Water resource assessment for the Victoria catchment

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

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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); 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 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 and Water Security; NT Department of Industry, Tourism and Trade; NT Farmers; NT Seafood Council; Office of Northern Australia; Parks Australia; Regional Development Australia; Roper Gulf Regional Council Shire; Watertrust

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 Dr Brian Keating (Independent consultant). Individual chapters were reviewed by Dr Rebecca Doble, CSIRO (Chapter 2); Dr Chris Pavey, CSIRO (Chapter 3); Dr Heather Pasley, CSIRO (Chapter 4); Mr Chris Turnadge, CSIRO (Chapter 5); Dr Nikki Dumbrell, CSIRO (Chapter 6); Dr Adam Liedloff, 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 xxv.

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

The Victoria River is the longest singularly named river in the NT with permanent water. Photo: CSIRO – Nathan Dyer

Director's foreword

Sustainable development and regional economic prosperity are priorities for the Australian 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 Victoria River 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 Victoria catchment. 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 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 Victoria catchment

The Victoria catchment has an area of approximately 82,400 km2. It flows into the Joseph Bonaparte Gulf in the Timor Sea which is an important part of northern Australia's marine environment with high ecological and economic values. Within the catchment, 31% of the land is Aboriginal freehold tenure, which includes the 16% of the catchment which is national park. The Bradshaw Field Training Area occupies 7%, to which access is restricted. The dominant land use across the Victoria catchment is grazing of beef cattle on native rangelands (62% of the catchment area). There is less than 100 ha of irrigated agriculture, which is about 0.001% of the catchment. There are no active mines in the study area, although known mineral occurrences include barite, copper, lead and prehnite. Mining and petroleum exploration licences cover 61% of the study area. The catchment has a population of approximately 1600 people, of whom about 75% are Indigenous Australians. In contrast, Indigenous Australians make up 25% of the population of the NT and 3% of Australia as a whole. There are no large urban centres. The population density of the Victoria catchment (1 person per 50 km2) is one of the lowest in Australia, and communities in the catchment are ranked as being among the most disadvantaged in Australia. Business and tourist visitation to the Victoria catchment is highly seasonal and modest in number (~27,000/year) and valued at less than $20 million/year. Tourists to the Victoria catchment area are mostly classified as self-drive tourists.

Indigenous Peoples have continuously occupied and managed the Victoria 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. Key language groups include the Gurindji, Ngarinyman, Ngaliwurru, Nungali, Miriuwung and Gajerrong. A number of related groups and subgroups occur within the traditional lands of these regional language groups.

The Victoria River, at approximately 560 km in length, is the second longest river with permanent water in the NT. However, unlike the NT's better known Daly and Roper rivers, late dry-season flows in the Victoria River are small, and most permanent waterholes are likely to be a result of residual flow from the previous wet season. The Victoria River has the second-largest median annual streamflow (5370 GL) of any river in the NT, and the fourth largest in northern Australia west of the Great Dividing Range. Approximately 93% of the streamflow in the Victoria catchment occurs between January and March. The Victoria catchment is unregulated (i.e. it has no dams or weirs) and existing annual licensed surface water extractions are approximately 2 GL (0.04% of median annual discharge). However, the study area includes a large earth embankment gully dam (35 GL capacity) in the catchment of Forsyth Creek, which flows into Joseph Bonaparte Gulf adjacent to the Victoria River. Current annual licensed surface water extractions from the catchment of Forsyth Creek are 150 GL.

With irrigation, the Victoria catchment has a climate that is suitable for a range of annual and perennial horticulture, and broadacre crops and forages. The regions in the Victoria catchment with the most potential for irrigated agriculture are areas adjacent to the upper West Baines River and the Victoria and Wickham rivers downstream of Yarralin, the sandy and loamy soils and clay soils north-east of Top Springs, and the extensive sandy and loamy soils along the south-eastern margin of the catchment. The opportunities and risks of development in each of these regions are starkly different. Opportunities for irrigated agriculture along the Wickham and Victoria rivers are generally limited by the availability of suitable soil and topography adjacent to the rivers, whereas along the West Baines River and near Top Springs and along the eastern margins of the catchment, irrigated agriculture is limited by available water.

The cracking clay soils on the broad alluvial plains of the West Baines River upstream of the Victoria Highway (54,000 ha) offer the greatest potential for broadacre irrigation in the Victoria catchment. Note that this estimate of soil area, and the ones below, includes land considered suitable but with limitations and would require careful soil management. Along the West Baines River upstream of the highway, it is physically possible to extract up to 100 GL of surface water in 75% of years, which is sufficient water to irrigate up to 7000 ha of dry-season broadacre crops. Further downstream there is an additional 50,000 ha of cracking clay soils; however, the suitability of soil for irrigated agriculture during the wet-season becomes increasingly marginal due to increasing seasonal wetness (leading to waterlogging and trafficability issues) and flooding, so enterprises would become increasingly less commercially viable. Nonetheless, it would be physically possible to extract an additional 300 GL of surface water in 75% of years from the West Baines River below the highway crossing. The proximity of West Baines to the Victoria Highway, and to the service town and cotton gin in Kununurra in WA, may offer an advantage to new irrigation developments relative to many other parts of northern Australia.

Less expansive opportunities for water harvesting exist adjacent (within 5 km) to the Wickham and Victoria rivers (22,000 ha), limited by where ringtanks for storing water can be constructed on heavier alluvial clay soils. The commercial viability of water harvesting enterprises along these river reaches would be highly variable due to increasing elevation away from the river and/or the width of sandy and loamy levee soils, both of which increase piping and pumping costs. Notwithstanding this, and including the Baines River, it is physically possible, although not necessarily commercially viable, to extract up to 690 GL of surface water in 75% of years from the major rivers in the Victoria catchment. That amount is sufficient water to irrigate up to 50,000 ha of alluvial clay and sandy and loamy soils where they exist as contiguous areas. This volume of water extraction would result in a reduction in mean and median annual discharges from the Victoria River into the Joseph Bonaparte Gulf of 9% and 12%, respectively. 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 150 GL (i.e. ~0.2% to ~3% of median annual discharge from the Victoria River), would be more likely.

North-east of Top Springs and along the eastern and southern margins of the Victoria catchment are approximately 62,000 and 695,000 ha, respectively, of well-drained sandy and loamy soils that are potentially suitable, with considerable limitations, for irrigated annual and perennial horticultural crops under dry-season trickle irrigation. However, there is only sufficient surface water to irrigate less than 0.3% of this area. Due to the absence of reliable surface water in this part of the study area, water would need to be sourced from the regional-scale Cambrian Limestone Aquifer (CLA), which underlies the eastern margin of the Victoria catchment. It is physically possible to extract 10 GL of groundwater each year from this part of the CLA, which is sufficient water to irrigate 1000 to 2000 ha of mixed broadacre cropping and horticulture. However, this part of the catchment is particularly remote, and transport costs pose a major constraint to irrigation enterprises in this region. Commercially viable opportunities would most likely be limited to annual horticulture targeting winter supply gaps in southern markets, such as from a wet-season planting (December to early March), which is possible on these well-drained soils.

Irrigated agriculture and aquaculture in the Victoria catchment are only likely to be financially viable where there is an alignment of good prices for high-value produce 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 that support development. New agricultural developments in the study area are most 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.

Along the very remote coastal margins of the study area, about 93,000 ha of land is suitable for prawn and barramundi aquaculture, using earthen ponds.

Growing irrigated forages or hay to feed cattle to be turned off at a younger age is unlikely to be financially viable. Feeding forages or hay increases beef production and total income, but increased costs mean that gross margins would be less than baseline cattle operations, and the high capital outlay would in most cases be prohibitive. Rainfed cropping in the catchment is likely to be opportunistic (i.e. only possible when suitable conditions allow) and depend upon farmers' appetite for risk and future local demand.

The total annual economic activity (direct and indirect) generated from 10,000 ha of irrigated mixed broadacre (65%) and horticulture (35%) agriculture in the Victoria catchment could potentially contribute up to $280 million, supporting up to 200 full-time-equivalent jobs. Economic data from the NT indicate benefits arising from agriculture developments have been heavily skewed to non-Indigenous households relative to Indigenous households.

The potential area of land actually developed for irrigated agriculture based on surface water and/or groundwater will depend heavily upon community and government values, acceptance of potential impacts to water-dependent ecosystems and existing groundwater users, the profitability of irrigated agricultural enterprises in the Victoria catchment, and those who would economically benefit.

Changes to 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 Victoria catchment and 47% projected 'little change'. The adopted future dry climate was based upon a global climate model that, in terms of mean precipitation, was 7% drier than the historical climate. Using this as an input, it was found that modelled reduction in median annual streamflow projected to 2060 at the Victoria River mouth was 25%. This value exceeded the modelled reduction in median annual streamflow under the largest potential water harvesting development scenarios (12%), assuming a historical climate.

The Victoria 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 summary is based provide information that can be used to help consider the trade-offs from potential developments.

Overview of the Victoria catchment

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

The Victoria catchment has 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 Victoria catchment is hot and semi-arid. Generally, the Victoria catchment is a water-limited environment, so effective methods for capturing, storing and using water are critical.

- The mean and median annual rainfall amounts – averaged across the Victoria catchment – are 681 mm and 690 mm, respectively. A strong rainfall gradient runs from the northernmost tip (1050 mm annual median) to the southernmost part (410 mm annual median) of the catchment.
- Averaged across the catchment, 5% of the rainfall occurs in the dry season (May to October). Median annual dry-season rainfall ranges from 18 mm in the west to 34 mm in the north.
- Annual rainfall totals in the Victoria catchment are highly variable. Annual totals are approximately 1.3 times more variable than in comparable parts of the world. Using Kalkarindji as an example, between 1890 and 2022, the highest annual rainfall (1204 mm in the 2000–2001 water year (1 September to 31 August)) was nearly eight times the lowest annual rainfall (159 mm in 1953–1954).

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 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, exceeding 1900 mm over the entire catchment. Unlike rainfall, potential evaporation does not exhibit a strong gradient across the catchment.
- 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 Victoria catchment is less exposed to cyclonic winds than are most other northerly draining catchments in Australia's north.

- Of the 53 consecutive cyclone seasons prior to 2021–22, the Victoria catchment had no tropical cyclones in 72% of those seasons, had one cyclone in 22% of seasons and two cyclones in 6% of seasons.

An almost equal number of global climate models project a drier future climate and a wetter future climate for the Victoria catchment. Consequently it is prudent to plan for water scarcity.

- For the Victoria catchment, 28% of climate models project a drier future, 25% project a wetter future and 47% 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, 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 businesses and the environment.
- Detailed scenario modelling and planning should be broader than just comparing results under the baseline climate to a single alternative future climate scenario.
- 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. 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 potentially large.

The Victoria River is one of northern Australia's largest free-flowing rivers

At approximately 560 km in length, the Victoria River is the longest singularly named river in the NT with permanent water and it has the second-largest median annual streamflow of any NT river.

- The mean and median annual river discharges from the Victoria catchment into the Joseph Bonaparte Gulf are 6990 and 5370 GL, respectively. A small proportion of very wet years bias the mean, which is 30% higher than the median annual discharge.
- Modelled annual streamflow ranges from 800 to 23,000 GL. The annual variability relative to the mean annual streamflow is comparable with other rivers in northern Australia of similar mean annual runoff (streamflow divided by catchment area), but the annual variability in runoff is two to three times greater than rivers from other parts of the world with similar climates.

- A unique characteristic of the Victoria River is that it has a 25 km wide mouth at Queens Channel, part of the Joseph Bonaparte Gulf.
- The Joseph Bonaparte Gulf region experiences some of the largest tides in the country. Tidal variation at the mouth of the Victoria River is up to 8 m, and tides propagate to just downstream of Timber Creek, about 140 km upstream of Queens Channel.
- Approximately 54% of streamflow into the Victoria River comes from the large tributary rivers of the Baines (22%), Angalarri (8%), Gregory (4%), Wickham (9%), Armstrong (7%) and Camfield (4%) rivers.

The Victoria River and its major tributaries are largely ephemeral. Most of the water in the main river channel during the late dry season is the result of residual flow from the previous wet season, rather than groundwater.

- On average, approximately 93% of the streamflow in the Victoria catchment occurs between January and March. This is higher than the better known Daly (80%) and Roper (84%) rivers, both of which are groundwater fed, but is typical of many rivers across northern Australia.
- Mid-to-late dry-season streamflow in the Victoria River and most of its major tributaries is low, less than 200 ML/day.
- Current licensed surface water extractions in the study area are approximately 152 GL/year; however, 150 GL is licensed in the catchment of Forsyth Creek, which flows into the Joseph Bonaparte Gulf adjacent to the Victoria River. Licensed surface water extractions from the catchment of the Victoria River are only about 2 GL/year (0.04% of median annual discharge).

Although the area of land frequently flooded in the Victoria catchment is proportionally less than that of many other catchments in northern Australia, the proximity of some Indigenous communities to the Victoria River makes them susceptible to large flood events.

- The incised nature of the Victoria River in its lower reaches means the most frequently flooded areas are the junctions of the Baines and Angalarri rivers with the Victoria River and a choke point on the Victoria River 55 km upstream of Victoria River Roadhouse.
- The Victoria Highway, a critical transport artery with about 33,000 freight trailer movements each year, can become impassable due to flooding at times during the wet season.
- Flood peaks typically take about 2 to 3 days to travel from Dashwood Crossing to Timber Creek at a mean speed of 3.4 km/h.
- Between 1953 and 2023 (70 years), there were 80 ‘observed’ streamflow events that broke the banks of the Victoria River at Coolibah Homestead (25 km downstream of Victoria River Roadhouse). All occurred between September and May (inclusive), and about 91% of the events occurred between December and March (inclusive).
- Of the ten events with the largest flood peak discharge at Coolibah Homestead, six occurred in March, three in February and one in December.
- In 2023, a large flood displaced the residents of the townships of Kalkarindji and Nitjpurru (Pigeon Hole) on the Victoria River for several months. Based on the observed record (1953 to 2023), this event had an annual exceedance probability (AEP) of 2.6% at Coolibah Homestead.

- Flooding is ecologically critical because it connects offstream wetlands to the main river channel, allowing the exchange of fauna, flora and nutrients to support the important ecological functions of wetlands.

Under a potential dry future climate (7% reduction in rainfall), median annual river discharge from the Victoria River into the Joseph Bonaparte Gulf is projected to decrease by 25%.

The Victoria catchment has many unique ecological characteristics and contains important species and habitats

The Victoria catchment contains a significant diversity of species and habitats, including freshwater, terrestrial and marine assets of great cultural, conservation and commercial importance.

- Much of the natural environment of the Victoria catchment consists of rolling plains, mesas, escarpments and plateaux with savanna, spinifex, grasslands and woodlands. The catchment and surrounding marine environment contain a rich diversity of important ecological assets. The region is considered the transitional zone and boundary between the Kimberley and Top End ecological communities.

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

- Previous studies have rated the riverine habitat in the Victoria catchment as being of high or very high overall quality and largely intact. They identified the catchment as having high wilderness value and being predominantly unaffected by clearing or development, although ecological threatening processes operate.
- Existing threatening processes include cattle grazing, roads, river crossings, and impacts from introduced species, including feral animals and weeds.
- Fishing in northern Australia is highly valuable, and the waters of the Victoria catchment and nearby marine zone contribute to important recreational, commercial and Indigenous catches, including barramundi, redleg banana prawn and a variety of other species.
- One of the most significant environmental threats to remote regions across northern Australia is that of introduced plants and animals. In the Victoria catchment, pig, water buffalo, cane toad and cat are among the invasive animals.
- Weed species of interest in and around the Victoria catchment include 20 species of national significance. Invasive plants of concern include gamba grass (*Andropogon gayanus*), para grass (*Brachiaria mutica*), giant sensitive plant (*Mimosa pigra*) and prickly acacia (*Vachellia nilotica*).

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

- Protected areas in the Victoria catchment include one gazetted national park (Judbarra), a proposed extension to an existing national park (Keep River), two marine national parks (Joseph Bonaparte Gulf Marine Park and North Kimberley Marine Park (Western Australia), which is adjacent to the Joseph Bonaparte Gulf Marine Park and follows the Western Australian coastline to the NT border), two Indigenous Protected Areas and two Directory of Important Wetlands in Australia (DIWA) sites (Bradshaw Field Training Area and the Legune coastal floodplain).

- The Legune coastal floodplain is a wetland identified as an Important Bird and Biodiversity Area by Birdlife International. Surveys have recorded more than 15,000 individuals from over 45 species, including magpie goose (*Anseranas semipalmata*), brolga (*Antigone rubicunda*) and red-capped plover (*Charadrius ruficapillus*).
- The freshwater sections of the Victoria catchment include diverse habitats such as persistent and ephemeral rivers, anabranches, wetlands, floodplains and groundwater-dependent ecosystems.
- Riparian habitats that fringe the rivers and streams of the Victoria catchment have been rated as having moderate to high tree cover and structural diversity compared to riparian vegetation elsewhere. Further away from the creeks and rivers, the overstorey vegetation in the Victoria catchment becomes sparser.
- Groundwater-dependent ecosystems occur across many parts of the Victoria catchment and have different forms, including aquatic, terrestrial and subterranean habitats. Aquatic groundwater-dependent ecosystems contain springs and river sections that hold water throughout most dry seasons.
- Groundwater discharge may be critical for maintaining some vegetation condition, such as the habitats of monsoon vine forest located within the Bradshaw Field Training Area DIWA site. Subterranean aquatic ecosystems in the Victoria catchment include known sinkholes associated with the Montejinni Limestone, which are mapped along the south-eastern edge of the Victoria catchment. The connection of these sinkholes to underlying groundwater systems is unknown.
- The mouth and estuary of the Victoria River, Queens Channel, is up to 25 km wide and includes extensive mudflats and mangrove stands. The mangrove communities along the estuary are recognised as being of high structural value, but low in species richness with about ten species recorded. The dominant mangrove species in the catchment is *Avicennia marina*, which is largely confined to the estuary.

The Victoria catchment supports listed and threatened species and many lesser-known plants and animals that are also of great importance.

- The Commonwealth's Protected Matters Search Tool includes 45 plant and animal species listed as Threatened for the Victoria catchment, four of which are listed as Critically Endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act): the nabarlek rock wallaby (*Petrogale concinna concinna*), Rosewood keeled snail (*Ordtrachia septentrionalis*), curlew sandpiper (*Calidris ferruginea*) and eastern curlew (*Numenius madagascariensis*). Also listed are 49 migratory bird species.
- The aquatic habitats of the Victoria catchment support some of northern Australia's most archetypical and important wildlife species. Sawfish, marine turtles, the Australian snubfin dolphin and river sharks inhabit the estuaries of the Victoria River and the coastal waters of the Joseph Bonaparte Gulf.
- Recent surveys demonstrate the river is a globally significant stronghold for three endangered species: freshwater sawfish (*Pristis pristis*; listed as Vulnerable under the EPBC Act and Critically Endangered on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species); speartooth shark (*Glyphis glyphis*; Critically Endangered, EPBC Act and

IUCN Red List); and northern river shark (*Glyphis garricki*; Endangered, EPBC Act and IUCN Red List).

- Healthy floodplain ecosystems and free-flowing rivers mean that very few freshwater fishes in the study area are threatened with extinction.
- Bird species including the red knot (*Calidris canutus*; Endangered, EPBC Act) and the critically endangered eastern curlew and curlew sandpiper use habitats such as the Legune coastal floodplain as an important stopover habitat.

Indigenous values, rights and development goals

Indigenous Peoples constitute almost 75% of the Victoria catchment population.

- Traditional Owners have Aboriginal freehold land ownership and hold native title and cultural heritage rights. They control, or are the custodians of, significant natural and cultural resources, including land, water, coastline and sea.
- Aboriginal freehold title, held under the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976* (ALRA) makes up 31% of the Victoria catchment. Over half of this holding is the jointly managed Judbarra National Park, for which a 99-year lease is held by the NT Government. ALRA land cannot be sold and is granted to Aboriginal Land Trusts, which have the power to grant an interest over the land.
- Native title exists in parts of the native title determination areas that cover an additional 34% of the catchment.
- Water-dependent fishing and hunting have key health and economic roles for Indigenous Peoples in the Victoria 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 Victoria 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.

- Ancestral 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.
- 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 included in future water-dependent development and planning.

- Effective Traditional Owner corporate and wider regional governance processes underpin successful catchment-scale processes and support Traditional Owner management of external pressure for development. Indigenous participants in the Assessment identified the Assessment itself as a manifestation of that pressure.

- Indigenous Peoples in the Victoria catchment have not had substantial exposure to water planning or catchment management processes. There is a clear need to build this capability before asking people to make decisions about water-dependent development.
- If water resources were to be developed, participants in the Assessment would generally prefer flood harvesting, which would fill offstream storages. There was widespread resistance to large instream dams in major rivers.
- Groundwater is currently used for a number of communities, but water quality concerns exist.
- Indigenous Peoples have business and water development objectives designed to create opportunities for existing residential populations 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 rainfed or irrigated cropping underway in the Victoria catchment, although several pastoral stations have grown a limited amount of forage to provide higher-quality feed to their cattle.

Although an abundance of soil is suitable for irrigated agriculture in the Victoria catchment, the lack of coincidence of suitable soil, water and favourable topography considerably constrains the area that could potentially be irrigated.

- Up to approximately 3 million ha of soils in the Victoria 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 soils.
- Just over 3 million ha of soils in the Victoria catchment are rated as Class 3 or better for trickle-irrigated intensive crops, such as melons, in the dry season. Most of this area is Class 2 land.
- About 2.9 million ha of the Victoria catchment are rated as Class 3 or better for annual hay, forage or silage crops such as forage sorghum using spray irrigation in the dry season; over 2 million ha of that area is Class 2. However, under furrow irrigation, only 625,000 ha are Class 3 or better in the dry season and only 425,000 ha in the wet season, highlighting the poor drainage (and thus waterlogging) of the heavier soils.

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

- For the purposes of evaluating the opportunities and risks of irrigation development, the Victoria catchment can be conceptualised as two river systems: the smaller Baines River subcatchment which includes the West and East Baines rivers (15,100 km^2), and joins the

Victoria River towards its estuary, and the larger Victoria River (55,300 km^2) upstream of this junction.

- Within the entire Baines catchment there are approximately 103,000 ha of contiguous clay soils suitable for broadacre irrigation, with considerable limitations, under surface irrigation. The cracking clay soils on the broad alluvial plains of the West Baines River upstream of the Victoria Highway offer the greatest potential for broadacre irrigation in the Victoria catchment. Further downstream, the suitability of soil for irrigated agriculture becomes increasingly marginal due to increasing seasonal wetness (leading to waterlogging and trafficability issues) and flooding, so enterprises would become increasingly less commercially viable and/or would operate with higher risk.
- Taking into consideration the need to site offstream storages on heavier clay soils, approximately 22,000 ha of contiguous alluvial clay and well-drained sandy and loamy soils within 5 km of the Wickham and Victoria rivers (allowing a 100 m riparian buffer) could potentially be developed for dry-season irrigation. However, the complexity of the landscape along these rivers, which includes sandy levee soils and increasing elevation away from the Wickham and Victoria rivers, means the location and configuration of water harvesting operations would need to be carefully planned to be commercially viable. Once the better opportunities were developed, additional developments would become increasingly less viable.
- North-east of Top Springs there are approximately 52,000 ha of clay soils potentially suitable, with considerable limitations, for broadacre irrigated agriculture under dry-season surface irrigation. There are also 62,000 ha of well-drained sandy and loamy soils potentially suitable, with considerable limitations, for irrigated annual and perennial horticultural crops under dry-season trickle irrigation.
- Along the very remote eastern and southern margins of the Victoria catchment are 695,000 ha of well-drained sandy and loamy soils that are potentially suitable, with considerable limitations, for irrigated annual and perennial horticultural crops under dry-season trickle irrigation.
- When of sufficient depth and water-holding capacity, the loamy soils of the Sturt Plateau on the eastern margins, as well as the sandy and loamy soils in the south-east and south-west of the Victoria catchment, are suitable for a broad range of spray- and trickle-irrigated crops planted in both wet and dry seasons.

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 Victoria 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 commercially viable with a dry-season planting (late March to August) include annual horticulture and cotton. 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, wet-season and dry-season cotton on a clay soil in a climate similar to Top Springs requires about 4.6 ML/ha and 5.7 ML/ha, respectively, of irrigation water in at least 50% of years. A high-yielding perennial forage such as Rhodes grass on a clay soil requires about 24.0 ML/ha each year, averaged across a full production cycle.
- Rainfed cropping is theoretically possible in some years, but agronomic and market-related constraints mean it is most likely to be opportunistic in the Victoria catchment based on rainfall received and stored soil water, or it may serve as an adjunct to irrigated farming.

How cleared 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.

- The cracking clay soils on the alluvial plains of some of the major rivers in the Victoria catchment have high to very high water-holding capacity, but much of the area is subject to frequent flooding and inadequate soil drainage. In some places, small and/or narrow areas have a level of landscape complexity that will 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.• Accumulation of soil salinity due to irrigation in these clay soils is currently unknown but must be monitored, especially in the imperfectly drained cracking clay soils on the lower Baines, Angalarri and Victoria rivers.

Establishing irrigated cropping in a new region (i.e. greenfield development) is challenging. It has high input costs and 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 Rhodes grass hay and wet-season cotton, noting that the gross margins of hay are highly sensitive to local demand, price and the cost of transport.
- Horticultural gross margins would have to be higher than broadacre crops, in 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. Horticulture will struggle to meet these gross margins in the Victoria catchment; perennial fruit trees may be more successful, although it will be difficult to achieve the higher gross margins required.

Bushfoods are an emerging niche industry across northern Australia. However, most bushfoods continue to be wild-harvested with very little grown commercially. Limited information on commercial bushfood operations is publicly available.

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 Victoria catchment's soils and climate. While somewhat opportunistic, the most likely sequential farming systems on the heavier clays could be those combining short-duration crops such as annual horticulture (e.g. melons), legumes such as mungbean and chickpea, and grass forages.
- Trafficability constraints on the alluvial clay soils will limit the options for sequential cropping systems because of the tight time frames to grow and harvest the first crop before preparing the land and planting the next crop. The well-drained loamy soils 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 that include cotton may not be possible in all years due to trafficability constraints; that is, it may not be possible to plant cotton early enough in the season for another crop to follow.
- Tight scheduling requirements mean that even viable crop sequences may be opportunistic. The challenges in developing locally appropriate sequential cropping systems, and the management practices 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 in these climates 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 serve to 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 Victoria 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 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. While beef production and total income increased, gross margins were less than for baseline cattle operations.

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

Along the very remote coastal margins of the study area, about 93,000 ha of land is suitable for prawn and barramundi aquaculture, using earthen ponds.

- Prawn and barramundi aquaculture elsewhere in northern Australia 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.

In the Victoria catchment, the potential for irrigated agriculture based on large instream dams is low relative to some other large catchments in northern Australia. This is due to the lack of coincidence between locations that are potentially suitable for large instream dams and the larger contiguous areas of soil suitable for irrigated agriculture.

- Due to the limited areas of contiguous soil suitable for irrigated agriculture and favourable topography for reticulation infrastructure, the more feasible potential dam sites are on smaller headwater catchments.
- Considering proximity to the Victoria Highway (~85 km) and the service centre of Kununurra (~220 km), a hypothetical large instream dam on the upper West Baines catchment could yield 64 GL in 85% of years and cost $396 million (−20% to +50%) to construct, assuming favourable geological conditions. This equates to a unit capital cost of $6188/ML. Due to the favourable topography at this location, a reticulation scheme with a nominal 3780 ha under irrigation is estimated to cost an additional $12.67 million or $3350/ha of irrigated area (excluding farm development and infrastructure). This is broadly representative of the cost of the better opportunities for large-scale water storage and irrigated agriculture in the Victoria catchment.
- The Victoria River Roadhouse is about 200 km from Katherine, the nearest point on the Darwin–Katherine Interconnected System (DKIS) regulated power network. This distance limits opportunities for hydro-electric power generation in the Victoria catchment. Even if transmission lines were to connect the Victoria catchment to the DKIS, the DKIS is electrically isolated from other grids in Australia, so any large-scale electrical generation infrastructure in the Victoria catchment would still be disconnected from the National Electricity Market.
- An instream dam upstream of Kalkarindji, designed and managed specifically for flood mitigation, could potentially reduce flood peak magnitude downstream. For the ten largest modelled rainfall events, the dam reduced peak flow by around 50% at Kalkarindji and less than 20% at Nitjpurru (Pigeon Hole).
- Suitably sited large farm-scale gully dams are a relatively cost-effective method of supplying water. The topography of the Victoria catchment is highly suitable for large farm-scale gully dams throughout much of the catchment. The major limitation is that the soil is rocky and shallow, so access would be required to a nearby clay borrow pit to provide material for the cut-off trench and dam wall core zone. Potential gully dams requiring material from elsewhere will be less economically viable.

The alluvial clay soils on the West Baines River upstream of the Victoria Highway and the narrow river frontages along the Victoria and Wickham rivers offer some opportunities for water harvesting.

- Although the upper West Baines River has more soil suitable for irrigated agriculture than water, some of the suitable soils would be needed for water storage. Along the Victoria River and its other major tributaries, the scale of potential surface water development is constrained by soil suitable for irrigated agriculture rather than by water.
- Along the Victoria River, loamy levees mean that soils suitable for ringtanks can be up to 1 km away. This distance and the increasing elevation away from the river considerably increase the capital and operational costs of water harvesting enterprises by increasing the cost of piping and pumping water.
- It is physically possible (based on coincidence of suitable soil, water and topography) to extract 690 GL and irrigate 50,000 ha of broadacre crops on the clay alluvial soil and sandy and loamy soils during the dry season in 75% of years. This would be achieved by pumping or diverting water from the Baines River (~28,000 ha with area limited by water) and the Victoria River and its other major tributaries (~22,000 ha with area limited by soil) and storing it in offstream storages such as ringtanks. This extraction results in a modelled reduction in the mean and median annual discharges from the Victoria catchment of about 9% and 12%, respectively.
- Using the Northern Territory Government's recently released surface water take policy, the annual consumptive pool available for the entire Victoria River catchment, including the Baines River, is approximately 130 GL (2% of median annual discharge), when using the 1890–2022 modelled period. If this period is reduced to 1970–2022, the annual consumptive pool increases to approximately 200 GL.

Groundwater in the Victoria catchment offers year-round niche opportunities that are locationally distinct from surface water development opportunities

- Groundwater is already widely used in parts of the Victoria catchment for providing drinking water for livestock but also for community water supplies and domestic use.

The most productive groundwater systems in the Victoria catchment are the regional-scale Cambrian Limestone Aquifer (CLA) along the very remote eastern margins of the catchment and the local- to intermediate-scale Proterozoic dolostone aquifers (PDAs) in the centre and south of the catchment.

- The CLA is a large regional-scale groundwater system that extends over 1500 km from north-west Queensland to north-west NT. It occurs across three sedimentary basins: the Georgina, Wiso and Daly geological basins.
- Currently no licensed groundwater entitlements from the CLA exist in the Victoria catchment. The nearest licensed entitlements from the CLA are about 150 km to the north-east of the Victoria catchment and occur in the proposed Flora Tindall Water Allocation Plan area in the Daly catchment.
- These three licensed entitlements are assigned for agricultural use and total 7.4 GL/year. However, actual groundwater use is currently less.

- There is currently very little development of groundwater from the PDAs other than for stock and domestic bores and the community water supply at Timber Creek. No water allocation plan currently exists for the Victoria catchment.
- Water in both the CLA and PDAs is mostly fresh (total dissolved solids <1000 mg/L) with chemistry reflective of the carbonate rocks within which they are hosted. This results in the water having a high hardness, which may result in scaling on water infrastructure.
- Water discharging from the CLA and PDAs supports numerous ecologically and culturally important springs. Spring flows depend on short-term rainfall patterns and are known to gradually decrease in discharge as the dry season progresses with some springs not being able to maintain permanent flows.
- Any extraction of groundwater for consumptive purposes will result in a corresponding reduction in discharge to rivers, springs and vegetation.
- The time lag between groundwater extraction and the corresponding change in the expression of groundwater where it naturally discharges may be many decades in intermediate-scale groundwater systems and longer in regional systems. This presents management challenges but also adaptive management opportunities.

With appropriately sited groundwater borefields along the eastern and southern margins of the Victoria catchment, an estimated 10 GL/year could potentially be extracted from the CLA to the south of Top Springs. This depends on community and government acceptance of impacts to groundwater-dependent ecosystems and existing stock and domestic groundwater users.

- This volume of groundwater could potentially enable up to an additional 1350 ha (0.015% of the catchment) of irrigated agriculture depending upon the percentage mix of broadacre crops, horticulture and hay production.
- The CLA discharges naturally via a combination of intermittent lateral outflow to streams where they are incised into the aquifer outcrop (Armstrong River and Bullock, Cattle and Montejinni creeks) and perennial localised spring discharge (Old Top, Lonely, Palm and Horse springs). Where groundwater in the CLA approaches the ground surface, it is also evaporated from the soil and riparian and spring-fed vegetation.
- Due to the relatively short groundwater flow paths (~20 km) between hypothetical groundwater extractions and groundwater discharge zones, a hypothetical groundwater extraction of 9 to 12 GL/year from the CLA would result in a 13% to 16% modelled reduction in groundwater discharge to spring complexes near Top Springs at about 2060.
- Modelled reduction in groundwater levels ranges from about 15 m at the centre of the hypothetical developments to 1 m up to 20 km away by about 2060. Due to the long distances and long timescales over which groundwater lateral flow occurs, modelled impacts to licensed entitlements in the proposed Flora Tindall Water Allocation Plan or the proposed Mataranka Water Allocation Plan would be negligible.
- Under a projected dry future climate that assumes a 10% reduction in rainfall across the entire CLA (rather than just within the Victoria catchment) and no future hypothetical groundwater development, the modelled reduction in groundwater recharge to the CLA near Top Springs is 32%, and the modelled reduction in groundwater discharge to the nearby spring complexes is 33%.

- The modelled changes in the water balance under a projected drier future climate are larger than for the modelled future hypothetical groundwater development. This highlights the sensitivity of groundwater storage in and discharge from the CLA near Top Springs to natural variations in climate.

There may be potential to extract up to 20 GL/year from the PDAs in the centre and south of the Victoria catchment.

- Very little data are available for these aquifers and opportunities will be localised.
- Outcropping and subcropping units of dolostone aquifers are scattered across the centre and southern parts of the Victoria catchment where they are actively recharged. They tend to steeply dip below the subsurface, but in many cases nearby units are likely to be hydraulically connected. Elsewhere, the aquifers are confined by overlying basalt, sandstone and shale.
- The PDAs discharge naturally via a combination of intermittent lateral outflow to streams where they are incised into the aquifer outcrops (East Baines River and Crawford, Giles and Middle creeks) and perennial localised discharge at discrete springs in contact with low-permeability basalt, sandstone and shale on the margin of the outcropping areas (Bulls Head, Kidman, Crawford, Depot, Farquharson and Wickham springs).
- Despite outcropping and subcropping dolostone aquifers covering approximately 7000 km^2 of the Victoria catchment, they only coincide with contiguous areas of soils suitable for irrigated agriculture at two locations.
- The largest area is along the south-west margin of the catchment, where 85,000 ha of loamy and sandy soils suitable for irrigated horticulture overlay a PDA and is traversed by the unsealed Buntine Highway. Elsewhere 15,000 ha of clay soils suitable for broadacre irrigated cropping along Battle Creek, a minor tributary of the Victoria River, overlay part of a PDA.

There are limited opportunities for managed aquifer recharge in the Victoria catchment.

- Areas of the Victoria catchment with permeable soils and favourable slope and storage capacity for managed aquifer recharge (e.g. Sturt Plateau along the eastern margin of the Victoria catchment) have rivers that are highly intermittent, so there is no reliable and cost-effective source of water for managed aquifer recharge.

Changes in volumes and timing of river flows have ecological impacts

- Although irrigated agriculture may occupy 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, 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, increase non-linearly with increasing scale of surface water development (i.e. large instream dams and water harvesting).
- At equivalent levels of water resource development (i.e. in terms of volume of water extracted), and without significant mitigation measures, instream dams have a larger mean impact to surface-flow-dependent ecology than water harvesting, averaged across the Victoria catchment.
- Impacts from water harvesting tend to accumulate downstream, so ecological assets found near the bottom of the catchment experienced the greatest average catchment impact. Cryptic waders, threadfin, prawns and floodplain wetlands are among the ecological assets most affected by flow changes for water harvesting. Catfish, grunter and inchannel waterholes, found throughout the study area, are the ecological assets least affected.
- Water harvesting developments extracting 80 to 690 GL/year of water without any mitigation strategies resulted in negligible changes to ecology flow dependencies of freshwater assets when averaged across the Victoria catchment. Local impacts below points of extraction, however, were moderate to major for some freshwater assets at the higher extraction volumes and moderate 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 to 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 Joseph Bonaparte Gulf, is an effective mitigation measure for water harvesting. However, because the early wet-season streamflow in the Baines River is only moderately correlated with the early wet-season streamflow in the Victoria River, assigning an EOS annual flow requirement for each river may result in more targeted ecological outcomes than a single EOS annual flow requirement for the entire catchment.
- For EOS annual flow requirements greater than 200 GL, additional mitigation measures (e.g. increasing pump-start capacity or decreasing pump rate) have little additional modelled ecological benefit for water harvesting.
- Relative to catchments with large dry-season flows maintained by groundwater discharge from a regional-scale groundwater system (e.g. the Roper catchment), increasing pump-start thresholds in the Victoria catchment to above 400 ML/day only results in marginal improvements to ecological flow dependencies.
- A dry future climate has the potential to have a larger mean impact on ecological flow dependencies across the Victoria catchment than the largest physically plausible water resource development scenario. 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 risks of large local impacts. Improved outcomes are associated with maintaining attributes of the natural flow regime.

- Potential dams located in small headwater catchments may result in a extreme change in the ecological flow dependency 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 transparent flows (flows allowed to 'pass through' the dam for ecological purposes) improves flow regimes for ecology by reducing the mean yield of potential dams. Mean outcomes for fish assets can 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 irrigated agriculture on the terrestrial environment are typically small. However, indirect impacts such as weeds, pests and landscape fragmentation may be considerable, particularly to 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. This may include some road causeways and low structures within a river to divert water or create pumping pools to enable water harvesting.

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

- Nitrogen, phosphorus, and potassium are the three nutrients used primarily in agricultural fertilisers. Irrigation outflows and tailwater run-off from irrigation events can be high in these nutrients as well as pesticides, herbicides and total dissolved solids.
- If best-practice is not followed, the concentrations of these contaminants can be elevated in receiving surface and groundwater bodies. However, the extent to which irrigated agriculture impacts the quality of receiving waters is highly variable and 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 but 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 are typically low, studies in the Ord River Irrigation Area have found.
- Vegetated areas can intercept agricultural run-off, reducing pesticide concentrations in surface waters approximately three times more than in 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, because of dilution and naturally occurring processes by which aquatic systems can partially process contaminants and regulate water quality, such as denitrification in the case of nitrogen and microbial degradation and ultraviolet photolysis in the case of pesticides. There are no equivalent natural processes for reducing phosphorus.

Commercial viability and other considerations

The economic value of irrigated agriculture in the Victoria catchment has the potential to increase substantially from a very low base.

- The total annual gross value of agricultural production in the Victoria catchment in 2020–21 was $110 million, all of which came from beef cattle production.
- About 29% of all jobs in the Victoria catchment are associated with the grazing industry.

Large public dams would be marginal in the Victoria catchment, but suitably sited on-farm water sources could provide good prospects for viable new irrigated 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, could likely support viable broadacre farms and horticulture where development costs were low.
- 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 Victoria catchment environments, (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 limit negative economic impact 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 past experiences of agricultural development in northern Australia.
- The Victoria catchment, unlike most northern Australian catchments, has the benefit of being close to the Ord River Irrigation Area (the Ord). Many of the more productive clay soils in the Victoria catchment are similar to those of the Ord, so experiences from the Ord will have some level of transferability to parts of the Victoria catchment. The recently announced 67,500 ha Keep Plains Agricultural Development adjacent to the Ord River Irrigation Area would also provide experiential learning for any new development in the Victoria catchment.

- 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 Victoria catchment 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 Victoria catchment associated with the construction phase would be approximately $180 million (assuming 65% leakage out of the study area). Additional benefits would flow to other regions, including Kununurra, Katherine, Darwin and potentially some areas outside the NT.
- The total annual increased economic activity (direct and indirect) from 10,000 ha of irrigated mixed broadacre (65%) and horticulture (35%) agriculture in the Victoria catchment could potentially amount to $280 million, supporting up to 185 full-time-equivalent jobs.
- Based on economic data for the entire NT, the additional income that flows to Indigenous households from beef cattle developments would be one-ninth of that which flows to non-Indigenous households. The additional income that flows to Indigenous households from other agricultural developments (excluding beef) would be one-seventeenth of that which flows to non-Indigenous households. This indicates that, if agricultural developments in the Victoria catchment 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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Note: Assessment team as at September, 2024. All contributors are affiliated with CSIRO unless indicated otherwise. Activity Leaders are underlined. For the Indigenous water values, rights, interests and development goals activity, Marcus Barber was Activity Leader for the project duration except August 2022 – July 2023 when Kirsty Wissing (a CSIRO employee at the time) undertook this role.

[1]James Cook University; [2]DBP Consulting; [3]Badu Advisory Pty Ltd; [4]Independent contractor; [5] Centre for Tropical Water and Aquatic Ecosystem Research. James Cook University; [6]CloudGMS; [7]NT Department of Environment, Parks and Water Security; [8]Rider Levett Bucknall; [9]Baynes Geologic

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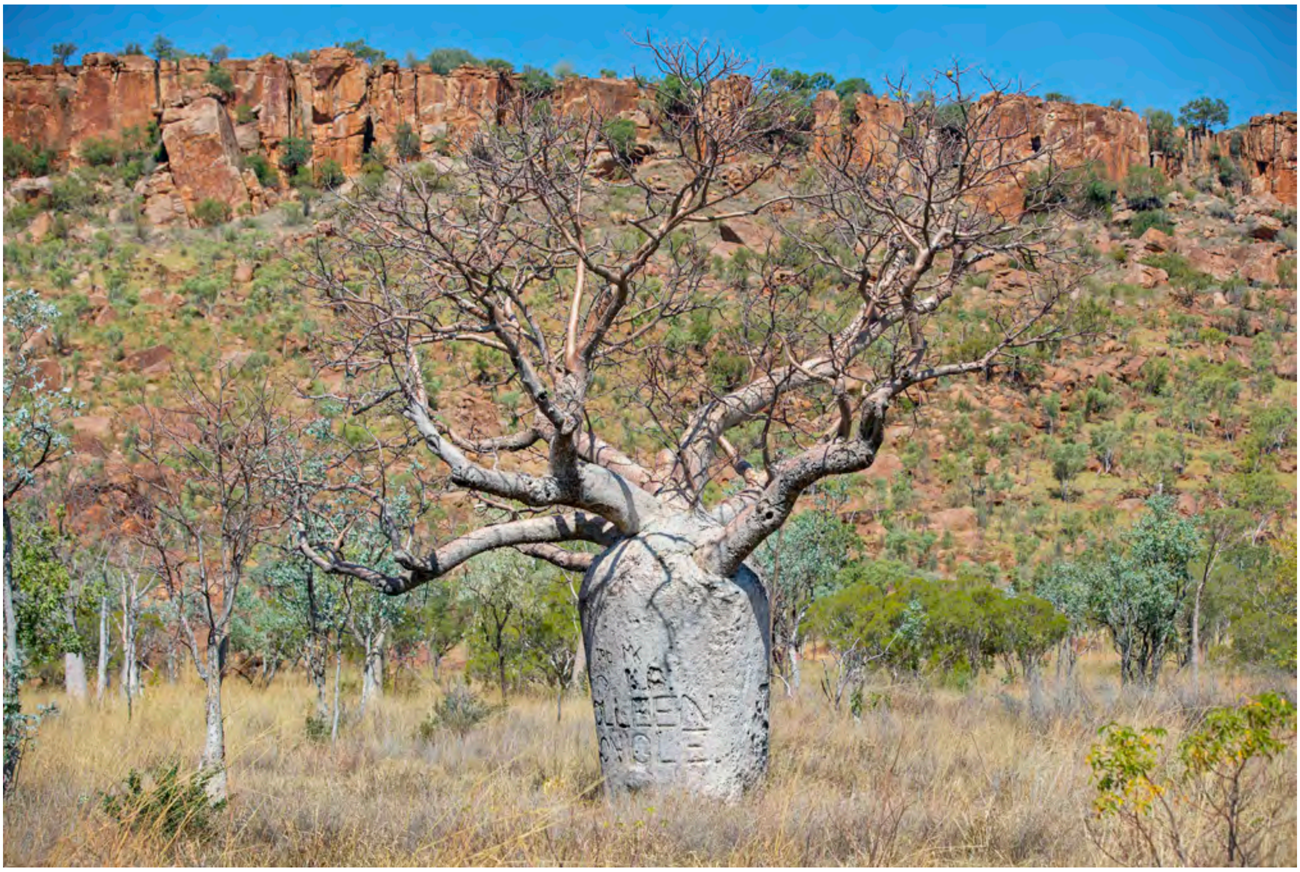

The Victoria catchment is the eastern most extent of the Boab tree in Australia

Photo: CSIRO – Nathan Dyer

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