam sites in the Southern Gulf catchments are on the Gregory River and Gunpowder Creek. In the 1960s and 1970s, the Queensland Water Supply Commission investigated potential dam sites on both drainage lines.
- Potential dam sites on the Gregory River at natural constrictions upstream of the township of Gregory are the highest yielding and most cost-effective due to the large streamflow and proximity to large contiguous areas of black and grey cracking clay soils of the Armraynald Plain. The topography, sloping away from the Gregory River, enables cheap gravity-based methods of distributing water.
- A hypothetical dam on the Gregory River upstream of Gregory with a reservoir full supply level such that it does not extend into the Boodjamulla National Park could yield 133 GL in 85% of years and cost $683 million (−20% to +50%) to construct, assuming favourable geological conditions. This would be sufficient water to support approximately 10,000 ha of dry-season cropping under surface irrigation, with the reticulation infrastructure costing approximately $38 million, or $3,800 per hectare of irrigated land.
- A previous study found that residents of Mount Isa place high value on particular rivers. The Gregory River, being one of the few perennial rivers in north-west Queensland, has a high value to Indigenous and non-Indigenous residents.

- A hypothetical dam on Gunpowder Creek could potentially yield 119 GL in 85% of years and cost $773 million. If used for agriculture, the nearest suitable soils are approximately 35 km downstream near the junction of Gunpowder Creek and the Leichhardt River. This would be sufficient to irrigate approximately 11,000 ha of dry-season broadacre and horticultural crops under spray irrigation. However, the grade of the land and the sandy texture of the surface soils mean that water would need to be piped from the river, greatly increasing the cost of reticulation infrastructure (estimated to be about $320 million or $29,000 per hectare of irrigated land).
- The higher cost of the irrigation schemes associated with a potential dam at Gunpowder Creek compared to the potential site on the Gregory River mean that high-value annual horticulture would need to be grown on the friable soils downstream of the former site to offset the higher costs, assuming there was a market for the produce.
- Although there are some potential dam sites on the Nicholson River, this part of the study area is particularly remote, greatly increasing capital and ongoing costs.

On-farm water storages may have more prospects of being commercially viable than large instream dams in the Southern Gulf catchments.

- Suitably sited large farm-scale gully dams are a relatively cost-effective method of supplying water. Although most sites are located in the uplands, where the soil is rocky and shallow and less suitable for their construction and irrigated agriculture, some locations – such as the north-western part of Settlement Creek, Mornington Island, the lower Leichhardt River and upper parts of Morning Inlet – have a coincidence of topography and soils that is favourable for gully dams and irrigated agriculture.

The alluvial clay soils on the Armraynald Plain offer different opportunities and risks to the loamy soils near Doomadgee.

- Approximately 21% of the Southern Gulf catchments has soils that are likely to be suitable for the construction of ringtanks. The most promising areas are the cracking clay soils of the Armraynald Plain east of the Gregory River and downstream of Gregory, where the natural slope away from the river enables the cost-effective conveyance of water using gravity.
- Except for in the lower reaches of the Nicholson River, the soils of the Nicholson catchment are generally too sandy for ringtanks. The Leichhardt River downstream of Kajabbi has soils suitable for ringtanks; however, sandy levees adjacent to the river can be up to 1 km wide, increasing conveyance costs and/or losses. Further downstream, although the soils are suitable for ringtanks adjacent to the Leichhardt River, to the west the land slopes towards the river, which would result in additional pumping costs.
- With water harvesting it is physically possible to extract 150 GL of water in 75% of years, assuming an even split between the Nicholson and Leichhardt catchments, without having impacts on the reliability of water supply to existing licensed users. This quantity of water is sufficient to irrigate about 12,000 ha of broadacre crops during the dry season by pumping or diverting water and storing it in offstream storages such as ringtanks. This would result in reductions in the mean and median annual discharges to the Gulf of Carpentaria from the Nicholson and Leichhardt catchments of about 3% and 5%, respectively.

Energy infrastructure constraints are a key consideration for energy-intensive enterprises in the Southern Gulf catchments

- Mount Isa and immediate surrounds are provided power by the North West Power System.
- As a grid isolated from the rest of the Queensland electricity grid, the availability of generation on the North West Power System is largely matched to the existing demand of the major mining customers. Dispatch protocols may place limits on availability of power to new large retail customers, such as a large irrigation development.
- Capacity on the existing Ergon 220kV transmission line that runs from Mount Isa to Century Mine is limited, and new developments would need to negotiate with both Ergon and major customers on the line to obtain the required energy and capacity.
- New energy-intensive enterprises would require development of dedicated electrical distribution infrastructure such as new substations and distribution lines.
- CopperString 2032 will connect the North West Power System to the National Electricity Market, alleviating any constraints in generation. However, constraints in the transmission and distribution system would remain.

Development of a large in-river storage solely for hydro-electric power purposes would not be commercially feasible in the Southern Gulf catchments.

Other existing and potential industries that depend on water

Mining

The Southern Gulf catchments fall within the North West Minerals Province, which is considered to be one of the world's most significant areas for producing base and precious metals. Mining is by far the largest industry in the study area and has an annual value more than 100 times that of grazing.

- Mining provides about 28% of all jobs in the Southern Gulf catchments.
- Mount Isa is in a period of transition, with major lead, copper and zinc mines in the region recently closing or scheduled to cease operations imminently. However, technological advances (e.g. batteries, super magnets, electronics, medical imaging) have resulted in increased demand for rare earth elements. These are referred to as critical minerals and strategic materials, and the NT and Queensland governments have programs to attract investment in exploration and infrastructure.
- Occurrences of critical minerals and strategic materials have been recorded in the Southern Gulf catchments, and mineral and petroleum exploration leases cover 67% of the study area. Future demand for minerals is highly speculative.

Across Australia, mining uses about one-tenth of the water used by irrigated agriculture, though water for mining is assigned a higher reliability than agriculture, which makes water use comparisons difficult.

- The amount of water used for mining is highly variable depending upon a wide range of factors, including mining methods, ore types, ore grades and processing treatments. With the exception of coal mines, which are not found in the Southern Gulf catchments, and large gold mines, individual mines typically use less than 0.5 GL/year.
- Many uses of water by mining enterprises (e.g. dust suppression, cooling, slurry and process water) do not require the water to be of potable quality.
- Because water is typically a very small fraction of the total input cost of a mine, and mining produces high-value products, mining enterprises have the capacity to develop their own water supplies. In the Southern Gulf catchments, the historical concentration of mining, industrial and urban activity around Mount Isa resulted in sufficiently high water demand for the construction of large, purpose-built reservoirs.
- Recent water use from existing reservoirs in the Mount Isa region is estimated to be modest relative to total supplemented entitlements (<35%), indicating that the existing dams have scope to supply water for a modest expansion of mining, depending upon the location of potential mines.
- There is limited scope for existing or new dams in the Southern Gulf catchments to be used for both mining and irrigated agriculture because high-value minerals are located in areas with hard rock, which tend to be distant from large contiguous areas of soil suitable for irrigated agriculture, such as alluvial plains.

Petroleum extraction and de-watering of mine pits produce water that needs to be treated and appropriately disposed.

Tourism

The Southern Gulf catchments have a highly seasonal and relatively low volume of visitation, largely due to their climate, remoteness, sparse population and limited tourism development.

- Annual visitation to the study area is estimated to result in approximately $150 million expenditure. Most visitors go to Mount Isa, and a large proportion (~60%) of visitors travelling to Mount Isa are on business (which cannot be separated in the visitation statistics).
- Although tourism in northern Australia consumes very small quantities of water relative to other industries, the state of northern Australia’s tourism economy is closely tied to the state and perceived attractiveness of its ecosystems, including its rivers and water-dependent ecosystems.
- Self-drive is the predominant tourism market, representing 87% of visitors to outback Queensland. Many self-drive visitors are motivated by experiencing an ancient, vast and ‘empty’ landscape with opportunities for exploration and solitude.
- With a large proportion of the Southern Gulf catchments in a relatively ‘undisturbed’ state, there is potential for growth in nature-based tourism, particularly as Mount Isa’s airport provides a commercial gateway to the region and critical infrastructure that many other parts of northern Australia lack. However, the remoteness of the region and lack of supporting infrastructure beyond Mount Isa considerably constrain tourism’s potential, as does the high seasonality of visitation, which limits enterprise profitability and year-round employment opportunities.

- Much of the appeal of the Southern Gulf catchments to self-drive tourists is likely to be the absence of human and commercial infrastructure, so development that alters the region's current characteristics could be either appealing or alienating to current tourist markets.

While water resource development for agriculture has the potential to negatively affect tourism opportunities in the Southern Gulf catchments, some developments and associated supporting infrastructure (e.g. roads, accommodation) may, conversely, present opportunities to foster tourism growth.

- Lake Argyle in the east Kimberley region (WA) developed as an irrigation dam to supply the Ord River Irrigation Area. It is now advertised as one of WA's most spectacular attractions, offering a wide range of tourism activities. Studies have identified that Lake Argyle is perceived by visitors in a similar fashion to some 'natural' local attractions such as billabongs. The cultivated land of the Ord River Irrigation Area, however, is reportedly perceived by visitors differently, as being 'domesticated'.
- Due to the presence of Lake Moondarra and Lake Julius, the recreational value of additional dams near Mount Isa is unlikely to make a discernible impact on the local economy, though dams in more remote regions of the Southern Gulf catchments could encourage self-drive tourists to stay in those regions longer.
- Tourism has the potential to enable economic development within Indigenous communities because Indigenous tourism enterprises, which are usually micro businesses, often have competitive advantages.
- While tourism offers economic and employment opportunities, it can also cause impacts such as clearing of vegetation and environmental damage due to foot, bike or vehicle traffic. This can reduce amenity for local residents and increase risks such as the potential for the spread of weeds, pests, or root rot fungus.

The Southern Gulf catchments have productive groundwater systems

Groundwater systems in the Southern Gulf catchments are poorly studied. Nonetheless, it is estimated that they could potentially supply up to approximately 40 GL of water per year in addition to the 3.5 GL/year of existing licensed entitlements, depending on community and government acceptance of impacts to groundwater-dependent ecosystems (GDEs) and existing groundwater users.

- Not all of this water could be used for irrigated agriculture, due to poor water quality, distance to suitable soil, and/or low bore yields.• The most promising groundwater resource in the Southern Gulf catchments is the regional-scale Cambrian Limestone Aquifer (CLA), which is mostly comprised of the Camooweal Dolostone and Thorntonia Limestone. With appropriately sited groundwater borefields, it is physically possible that multiple small- to intermediate-scale (1 to 3 GL/year) groundwater-based enterprises could extract approximately 10 to 20 GL/year of water from the CLA, depending on community and government acceptance of impacts to GDEs and existing groundwater users.
- The mean annual recharge across the CLA within the Southern Gulf catchments is estimated to be approximately 160 GL. The conservative mean annual recharge is estimated to be between 40 and 80 GL.

- The CLA outcrops along the south-western part of the Southern Gulf catchments. Groundwater discharge from the aquifer occurs from ecologically and culturally important springs and points of lateral outflow where the streams are incised into the CLA along Lawn Hill Creek and the Gregory and O'Shannassy rivers.
- Groundwater from the CLA varies from very fresh (<500 mg/L total dissolved solids (TDS)) to brackish (<3,000 mg/L TDS), which is towards the upper limit of salinity for most crops.

The regional-scale Gilbert River Aquifer (GRA) within the geological Carpentaria Basin underlies the central and northern parts of the study area.

- The GRA does not outcrop within the Southern Gulf catchments, so there is no direct recharge to this aquifer within the study area. Recharge predominantly occurs as lateral inflow of groundwater from the east of the Leichhardt catchment boundary.
- With appropriately sited groundwater borefields, it is possible that multiple small- to intermediate-scale (1 to 3 GL/year) developments could extract up to approximately 5 GL/year from the GRA.
- The GRA is shallowest (<250 m below ground level (mBGL)) at its south-western basin margin in the mid-reaches of the study area. It hosts some fresh water (<1,000 mg/L TDS) in places along its south-western margin between Settlement Creek and the Leichhardt River. The GRA increases in depth in a north-east direction towards the coast (>400 mBGL), and the water becomes increasingly brackish (>2,000 mg/L TDS), presenting economic challenges for groundwater infrastructure.
- The GRA becomes artesian approximately 20 to 50 km from its southern basin margin, and artesian conditions extend into the Gulf of Carpentaria.
- Potential opportunities for future groundwater resource development are likely to be limited near existing licensed groundwater users, such as the communities of Burketown and Gununa, where the GRA is at depths of greater than 500 mBGL. Neither licence is currently in use, due to the naturally poor water quality of the aquifer.
- It is unknown whether the GRA contributes groundwater to springs and seeps within the study area, though it is unlikely, given the depth of the aquifer.

Collectively, other groundwater systems in the Southern Gulf catchments may yield approximately 15 GL/year.

- The Cenozoic alluvial aquifers in the mid- to lower reaches of the Nicholson, Gregory and Leichhardt rivers, and Settlement Creek and its tributaries, host local-scale groundwater systems. However, data are very sparse, and these water resources remain poorly understood. Imagery of the study area appears to indicate that alluvial material is more laterally extensive than found elsewhere in northern Australia.
- Alluvial aquifers have potential for multiple small-scale (<0.5 GL/year) localised developments or as a conjunctive water resource where surface water is available. Opportunities are likely to be limited where the saturated thickness of the aquifer is thin (<10 m), as well as in areas within 1 km of the prescribed watercourses of the Nicholson, Gregory and Leichhardt rivers. Impacts on local GDEs would need to be evaluated, because streamflow and persistent waterholes in some rivers are potentially supported by groundwater discharge from the alluvium.

- The sparse groundwater data available for the alluvial aquifers suggest that the groundwater quality in these systems is good (<600 mg/L TDS) in places.
- Fractured and weathered rock aquifers are hosted in a variety of Proterozoic rocks across the southern, central and northern parts of the study area. These aquifers are highly variable in composition and water quality, and typically groundwater bores yield little water (<2 L/s). Where these aquifers occasionally exhibit higher yields, due to extensive fracturing and jointing, they are often storage limited.

There is potential to undertake managed aquifer recharge in aquifers of the Cenozoic alluvium and in the CLA.

- The most promising aquifers for infiltration-based managed aquifer recharge in the Southern Gulf catchments are aquifers within the Cenozoic alluvium, which is associated with many of the major rivers in the study area. However, there are few bore logs and limited groundwater-level information available for the Cenozoic alluvium, and it is likely the opportunity for MAR may vary between locations. If an alluvial aquifer is found to be suitable for MAR, it will be more cost-effective to extract groundwater in the first instance.

Changes in volumes and timing of river flows have ecological impacts

- Although irrigated agriculture occupies only a small percentage of the landscape, relatively small areas of irrigation can use large quantities of water, and the resulting changes in the flow regime can have profound effects on flow-dependent flora and fauna and their habitats.
- Changes in river flow may extend considerable distances downstream and onto the floodplain, including into the marine environment, and their impacts can be exacerbated by other changes, including changes to connectivity, water quality and invasive species. The magnitude and spatial extent of ecological impacts arising from water resource development are highly dependent on the type of development, location, timing, extraction volume and mitigation measures implemented.
- Ecological impacts, inferred here by calculating change in ecological flow dependency for a range of fresh water–dependent ecological assets for the Nicholson and Leichhardt catchments, increases non-linearly with increasing scale of surface water development (i.e. large instream dams and water harvesting). A change in ecological flow dependency does not necessarily correlate to change in ecological condition. Change in ecological condition varies between assets depending on the importance of river flow to each asset's condition and other drivers (e.g. rainfall, local runoff, groundwater).
- At equivalent levels of water resource development (i.e. in terms of volume of water extracted), and without mitigation measures the mean impact on surface-flow-dependent ecology of an instream dam on a major tributary of the Leichhardt River was found to be less than water harvesting averaged across the Leichhardt catchment. The mean impact of an instream dam on the Gregory River averaged across the Gregory –Nicholson catchment was found to be larger than water harvesting.
- Mud crabs, mullet, threadfin and prawn species are among the ecological assets most affected by flow changes for water harvesting. However, different types of development affected assets differently.

- Water harvesting developments extracting a total of 50 to 300 GL/year of water from the Nicholson and Leichhardt catchments without mitigation strategies resulted in minor and negligible changes to ecology flow dependencies of freshwater assets when averaged across each catchment respectively. Local impacts below points of extraction, however, were generally moderate for freshwater assets at the higher extraction volumes and generally minor for near-shore marine assets at higher extraction volumes.

Mitigation strategies that protect low flows and first flows of a wet season are successful in reducing impacts on ecological assets. These can be particularly effective if implemented for water harvesting developments.

- At equivalent volumes of water extraction, imposing an end-of-system (EOS) annual flow requirement, where water harvesting can only commence after a specified volume of water has flowed past the EOS and into the Gulf of Carpentaria, is an effective mitigation measure for water harvesting. However, the efficacy of this mitigation measure is reduced with a pump-start threshold of 600 ML/day, as is required to ensure there are no impacts on existing consumptive water users.
- The additional impact caused by water harvesting developments extracting 150 GL/year and with a pump-start threshold of 600 ML/day is less across most ecological assets than the impact of existing levels of development and use compared with pre-European development.
- A dry future climate has the potential to have a larger mean impact on ecological flow dependencies across the Nicholson and Leichhardt catchments than the largest physically plausible water resource development scenarios. However, the perturbations to flow arising from a combined drier future climate and water resource development result in greater impacts on ecology flow dependency than either factor on their own.

For instream dams, location matters, and there is potential for high risks of local impacts. Improved outcomes are associated with maintaining attributes of the natural flow regime.

- Potential dams may result in an extreme change in the ecological flow dependency of some assets immediately downstream of the dam. However, impacts reduce downstream with the accumulation of additional tributary flows, so when averaged over the entire catchment or measured at the EOS, the change in ecological flow dependency is minor.
- Providing translucent flows (flows allowed to 'pass through' the dam for ecological purposes) improves flow regimes for ecology, particularly for perennial rivers like the Gregory River. It does, however, reduce the yield from the dam's reservoir.

But it is not just flow, other impacts and considerations are also important.

- At catchment scales, the direct impacts of irrigated agriculture on the terrestrial environment are relatively small. However, indirect impacts such as weeds, pests and landscape fragmentation may be considerable, particularly in riparian zones.
- Loss of connectivity associated with new instream structures and changes in low flows may limit movement patterns of many species within the catchment.

Inefficient farm practices, poorly managed irrigation outflows and uncontrolled runoff from irrigation areas close to drainage lines may have a larger impact on ecological condition than likely changes in river flow patterns and volume in the Southern Gulf catchments.

- Nitrogen, phosphorus and potassium are the three primary nutrients used in agricultural fertilisers. Irrigation outflows and tailwater runoff from irrigation events can be high in these nutrients as well as in pesticides, herbicides and total dissolved solids.
- If best practice is not followed, the concentrations of these contaminants can be elevated in receiving surface water and groundwater bodies. However, the extent to which irrigated agriculture affects the quality of receiving waters is highly variable. It depends on a wide range of factors, including crop type, farm management and mitigation measures, type and scale of development, water application method, proximity to drainage lines and environmental factors such as climate, soil type, topography, hydrogeochemistry and susceptibility of irrigated land to flooding.
- Studies in parts of Queensland with a seasonal hydrology have found that first-flow events following irrigation or rainfall play a critical role in determining water quality. Studies have shown that pesticide concentrations in furrow irrigation runoff are highest following initial irrigation events and decrease in subsequent events.
- When pesticide application rates are managed well and irrigation schedules are aligned with crop growth stages, the concentration of pesticides in receiving waters is typically low, studies in the Ord River Irrigation Area have found.
- Vegetated areas can intercept agricultural runoff, reducing pesticide concentrations in surface waters approximately three times more than areas of bare soil. This highlights the importance of maintaining a wide riparian buffer zone.
- Water quality issues will be most significant closest to the source of the contaminant, because of dilution and naturally occurring processes by which aquatic systems can partially process contaminants and regulate water quality. Such processes include denitrification of nitrogen and microbial degradation and ultraviolet photolysis of pesticides. There are no equivalent natural processes for reducing phosphorus.

Commercial viability and other considerations

The total annual economic value of irrigated agriculture in the Southern Gulf catchments has the potential to increase substantially, from less than $1 million to over $190 million.

- The estimated total annual gross value of agricultural production in the Southern Gulf catchments in 2020–21 was $243.6 million. Livestock commodities accounted for most of this, and cropping accounted for only $0.9 million.
- Agriculture is a relatively small employer in the Southern Gulf Catchments; it is not listed in the top five industries of employment.

Large dams could be marginally viable if public investors accepted a 3% discount rate or partial contributions to water infrastructure costs, similar to established irrigation schemes in other parts of Australia.

- On-farm water storages provide better prospects and, where sufficiently cheap water development opportunities can be found, could likely support viable broadacre farms and horticulture with low development costs.
- Proponents of large infrastructure projects have a systematic tendency to substantially under estimate development costs and risks and to over estimate the scale and rate at which benefits will be achieved. This Assessment provides information on realistic unit costs and demand trajectories to allow potential irrigation developments to be benchmarked and assessed on a like-for-like basis.
- The viability of irrigated developments would be determined by: (i) markets and supply chains that can provide a sufficient price, scale and reliability of demand, (ii) farmers' skills in managing the operational and financial complexity of adapting crop mixes and production systems suited to the environments of the Southern Gulf catchments, (iii) the nature of water resources in terms of the volume and reliability of supply relative to optimal planting windows, (iv) the nature of the soil resources and their proximity to supply chains, and (v) the costs needed to develop those resources and grow crops compared with alternative locations.

It is prudent to stage developments to manage financial risk and to allow small-scale trialling on new farms.

- Farm productivity is subject to a range of risks, and setbacks that occur early have the greatest effect on a development's viability. A period of initial underperformance must be anticipated for establishing greenfield farming in a new location, and this must be planned for.
- There is a strong incentive to start any new irrigation development with well-established and understood crops, farming systems and technologies, and to incorporate lessons from agricultural development elsewhere in northern Australia. Local experience and experience from the neighbouring Flinders catchment, complemented by learnings from long-established irrigation schemes such as the Ord River Irrigation Area and the Burdekin Haughton Water Supply Scheme, would provide some guidance.
- New agricultural developments in the study area are likely to start irrigating broadacre crops and pastures on heavier clay soils before progressing to higher-value and more costly enterprises such as horticulture on sandy and loamy soils.
- Staging allows 'learning by doing' at a small scale, where risks can be contained while testing initial assumptions of costs and benefits and while farming systems adapt to unforeseen challenges in local conditions.

Irrigated agriculture has a greater potential than rainfed production to generate economic and community activity.

- Studies in the southern Murray–Darling Basin have shown that irrigation generates a level of economic and community activity that is three to five times higher than would be generated by rainfed production.
- Irrigated developments can unlock the economies of scale for supply chains and support services that allow rainfed farming to establish more easily around the irrigated core.
- A large proportion of increased economic activity during the construction phase of potential irrigation developments in the Southern Gulf catchments would be expected to leak outside the study area. Assuming $250 million in capital costs, which could potentially enable 10,000 ha of irrigated agriculture (~20 new farm-scale developments with on-farm water sources) the total regional economic activity within the Southern Gulf catchments associated with the construction phase would be approximately $200 million (assuming 50% leakage out of the study area). Additional benefits would flow to other regions, including Townsville, Brisbane and potentially some areas outside Queensland and the NT.
- The total annual increased economic activity (direct and indirect) from 10,000 ha of irrigated mixed broadacre (85%) and horticulture (15%) agriculture in the Southern Gulf catchments could potentially amount to $190 million, supporting up to 360 full-time-equivalent jobs.
- • Based on economic data for North West Queensland, the additional income that flowed to Indigenous households from beef cattle developments was about 5% of that which flowed to non-Indigenous households. For aquaculture, forestry and fishing together the figure was about 2.5% and for mining about 6%. The additional income that flowed to Indigenous households from other agricultural developments (excluding beef) was about 1.5% of that which flowed to non-Indigenous households. This indicates that, if agricultural developments in the Southern Gulf catchments are to equally benefit Indigenous and non-Indigenous households, concerted action will need to be taken by all stakeholders, including government, industry groups and proponents.

Sustainable irrigated development requires resolution of diverse stakeholder values and interests.

- Establishing and maintaining a social licence to operate is a precondition for substantial irrigation development.
- The geographic, institutional, social and economic diversity of stakeholders increases the resources required to develop a social licence and reduces the size of the ‘sweet spot’ in which a social licence can be established.
- Key interests and values that stakeholders seek to address include the purpose and beneficiaries of development, the environmental conditions and environmental services that development may alter, and the degree to which stakeholders are engaged.

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Some of the CSIRO staff involved in field work in northern Australia water resource assessments who applied their experience to the Southern Gulf analyses

Photo: CSIRO – Nathan Dyer

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