Water resource assessment for the Roper catchment

A report from the CSIRO Roper River Water Resource Assessment for the National Water Grid

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Important disclaimer

CSIRO Roper River Water Resource Assessment acknowledgements

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Aspects of the Assessment have been undertaken in conjunction with the Northern Territory Government.

The Assessment was guided by two committees:

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

ii. The Assessment's joint Roper and Victoria River catchments Steering Committee: Amateur Fishermen's Association of the NT; Austrade; Centrefarm; CSIRO, National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Cattlemen's Association; NT Department of Environment, Parks Australia; Parks and Water Security; NT Department of Industry, Tourism and Trade; Regional Development Australia; NT Farmers; NT Seafood Council; Office of Northern Australia; Roper Gulf Regional Council Shire

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 its release.

This report was reviewed by Kevin Devlin (Independent consultant).

For further acknowledgements, see page xxii.

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

Looking along the Roper River at Red Rock, Northern Territory. Source: CSIRO – Nathan Dyer

Director’s foreword

Sustainable regional development is a priority for the Australian and Northern Territory governments. Across northern Australia, however, there is a scarcity of scientific information on land and water resources to complement local information held by Indigenous owners and landholders.

Sustainable regional development requires knowledge of the scale, nature, location and distribution of the likely environmental, social and economic opportunities and the risks of any proposed development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpins the resource security required to unlock investment.

In 2019 the Australian Government commissioned CSIRO to complete the Roper River Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to provide data and insight to support consideration of the use of land and water resources for development in the Roper catchment. While the Assessment focuses mainly on the potential for agriculture, the detailed information provided on land and water resources, their potential uses and the impacts of those uses are relevant to a wider range of regional-scale planning considerations by Indigenous owners, landholders, citizens, investors, local government, the Northern Territory and federal governments.

Importantly the Assessment will not recommend one development over another, nor assume any particular development pathway. 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.

Chris Chilcott

Project Director

Key findings for the Roper catchment

The Roper catchment has an area of approximately 77,400 km^2 and flows into the western Gulf of Carpentaria, an important part of northern Australia's marine environment with high ecological and economic values. Within the catchment, 45% of the land is Aboriginal freehold tenure, 46% is pastoral leasehold land used for extensive grazing of beef cattle on native rangelands and 6% is national park. Dryland and irrigated agriculture each occupy about 0.02% of the catchment (~ 2000 ha) and mining occupies less than 0.01%. The catchment has a population of approximately 2500 people, of which about 73% are Indigenous Australians, compared to Indigenous Australians being 25% of the population for the Northern Territory (NT) and 3% of Australia as a whole. There are no major urban centres. The population density of the Roper catchment is one of the lowest in Australia and communities in the catchment are ranked as being among the most disadvantaged in Australia.

Indigenous peoples have continuously occupied and managed the Roper catchment 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. The Indigenous owners of the Roper catchments include the Jawoyn, Mangarrayi, Yangman, Dalabon, Rembarrnga, Ngalakgan, Ngandi, Alawa, Yukgul, and Warndarrang peoples. There is also a range of related groups and subgroups within these regional ownership descriptors.

The Roper River is unique among rivers in northern Australia due to extensive braiding in its mid-reaches coupled with its large dry-season flows, with these baseflows sourced from groundwater in the regional-scale Cambrian Limestone Aquifer (CLA) and the intermediate-scale Dook Creek aquifer. The Roper River has the third-largest median annual streamflow of any river in the NT, 4341 GL, which is the fifth largest in northern Australia. However, over half the total flow enters the Roper River below Roper Bar, the most upstream point of detectable tidal influence. The median annual streamflow at Roper Bar is 1925 GL. The river is unregulated (i.e. it has no dams or weirs), and existing licensed surface water extractions are approximately 0.1 GL.

The Roper catchment has a climate that is suitable for a wide range of annual and perennial horticulture and broadacre crops and forages. The regions in the catchment that have the most potential for irrigated agriculture are the 'riverless' Sturt Plateau and the alluvial clay soils found on river frontages along the Roper River and its major tributaries. The opportunities and risks of development in each of these regions are starkly different. While irrigation on the Sturt Plateau is 'water limited', irrigation along the river-frontage country, which is heavily dissected, is more limited by soils suitable for farming operations close to the river rather than by water.

On the Sturt Plateau there are approximately 2.6 million ha of loamy soils that are suitable, with some limitations, for irrigated annual and perennial horticultural crops under spray or trickle irrigation. A similar area is suitable for broadacre cropping under spray irrigation. However, there is sufficient water to irrigate only about 0.5% of this area. On these well-drained soils wet-season planting (December to early March) would be possible, particularly for annual horticulture – targeting harvests for winter gaps in supply in southern markets. The proximity of parts of the Sturt Plateau to the service town and new cotton gin in Katherine may offer an advantage to new irrigation developments relative to many other parts of northern Australia. Due to the absence of reliable surface water, water would need to be sourced from the regional-scale CLA that underlies much of the Sturt Plateau. Existing groundwater licences in the CLA total about 33 GL/year. It is physically possible that between 35 and 105 GL of additional groundwater could be extracted each year from the CLA, sufficient water to irrigate between 5,000 and 17,000 ha of mixed broadacre cropping and horticulture, potentially generating between $100 million and $340 million in revenue annually, directly from the agricultural development. The annual total economic activity generated (direct and indirect) could potentially amount to between $150 million and $500 million, supporting between 100 and 340 full time equivalent jobs. Economic data from the NT indicate benefits arising from agriculture developments have been heavily skewed to non-Indigenous households at the expense of Indigenous households. The potential area actually developed, however, would depend upon community and government acceptance of potential impacts to groundwater-dependent ecosystems and existing groundwater users. Due to the time lags associated with groundwater flow in regional-scale systems, it would take many decades to observe long-term change in groundwater discharge to the Roper River arising from extractions south-west of Larrimah, and many hundreds of years for the full extent of reductions in groundwater level and discharge to be realised.

Along the river-frontage country of the Roper River and its major tributaries, after allowing for a 100 m riparian buffer, it is physically possible to irrigate up to 40,000 ha of alluvial clay soils in 75% of years by pumping and/or diverting about 660 GL/year of water from these rivers into offstream storages such as ringtanks. This would result in a reduction in median annual streamflow of about 35% at Roper Bar and 15% at the end-of-system, where the river meets the Gulf of Carpentaria. Unlike the red loamy soils of the Sturt Plateau, the alluvial clay soils have higher water-holding capacity and are better suited to furrow irrigation, but poor drainage, especially in the wet season, limits their use to irrigated broadacre crops and forages during the dry season. The area of the alluvial clay soils, if fully developed, could potentially generate up to $240 million in agricultural revenue annually, with an upper bound of $350 million total economic activity and 240 full time equivalent jobs. In reality, however, the nature and scale of potential future development of river-frontage country would depend heavily upon community and government values and acceptance of potential impacts to water-dependent ecosystems. Other factors include there being suitable markets for the products, investment in fundamental infrastructure such as all-weather roads and bridges to access land north of the Roper River, and land tenure arrangements. Based on historical trends in irrigation development and existing surface water plans across northern Australia, more modest scales of surface water development, for example 10 to 100 GL (i.e. 0.5% to 5% of median annual flow at Roper Bar) would be the most likely. Along the lower coastal reaches, about 43,000 ha of land is suitable for prawns and barramundi aquaculture, using earthen ponds. For all of these above uses the land is considered suitable but with limitations and would require careful soil management.

Irrigated agriculture and aquaculture in the Roper catchment is only likely to be financially viable where there is an alignment of good prices for high-value crops and market advantages, which makes achieving scale challenging.

Growing forages or hay to feed young cattle for the export market is unlikely to be financially viable. Irrigation increases beef production, however gross margins would be reasonably similar to, or less than, baseline cattle operations, but with high capital outlay. Consistent rainfed cropping in the catchment is likely to be opportunistic and depend upon farmers' appetite for risk and future local demand.

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, 28% projected a drier future climate over the Roper catchment and 56% projected 'little change'. Adopting a conservative position, and assuming a 10% reduction in long-term mean annual rainfall and an equivalent increase in potential evaporation, it was found that modelled reductions in groundwater discharge and streamflow projected to 2060 at Roper Bar were 22% and 35% respectively. These values exceeded the modelled reductions in groundwater discharge (11%) and were comparable to reductions in streamflow (34%) under the largest potential groundwater and water harvesting development scenarios projected to 2060, assuming a historical climate.

The Roper River, although not pristine, has many unique characteristics and valuable ecological assets, which support existing industries such as commercial and recreational 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 is based provide information that can be used to help quantify the trade-offs required for agreed development plans.

Overview of the Roper catchment

The Roper catchment sits inside the Australian savanna biome, the world's largest intact tropical savanna, and like much of Australia's north has free-flowing wild rivers.

A highly variable climate

The world's tropics are united by their geography but divided by their climates. 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 Roper catchment is hot and semi-arid to dry subhumid. Generally, it is a water-limited environment, so efficient and effective methods for capturing, storing and using water are critical.

- The mean and median annual rainfall – averaged across the Roper catchment – are 792 mm and 789 mm, respectively. A strong rainfall gradient runs from the northernmost tip (1150 mm annual median) to the southernmost part (650 mm annual median) of the catchment.
- Averaged across the catchment, 4% of the rainfall occurs in the dry season (May to October). Median annual dry-season rainfall ranges from 10 mm in the east to 25 mm along the western boundary.
- Annual rainfall totals in the Roper catchment are unreliable. Annual totals are approximately 1.3 times more variable than in comparable parts of the world.

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

- Important information about water availability (i.e. soil water and water in storages) is available when it is most important agriculturally – before planting time for most crops. Therefore, farmers can manage risk by choosing crops that optimise use of the available water or by deciding to forfeit cropping for that season.

Rainfall is difficult to store.

- Mean annual potential evaporation is higher than rainfall, exceeding 1850 mm over most of the catchment. Like rainfall, potential evaporation has a relatively strong north (lower) to south (higher) gradient.
- Large farm-scale ringtanks lose about 30% to 40% of their water to evaporation and seepage between April and October. Deeper farm-scale gully dams lose about 20% to30% 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 on the Sturt Plateau is protected from the most destructive cyclonic winds by its distance inland.

- On average, the Roper catchment is affected by at least one cyclone every 2 years. Between 1970 and 2022, 40% of years had a single cyclone and 8% had 2.

Even though mean annual rainfall over the last 20 years has been above the long-term mean, runs of dry years are evident in the recent climate and palaeoclimate records and it is prudent to plan for water scarcity, particularly given more global climate models project a drier future climate than the number that project a wetter future climate for the Roper catchment.

- Palaeoclimate records indicate past climates have been both wetter and drier over the last 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 businesses and the environment.
- Detailed scenario modelling and planning should be broader than just comparing a single climate scenario to an alternative future.
- For the Roper catchment, 28% of climate models project a drier future, 16% project a wetter future and 56% project a future within ±5% of the historical mean, indicating 'little change'. Recent research indicates tropical cyclones will be fewer but more intense in the future, though uncertainties remain.
- Future changes in temperature, vapour pressure deficit, solar radiation, wind and carbon dioxide will result in positive and negative changes to crop-applied irrigation water and crop yield under irrigation in northern Australia. However, 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 likely to be large.

The Roper River

The Roper River has the third-largest median annual streamflow of any river in the NT and the fifth largest in northern Australia. It flows 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 discharge from the Roper catchment into the Gulf of Carpentaria are 5557 and 4341 GL, respectively. A small proportion of very wet years bias the mean, which is 28% higher than the median annual discharge.
- Current licensed surface water extractions in the Roper catchment are about 0.1 GL/year (i.e. <0.002% of median annual discharge).
- Approximately 56% of streamflow into the Roper River comes from the large tributary rivers of the Wilton (29%) and Hodgson (13%) and from runoff from coastal floodplains (14%), all downstream of Roper Bar. Consequently, mean and median annual streamflow at Roper Bar, which is around 130 km from the Roper River mouth and the most upstream point of detectable tidal influence, are 2413 and 1925 GL, respectively.
- Annual variability in streamflow is comparable with other rivers in northern Australia with similar mean annual runoff, but two to three times greater than rivers from the rest of the world in similar climates.

The Roper River has many unique characteristics for a large northern Australian river.

- The Roper River is perennial for over 200 km upstream of the detectable tidal limit, with large baseflows derived from the CLA near Mataranka in the river's upper reaches. In the Roper River, baseflow sourced from groundwater at the end of the dry season is highest below the junction with Elsey Creek. Through seepage and evaporation the Roper River loses approximately 60% of baseflow at the end of the dry season between Elsey Creek and Roper Bar (approximately 175 km).
- The Roper River and several of its major tributaries are characterised by extensive braiding. This is a result of the flat landscape and the build-up of sediment behind outcropping rock choke points (where build-up is at its highest, water will seek a lower path and flow down a new channel). Braiding serves an important ecological function and has implications for development.
- On average, approximately 84% of the streamflow in the Roper catchment occurs between January to March. This is lower than most northern Australian rivers and is a consequence of the relatively large dry-season baseflows.

Broad-scale flooding occurs along the mid-reaches of the Roper River and coincides with the heavy clay alluvial soils, limiting their use during the wet season.

- Vehicle access north of the Roper River is difficult or impossible during the wet season, particularly during and after flood events.
- Flood peaks typically take about 3 days to travel from Mataranka Homestead to Roper Bar, at a mean speed of 3.3 km/hour.
- Between 1966 and 2019, all streamflow events that broke the banks of the Roper River occurred between September and May (inclusive), with about 85% of events occurring between December and March (inclusive). Of the ten events with the largest flood peak

discharge at Roper Bar on the Roper River, four occurred in December, three in January and one in each of February, March and April.

- Flooding is ecologically critical because it connects offstream wetlands to the main river channel, allowing the exchange of fauna, flora and nutrients to help wetlands survive and thrive.
- Floods have economic significance because they underpin the health of the recreational and commercial fisheries in the Gulf of Carpentaria, including a barramundi fishery and the Northern Prawn Fishery, whose catch of prawns was worth $85 million in 2019/20.

Under a potential dry future climate (10% reduction in rainfall), median annual streamflow in the Roper River at Roper Bar and out to the Gulf of Carpentaria are projected to decrease by 35% and 34%, respectively.

The Roper River has many unique characteristics and valuable ecological assets

- The Roper River is free-flowing and drains the largest catchment flowing into the western Gulf of Carpentaria.
- Parts of the Roper catchment are perennial, with dry-season flow supported by discharge from aquifers including the CLA and the DCA, a sedimentary dolostone aquifer in the north-east of the catchment.
- The carbonate-rich groundwater inflows to the upper reaches of the Roper River precipitate suspended material in the river water in the early dry season, leading to low light attenuation in the water. In the neighbouring Daly catchment this process has been observed to drive strong primary production within the river.

The Roper catchment is largely intact, but it is not pristine.

- Riparian vegetation of the Roper catchment is not considered to have experienced impacts from extensive clearing or development. However, impacts from livestock and introduced species occur across many parts of the Roper catchment and often affect riparian habitats.
- The intertidal and near-shore habitats of the Roper catchment, including salt flats, mangroves and seagrasses, are in good condition and of 'national significance'. Commercial fisheries, including barramundi, mud crab and prawns, operate in near-coastal and estuary habitats.
- In the Roper catchment, cane toad, water buffalo and wild pig are among the introduced animals that threaten catchment habitats. Weed species of interest in and around the Roper catchment include gamba grass, para grass, giant sensitive tree and prickly acacia.

The Roper catchment includes wetlands of national importance and other important habitats for biodiversity conservation.

- The Roper catchment includes two Directory of Important Wetlands in Australia (DIWA) sites: the groundwater-fed Mataranka Thermal Pools and the coastal Limmen Bight (Port Roper) Tidal Wetlands System.
- The protected areas in the Roper catchment include two national parks, Elsey National Park (140 km2) and Limmen National Park (total area 9300 km2), as well as Indigenous Protected Areas and other conservation parks. In the marine region are two contiguous marine parks, Limmen Bight in NT waters and the Limmen Marine Park in Commonwealth waters, covering an area of

approximately 870 km2 and 1400 km2, respectively. Further out in the Gulf of Carpentaria is the Anindilyakwa Indigenous Protected Area and areas closed to commercial fishing.

- Limmen Bight is a declared ‘Important Bird Area’ by BirdLife International because it provides important habitat for migrating shorebirds listed under international agreements.

The Roper catchment contains significant diversity of species and habitats, including freshwater, terrestrial and marine habitats of great social, conservation and commercial importance.

- The freshwater reaches of the Roper catchment contain diverse habitats including persistent and ephemeral rivers, anabranches and braided channels, wetlands, floodplains and groundwater-dependent ecosystems.
- The riparian habitats of the Roper catchment are largely intact and include river red gum overstorey with cabbage palms, *Pandanus* spp. and paperbark communities. Riparian vegetation provides important habitat for a broad range of species including birds and mammals.
- Groundwater-dependent ecosystems occur across many parts of the Roper catchment and come in different forms including aquatic, terrestrial and subterranean habitats. They include Mataranka Thermal Pools.
- The Roper catchment has extensive intertidal flats and estuarine communities including mangrove forests, salt flats and seagrass habitats. These habitats are highly productive and have high ecosystem-service, cultural and social values.
- Persistent waterholes are key aquatic ‘refugia’, important for sustaining ecosystems during the dry season and supporting recolonisation of the broader catchment during the wet season.
- Seasonal rainfall produces flood pulses that inundate floodplains, connect rivers and wetlands, drive productivity and provide discharges into near-coastal habitats.

The Roper River supports a high species richness and endemism and has species of high conservation value.

- Diversity in the Roper catchment is high, with an estimated 270 vertebrate species.
- The Roper catchment has over 130 species of freshwater fishes, sharks and rays (including freshwater sawfish). Supported by healthy floodplain ecosystems and free-flowing rivers, very few freshwater fishes in the catchment are threatened with extinction.
- Shallow coastal habitats support dugong, marine turtles and sawfish (several species are Endangered or Critically Endangered).
- Five of the NT’s ten species of freshwater turtle have been recorded in the Roper River. This includes the regionally endemic Gulf snapping turtle (Endangered), which can be found in association with vegetated freshwater reaches of the catchment.
- The Roper catchment is an important stopover habitat for migratory shorebird species listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), including Critically Endangered species.
- The Australian Government’s ‘Protected Matters Search Tool’ lists 47 migratory species and 43 Threatened species for the Roper catchment, four of which are listed as Critically Endangered.

Indigenous values, rights and development goals

Indigenous peoples are significant and predominant in the population of the Roper catchment.

- Traditional Owners have Aboriginal freehold land ownership, hold native title and cultural heritage rights, and they control, or are the custodians of, significant natural and cultural resources, including land, water and coastline.
- Aboriginal freehold title, held under the *Aboriginal Land Rights (Northern Territory) Act 1976* (ALRA) makes up 45% of the Roper catchment. The title is inalienable freehold, which cannot be sold and is granted to Aboriginal Land Trusts which have the power to grant an interest over the land, and is managed by Land Councils. Native title exists in parts of the native title determination areas that occur in an additional 37% of the catchment.
- Over 80% of the land within the Mataranka Water Allocation Plan is eligible Aboriginal land, meeting the primary requirement under the *Northern Territory Water Act 1992* for the creation of a Strategic Aboriginal Water Reserve in the plan.
- Water-dependent fishing and hunting play a key health and economic role for Indigenous peoples in the Roper catchment. The river supports food security, good nutrition, gathering and knowledge sharing and is crucial to the songlines that connect geographical and cultural relationships.
- The history of pre-colonial and colonial patterns of land and natural resource use in the Roper catchment is important to understanding present circumstances. This history has shaped residential patterns and it also informs responses by the Indigenous peoples to future development possibilities.

From an Indigenous perspective, ancestral powers are still present in the landscape and intimately connect peoples, country and culture.

- Those powers must be considered in any action that takes place on country.
- Riverine and aquatic areas are known to be strongly correlated with cultural heritage sites.
- There are current cultural heritage considerations that restrict Indigenous capacity to respond to development proposals. There are current cultural heritage considerations that 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 catchment, see environmental impact assessments as crucial tools to assist them to make decisions about water-dependent development.
- Should development of water resources occur, participants in this study generally preferred flood harvesting, which would fill offstream storages. Groundwater use was identified as an option in the upper parts of the catchment. Large instream dams in major rivers were consistently among the least preferred options.

- Indigenous peoples have business and water development objectives designed to create opportunities for existing residential populations, to aid the resettlement of people to outstations and to improve nutrition and safe, remote-community water supply.
- 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.

Opportunities for agriculture and aquaculture

There is very little broadacre cropping in the Roper catchment, although hay and horticultural crops such as melons and mangoes are produced between Katherine and Mataranka and around Mataranka.

While there is an abundance of soil suited for irrigated agriculture in the Roper catchment, it is not well located to take advantage of surface water capture and storage options.

- Nearly 4 million ha of the Roper catchment 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.
- The Roper catchment has a higher proportion of Class 2 soils than many other catchments in northern Australia. These are principally found on the Sturt Plateau.
- About 3.2 million ha of the Roper catchment are rated as Class 3 for irrigated grain crops and cotton using spray irrigation in the dry season. However, only about 290,000 ha are Class 3 or better using furrow irrigation in the dry season for the same crops.
- About 2.3 million ha of the Roper catchment are rated as Class 3 for Rhodes grass using spray irrigation and another 1.7 million ha are rated as Class 2. Under furrow irrigation there is no Class 2 land and only 325,000 ha rated as Class 3, highlighting the poor drainage (and thus, waterlogging) on the heavier soils.
- These area estimates represent an upper biophysical limit. They do not consider risk of flooding, secondary salinisation or water availability. The area estimates are an upper starting point derived from assessing soil, landscape and climate factors within the whole catchment. The area actually available for irrigation will be less once considerations relating to land tenure, land ownership and use, community acceptance, flooding risk, availability and proximity of water for irrigation, and other factors are taken into account.

When of sufficient depth and water-holding capacity, the loamy soils of the Sturt Plateau are suitable for a broad range of crops planted in both wet and dry seasons. These soils have lower water-holding capacity and are suited to spray and trickle irrigation. Unlike the clay soils adjacent to the major rivers, which are constrained by poor trafficability and inadequate drainage, the loamy soils of the Sturt Plateau can be sown during the wet season.

- Bushfoods are an emerging niche industry across northern Australia, with Kakadu plum one of the best known and with 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 bush food operations is publicly available.

Irrigation enables higher yields and more flexible and reliable production compared with dryland crops

- Many annual crops can be grown at most times of the year with irrigation in the Roper catchment. 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 viable with a dry-season planting (late March to August) include annual horticulture, cotton and mungbean. Irrigated crops likely to be 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 duration of growth, rooting depth), season of growth, soil type and rainfall received. For example, wet-season and dry-season cotton require about 6 and 8 ML/ha, respectively, of irrigation water in at least 50% of years, while a high-yielding perennial forage such as Rhodes grass requires up to 20 ML/ha each year, averaged across a full production cycle.
- Dryland cropping is theoretically possible but most likely to be opportunistic in the Roper catchment based on rainfall received and stored soil water, or to act as an adjunct to irrigated farming, due to agronomic and market-related constraints.

An excess of rainfall can also constrain crop production on some soils.

- The cracking clay soils on the broad alluvial plains of the major rivers in the Roper catchment have high to very high water-holding capacity, but much of the area is subject to frequent flooding, inadequate drainage and landscape complexity, which constrain farming practices.
- High rainfall and possible inundation mean that wet-season cropping on the alluvial clay soils carries considerable risk due to potential difficulties with access to paddocks, trafficability and waterlogging of immature crops.

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

- For broadacre crops, gross margins of the order of $4000 per ha per year are required to provide a sufficient return on investment. Crops likely to achieve such a return include Rhodes grass hay and wet-season cotton.
- Horticultural gross margins would have to be higher (of the order of $7,000 to $11,000 per ha 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. Wet-season-planted annual horticulture row crops would be the most likely to achieve these returns in the Roper catchment.

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 Roper catchment's soils and climates. The most likely sequential farming systems could be those combining short-duration crops such as annual horticulture (melons), mungbean, chickpea and grass forages.
- Trafficability constraints on the alluvial clay soils will limit the options for sequential cropping systems. The well-drained loamy soils of the Sturt Plateau pose fewer constraints for scheduling sowing times and farm operations required for sequencing two crops in the same field each year.
- Tight scheduling requirements mean that even viable crop sequences may be opportunistic (only possible in suitable years). 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 and 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 through handling 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.

- The dominant beef production system in the Roper catchment is breeding cattle, rather than fattening them for slaughter, with the major market being the sale of young animals for live export.
- 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 or different markets. These species could include perennial grasses, forage crops and legumes.

- Grazing of irrigated forages by young cattle, or feeding hay to them, decreases the time it takes for them to reach sale weight and, in particular, increases their daily weight gain through the dry season.
- While ostensibly simple, there are many unknowns regarding how to best 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. 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

- 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 of these species, while other species could experience a negative impact through loss of habitat.

The potential for large instream and gully dams in the Roper catchment is low relative to other large catchments in northern Australia.

- The catchment is also ill-suited to large instream dams as the dissected nature of the landscape along the mid-Roper River and its major tributaries limits the size of contiguous areas of suitable soil, large areas of which are necessary for the efficient development of large irrigation schemes.

- The relatively low relief and limited areas of contiguous soil suitable for irrigated agriculture mean it would only be feasible to site potential dams on small headwater catchments. The small catchment area of these potential dam sites limits their water yield.
- The most cost-effective potential large instream dam in the Roper catchment could yield 89 GL in 85% of years and cost $250 million (−20% to +50%) to construct, assuming favourable geological conditions. This equates to a unit capital cost of $2800/ML. A nominal 9560 ha reticulation scheme was estimated to cost an additional $13,230/ha or $126.5 million (excluding farm development and infrastructure).
- While there are potentially high-yielding dam sites on the lower reaches of the Roper River and the Wilton River, the contiguous areas of soil suitable for irrigated agriculture below these sites are small. The long distances to the nearest transmission line network precludes the use of these dams for hydro-electric power generation.
- Suitably sited large farm-scale gully dams are a relatively cost-effective method of supplying water. However, the more favourable sites for gully dams in the Roper catchment, which are predominantly located north of the road between Mataranka and Bulman, are situated where the soil is rocky and shallow and generally less suited to irrigated agriculture.

The alluvial clay soils found on river frontages along the Roper River and its major tributaries offer different opportunities and risks to the loamy soils of the Sturt Plateau.

- Unlike most catchments in northern Australia, contiguous areas of soil suitable for irrigation is more limiting than surface water along the Roper River and its major tributaries.
- It is physically possible to extract 660 GL and irrigate 40,000 ha of broadacre crops such as cotton on the clay alluvial soil during the dry season in 75% of years by pumping or diverting water from the Roper River and its major tributaries and storing it in offstream storages such as ringtanks. This resulted in a modelled reduction in the mean and median annual discharge from the Roper catchment by about 11% and 15% respectively.

The Roper catchment has productive groundwater systems

Major groundwater systems in the Roper catchment could potentially supply between 40 and 125 GL of water per year, depending on community and government acceptance of impacts to groundwater dependent ecosystems (GDEs) and existing groundwater users. This is in addition to the 33 GL/year of existing licensed entitlements. These volumes of groundwater could potentially enable up to an additional 6,000 to 23,000 ha (0.1% to 0.3% of the catchment) of broadacre crops, horticulture and hay production.

- 6,000 to 23,000 ha of broadacre crops like cotton and a mix of annual and perennial horticulture could generate an annual gross value of between $120 and $460 million. This could potentially create between $175 and $670 million of annually recurring economic activity and generate between 120 and 460 full time equivalent jobs.

The largest groundwater resource in the Roper catchment is the regional-scale Cambrian Limestone Aquifer (CLA) which is hosted within the sedimentary limestone aquifers of the interconnected Daly, Wiso and Georgina basins. This includes the Tindall Limestone and its

lithological and age equivalent hydrogeological units – the Montejinni Limestone and Gum Ridge Formation.

- The CLA outcrops along the Roper River between Mataranka and just downstream of the Elsey Creek junction. Groundwater discharge from the aquifer occurring as diffuse seepage or localised spring discharge sustains large dry-season baseflows to this portion of the Roper River and some of its small neighbouring tributaries, supporting GDEs and tourism enterprises near Mataranka. Further to the south, groundwater in the CLA is deep (up to about 130 m) and does not support GDEs. However, groundwater in the Wiso Basin of the CLA discharges into the Flora, Katherine, Douglas and Daly rivers to the north of the Roper catchment.
- Recharge to the CLA occurs as infiltration of rainfall directly where the aquifer outcrops at the ground surface or through an overlying veneer of claystone and sandstone. Recharge occurs following intense wet-season rainfall events and from streamflow where rivers traverse the outcropping rock. Recharge can occur preferentially via karst features, such as dolines and sinkholes, which are prominent in the outcrop and occur sporadically across parts of the Sturt Plateau. However, contributions from these features are difficult to quantify. Mean annual recharge across the entire CLA is estimated to be about 995 GL.
- Water plans seek to mitigate the impacts of groundwater extraction on GDEs and other water users. The proposed Mataranka Tindall Limestone Aquifer and current Georgina Wiso water allocation plans, which extend over the south eastern part of the CLA in the Roper catchment, encompass four water management zones (WMZs) – the proposed North Mataranka, South Mataranka, Larrimah and current Georgina WMZs.
- Existing groundwater licences totalling 24 GL/year occur in the proposed North and South Mataranka WMZs and these WMZs are considered fully allocated by the Northern Territory Government. Between 40 and 100 km to the south is the proposed Larrimah WMZ, which has a consumptive pool of 40 GL/year of which about 8 GL is currently allocated. The Georgina WMZ, of which only a small portion underlies the southern most surface water boundary of the Roper catchment, has a consumptive pool of 222 GL/year of which about 1 GL/year is currently allocated.
- Assuming full use of existing groundwater licences in the CLA, groundwater discharge from the CLA to the Roper River near Mataranka was modelled to reduce by 8% by about the year 2070.
- The magnitude of the inputs and outputs to the groundwater balance for the CLA suggest it is possible for hypothetical groundwater borefields sited in the Larrimah WMZ and the northern part of the Georgina WMZ to extract between 35 and 105 GL/year depending on community and government acceptance of impacts to GDEs and existing groundwater users. This is in addition to the existing 32 GL of licensed entitlements in the CLA. Due to the long time lags associated with groundwater flow over long distances, the additional hypothetical extractions result in only a further 3% reduction in modelled groundwater discharge to the Roper River near Mataranka by about the year 2070. However, the modelled reduction in groundwater levels ranges from about 12 m at the centre of the hypothetical developments to 0.5 m up to 110 km away.
- Groundwater from the CLA varies from fresh (<500 mg/L total dissolved solids (TDS)) to brackish (<3000 mg/L TDS), which is towards the upper limit of salinity for most crops and would cause a reduction in yield.

The Dook Creek Formation of the Mount Rigg Group in the McArthur Basin hosts the sedimentary dolostone Dook Creek Aquifer (DCA), a productive intermediate-scale groundwater system.

- The DCA outcrops along the western side of the Central Arnhem Road between Barunga and Bulman. Recharge occurs as rainfall infiltration directly in the outcrop or via a patchy veneer of overlying claystone and sandstone. Similar to the CLA, recharge to the DCA can occur preferentially via karst features, which are prominent in the outcrop and occur sporadically across parts of the Wilton River plateau. However, contributions from these features are difficult to quantify.
- There is currently very little development of groundwater from the DCA other than stock and domestic bores, and no water allocation plan exists.
- Groundwater from the DCA discharges into Flying Fox Creek and the Mainoru and Wilton rivers, and springs such as Top Spring, Lindsay Spring and Weemol Spring. Groundwater from the DCA also discharges to the north of the Roper catchment into the northerly draining Blyth and Goyder rivers and their tributaries. This natural discharge supports a range of GDEs including discrete springs, permanent instream waterholes and groundwater dependent vegetation.
- With appropriately sited groundwater borefields, it is possible that multiple small to intermediate-scale (1–3 GL/year) developments could extract up to a total of about 18 GL/year of water from the DCA depending on community and government acceptance of impacts to GDEs and existing groundwater users. Reductions in groundwater discharge were modelled to be between 3% and 12% by 2070.

Collectively, other groundwater systems in the Roper catchment may yield about 10 GL/year.

- The sedimentary sandstone aquifers of the Bukalara Sandstone and Roper Group, sedimentary dolostone aquifers of the Nathan Group near Ngukurr and the fractured and weathered rock aquifers of the Derim Derim Dolerite of the McArthur Basin and Antrim Plateau Volcanics host local-scale groundwater systems that are low-yielding and poorly characterised.
- Groundwater use from these systems would largely be limited to stock and domestic purposes (<0.5 GL/year). There may be some localised opportunities for small-scale irrigation from these aquifers but impacts on local GDEs would need to be evaluated.

Dry-season flows in the Roper River are particularly vulnerable to long-term reductions in rainfall.

- Under a projected dry future climate (10% reduction in rainfall), localised groundwater recharge to the CLA near Mataranka results in a 22% reduction in modelled groundwater discharge to the Roper River at Elsey Creek by about the year 2060. This is considerably larger than the decrease in modelled groundwater discharge due to the hypothetical 105 GL/year of additional groundwater extraction from the CLA south of Larrimah. This highlights the sensitivity of groundwater storage in and discharge from the CLA near Mataranka to natural variations in climate.

There are limited opportunities for managed aquifer recharge (MAR) in the Roper catchment.

- Areas of the Roper catchment with permeable soils and favourable slope and storage capacity for MAR (e.g. Sturt Plateau) have rivers that are highly intermittent, meaning there is not a reliable and cost-effective source of water for MAR.

Changes in volumes and timing of flows have ecological impacts

- The freshwater, terrestrial and near-shore marine zones of the Roper catchment contain important and diverse species, habitats, industries and ecosystem functions supported by the patterns and volumes of river flow.
- Although irrigated agriculture may occupy only a small percentage of the landscape, changes in the flow regime can have profound effects on flow-dependent flora and fauna and their habitats and these changes may extend considerable distances onto the floodplain and downstream, including into the marine environment.

The magnitude and spatial extent of ecological impacts arising from water resource development are highly dependent on the type of development, the extraction volume and the mitigation measures implemented.

- Ecological impacts increase non-linearly with increasing scale of surface water development (i.e. large instream dams and water harvesting). Increasing scale of groundwater extraction, however, results in a negligible change to streamflow and impact to surface-flow-dependent ecology by the year 2060 due to the long time lags associated with groundwater flow processes and the limited overall contribution that groundwater has towards total surface water flow.
- At equivalent levels of water resource development (i.e. in terms of volume of water extracted) and without significant mitigation measures, groundwater development results in the smallest changes to streamflow and surface-flow-dependent ecology. While large instream dams and water harvesting have a comparable mean impact to surface-flow-dependent ecology averaged across the Roper catchment, large instream dams result in significantly larger local impact to ecology in those reaches below the dam wall than water harvesting.

Groundwater development results in negligible changes to streamflow and surface-flow-dependent ecology at the catchment scale, although impacts to some species such as grunter which require riffle habitat for some life stages, are moderate at some sites.

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

- Water harvesting developments extracting between 100 and 660 GL/year of water without any mitigation strategies resulted in minor changes to ecology flow dependencies averaged across the Roper catchment with impacts often accumulating downstream past multiple extraction points.
- Threadfin, prawn species and mullet are among the ecology assets most affected by flow changes for water harvesting.

- At equivalent volumes of water extraction, imposing an end-of-system (EOS) flow requirement, where water harvesting can only commence after specified volumes of water have flowed past Ngukurr and into the Gulf of Carpentaria, is the most effective mitigation measure for water harvesting. Reductions in modelled ecological impacts can be achieved with EOS flow requirements of 100 GL, with additional incremental reductions for volumes greater than this.
- Increasing pump start threshold to 600 ML/day results in significant reduction in modelled mean impact. Increasing the pump start threshold above 600 ML/ day results in incremental ecological improvements without any substantial improvement to ecology flow dependencies above 1400 ML/day.
- Limiting the volume of water that could be extracted each day (e.g. through pump capacity or licence restriction) results in small improvements in ecological outcomes and is considerably less effective than other mitigation measures.
- A dry future climate has the potential to have a larger mean impact on ecology across the Roper catchment than the largest physically plausible water resource development scenarios (i.e. five dams or 660 GL of water harvesting). However, the perturbations to flow arising from a combined drier future climate and water resource development result in greater impacts on ecology than either factor on their own.

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

- In the Roper catchment, the more promising dams are limited to relatively small headwater catchments and consequently individually result in negligible mean change to ecology flow dependencies at the catchment scale. Two of the more cost-effective dams combined result in minor change to ecological asset flows. At the largest physically plausible development of five instream dams, the change to ecology flow dependencies is moderate averaged across the whole catchment. Local impacts downstream of dams are extreme for some ecology assets – and impacts reduce downstream with the accumulation of additional tributary flows.
- Sawfish, grunters and some of the waterbird groups and floodplain wetlands are among the most affected ecology assets from instream dams.
- Providing translucent flows (flows allowed to 'pass through' the dam for ecological purposes) improve flow regimes for ecology though reducing the mean yield of potential dams by 18%. Mean outcomes for fish assets are able to be improved from minor to negligible, and for waterbirds from moderate to minor at catchment scales.

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

- At catchment scales, the direct impacts of irrigation on the terrestrial environment are typically small. However, indirect impacts such as weeds, pests and landscape fragmentation, particularly to riparian zones, may be considerable.
- Loss of connectivity associated with new instream structures and changes in low flows may limit movement patterns of many species within the catchment.
- Changes in ecosystem productivity, including in marine environments, are often associated with a combination of floodplain inundation and the resulting discharge, which may change due to water resource development. Poorly managed runoff from irrigation areas close to drainage lines may also affect nutrient levels and water quality.

Commercial viability and other considerations

There is potential for the economic value of irrigated agriculture in the Roper catchment to increase at least ten-fold.

- The projected total annual gross value of agricultural production in the Roper catchment in 2019-20 was $73 million. Of this, livestock commodities account for just over 75% of the total ($55 million) and cropping about 25% ($18 million).
- Agriculture provides about 14% of all jobs in the Roper catchment.

Large public dams would be marginal in the Roper catchment, but on-farm water sources, suitably sited, could provide good prospects for viable new enterprises.

- 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 sources provide better prospects and, where sufficiently cheap water development opportunities can be found, these could likely support viable broadacre farms and horticulture with low development costs.
- There is a systematic tendency of proponents of large infrastructure projects 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 finding markets and supply chains that can provide a sufficient price, scale and reliability of demand; farmers' skill in managing the operational and financial complexity of adapting crop mixes and production systems suited to Roper catchment environments; the nature of water resources in terms of the volume and reliability of supply relative to optimal planting windows; the nature of the soil resources and their proximity to supply chains; and the costs needed to develop those resources and grow crops relative to alternative locations.

It is prudent to stage developments to limit negative economic impact and to allow small-scale testing on new farms.

- Farm productivity is subject to a range of risks, and setbacks that occur early on have the greatest effect on a development's viability. For greenfield farming establishing in a new location, a period of initial underperformance needs to be anticipated and planning for this is required.
- There is a strong incentive to start any new irrigation development with well-established and understood crops, farming systems and technologies, and incorporate lessons from past experiences of agricultural development in northern Australia.
- 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 to generate economic and community activity than rainfed production.

- 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 dryland production. Irrigated developments can unlock the economies of scale for supply chains and support services that allow further dryland farming to establish more easily around the irrigated core.
- In the Roper catchment, irrigation development could result in an additional $1.1 million of indirect regional economic benefits for every $1 million spent on construction during the construction phase.
- During the ongoing production phase of a new irrigation development, there could be an additional $0.46 to $1.82 million of indirect regional benefits for each $1 million of direct benefits from increased agricultural activity (gross revenue), depending on the type of agricultural industry. Indirect regional benefits would be reduced if there was leakage outside the catchment of some of the extra expenditure generated by a new development.
- Each $100 million increase in annual agricultural activity could create about 100 to 850 jobs, depending on the agricultural industry.
- Based on economic data for the entire NT, the additional income that flowed to Indigenous households from beef cattle developments was 1/9th of that which flowed to non-Indigenous households. The additional income that flowed to Indigenous households from other agricultural developments (excluding beef) was 1/17th of that which flowed to non-Indigenous households. This indicates that if agricultural developments in the Roper catchment are to equally benefit Indigenous households 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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