CSIRO LAND AND WATER
www.csiro.au

# Water resource assessment for the Fitzroy catchment

A report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments

Editors: Cuan Petheram, Caroline Bruce, Chris Chilcott and Ian Watson

Australian Government
Department of Infrastructure, Regional Development and Cities

ISBN 978-1-4863-1070-8 (paperback)

ISBN 978-1-4863-1071-5 (PDF)

## Our research direction

Provide the science to underpin Australia's economic, social and environmental prosperity through stewardship of land and water resources ecosystems, and urban areas.

Land and Water is delivering the knowledge and innovation needed to underpin the sustainable management of our land, water, and ecosystem biodiversity assets. Through an integrated systems research approach we provide the information and technologies required by government, industry and the Australian and international communities to protect, restore, and manage natural and built environments.

Land and Water is a national and international partnership led by CSIRO and involving leading research providers from the national and global innovation systems. Our expertise addresses Australia's national challenges and is increasingly supporting developed and developing nations response to complex economic, social, and environmental issues related to water, land, cities, and ecosystems.

## Citation

Petheram C, Bruce C, Chilcott C and Watson I (eds) (2018) Water resource assessment for the Fitzroy catchment. A report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments. CSIRO, Australia.

Chapters should be cited in the format of the following example: Petheram C, Bruce C, Chilcott C, Tetreault Campbell S and Watson I (2018) Chapter 1: Preamble. In: Petheram C, Bruce C, Chilcott C and Watson I (eds) (2018) Water resource assessment for the Fitzroy catchment. A report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments. CSIRO, Australia.

## Copyright



## Important disclaimer



## CSIRO Northern Australia Water Resource Assessment acknowledgements

This report was prepared for the Department of Infrastructure, Regional Development and Cities. The Northern Australia Water Resource Assessment is an initiative of the Australian Government's White Paper on Developing Northern Australia and the Agricultural Competitiveness White Paper, the government's plan for stronger farmers and a stronger economy. Aspects of the Assessment have been undertaken in conjunction with the Northern Territory Government, the Western Australian Government, and the Queensland Government.

The Assessment was guided by three committees:

(i) The Assessment's Governance Committee: Consolidated Pastoral Company, CSIRO, DAWR, DIIS, DoIRDC, Northern Australia Development Office, Northern Land Council, Office of Northern Australia, Queensland DNRME, Regional Development Australia - Far North Queensland and Torres Strait, Regional Development Australian Northern Alliance, WA DWER

(ii) The Assessment's Darwin Catchments Steering Committee: CSIRO, Northern Australia Development Office, Northern Land Council, NT DENR, NT DPIR, NT Farmers Association, Power and Water Corporation, Regional Development Australia (NT), NT Cattlemen's Association

(iii) The Assessment's Mitchell Catchment Steering Committee: AgForce, Carpentaria Shire, Cook Shire Council, CSIRO, DoIRDC, Kowanyama Shire, Mareeba Shire, Mitchell Watershed Management Group, Northern Gulf Resource Management Group, NPF Industry Pty Ltd, Office of Northern Australia, Queensland DAFF, Queensland DSD, Queensland DEWS, Queensland DNRME, Queensland DES, Regional Development Australia - Far North Queensland and Torres Strait

Note: Following consultation with the Western Australian Government, separate steering committee arrangements were not adopted for the Fitzroy catchment, but operational activities were guided by a wide range of contributors.

This report was reviewed by Richard George (Western Australian Government) and the summary by Peter Stone (Bureau of Meteorology).

For further acknowledgements, see page xxii.

## Photo

Fitzroy River, Western Australia. Source: CSIRO - Nathan Dyer

# Director's foreword

Sustainable regional development is a priority for the Australian, Western Australian, Northern Territory and Queensland governments. In 2015 the Australian Government released the 'Our North, Our Future: White Paper on Developing Northern Australia' and the Agricultural Competitiveness White Paper, both of which highlighted the opportunity for northern Australia's land and water resources to enable regional development.

Sustainable regional development requires knowledge of the scale, nature, location and distribution of the likely environmental, social and economic opportunities and 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.

The Australian Government commissioned CSIRO to complete the Northern Australia Water Resource Assessment (the Assessment). In collaboration with the governments of Western Australia, Northern Territory and Queensland, they respectively identified three priority areas for investigation: the Fitzroy, Darwin and Mitchell catchments.

In response, CSIRO accessed expertise from across Australia to provide data and insight to support consideration of the use of land and water resources for development in each of these regions. While the Assessment focuses mainly on the potential for agriculture and aquaculture, 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 development and other interests.

C. Chilcott

Chris Chilcott

Project Director

# Key findings for the Fitzroy catchment

## Introduction

The Fitzroy catchment covers an area of approximately 94,000 km$^2$. The Fitzroy River flows more than 700 km from its upper reaches to King Sound. The population is approximately 7500 people with two main population centres at Derby and Fitzroy Crossing. The dominant land use is pastoralism (over 95% of the catchment) with natural and conservation uses prioritised in the remaining areas.

Indigenous people have continuously occupied and managed the Fitzroy catchment for tens of thousands of years and 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.

## Agriculture and aquaculture opportunities

The Fitzroy catchment has up to 5.4 million ha of potentially irrigable agricultural soils. Of this land area, 4.0 million ha are suitable for spray irrigation of cereals, between 400,000 ha and 590,000 ha for furrow irrigation of cereals, 2.8 million ha for spray-irrigated sugarcane, and about 400,000 ha for sugarcane with furrow irrigation. For aquaculture, such as prawns and barramundi, about 55,000 ha of land are suitable using lined ponds. For all of these uses the land is considered moderately suitable with considerable limitations and would require careful soil management.

Livestock enterprises are already proven in the Fitzroy catchment. The use of irrigated forage (Figure 1-1) to overcome the feed gap, especially for lactating cows, could significantly increase beef production by increasing calving percentage, enabling earlier weaning and increasing rate of weight gain.

Up to 120 GL/year of groundwater (<5% of recharge) could be extracted from the interconnected Grant Group and Poole Sandstone aquifers. Under a wet season sowing on loamy soils, this volume of water could irrigate about 20,000 ha of a crop such as cotton at an annual gross value of production of approximately $90 million, creating about $140 million of regional economic activity reoccurring annually and the generation of about 560 jobs. There is up to 50 GL/year of additional groundwater across the catchment that would allow numerous small (<1 GL) to medium-scale (1 to 5 GL) developments suited to irrigated forage production.

It is physically possible to pump 1700 GL of water in 85% of years from major rivers and tributaries in the Fitzroy catchment into ringtanks near agricultural soils. This volume of water would fill 425 ringtanks (each of capacity 4 GL) and cost approximately $935 million. This would enable 160,000 ha of clay soils under dry-season cotton to be irrigated. This could generate an annual gross value of production of approximately $750 million, and the region would benefit from $1.1 billion of additional annual economic activity and generation of about 4700 jobs.

## Impacts and risks

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 catchment report is based provide information that can be used to quantify the trade-offs required for agreed development plans.

Streams, wetlands and riparian areas remain of critical importance to Indigenous people. They have cultural significance and provide nutritional food. These habitats are also key to the movement of animals, plants and nutrients through a highly interconnected system, keeping the ecosystem healthy, supporting critical downstream habitats like mangroves and salt flats and providing food for recreational and commercial fishing. The catchment harbours a diverse assemblage of fish. Forty-two different species have been recorded, many of which depend on being able to move up and down the river systems to complete their life cycle. Many of the fish species are dependent on the highly seasonal flow pulses that characterise the Fitzroy River. King Sound and the adjacent Fitzroy catchment is one of the few known remaining habitats for the early life stages of the remnant population of freshwater sawfish.

**Figure 1-1 Irrigated hay production near Fitzroy Crossing**

## Overview of the Fitzroy catchment

### A HIGHLY VARIABLE CLIMATE

The world's tropics are united by their geography but divided by their climates. Northern Australia's tropical climate is unique for the extremely high variability of rainfall between seasons and especially between years. This has major implications for the assessment and management of risks to development, infrastructure and industry.

**The Fitzroy catchment has a hot and semi-arid climate with unreliable rainfall.**

- The mean and median annual rainfall – averaged across the Fitzroy – are 552 mm and 557 mm, respectively. However, there is a strong rainfall gradient that runs from the north (925 mm annual mean) to the south of the catchment (400 mm annual mean).
- Averaged across the catchment, 93% of the mean annual rainfall occurs in the wet season (November to April). Median dry-season rainfall is less than 50 mm throughout the Fitzroy catchment.
- Rainfall is considerably more seasonal than in southern Australia. During the wet season rainfall can be very intense, increasing the risks of flooding, erosion and soil structural decline and reducing trafficability and access to paddocks.
- Annual rainfall totals in the Fitzroy catchment are unreliable and unpredictable against both national and global benchmarks; these totals are approximately 1.3 times more variable year on year than in comparable parts of the world.

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

- While annual rainfall is not always reliable and seasonal forecasting poor, farmers have the advantage of a clear view of water availability, i.e. soil water and dam storage, when they need it most; at the end of the wet season when planting decisions are made. This means 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.**

- Potential evaporation is higher than rainfall, exceeding 1900 mm over the majority of the catchment.
- Large farm-scale offstream storages (ringtanks) will lose about half their water storage to evaporation and seepage between April and December. Deeper farm-scale gully dams lose about 20% to 30% of their capacity over the same period. Using stored water early in the season is the most effective way to reduce losses.

**Even though annual rainfall is increasing, plan for water scarcity.**

- While a trend for increasing rainfall has been observed in the Fitzroy catchment over the last four decades, there are no guarantees this trend will continue.
- Climate and hydrology data to support short- to medium-term water resource planning should encapsulate the full range of likely/plausible conditions and variability at different time scales,

and particularly 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.

**The Fitzroy catchment has large areas of agriculturally-suitable land protected from the most destructive cyclonic winds by their distance inland.**

- The tropical cyclone season in the Fitzroy catchment is between November and April, and while the storms bring rainfall, the winds that harm perennial tree crops are generally limited to the coastal regions.
- Cyclones bring rain. More than 30% of the rain in the Fitzroy catchment, and north-western Australia more generally, is associated with cyclones. In most of northern Australia cyclones are associated with about 10% of rainfall.
- Between 1970 and 2016, the Fitzroy catchment experienced at least one tropical cyclone in 66% of wet seasons. Two cyclones occurred in 21% of seasons and no cyclones occurred in 34% of wet seasons.

**Climate change is unlikely to pose significant limitations to irrigated agriculture.**

- For the Fitzroy catchment, 19% of climate models project a drier future, 48% project a wetter future and 33% are within ±5% of the historical mean, indicating 'little change'. Recent research indicates tropical cyclones will be fewer but more intense in the future, although large uncertainties remain.
- Annual variability, particularly in rainfall, is likely to pose the greatest climate challenge for irrigated agriculture. The evidence suggests that challenges arising from any long-term trends in temperature or other climate variables can be addressed via improvements in new crop varieties and other improved technologies.

## THE FITZROY RIVER

**The Fitzroy River has the ninth-largest median annual discharge of the rivers in northern Australia.**

- The mean annual discharge from the Fitzroy catchment is about 6600 GL. Due to several very wet years 'biasing' the mean, this volume of water is 34% larger than the median annual discharge.
- Annual variability in streamflow is comparable with other rivers in Australia that have similar mean annual runoff, but is two to three times greater than rivers from the rest of the world in similar climates.
- Approximately 87% of the runoff in the Fitzroy catchment occurs between January and March. Monthly runoff is highest during February.
- The only river regulation is a low weir midway along the Fitzroy River near Camballin.
- There is a strong positive relationship between streamflow and fishery catches, including for barramundi.

- Persistent waterholes that are key ecological refugia are located throughout the Fitzroy catchment. The most persistent waterholes occur along the Fitzroy River between Fitzroy Crossing and Camballin and upstream of Dimond Gorge. Some waterholes are replenished in part by groundwater.

**Flooding poses a major challenge to wet-season cropping along the Fitzroy and Margaret rivers: floods are relatively common, large and persistent.**

- Flood protection levees will be needed in many areas along the alluvial clay soils in order to enable wet-season cropping. Floods with a probability of occurring in 6% of years will inundate 85% of the alluvial clay soil. Even for floods with a probability of occurring in 20% of years, 70% of these areas will be inundated.
- Of the ten largest flood events over the last 35 years at Noonkanbah on the Fitzroy River, one event occurred during January, six in February and three in March. Without flood protection, sowing before April is a risky proposition.
- Flooding is ecologically critical because it connects offstream wetlands to the main river channel, allowing the exchange of animals, plants and nutrients, and supports a boost of productivity in the lower estuary.

## A DIVERSITY OF HABITATS

**The Fitzroy catchment is largely intact, but not pristine.**

- There has been relatively little clearing and little agricultural development other than pastoralism.
- Livestock grazing has reduced ground-cover vegetation and increased soil erosion, especially along some of the more highly productive river country. Deliberate and accidental plant and animal introductions have altered catchment landscape function.
- The aquatic ecosystems of the Fitzroy catchment are largely intact, and there are no introduced aquatic invasive species.

**The Fitzroy catchment has a number of wetlands of national importance.**

- The Geikie Gorge wetland is of national importance and is located within Geikie Gorge National Park, a popular tourist attraction.
- The Camballin floodplain supports internationally significant waterbird populations, providing an important refuge for breeding waterbirds and a major resting area for migratory waterbirds.
- The Fitzroy River estuary and nearby King Sound contain ecologically significant mangroves.
- King Sound in particular, with 13 species of mangrove, is one of the most species-rich tidal flat systems in the world. Mangroves and salt flats support diverse and complex food webs, including crustaceans such as prawns and mud crabs, and a diversity of fish species.

**The Fitzroy catchment supports a number of important species and river habitats.**

- Riparian zones are highly water dependent and are vulnerable to disturbances. They provide critical habitat and resources for birds, insects and animals and play an important role in instream plant growth, bank stability and instream habitat diversity.

- Forty-two fish species have been recorded in the Fitzroy catchment of which 28 complete their entire life cycle in fresh water. The remaining 14 species are either marine, estuarine or rely on freshwater and marine life stages, including black catfish, spangled perch, barramundi (a species of commercial and recreational significance) and freshwater sawfish, which are listed in the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act).
- The catchment is also home to the little-known freshwater whipray; although, due to their rarity, there are few recorded observations in the Fitzroy catchment.

## INDIGENOUS VALUES, RIGHTS AND DEVELOPMENT GOALS

**Indigenous people make up a significant and growing proportion of the population of the Fitzroy catchment.**

- Traditional Owners have recognised native title and cultural heritage rights, and control significant natural and cultural resources, including land, water and coastline.
- Water-dependent fishing and hunting play a key health and economic role for the more than 50 Indigenous communities in the Fitzroy catchment, supporting food security and good nutrition in an area where incomes are low and food costs are high.
- The history of pre-colonial and colonial patterns of land and natural resource use in the Fitzroy catchment is important to understanding present circumstances. That history also informs Indigenous responses to future development possibilities.

**From an Indigenous perspective, ancestral powers are still present in the landscape and intimately connect people, 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.

**Indigenous land use agreements, native title, and Aboriginal cultural heritage legislation are important ways in which Indigenous interests in country are recognised and managed.**

- Securing recognition through these pathways remains an important development goal for Indigenous people in the Fitzroy catchment.
- Indigenous people have strong expectations for ongoing involvement in water, catchment and development planning.
- Should development of water resources occur, participants in this study generally expressed preference for flood harvesting, which would fill offstream storages. Large instream dams in major rivers were consistently amongst the least-preferred options.
- Indigenous people have business development objectives designed to create opportunities for existing residential populations and to aid the resettlement and return of people currently living elsewhere.
- Indigenous people 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 for the foreseeable future.

*It is living water, and we survive from the river. It is everything we need. Drink water, catch fish, that is your food bowl in the river.*

*Fitzroy catchment Traditional Owner*

*We are talking about values. There has to be restrictions that lead to coexistence. I need to be able to say 'you can't come to this area, I need it' but then nominate another area for agriculture.*

*Fitzroy catchment Traditional Owner*

## OPPORTUNITIES FOR AGRICULTURE AND AQUACULTURE

- There is very little broadacre cropping in the Fitzroy catchment, although some hay is produced and crops such as cotton and rice have been grown in the past.

**There is much more soil suitable for irrigated agriculture in the Fitzroy catchment than there is water to irrigate it.**

- Up to 5.4 million ha of the Fitzroy catchment are classified as moderately suitable with considerable limitations (Class 3) for irrigated agriculture, depending on the crop and irrigation method chosen.
- These Class 3 soils have considerable limitations that lower production potential or require more careful management than more suitable soils (i.e. Class 1 or Class 2). In this respect, they do not differ from many of Australia's agricultural soils.

The classes (1–5[1]) were derived from a set of attributes such as erodibility, slope, soil depth, permeability, rockiness and others.

*The area estimates below are derived from assessing soil, landscape and climate factors within the whole catchment, as an upper starting point. The area actually available for irrigation will be less – once considerations relating to land tenure, land use, flooding risk, availability of water for irrigation and other factors are taken into account.*

- About 5.4 million ha of the Fitzroy catchment are considered to be Class 3 for Rhodes grass under spray irrigation and a little less for mango under trickle irrigation.
- For some cereals such as grain sorghum, cotton, silage maize and the forage legume lablab there are a little over 4.0 million ha of the Fitzroy catchment considered to be Class 3 for irrigated cropping using spray irrigation in the dry season. Under furrow irrigation, between about 400,000 and 590,000 ha are Class 3 in the dry season for the same crops.
- About 2.8 million ha of the Fitzroy catchment are considered to be Class 3 for irrigated sugarcane using spray irrigation, but only about 400,000 ha are Class 3 for furrow irrigation.
- While the catchment has 5.4 million ha of irrigable soil, water from offstream storages and groundwater is capable of reliably irrigating only 180,000 ha, or about 2% of the catchment.

[1] Class 1 – Highly suitable land with negligible limitations. Class 2 – Suitable land with minor limitations. Class 3 – Moderately suitable land with considerable limitations. Class 4 – Currently unsuitable land with severe limitations. Class 5 – Unsuitable land with extreme limitations.

**Opportunistic dryland cropping is possible but carries considerable risk.**

- Dryland cropping has limited potential in the Fitzroy catchment.
- The soils best suited to dryland production, the heavier-textured alluvial clays, are limited in extent. They comprise less than 10% of the catchment and are principally restricted to the alluvial areas associated with the Fitzroy and Margaret rivers. In some years these cropping areas may not be trafficable due to wet conditions.
- Gross margins for dryland crops are mostly negative, especially on lighter soils. On the suitable clay soils, gross margins are positive in only 50% of years for medium-duration crops and up to 70% of years for short-duration crops such as mungbean.
- When planted at an appropriate time, moderate yields can be obtained from dryland crops of maize, sorghum, mungbean and cotton.

**Irrigation provides not only for higher yields, but also more reliable production compared with dryland crops.**

- A wide range of crops is potentially suited to irrigated production in the Fitzroy catchment. These include cereals, pulses, forages, vegetables and perennial fruit tree crops, as well as industrial crops such as sugarcane and cotton.
- Seasonal water use by crops can vary enormously depending on crop type (e.g. its duration of growth), season of growth and, to a lesser extent, soil type. At Fitzroy Crossing, a crop under full canopy cover for most of the year (such as sugarcane) would use about 12.6 ML/ha per year before losses. A short-season crop such as mungbean would use less than 5 ML/ha per year.

**An excess of water also carries risks.**

- High rainfall and possible flooding mean that wet-season cropping carries considerable risk due to potential difficulties with access to paddocks, trafficability and waterlogging of immature crops.
- Due to inadequate drainage of the soil profile in heavier soils, the area suitable for furrow irrigation is much less than that suitable for spray or trickle irrigation.
- The area of crop that can be reliably irrigated must be carefully assessed each year, with reference to the available stored soil water, the likelihood of future in-season rainfall, and the volume and availability of stored water.
- While dryland cropping is unlikely to be viable on its own, it is likely to be a component of irrigated farming systems, expanding or contracting based on the amount of land that can be irrigated each year and on the spare capacity of time, labour and machinery.

**Establishing irrigated cropping is challenging, with high input costs and high capital requirements for greenfield development.**

- Gross margins are highly variable between crops, with the industrial crops (sugarcane and cotton) and the forage hays, particularly Rhodes grass, returning the highest gross margins. For sugarcane and cotton, positive gross margins are only achieved if processing facilities (sugar mill, cotton gin) were available locally, which they are not at present, to reduce cartage costs.
- The gross margins for cotton are consistent with other regions in northern Australia while those for sugarcane are somewhat lower than other areas, such as the Lower Burdekin region in Queensland, because of higher input costs and slightly lower yields.

- Compared with broadacre crops, gross margins for horticultural crops are considerably higher for bananas, melons and mangoes. Horticultural returns are highly sensitive to prices received, so the locational advantage of supplying markets earlier than other regions is critical to viability.

**More than one crop per year may be required to sustain greenfield irrigation development.**

- The cash generated from a single crop each year is unlikely to enable the capital costs of development to be met.
- There has been relatively little experience in implementing rotational, two-crops-per-year, farming systems in the Fitzroy catchment.
- In addition to the potential for higher gross margins, rotations can be designed to help manage disease, pests and weeds, minimise soil and nutrient losses and reduce the need for inorganic nitrogen inputs.
- A rotation system of cotton and mungbean, or cotton followed by forage sorghum, may be capable of producing yields similar to the sum of the individual crops, and could be sufficient to meet capital costs of development in the order of $18,000/ha.
- The development of a range of two-crops-per-year rotation alternatives, and the management packages and skills to support them, is a likely pre-requisite for economically sustainable irrigated broadacre cropping. The challenges in developing these should not be under-estimated.

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

- The pesticide and fertiliser application rates required to sustain crop growth vary widely amongst crop types. Selecting crops and production systems that minimise the requirement for these can simultaneously reduce costs and environmental impacts.
- Careful water management will be required on some of the older clay soils (i.e. Fossil group) to avoid on-site and off-site impacts of irrigation-induced salinisation.
- Refining application rates of fertiliser to better match crop requirements, using controlled-release fertilisers, and improving irrigation management are all effective ways to minimise nutrient additions to waterways and, therefore, the risk of harmful microalgae blooms.
- The use of best management practices including controlled traffic and banded application of herbicides can substantially reduce their efflux into waterways.
- Adherence to well-established best management practices can significantly reduce erosion where intense rainfall and slope would otherwise promote risk.
- Genetically modified (GM) crops allow industry to substantially reduce insecticide and herbicide application. In recent years GM cotton has enabled Australian cotton farmers to use 85% less insecticide, 62% less residual-grass herbicide and 33% less residual-broadleaf weed herbicide. This technology has considerable application to northern Australia.

**Irrigated forages can improve beef turnoff and profitability of cattle enterprises.**

- The dominant beef production system in the Fitzroy catchment is native pasture-based cow–calf breeding, with young males and females sold into the live-export market. Less commonly, some cattle are transported south after weaning to graze pastures before being lot-fed. An additional opportunity has recently emerged due to the opening of a local abattoir near Derby.

- While native pastures are generally well-adapted to harsh environments, they impose constraints on beef production through their low productivity and digestibility. An opportunity exists to complement native pastures with improved forage species such as Rhodes grass, forage sorghum and lablab that are suited to the Fitzroy.
- Irrigated forage sorghum with moderate levels of fertiliser can produce about 18 t dry matter/ha, while dryland forage sorghum, sown halfway through the wet season when soil profiles are full of water, could produce only one-third of that.
- Irrigated Rhodes grass can produce forage yields in excess of 30 t dry matter/ha, when it is fertilised with large amounts of nitrogen and other major nutrients. However, a large amount of water is required throughout the year, 17 to 19 ML/ha, to achieve these yields.
- Irrigated forages in tropical Australia have until now mostly been used for small-scale hay production rather than direct grazing. There is the opportunity for irrigated forages, grown at the hundreds of hectares scale, to fundamentally alter production of particular animal cohorts and so transform management of large pastoral enterprises. The potential options to do this are numerous. For example:
  - grazing of forages by young cattle to increase their weight at sale from approximately 300 kg to 450 kg so that sale options and returns are increased
  - producing high-quality hay to enable early weaning of calves, thereby reducing lactation pressures on cows and increasing their body condition to improve subsequent calving percentages.
- Analysis shows that both of these options markedly increase the total amount of beef produced per year. Infrastructure and establishment costs are high, especially for large areas of direct grazing. Consequently, the hay option can produce higher profits even though the scale of irrigation is much smaller because of its value-add effect through the associated breeding herd.

**Pond-based black tiger prawns or barramundi offer potentially high returns in saltwater, near the coastal margins of the catchment.**

- For marine species, there are approximately 55,000 ha of coastal land moderately suitable with considerable limitations for lined aquaculture ponds.
- Although other aquaculture species are being trialled in northern Australia, prawns and barramundi have established land-based culture practices and well-established markets for harvested products.
- Prawns could potentially be cultured in either extensive (low density, low input) or intensive (higher density, higher inputs) pond-based systems. Land-based culture of barramundi would likely be intensive.
- Long transport distances for specially formulated feed and finished products contribute to the high cost of aquaculture production. Even so, skilfully managed prawn and barramundi pond-based aquaculture can be highly profitable enterprises in the Fitzroy catchment.
- The remote location of the Fitzroy catchment confers some biosecurity advantages to aquaculture production.
- Aquaculture enterprises are likely to encounter fewer regulatory constraints than those in catchments in other parts of Australia, such as those draining into the Great Barrier Reef. For example, while Australian prawn farms have been found to be some of the most

environmentally sustainable in the world, approval processes and strict regulation constrain development along the east coast of Australia.

## THE FITZROY CATCHMENT IS WELL-ENDOWED IN GROUNDWATER RESOURCES

**The Fitzroy catchment's major groundwater systems may yield up to 170 GL/year, which could enable up to 30,000 ha (0.3% of the catchment) of hay production from forage sorghum.**

- Major aquifer systems in the Fitzroy catchment are found in the geological Canning Basin. These include the Devonian reef complexes, Grant Group, Poole Sandstone, Liveringa Group, Erskine Sandstone and Wallal Sandstone aquifers.
- Town and community water supplies in the Fitzroy catchment are heavily dependent upon groundwater.
- The interconnected Grant Group and Poole Sandstone aquifers offer the greatest opportunity for groundwater resource development in the Fitzroy catchment.
  - The interconnected Grant Group and Poole Sandstone aquifers are artesian or close to artesian over large parts of the Fitzroy catchment. Artesian conditions mean that the water is currently under pressure sufficient to make bores flow without the cost of pumping. Extracting large volumes of artesian groundwater reduces pressure and can cease artesian flow and increase the depth of pumping.
  - Recharge to the interconnected Grant Group and Poole Sandstone aquifers occurs as infiltration, in and near the vicinity where aquifers outcrop at the ground surface. This can occur directly following intense wet-season rainfall events and in some places from streamflow where rivers and the alluvium traverse the outcropping rock. Recharge is estimated to be 3500 GL/year.
  - Groundwater discharges via several routes that ensure that, in the long run, groundwater discharge equals groundwater recharge. Human activity creates both intentional (stock, domestic and community water supplies [0.5 GL]), and unintentional (unsealed bores) groundwater discharge. Natural discharge to land supports a range of environments, such as waterholes and groundwater-dependent ecosystems. 'Submarine' discharge to the ocean sustains unique marine ecosystems.
  - Groundwater is fresh, with low salinity (>800 µS/cm) and low ionic composition making the water suitable for a variety of uses.
  - Extractable groundwater can be found at potentially economical depths (<300 m) along outcropping areas along its eastern-most extent, north and east of Fitzroy Crossing, near Camballin and south of Noonkahbah.
  - Approximately 990,000 ha of the Fitzroy catchment (11%) has land moderately suitable for irrigated forage sorghum that is not susceptible to broad-scale flooding and below which the interconnected Grant Group and Poole Sandstone aquifers are at a potentially economical depth (<300 m).
  - With appropriately-sited groundwater bores, up to 120 GL/year of groundwater (< 5% recharge) could be extracted from the interconnected Grant Group and Poole Sandstone aquifers. Assuming unconstrained development, this volume of water could be used to irrigate about 20,000 ha of dry-season forage sorghum or under a wet season sowing on

loamy soils, 20,000 ha of a single crop like cotton at an annual gross value of production of approximately $90 million. This area of cotton would create approximately $140 million of annually-recurring economic activity in the region and would generate about 560 full-time equivalent jobs.

**Collectively, other groundwater systems in the Fitzroy catchment may yield up to 50 GL/year.**

- Erskine Sandstone and Wallal Sandstone (<20 GL) near the coast may support numerous medium-scale developments (1 to 5 GL), although opportunities will be limited near the coast due to high potential for seawater intrusion.
- Fitzroy and Margaret river alluvium (<10 GL) may support small-scale developments (<1 GL). Bore yields and water quality are highly variable and there is a high likelihood that pumping would reduce groundwater discharge to major rivers.
- Liveringa Group (<10 GL) has variable bore yields and water quality and is likely to only offer potential for small-scale (<1 GL) developments. There is high potential for reducing groundwater discharge flow where the aquifers are connected to the Fitzroy River.
- Devonian reef complex (<10 GL) may support small-scale developments (<1 GL). Opportunities are likely to be limited due to their proximity to and hence high potential for affecting dry-season flows in the Fitzroy and Margaret rivers.

**Groundwater, which is more economically attractive than managed aquifer recharge (MAR), will always be developed first. However, MAR can enhance the quantity of water available for extraction and help mitigate impacts to the environment.**

- An advantage of MAR over surface water storage options is that evaporative losses can be avoided.
- Approximately 6,800 $km^2$ (7%) of the Fitzroy catchment may have alluvial, sedimentary sandstone or limestone aquifers with potential for infiltration-based MAR within 5 km of a major river.
- In some ephemeral river reaches streambed recharge structures, such as 'upside down weirs', have potential to augment groundwater recharge in areas of groundwater extraction. The potential for siltation to reduce their effectiveness over time would need to be investigated.
- The cost-effectiveness of these structures is similar to large farm-scale ringtanks and lower than large farm-scale gully dams, measured as combined capital and operational costs per ML water supplied.
- A likely impediment to the uptake of MAR in northern Australia is that the site-specific investigative costs are higher and more risky than those for farm-scale ringtanks and gully dams of equivalent yield.

## SURFACE WATER STORAGE POTENTIAL

**Surface water storage could enable broadacre cropping at scales sufficient to attract the supporting infrastructure, such as cotton gins or sugar mills, necessary for broadacre crops to be profitable.**

- Approximately 66% of the Fitzroy River water discharged at King Sound is generated in the rocky headwater catchments upstream of Fitzroy Crossing. This area, comprising approximately 45% of the catchment, has topography suitable for major dams.
- No new studies of major dams in the Fitzroy catchment were undertaken as part of the Assessment.
- According to previous studies, the total amount of controlled water release possible from two of the most commercially viable major instream dams in the Fitzroy catchment (Dimond Gorge and a dam on the Margaret River) is approximately 2270 GL in 85% of years, sufficient water to irrigate about 100,000 ha of land all year round, even after taking into consideration conveyance and field application losses. Collectively the two dams would cost about $735 million, or $325/ML released at the dam wall in 85% of years.
- It is highly likely that the previously identified dams and their reservoirs would inundate culturally and ecologically sensitive areas, impede the movement of aquatic species and considerably change the volume and timing of river flow in the Fitzroy River. If used to their full amount the two dams would result in large reductions in mean and median annual discharge from the Fitzroy River, approximately 42% and 51%, respectively. Those reaches of the Fitzroy and Margaret rivers between the dam and irrigation areas would become perennial.

**The majority of streamflow within the Fitzroy catchment cannot be readily captured or stored offstream. In the Fitzroy River, 79% of total streamflow is discharged in the highest 10% of days, of which only a small proportion could be pumped or diverted.**

- Water released from ringtanks for irrigation (after evaporative and seepage losses) to irrigate crops with short (2 to 3 months) or medium (4 to 6 months) growing seasons would cost about twice that of groundwater, including the cost of operation.
- In 85% of years, it is physically possible to pump/divert 1700 GL of water from the Fitzroy catchment into ringtanks adjacent to soil suitable for irrigated agriculture. This volume of water is approximately 25% and 35% of the mean and median annual streamflow near the mouth of the Fitzroy River, respectively.
- This volume of water could potentially be stored in 425 ringtanks (each of capacity 4 GL) at a total cost of about $935 million. Assuming unconstrained development, this water could irrigate up to 160,000 ha (1.7% of the catchment) of clay soils under dry-season crops such as cotton after considering evaporative, conveyance and field application losses.
- This could potentially generate an annual gross value of production of approximately $750 million that would create $1.12 billion of annually-recurring regional economic activity and generate about 4690 full-time equivalent jobs.
- Conceptually, 425 4 GL ringtanks and 160,000 ha of irrigated land would occupy an area 4 km either side of the Fitzroy River between Fitzroy Crossing and Willare (approximately 270 km).
- Pumping water into ringtanks would slightly reduce floodplain inundation during ‘low flood’ years (<1 in 2 annual exceedance probability) and have a negligible effect on floodplain inundation during ‘moderate’ and ‘large’ flood events because the volume of flood water far exceeds the capacity of the pumps.

**There is no single 'best' water solution. Combinations of a variety of water sources and technologies will be required to balance the competing demands of water availability, cost-effectiveness and environmental and cultural needs.**

- At some locations it may be possible to use groundwater in conjunction with surface water, to enable year-round irrigation at a larger scale than would be possible from either alone. For example, at some locations it may be possible to use groundwater to sow a crop before the wet-season rains make heavier soils too wet for machinery, and then switch to surface water irrigation once the rivers start flowing.
- Suitably-sited large farm-scale gully dams are a relatively cost-effective method of supplying water compared to other options. However, most of the favourable locations for large farm-scale gully dams in the Fitzroy coincide with those parts of the catchment in which soils are less suitable for irrigated agriculture.

## CHANGES IN TIMING AND VOLUME OF FLOW HAVE ECOLOGICAL IMPACTS

- Although irrigated agriculture inevitably occupies a small percentage of the landscape (<3%), it can result in large changes to volume and timing of river flow and, hence, ecological function.

**Pumping water has a minor impact on key habitats such as offstream wetlands and inchannel waterholes, and a minor-to-moderate impact on riparian vegetation and salt flats.**

- High volume (>1700 GL/year) water harvesting across the Fitzroy catchment is likely to have a minor impact on the connectivity of offstream wetlands to the river because it is physically possible to pump only a small proportion of a flood’s volume.
- Commence-to-pump thresholds ensure that, irrespective of the total extraction volume, water harvesting would have a minor impact on inchannel waterholes. Even low commence-to-pump thresholds are likely to sustain the low flows that maintain permanent waterholes. The volume of flood events that can ‘flush’ waterholes after a long dry season would be reduced only slightly by water harvesting.
- At most locations, riparian vegetation was the habitat most affected at low commence-to-pump extractions. There was less difference in the relative impact to habitat under high commence-to-pump extractions. Water harvesting has a minor impact on riparian vegetation for catchment extraction volumes of up to 1800 GL/year.

**High commence-to-pump thresholds can result in considerably less impact to species and habitat with small-to-moderate reductions in reliability of extracting the full allocation of water.**

- At a high commence-to-pump threshold (i.e. 1800 ML/day), the impacts of water harvesting on flow habitats of all species assessed, including barramundi and freshwater sawfish, was minor up to a whole-of-catchment extraction volume of 1800 GL/year.
- No change to important flow habitat for waterholes or stable flow spawners (which are food for larger predator species) was evident under any of the water harvesting extraction scenarios undertaken as part of the Assessment.

**Although intensive land management has the potential to improve some ecological outcomes, past experience suggests this is unlikely to occur; there are currently no incentives for irrigation**

**developments to manage beyond their boundaries or for issues that do not affect their production.**

- 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.
- Generally, irrigated cropping systems have relatively well-developed pest management protocols and the economics of such systems is such that they can bear the cost of controlling weeds and pests that are of concern to them.

## COMMERCIAL VIABILITY AND OTHER CONSIDERATIONS

**There is potential for the economic value of irrigated agriculture to increase in the Fitzroy catchment more than ten-fold.**

- Beef production is the most significant agricultural activity in the study area, with a gross value of production of approximately $70 million.
- Irrigated agriculture is not well-established in the Fitzroy catchment; it has a current economic value of about $2.4 million, nearly all from 240 ha of irrigated forage.

**While the natural environment of northern Australia presents some challenges for agriculture, the most important factors determining the commercial viability of new developments are management, planning and finances.**

- Large developments for agriculture are complex and costly. It would be prudent to ensure there are sufficient funds remaining after the construction phase to safeguard the operation of new enterprises in the likely occurrence of 'failed' years at the start of their operation.
- There is a strong incentive to start any new irrigation development with well-established and understood crops, farming systems and technologies as this will reduce the likelihood of initial setbacks and failures.
- There is a systematic tendency of proponents of large infrastructure projects to substantially under-estimate development costs and risks and/or over-estimate benefits. This can be in part due to financial return imperatives driving an overly optimistic assessment of the time frame for positive returns, unanticipated difficulties and project delays, and the difficulty of accurately planning and budgeting over many years.

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

- The initial challenge of establishing and adapting agriculture in a new location can be mitigated by learning from past experiences in northern Australia. However, even if well-prepared, each new location and development will provide unique challenges.
- Staging and allowing for sufficient learning time can limit losses where small-scale testing proves initial assumptions of costs and benefits to be overly optimistic, or it reveals unanticipated challenges in adapting farming practices to local conditions.

**Synergies through vertical and horizontal integration present opportunities for commercial returns but increase risk.**

- Aggregated farm revenue from broadacre agriculture is unlikely to cover the cost of infrastructure for an irrigation scheme under current farming systems. Value adding through processing will increase revenues and will greatly assist in improving the commercial viability of an irrigation scheme.
- Analysis of building a local sugar mill with electricity cogeneration resulted in a substantial increase in return on investment, making an integrated sugar development viable and potentially attractive to an investor.
- Vertically integrated agricultural enterprises require a sufficient scale of development in order to be viable, with supply commitments of raw farm products to justify the investment in processing facilities.
- The more complex a scheme becomes and the more strongly interdependent the components become, the greater the risk that underperformance of one component could undermine the viability of the entire scheme.

**Distance from the farm gate to agricultural processing plants or markets places a significant cost burden on industry in the Fitzroy catchment.**

- The current road network is sparse and the major roads are often prone to flooding, restricting wet-season access.
- The nearest processing facilities for higher value broadacre crops, such as sugar and cotton, are in Queensland.
- Transport costs to major southern markets will add significant costs and make supplying low-value broadacre crops unviable when competing against southern production. There are established export supply chains for live cattle, however, exports of locally-processed beef and horticultural or broadacre crops out of Broome port are not yet at a sufficient scale to justify investment in port infrastructure. There are currently limited refrigerated backloading opportunities in the Fitzroy catchment.

**Irrigated agriculture has a greater potential to generate economic and community activity than dryland 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 that generated by dryland production.
- In the Fitzroy catchment, irrigation development could result in an additional $0.89 of indirect regional economic benefits per year for every $1.00 spent during the construction phase. The regional economic impact of an annual increase in irrigated agricultural output of $100 million/year is estimated to be an additional $59 million of increased economic activity.
- During the construction phase, aquaculture development may result in a regional economic benefit similar to that from irrigated agriculture. Once a business has been established, the regional economic impact of aquaculture is higher; $100 million/year of output is estimated to create an additional $80 million of increased economic activity.

**Community infrastructure in the Fitzroy catchment requires investment in the event of a large-scale irrigation development.**

- The population increase required to sustain a substantial irrigation development would require significant investment in community infrastructure and services, such as schools, medical services and housing.
- Recent developments in the north-west of northern Australia (such as the expansion of the Ord River Irrigation Area in WA) have shown that significant investment in community infrastructure is required to support new irrigation schemes.

**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.
- Potential agricultural investors identified institutional certainty, simplicity and bureaucratic speed as key to enabling investment in irrigated agriculture.

# The Northern Australia Water Resource Assessment Team

| | |
|---|---|
| Project Director | Chris Chilcott |
| Project Leaders | Cuan Petheram, Ian Watson |
| Project Support | Caroline Bruce, Maryam Ahmad, Tony Grice[1], Sally Tetreault Campbell |
| Knowledge Delivery | Jamie Vleeshouwer, Simon Kitson, Lynn Seo, Ramneek Singh |
| Communications | Thea Williams, Siobhan Duffy, Anne Lynch |
| **Activities** | |
| Agriculture and aquaculture viability | Andrew Ash, Mila Bristow[2], Greg Coman, Rob Cossart[3], Dean Musson, Amar Doshi, Chris Ham[3], Simon Irvin, Alison Laing, Neil MacLeod, Alan Niscioli[2], Dean Paini, Jeda Palmer, Perry Poulton, Di Prestwidge, Chris Stokes, Ian Watson, Tony Webster, Stephen Yeates |
| Climate | Cuan Petheram, Alice Berthet, Greg Browning[4], Steve Charles, Andrew Dowdy[4], Paul Feikema[4], Simon Gallant, Paul Gregory[4], Prasantha Hapuarachchi[4], Harry Hendon[4], Geoff Hodgson, Yrij Kuleshov[4], Andrew Marshall[4], Murray Peel[5], Phil Reid[4], Li Shi[4], Todd Smith[4], Matthew Wheeler[4] |
| Earth observation | Neil Sims, Janet Anstee, Olga Barron, Elizabeth Botha, Eric Lehmann, Lingtao Li, Timothy McVicar, Matt Paget, Catherine Ticehurst, Tom Van Niel, Garth Warren |
| Ecology | Carmel Pollino, Emily Barber, Rik Buckworth, Mathilde Cadiegues, Aijun (Roy) Deng, Brendan Ebner[6], Rob Kenyon, Adam Liedloff, Linda Merrin, Christian Moeseneder, David Morgan[7], Daryl Nielsen, Jackie O'Sullivan, Rocio Ponce Reyes, Barbara Robson, Ben Stewart-Koster[8], Danial Stratford, Mischa Turschwell[8] |

| | |
|---|---|
| Groundwater hydrology | Andrew R. Taylor, Karen Barry, Jordi Batlle-Aguilar[9], Kevin Cahill, Steven Clohessy[3], Russell Crosbie, Tao Cui, Phil Davies, Warrick Dawes, Rebecca Doble, Peter Dillon[10], Dennis Gonzalez, Glenn Harrington[9], Graham Herbert[11], Anthony Knapton[12], Sandie McHugh[3], Declan Page, Stan Smith, Nick Smolanko, Axel Suckow, Steven Tickell[2], Chris Turnadge, Joanne Vanderzalm, Daniel Wohling[9], Des Yin Foo[2], Ursula Zaar[2] |
| Indigenous values, rights and development objectives | Marcus Barber, Carol Farbotko, Pethie Lyons, Emma Woodward |
| Land suitability | Ian Watson, Kaitlyn Andrews[2], Dan Brough[11], Elisabeth Bui, Daniel Easey[2], Bart Edmeades[2], Jace Emberg[3], Neil Enderlin[11], Mark Glover, Linda Gregory, Mike Grundy, Ben Harms[11], Neville Herrmann, Jason Hill[2], Karen Holmes[13], Angus McElnea[11], David Morrison[11], Seonaid Philip, Anthony Ringrose-Voase, Jon Schatz, Ross Searle, Henry Smolinski[3], Mark Thomas, Seija Tuomi, Dennis Van Gool[3], Francis Wait[2], Peter L. Wilson, Peter R. Wilson |
| Socio-economics | Chris Stokes, Jane Addison[14], Jim Austin, Caroline Bruce, David Fleming, Andrew Higgins, Nerida Horner, Diane Jarvis[14], Judy Jones[15], Jacqui Lau, Andrew Macintosh[15], Lisa McKellar, Marie Waschka[15], Asmi Wood[15] |
| Surface water hydrology | Justin Hughes, Dushmanta Dutta, Fazlul Karim, Steve Marvanek, Jorge Peña-Arancibia, Quanxi Shao, Jai Vaze, Bill Wang, Ang Yang |
| Water storage | Cuan Petheram, Jeff Benjamin[16], David Fuller[17], John Gallant, Peter Hill[18], Klaus Joehnk, Phillip Jordan[18], Benson Liu[18], Alan Moon[1], Andrew Northfield[18], Indran Pillay[17], Arthur Read, Lee Rogers |

Note: All contributors are affiliated with CSIRO unless indicated otherwise. Activity Leaders are underlined.
[1]Independent Consultant, [2]Northern Territory Government, [3]Western Australian Government, [4]Bureau of Meteorology, [5]University of Melbourne, [6]CSIRO/James Cook University, [7]Murdoch University, [8]Griffith University, [9]Innovative Groundwater Solutions, [10]Wallbridge Gilbert Aztec, [11]Queensland Government, [12]CloudGMS, [13]CSIRO and Western Australian Government, [14]CSIRO and James Cook University, [15]Australian National University, [16]North Australia Water Strategies, [17]Entura, [18]HARC

# Acknowledgements

A large number of people provided a great deal of help, support and encouragement to the Northern Australia Water Resource Assessment (the Assessment) team over the past two and a half years. Their contribution was generous and enthusiastic and we could not have completed the work without them.

Each of the accompanying technical reports (see Appendix A) contains its own set of acknowledgements. Here we acknowledge those people who went 'above and beyond' and /or who contributed across the Assessment activities.

Much of our fieldwork and the data that were collected as part of the fieldwork were improved by the support that local communities provided to the Assessment team. They provided: hospitality; historical and contextual information; access to land and help in finding waterholes, bores and other features; and answers to a bewildering array of questions from the Assessment team. Importantly, they also gave us 'the time of day', showing us around the catchment and their landholdings and providing the local context that is so important for work of this kind. Land managers and landholders at a number of properties provided hospitality and support in many ways. They include Peter and Deborah Hagan, Mark and Isla Upham, Phil (Brolga) Yam and Louis, David and Greg Alloway, Trent and Christie Wild, Jack Brumby, Joe Edward Callope, Sylvester John Brumby, Simon and Kristy Cobb, Troy Setter, Colin Hughes, Bruce White, Jeff Pendarvis, Dean McFarlane and Nadine Thomas, Phil Hams, Jed (Peter) O'Brien, Brett Blanchett and Rob Boshammer.

A large number of people in private industry, universities and other organisations also helped us. Peter Stone, ex-Director of the Assessment and ex-CSIRO provided us with a great deal of support and was responsible for initiating the Assessment. Also, Clayton Lynch, Ian Baker, Steve Dwyer, Emma Jackson, John Brisbin, Ian Bate, Peter Jolly, Lindsay Hutley, Roger Nowland and Adrian Crook, Steve Austin, Tim Macnamara and James Coad.

Our documentation, and its consistency across multiple reports, were much improved by a set of copy-editors and Word-wranglers who provided great service, fast turnaround times and patient application (often multiple times) of the Assessment's style and convention standards. They include Sonja Chandler, Joely Taylor, Sophie Dowling, Karen Mobbs, Kath Kovac and Jill Sharkey. Greg Rinder provided graphics assistance, Nathan Dyer produced some wonderful videos of our findings and Adrian King and his team developed a great animation.

Colleagues in CSIRO, both past and present, provided freely of their time and expertise to help with the Assessment. This was often at short notice and of sufficient scale that managing their commitment to other projects became challenging. The list is long, but we'd particularly like to thank Bec Bartley, Brian Murphy, Oswald Marinoni, Harry King, Libby Pinkard, Liz Stower, Mike Grundy, Stephen McFallan, Philip Jackson, Melita Dahl, Heinz Buettikofer and Simon Gallant. CSIRO Communications, including Amy Edwards, Chris McKay, Siobhan Duffy and Anne Lynch but especially Thea Williams provided tremendous support to the Assessment team in terms of managing input to various media opportunities and co-ordinating the process of producing a number of web and hardcopy outputs. CSIRO administrative, financial, IT, knowledge management and legal staff provided great support, especially Dharma Ariaratnam, Sharyn Butts, Ali Wood, Paul Jupp, Jacky Rigby, Rachel Harms, Suzanne Blankley, Mick Hartcher, Meryn Scott, Nathan Morris, Lissett Florido, Allama Idris, Dominic Hogan, Nathan Stride, Sally Tetreault Campbell, Chris Le, Andrew Laurence, Scotty Hardy, Brendan Speet and Andrew Freebairn.

The Assessment gratefully acknowledges the members of the Indigenous Traditional Owner groups and corporations from the Fitzroy catchment who participated in the Assessment and who shared their deep perspectives about water, country, culture, and development. This includes people from the Gooniyandi, Bunuba, Nyikina Mangala, Ngurrara, and Yungngora groups. Our thanks also go to Damien Parriman and Frank Weisenberger from Walalakoo Aboriginal Corporation, Mel Sheppard and Andrea Myers from Bunuba Dawangarri Aboriginal Corporation, and to Vaughan Duncan, Keith Wood, and Tania Smith from Gooniyandi Aboriginal Corporation. Key assistance was provided by the Kimberley Land Council, particularly Will Durack of the Land and Sea Unit, and the KLC Research Ethics Advisory Committee. Further thanks to Professor Sue Jackson and Dr Sarah Laborde of Griffith University, and Professor Michael Douglas of the University of Western Australia. Thanks to Rangelands NRM, to Ben Drewe at the WA Department of Water, and to Catherine Marriott from the Kimberley and Pilbara Cattleman's Association.

Our client, the Commonwealth Department of Agriculture and Water Resources and then the Department of Infrastructure, Regional Development and Cities provided us with the challenge of attempting such a complex multi- and inter-disciplinary project in a very short time. Richard McLoughlin, Stephen Taylor, Drue Edwards, Nicole Pearson, Lucinda Burchfield, Leann Palmer and Lisa Hansen were critical to ensuring the Assessment proceeded smoothly.

The Assessment team received tremendous support from a large number of people in the Western Australia, Northern Territory and Queensland government departments and associated agencies. They are too numerous to all be mentioned here but they not only provided access to files and reports, access to spatial and other data, information on legislation and regulations, access to groundwater bores and answered innumerable questions but they also provided the team with their professional expertise and encouragement. For Western Australia, Leith Bowyer, Jacqueline Schopf, Geoff Moore, Clinton Revell, Trevor Price and Alistair Hoare. Rob Cossart, Richard George and Chris Ham deserve special thanks for the tremendous input they provided to multiple Activities within the Assessment. They put up with multiple visitors, asking multiple questions and gave great feedback and review on progress.

A long list of expert reviewers provided advice that improved the quality of our methods report, the various technical reports, the two catchment reports and the case study report. The Governance Committee and Steering Committees (listed on the verso pages) provided important input and feedback into the Assessment as it progressed.

Finally, the complexity and scale of this Assessment meant that we spent more time away from our families than we might otherwise have chosen. The whole team recognises this can only happen with the love and support of our families, so thank you.

# Contents