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Water resource assessment for the Mitchell 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

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Australian Government
Department of Infrastructure, Regional Development and Cities

ISBN 978-1-4863-1072-2 (paperback)

ISBN 978-1-4863-1073-9 (PDF)

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Citation

Petheram C, Watson I, Bruce C and Chilcott C (eds) (2018) Water resource assessment for the Mitchell 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: Watson I, Bruce C, Chilcott C, Petheram C and Tetreault Campbell S (2018) Chapter 1: Preamble. In: Petheram C, Watson I, Bruce C and Chilcott C (eds) (2018) Water resource assessment for the Mitchell 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.

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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 Colin Creighton (Independent Consultant) and the summary by Peter Stone (Bureau of Meteorology).

For further acknowledgements, see page xxii.

Photo Tate River, Mitchell catchment, Queensland. Source: CSIRO

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.

Chris Chilcott

Project Director

Key findings for the Mitchell catchment

Introduction

The Mitchell catchment is approximately 72,000 km^2 and flows into the Gulf of Carpentaria. It includes part of the Mareeba–Dimbulah Water Supply Scheme (MDWSS) (Figure 1-1) and supports a population of approximately 6000 people. There are no major urban centres. Pastoralism comprises over 95% of the catchment land use. The second largest land use, conservation reserves, covers about 3% of the catchment.

Indigenous people have continuously occupied and managed the Mitchell 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 Mitchell catchment has up to 3 million ha of potentially irrigable agricultural soils. Of this land area, 2.5 million ha are suitable for dry-season spray irrigation of cereals, cotton and soybean. The area suitable for furrow irrigation of the same crops is 1.3 million ha. There are 2.5 million ha and 1.3 million ha suitable for irrigation of sugarcane by spray and furrow irrigation, respectively. Just over 3 million ha are suitable for Rhodes grass with spray irrigation and 600,000 ha suitable for wet-season forage sorghum with spray irrigation. About 235,000 ha are suitable for aquaculture, such as prawns and barramundi grown in lined ponds. For all of these uses the land is considered moderately suitable with considerable limitations and would require careful soil management.

The total amount of beef produced each year by existing cattle breeding enterprises could be increased by using irrigated forages to overcome some of the productivity constraints inherent with reliance on native pastures. Access to standing green forage or high-quality hay (Figure 1-1) could increase weight gain in young cattle and enable early weaning of calves which, in turn, increases subsequent calving percentage by reducing nutritional pressure on lactating cows.

Significant new instream storages are possible. The four most cost-effective major instream dams in the Mitchell catchment are capable of delivering approximately 2800 GL in 85% of years, which is sufficient water to irrigate 140,000 ha of sugarcane. This could generate an annual gross value of production of approximately $720 million, and the region would benefit from $1.5 billion of economic activity reoccurring annually and the generation of about 7250 jobs.

Of the 2800 GL, 65% could be delivered by two potential dams, the Pinnacles dam site on the Mitchell River (2316 GL capacity) and Rookwood dam site on the Walsh River (1288 GL storage). These would yield 1248 GL and 575 GL, respectively, to agriculture in 85% of years.

Offstream water harvesting could extract 2000 GL annually, with 85% reliability, which would be sufficient to irrigate 200,000 ha of cotton. Groundwater opportunities in the catchment are relatively small and localised, with the Bulimba aquifer offering up to a total of 5 GL/year with well-placed bores.

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.

Instream storages, such as the potential Pinnacles and Rookwood dams, require trade-offs that occur over both time and space. The upfront cost of the potential Pinnacles dam is estimated at $755 million and would generate an income stream that may contribute to the cost of construction. The dam would have a major impact on habitat immediately below the dam, and would potentially have an ongoing moderate impact downstream by affecting the perennial flow of the Mitchell River. Pumping water into offstream storages (water harvesting) was predicted to have a minor impact to the flow habitat of freshwater aquatic, riparian and marine ecosystems. Offstream water storages usually have lower impacts than major instream dams, partly because water extraction occurs during floods and is restricted in low-flow periods. Streams, wetlands and riparian areas remain of critical importance to Indigenous people. They have cultural significance and provide nutritional food.

Figure 1-1 Hay production in the Mareeba–Dimbulah Water Supply Scheme

Overview of the Mitchell 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 climate of the Mitchell catchment is hot and semi-arid to dry subhumid. Generally, it is a water-limited environment and, as such, efficient and effective methods for capturing, storing and using water are at a premium.

- The mean and median annual rainfall – averaged across the Mitchell catchment – are 996 mm and 1002 mm, respectively. There is a strong rainfall gradient that runs from the flat north-west coastal corner (1300 mm annual mean) to the hilly south-east corner of the catchment (700 mm annual mean).
- Averaged across the catchment, 4% of rainfall occurs in the dry season (May to October). However, along the easternmost margins of the catchment, including in the MDWSS, low monthly rainfall totals (20 to 50 mm per month) occur throughout the dry season.
- Annual rainfall totals in the Mitchell catchment are unreliable 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, farmers and water managers can manage risk by using seasonal rainfall outlooks. Seasonal rainfall outlooks in January can be made with 65% skill.
- Important information about water availability (i.e. soil water and water in dams) is available when it is most important agriculturally – before planting time for most crops. By this means farmers can manage risk by choosing crops that optimise use of the available water, or by deciding to forfeit cropping.

Rainfall is difficult to store.

- Potential evaporation is higher than rainfall and exceeds 1500 mm over most of the catchment.
- Large farm-scale ringtanks lose about half their capacity to evaporation and seepage between April and December. Deeper farm-scale gully dams lose about 20% of their capacity over the same period. Using stored water early in the season is the most effective way to reduce losses.

No trend in annual rainfall is evident over the Mitchell catchment.

- Paleo-climate records indicate past climates have been both wetter and drier.
- Climate and hydrology data that 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 for periods when water is scarce. These are the periods that most affect businesses and the environment.

- Detailed scenario modelling and planning should be broader than just comparing a single climate scenario to an alternative future.

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

- Tropical cyclone season in the Mitchell 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.
- On average, the Mitchell catchment receives at least one cyclone in 75% of years. Between 1970 and 2016, a single cyclone occurred in 49% of years and two or more in 25% of years.

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

- For the Mitchell catchment, 24% of climate models project a drier future for the Mitchell catchment, 33% project a wetter future and 43% are within ±5% of the historical mean, indicating 'little change'. Recent research indicates tropical cyclones will be fewer but more intense in the future, though uncertainties remain.
- Annual variability, particularly in rainfall, is likely to pose the greatest climate challenge for irrigated agriculture.
- Future changes in temperature, vapour pressure deficit, solar radiation, wind and carbon dioxide will result in positive and negative changes to crop applied irrigation water and yield under irrigation in northern Australia. However, changes to irrigated crop applied irrigation water and yield under future climates are likely to be modest compared to improvements arising from new crop varieties over the next 40 years. These changes will be large and are unpredictable.

THE MITCHELL RIVER

The Mitchell River has the largest median annual streamflow of any river in northern Australia. It flows into the Gulf of Carpentaria, an important part of northern Australia's marine environment with high ecological and economic values.

- The mean annual streamflow from the Mitchell catchment into the Gulf of Carpentaria is 15,570 GL. A small proportion of very wet years bias the mean, such that it is 20% higher than the median annual streamflow.
- Annual variability in streamflow is comparable with other rivers in Australia that have similar mean annual runoff, but two to three times greater than rivers from the rest of the world in similar climates.
- Approximately 95% of the runoff in the Mitchell catchment occurs during the wet season. This means that in the absence of suitable groundwater, irrigation during the dry season will require surface water storage.

Broadscale flooding is common below the confluence of the Palmer and Mitchell rivers.

- The current apex of the Mitchell River Fan Aggregation, a series of alluvial plains of varying geological ages, is located near the confluence of the Palmer and Mitchell rivers. Below the apex flood flows spread extensively across a large number of distributary channels.

- Although large areas of potential agricultural soil below the apex are prone to broadscale flooding and access limitations, there are large areas of land above the confluence of the Palmer and Mitchell rivers that do not regularly flood.
- Of the ten largest flood events over the last 35 years at Gamboola, a gauging station about halfway down the catchment, one event occurred during January, six in February and three in March. Even with flood protection, sowing on the flood-prone areas of the Mitchell Fan Aggregation before April is challenging due to access limitations.
- Flooding is ecologically critical because it connects offstream wetlands to the main river channel, allowing the exchange of fauna, flora and nutrients required for wetland survival.
- Floods are economically critical because they underpin the health of the recreational and commercial fisheries in the Gulf of Carpentaria, including a barramundi fishery and the Northern Prawn Fishery, whose catch of prawns was worth $107 million in 2015.

THE MITCHELL CATCHMENT SUPPORTS HIGH-VALUE CONSERVATION AND RECREATIONAL AND COMMERCIAL USES

The Mitchell catchment is largely intact, though it is not pristine.

- The rivers of the Mitchell catchment mainly flow freely. Interruptions to flow have been restricted to the creation of Lake Mitchell in the upper reaches of the Mitchell River and riparian pumping and releases into the upper Walsh River from the Barron River system.
- There has been relatively little clearing, except in the MDWSS, 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. There have been deliberate and accidental plant and animal introductions, including the release of exotic fish such as the spotted tilapia.

The Mitchell catchment supports wetlands of national importance.

- The Mitchell catchment has three wetlands of national importance: the Mitchell River Fan Aggregation (Mitchell River delta), the Spring Tower Complex, and the Southeast Karumba Plain Aggregation.
- Being perennial, the Mitchell River differs from its four major tributaries: the Alice, Palmer, Walsh and Lynd rivers and the many minor tributaries, which only flow for part of the year.
- The Southeast Karumba Plain Aggregation is one of four important bird habitats in the catchment. It supports the second largest summer population of wader birds in Australia.

The Mitchell catchment supports several important habitats, including riparian vegetation, permanent waterholes, mangroves and salt flats.

- Riparian vegetation lines many of the larger watercourses and are generally more fertile and productive than surrounding terrestrial vegetation.
- Persistent waterholes are key aquatic ‘refugia’, important for sustaining ecosystems in the Mitchell catchment. Some persistent waterholes have cultural significance.

The Mitchell River supports a high species richness of freshwater fishes, with 57 species recorded, as well as high endemism for fish.

- Several fish in the Mitchell catchment are migratory, undertaking large-scale movement through streams and across the floodplain during their life cycle, including the freshwater sawfish, black catfish, spangled perch and barramundi (a species of commercial and recreational significance).
- The freshwater sawfish, which is listed as vulnerable in the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) is found in the Mitchell catchment. This fish is now rarely detected on the east coast of Queensland.
- The catchment is also home to the little-known freshwater whipray; although, due to their rarity, there are few recorded observations in the Mitchell catchment.

INDIGENOUS VALUES, RIGHTS AND DEVELOPMENT GOALS

Indigenous people are a significant and growing population of the Mitchell 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 Indigenous people in the Mitchell catchment. The river supports food security and good nutrition, particularly at Kowanyama 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 Mitchell catchment is important to understanding present circumstances. This history also informs responses by the Indigenous people 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.
- There are current cultural heritage considerations that restrict Indigenous capacity to respond to development proposals.

Native title and Indigenous land use agreements are important ways in which Indigenous interests in country are recognised and managed. Securing native title remains an important development goal for Indigenous people in the Mitchell catchment.

- Indigenous people established the first catchment management group in the Mitchell catchment and have strong expectations for ongoing involvement in water, catchment and development planning.
- Should development of water resources occur, participants in this study area generally preferred flood harvesting, which would fill offstream storages. Large instream dams in major rivers were consistently among 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.

Our wetlands provides bush tucker for future generations, when we die we want our kids living like that. Not living off whiteman's tucker, (but) free tucker. Got to have water or this country would be dead.

Mitchell catchment Traditional Owner

We need state, federal and local governments to take us seriously to develop Traditional Owner economic opportunities. We need investment in our region that includes Traditional Owners.

Mitchell catchment Traditional Owner

OPPORTUNITIES FOR AGRICULTURE AND AQUACULTURE

- About two-thirds (16,000 ha) of the MDWSS is in the upper Walsh River part of the Mitchell catchment. Production is dominated by mangoes, bananas, avocados, sugarcane and a range of other tree, field and horticultural crops.
- Compared to the rest of the catchment, this irrigation area, about 0.2% of the catchment, experiences a more forgiving, temperate climate for cropping, including receiving more dry-season rainfall.
- There is very little broadacre cropping in the Mitchell catchment below the MDWSS, although trials in the early 1950s grew sorghum, cowpea, lucerne, Rhodes grass and other crops further downstream.

There is much more soil suited for irrigated agriculture in the Mitchell catchment than there is water to irrigate it.

Up to 3 million ha of the Mitchell 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.

[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.

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 2.5 million ha of the Mitchell catchment are Class 3 for irrigated cereals, cotton and soybeans using spray irrigation, but only about 1.3 million ha are suitable using furrow irrigation for the same crops.
- About 2.5 million ha of the Mitchell catchment are Class 3 for irrigated sugarcane using spray irrigation, but only about 1.3 million ha are suitable using furrow irrigation.
- Just over 3 million ha of the Mitchell catchment are Class 3 for Rhodes grass using spray irrigation. About 600,000 ha are classified similarly for wet-season forage sorghum using spray irrigation.

Opportunistic dryland cropping is possible, but it carries considerable risk.

- For many dryland crops January is the sowing window for maximum yield. When trafficability allows for sowing in this period, yields that achieve break-even gross margins can be obtained with most crops in 80% of years. However in practice, break-even yields are unlikely to be achieved in 80% of years because trafficability will be limited at optimum sowing time.
- Dryland cropping has potential on the heavier-textured (clay) soils of the Mitchell catchment as a consequence of their higher soil water storage capacity. These soils are mainly found on the Mitchell River delta and in the mid-catchment.
- The better clay soils are, however, often not trafficable during the wet season. This provides significant operational challenges for dryland cropping, and potential yields may not be realised in many years.

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

- Irrigation can increase yield by up to about 50% compared with dryland crops, and can increase the likelihood of achieving break-even gross margins by about 25%.
- A wide range of crops is potentially suited to irrigated production in the Mitchell catchment. These include cereals, pulses, forages, vegetables and perennial fruit tree crops, as well as industrial crops such as sugarcane and cotton.
- Broadacre crop yields under irrigation compare favourably with crop yields for other irrigated areas of north Queensland (e.g. the Burdekin).

Seasonal applied irrigation water by crops can vary enormously with crop type (i.e. its duration of growth), season of growth and, to a lesser extent, soil type. For example, sorghum planted during the wet season will usually require 2 ML/ha of supplementary irrigation only in the final stages of growth, while a high-yielding perennial forage such as Rhodes grass requires up to 15 ML/ha during the production cycle.

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.

- The alluvial lowlands in the western part of the catchment and the clay soils in the mid-catchment are most suitable for furrow irrigation, although there are risks due to flooding and secondary salinisation.
- While dryland cropping is unlikely to be viable on its own, particularly due to poor trafficability at sowing time, 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 peanuts returning the highest gross margins. For sugarcane and cotton, positive gross margins are only achieved if processing facilities (sugar mill, cotton gin) are available locally to reduce cartage costs.
- The gross margins for sugarcane and cotton are consistent with other regions in Queensland.
- Compared with broadacre crops, gross margins of horticultural crops are considerably higher for avocados, 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.
- Outside of the MDWSS there is relatively little experience in implementing rotational two crop per year farming systems.
- 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.
- A rotation system of cotton and mungbean grown within a year is capable of producing yields similar to the sum of the individually grown crops, and could be sufficient to meet capital costs of development in the order of $25,000/ha.
- The development of a range of alternatives for rotational two crop per year farming systems, 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 mitigated by good management and new technology.

- The pesticide and fertiliser application rates required to sustain crop growth vary widely among crop types. Selecting crops and production systems that minimise the requirement for pesticides and fertilisers can simultaneously reduce costs and negative environmental impacts.
- Poorly managed irrigated agriculture can result in the addition of nutrients to waterways and a rise in groundwater levels. This has the potential to boost production of algae, which can result in ecological changes.

- 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.
- 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 relevance to northern Australia.

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

- The dominant beef production system in the Mitchell catchment is cow–calf breeding, with several variations in the post-weaning management and marketing of male animals produced by the breeding herds.
- 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, which are suited to the Mitchell catchment.
- Dryland forage sorghum, sown halfway through the wet season when soil profiles are full of water, can produce up to about 10 t/ha of forage, especially on a clay soil that can store soil water well into the dry season.
- Irrigated forage sorghum can produce yields of around 20 t dry matter/ha, while Rhodes grass can produce forage yields in excess of 30 t dry matter/ha, especially when it is fertilised with large amounts of nitrogen and other major nutrients.
- Until now, irrigated forages in tropical Australia have mostly been used for small-scale hay production rather than direct grazing. There is an opportunity for irrigated forages, grown at the hundreds of ha 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:
  - grazing of forages by young cattle to increase their weight at sale from approximately 300 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. Furthermore, both options yield positive net profits. However, when the on-farm capital costs of development are considered in a Net Present Value (NPV) analysis, very few options can achieve a positive NPV. The forage options that can produce a positive NPV assume moderate capital costs of around $12,000 per ha and beef prices of at least $3.00/kg.

Pond-based black tiger prawns or barramundi in saltwater or red claw crayfish in freshwater ponds offer potentially high returns.

- For marine species, there are approximately 235,000 ha of coastal land suitable for lined aquaculture ponds.
- Prawns and barramundi have proven land-based culture 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 cultured in either extensive (low density, low input) or intensive (higher density, higher input) pond-based systems. Land-based culture of barramundi would likely be intensive.
- Long transport distances for specially formulated feed and finished products contribute to high costs of aquaculture production, and year–round road access to coastal areas is not currently possible. Overcoming these challenges, skilfully managed prawn and barramundi pond-based aquaculture enterprises can be profitable in the Mitchell catchment.
- The remote location of the Mitchell catchment confers some biosecurity advantages to aquaculture production.
- Aquaculture enterprise development in the Mitchell catchment will face fewer regulatory constraints than those in catchments that drain 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 regulations constrain development along the east coast of Australia.

GROUNDWATER RESOURCES IN THE MITCHELL CATCHMENT ARE LOCALISED

- The Bulimba Formation aquifer, within the Karumba Basin and overlapping the lower half of the Mitchell catchment, offers the greatest opportunity for groundwater resource development in the Mitchell catchment.
  - This aquifer is artesian and located approximately 50 km west of where the rocks of the Bulimba Formation aquifer outcrop the aquifer. This means that water is currently under pressure, sufficient to make bores flow without the cost of pumping. If sufficiently large quantities of groundwater were extracted from this aquifer, then it may cease being artesian.
  - Recharge to the Bulimba Formation aquifer occurs as infiltration, in the vicinity of where the aquifer outcrops at the ground surface, following intense wet-season rainfall events and from streamflow where rivers traverse the outcropping rock. It is estimated to be 10 GL/year.
  - Groundwater is fresh, with low salinity (<1000 µS/cm) and low ionic composition making the water suitable for a variety of uses. However, low pH groundwater can be corrosive to bore infrastructure.
  - The aquifer is located at potentially economic depths at most locations, with the depth below land surface ranging from approximately 20 m in the outcrop and subcrop area to 150 m towards the coast.

  - With appropriately sited groundwater bores, up to 5 GL of water could be extracted from the Bulimba Formation aquifer. Site-specific extraction volumes will vary for each location depending on vicinity to and impact on existing users or environmental assets.
- The Gilbert River Formation may offer up to 5 GL of water for extraction in and near (within 50 km) of the aquifer outcrop. However, this formation is deeper than the Bulimba Formation and, beyond 50 km of the outcrop, drilling costs will be prohibitively expensive.
- Elsewhere in the Mitchell catchment, groundwater use is largely limited to stock and domestic use (<0.5 GL/year). There may be some localised opportunities for small-scale irrigation from alluvial aquifers.

Groundwater discharge supports a diverse range of ecosystems.

- Natural discharge to the land surface supports a range of groundwater-dependent ecosystems such as dry-season streamflows, persistence of instream waterholes and groundwater-fed vegetation. 'Submarine' discharge to the ocean sustains unique marine ecosystems.
- Extraction of groundwater for consumptive purposes will result in a corresponding reduction in 'natural' discharge to water bodies and vegetation. These changes will be location dependent and will need to be considered on a case-by-case basis if in the vicinity of new groundwater developments.

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.
- In some ephemeral river reaches streambed recharge weirs, up to 3 m in height, 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 current 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

Large water resource developments in the Mitchell will require surface water capture and storage.

- Less than 33% of the catchment's water presents itself for storage in major dams. Approximately 67% of runoff from the Mitchell catchment is generated below the confluence of the Mitchell and Lynd rivers, where the topography and geology are unsuitable for major dams.
- The total amount of controlled water releases possible from four of the most commercially favourable major instream dams in the Mitchell catchment is approximately 2800 GL in 85% of years. This is sufficient water to irrigate 140,000 ha of sugarcane (2% of the catchment) after

accounting for conveyance and field application losses. Collectively, the four dams would cost about $2.75 billion, or $980/ML released at the dam wall. This could generate an additional $770 million per year in ongoing regional economic benefits and an additional 3700 jobs.

- If used to their full amount, the four potential dams would reduce mean and median annual discharge from the Mitchell River by about 22% and 24%, respectively.
- Suitably sited large farm-scale gully dams are a relatively cost-effective method of supplying water. Favourable sites in the Mitchell catchment are mainly limited to the Alice River system, where there is a coincidence of suitable topography and soil for embankments close to soils suitable for irrigated agriculture.
- Indigenous customary residential and economic sites were usually concentrated along major watercourses and drainage lines. Consequently, potential instream dams are more likely to impact on areas of high cultural significance than most other infrastructure developments of comparable size.
- Most potential dam sites in the Mitchell catchment would inundate some regional ecosystems considered to be 'of concern'. Complex changes in habitat resulting from inundation could create new habitat to benefit some of these species, while other species would be negatively impacted by loss of habitat.

Most streamflow within the Mitchell catchment cannot be readily captured or stored offstream. Approximately 80% of total streamflow is discharged in the highest 10% of days, of which only a small proportion could be pumped.

- Water released from ringtanks for irrigation (after evaporative and seepage losses) would cost about $780/ML. This estimate does not including pumping costs, and assumes irrigation of short (2 to 3 months) or medium (4 to 6 months) duration crops. The cost of ringtanks would be about twice that of the more cost-effective major dams, including the operating costs.
- It is physically possible to pump 2000 GL of water in 85% of years from the Mitchell catchment into ringtanks adjacent to soils suitable for irrigated agriculture. This would reduce the mean and median streamflow by approximately 15% and 28% respectively, near the mouth of the Mitchell River.
- This volume of water could potentially be stored in 500 ringtanks (each of 4 GL capacity). Assuming unconstrained development, this could irrigate up to 200,000 ha of cotton (2.7% of the catchment) after accounting for evaporative, conveyance and field application losses.
- This could potentially generate an annual gross value of production of approximately $1.2 billion, creating an additional $1.3 billion/year of regional economic benefits and generating about 11,800 full-time equivalent jobs.
- Pumping water into ringtanks will slightly reduce floodplain inundation during 'low flood' years (<1 in 2 annual exceedance probability) and have negligible effect on floodplain inundation during 'moderate' and 'large' flood events.
- The scale of irrigation that natural waterholes could support is typically small (e.g. 1 to 60 ha). However, where they coincide with land suitable for irrigation they may be cost-effective in staging a development, where lessons are learned and mistakes made on a small-scale area before large capital investment occurs.

- The main limitations to the use of wetlands and persistent waterholes for the consumptive use of water is that they have considerable ecological and, in some cases, cultural significance.

The two most cost-effective potential dam sites in the Mitchell catchment illustrate the opportunities to provide sufficient water to support an area of sugarcane the size of the lower Burdekin.

- The potential Pinnacles dam site on the Mitchell River, located approximately 80 km upstream of the confluence of the Mitchell and Walsh rivers where there is a large area (greater than 100,000 ha) of soils that are moderately suitable for irrigated agriculture.
- The optimum construction for the potential Pinnacles dam is a roller compacted concrete dam. At the nominated full supply level it would require a 1.85 km long earth-fill embankment saddle dam, both of which could be constructed for an estimated $755 million.
- The reservoir of the potential Pinnacles dam site could potentially store 2316 GL and would yield 1248 GL at the dam wall in 85% of years.
- Water from the potential Pinnacles dam is likely to cost approximately $605/ML when supplied at the dam wall in 85% of years; losses in conveying water down the river and along supply channels to the farm gate would significantly increase on-farm water costs.
- If used to its full extent, the potential Pinnacles dam would reduce mean and median annual discharge from the Mitchell catchment by about 8% and 10%, respectively.

The next most cost-effective potential major dams are on the Walsh and Palmer rivers; the former is closer to soils suitable for irrigated agriculture.

- The potential Rookwood dam on the Walsh River would be a roller compacted concrete dam located about 28 km north-west of Chillagoe, below which a large area of soils (greater than 100,000 ha) exists that are moderately suitable for irrigated agriculture.
- The reservoir impounded by the dam could potentially store 1288 GL at the nominated full supply level and yield 575 GL in 85% of years.
- Water from the potential Rookwood dam is likely to cost approximately $1140/ML when released at the dam wall in 85% of years; losses in conveying water down the river and along supply channels to the farm gate would significantly increase on-farm water costs.

A dam at the Nullinga site on the upper Walsh River could provide for an expansion of irrigated production in the MDWSS and with a delivery pipeline could irrigate areas currently supplied from Tinaroo Falls Dam.

- Although the Nullinga site has a high cost to yield ratio, its proximity to the existing MDWSS and its potential to ensure the long-term security of the Cairns water supply have led to interest in its possible development.

CHANGES IN TIMING AND VOLUME OF FLOW HAVE ECOLOGICAL IMPACTS

- While irrigated agriculture might, at its upper limit, occupy only 3% of the landscape, it can result in substantial changes to river flow volumes and patterns.

The impact of a major instream dam on aquatic, riparian and near-shore marine ecology is strongly related to its position in a catchment and the size of the reservoir relative to the volume of streamflow.

- The potential Pinnacles dam would have a major impact on freshwater sawfish immediately below the dam, but would have a minor impact on sawfish near the mouth of the Mitchell River.
- The potential Pinnacles dam would have a moderate impact on the flow habitat of 1 of 11 marine and estuarine species and habitats examined at the Mitchell River mouth and a minor impact on the other 10. By contrast, dams on the Palmer, Mitchell, Walsh or Lynd would have negligible impact on the flow habitat of species near the river mouth.
- A potential single dam on the Mitchell River would have a considerably larger impact on species and habitats at the river mouth and floodplain than single dams on the Walsh or Palmer rivers. This is partly due to the larger capacity of the potential Pinnacles dam. It also highlights the importance of the perennial flow regime of the Mitchell River above its confluence with the Walsh River relative to its ephemeral tributaries.
- The high position of the potential Nullinga dam site in the Walsh River catchment and the reservoir's relatively small capacity mean that its impact is highly localised. The impact of the potential Nullinga dam on species and key habitats at the mouth of the Mitchell River is negligible.

At equivalent storage capacities, pumping water into offstream storages (water harvesting) has less impact on freshwater aquatic, riparian and marine ecosystems than major instream dams.

- Water harvesting at high commence-to-pump thresholds of 2400 GL/year will have minor environmental impacts.
- There are several effective strategies for minimising the impacts of water extraction on species and habitat, such as increasing the water-level thresholds above which water can be pumped, or only permitting pumping to commence once a certain volume of water has flowed past the lowermost gauge. These strategies, however, all lower the reliability at which potential irrigators can extract their allocation of water.
- The species most heavily impacted by water harvesting are migratory fish, and the species least impacted are the stable-flow spawners, which are food for the larger predatory species.
- A reduction in annual streamflow of 20% from the Mitchell catchment was calculated to reduce the median annual prawn catch across the whole Northern Prawn Fishery by about 2.5%, though the median annual reduction in some regions could be as high as 11%.

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 impact 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.

COMMERCIAL VIABILITY AND OTHER CONSIDERATIONS

There is potential for the economic value of irrigated agriculture in the Mitchell catchment to increase three to four times.

- The total gross value of agricultural production in 2015–16 was approximately $225 million. Of this, livestock commodities account for just over 50% of the total ($117 million) and cropping about 40% ($95 million).
- Agriculture provides about 32% of all jobs in the Mitchell catchment.

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 infrastructure developments are complex and costly. It would be prudent to ensure that sufficient funds remain after the construction phase to safeguard the operation of new enterprises in the likely occurrence of 'failed' years at the start of its 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 partly due to financial return imperatives driving an overly optimistic assessment of the time frame for positive returns; unanticipated difficulties, particularly where subsurface excavations are required; and the difficulty of accurately planning and budgeting over many years.

It is prudent to stage developments to limit negative economic impact 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, despite these learnings, each new location and development will provide unique challenges.
- Staging and allowing 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 revenues, 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, and the more strongly interdependent its components are, 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 places a significant cost burden on industry in the Mitchell catchment.

- The current road network is sparse and the major roads are often prone to flooding, restricting wet-season access. The main road to Kowanyama is typically closed between December and April, which presents challenges to coastal aquaculture and large scale water harvesting.
- Most truck movements comprise cattle to southern feedlots, to Karumba Port for export or to export-certified abattoirs in north Queensland.
- There is currently no broadacre cropping in the catchment. The nearest cotton gin to the catchment is in Emerald, a road trip of 995 km. There is a sugar mill in Mareeba.
- Transport costs to major southern markets will add significant costs and make supplying low-value crops unviable when competing against southern production. Local processing will ensure better farm gate returns and potentially generate by-products such as the cogeneration of energy.
- There are established export supply chains for live cattle and wild harvested fisheries. Exports of locally processed beef and horticultural or broadacre crops out of local ports and airports are not yet at a sufficient scale to justify investment in export infrastructure. There are currently no refrigerated backloading opportunities in the Mitchell catchment, although any future development could use consolidation, packing and transport facilities at Mareeba or Cairns.

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 would be generated by dryland production.
- In the Mitchell catchment, irrigation development could result in an additional $1.22 of indirect regional economic benefits for every $1.00 spent on construction during the construction phase. The regional economic impact of an annual increase in irrigated agricultural output of $100 million per year is estimated to be an additional $110 million of increased economic activity.
- During the construction phases, aquaculture development may result in a regional economic benefit similar to that of irrigated agriculture. Once the business has been established, the regional economic impact of aquaculture, for every $100 million per year output, is estimated to be an additional $96 million of increased economic activity.

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

- The population increase needed to sustain a substantial irrigation development would require significant investment in community infrastructure and services, such as schools, medical services and housing.

- Recent developments (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.

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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. In addition to excellent hospitality they 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. We especially thank the town of Chillagoe for providing use with the hospitality to run a major workshop, and to participate in another, which stretched the town’s facilities. In both cases, the workshops were a great success. 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. We’d especially like to thank John Brisbin and his colleagues in the Northern Gulf Natural Resource Management Group. 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, 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 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 Mitchell catchment who participated in the Assessment and who shared their deep perspectives about water, country, culture, and development. This includes members of the Western Yalanji, Kuku Djungan, Mbabaram, Muluridji, and Wakaman peoples, and the Traditional Owners of Kowanyama lands. The support and assistance of multiple regional Indigenous organisations and their staff also made this work possible. In particular the Assessment would like to thank Julia Taylor from the North Queensland Land Council, Michael Yam from Kowanyama Aboriginal Council, and Chris Hannocks and John Clark from the Kowanyama Aboriginal Land and Natural Resource Management Office. Ron Archer from the Alliance of the Northern Gulf Indigenous Corporations (ANGIC), Gerry Turpin of the Mitchell River Traditional Custodian Advisory Group (MRTCAG), and the Board of the Cape York Land Council (CYLC) provided crucial initial guidance to the Assessment, and support from Northern Gulf Resource Management (NGRM) enabled CSIRO and Traditional Owner participation in a major regional workshop.

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 Australian, 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 Queensland, Gareth Jones, Greg Mason, Mark Poggio, Warwick Squire, Irene Kernot, Bill Johnston, Darren Thompson, Bernie English, Joe Rolfe, Graham Herbert, Sasha Smith, Edward Thomas, Alex Loy, Shannon Dempster, Nigel Kelly, Vince Manley, Margaret Barker and Neil Enderlin deserve special thanks.

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

Part I Introduction

Chapter 1 provides background and context for the Assessment.

This chapter provides the context for and critical foundational information about the Assessment with key concepts introduced and explained.

1 Preamble

Authors: Ian Watson, Caroline Bruce, Chris Chilcott, Cuan Petheram and Sally Tetreault Campbell

1.1 Context

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’ (PMC, 2015), which highlighted the opportunities for regional development based on northern Australia’s water resources. In particular, many rural communities in northern Australia see irrigated agriculture as a means of reversing the long-term human population declines in these areas and as a critical element of broader regional development. This belief is supported by commentators overseas who have observed that no country or region in a tropical or sub-tropical climate has experienced significant economic development without developing their water resources (Biswas, 2012). Furthermore, studies in Australia have shown that irrigation production in the southern Murray–Darling Basin generates a level of economic and community activity that is three to five times higher than would be generated by rainfed (dryland) production (Meyer, 2005). Domestic investors in irrigation in southern Australia are also increasingly looking north for agricultural opportunities due to recent experience of drought, overallocation of water resources, future projections of reduced rainfall in southern Australia, and perceptions of an abundance of water in northern Australia. Some foreign companies have already invested heavily in irrigation in northern Australia and this trend is likely to continue.

Development of northern Australia is not a new idea; there is a long history of initiatives to develop cultivated agriculture in the tropical north of Australia. Many of these attempts have not fully realised their goals, for a range of reasons. It has recently been highlighted that, although northern Australia’s environment poses challenges for irrigated agriculture, the primary reason that many of the schemes did not fully realise their goals is that they did not have sufficient or patient capital to overcome the failed years that inevitably accompany every new irrigation scheme (Ash et al., 2014). The only large schemes still in operation in northern Australia had substantial government financial support during the construction phase, as well as ongoing support during establishment and learning phases.

Although 95% of Australia’s irrigated land lies south of the Tropic of Capricorn, and 65% of this is located in the Murray–Darling Basin, northern Australia is now seen as an opportunity to implement ‘the right policies, at the right time’ (PMC, 2015).

Between 2000 and 2050, the world’s population is projected to grow from 6 to 9 billion people (UNESCO, 2009), and increased food and fibre production is needed to meet anticipated increased demand. Most of this growth is projected to occur in the tropics, particularly sub-Saharan Africa and South-East Asia. Two-thirds of the world’s food insecurity is in Asia, and sharp upward price movements in food have the potential to result in political and social unrest in this region. At the same time, it is projected that Asia will become home to the majority of the world’s middle class, which will result in an increasing demand for high-quality food produce. Irrigated agriculture in northern Australia has the potential to meet some of that demand as well as the increasing demand for beef.

The efficient use of Australia's natural resources by food producers and processors requires a good understanding of soil, water and energy resources so they can be managed sustainably. Finely tuned strategic planning will be required to ensure that investment and government expenditure on development are soundly targeted and designed. Northern Australia presents a globally unique opportunity (a greenfield development opportunity in a first-world country) to strategically consider and plan development. Northern Australia also contains ecological and cultural assets of high value and decisions about development will need to be made within that context. Good information is critical to these decisions.

Most of northern Australia's land and water resources have not been mapped in sufficient detail to provide for reliable resource allocation, mitigate investment or environmental risks, or build policy settings that can support decisions. Better data are required to inform decisions on private investment and government expenditure, to account for intersections between existing and potential resource users, and to ensure that net development benefits are maximised.

In 2013, the Australian Government commissioned CSIRO to undertake the Flinders and Gilbert Agricultural Resource Assessment in north Queensland. This assessment developed fundamental soil and water datasets, and provided a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of agricultural development in two catchments in north Queensland (Petheram et al., 2013a, 2013b). It identified several opportunities for large-scale (>10,000 ha) irrigation development, based on the coincidence of suitable soils and new water storage capacity. The Flinders and Gilbert Agricultural Resource Assessment described the data and analysis required to identify and support development opportunities in north Queensland. The outcome of the assessment was to reduce the uncertainty for investors and regulators, and to give the base information to allow development to occur in a sustainable manner. However, this previous study covered only 155,000 km^2 (approximately 5%) of northern Australia, and acquiring a similar level of data and insight across northern Australia's more than 3 million km^2 would require more time and resources than were available at the time.

Consequently, the 2015 Northern Australia White Paper prioritised about a dozen regions in northern Australia where more detailed water and agriculture resource assessments should be undertaken. It also provided $15 million to initiate the Northern Australia Water Resource Assessment in the Fitzroy catchment (Western Australia), Darwin catchments (Northern Territory) and Mitchell catchment (Queensland) (Figure 1-1).

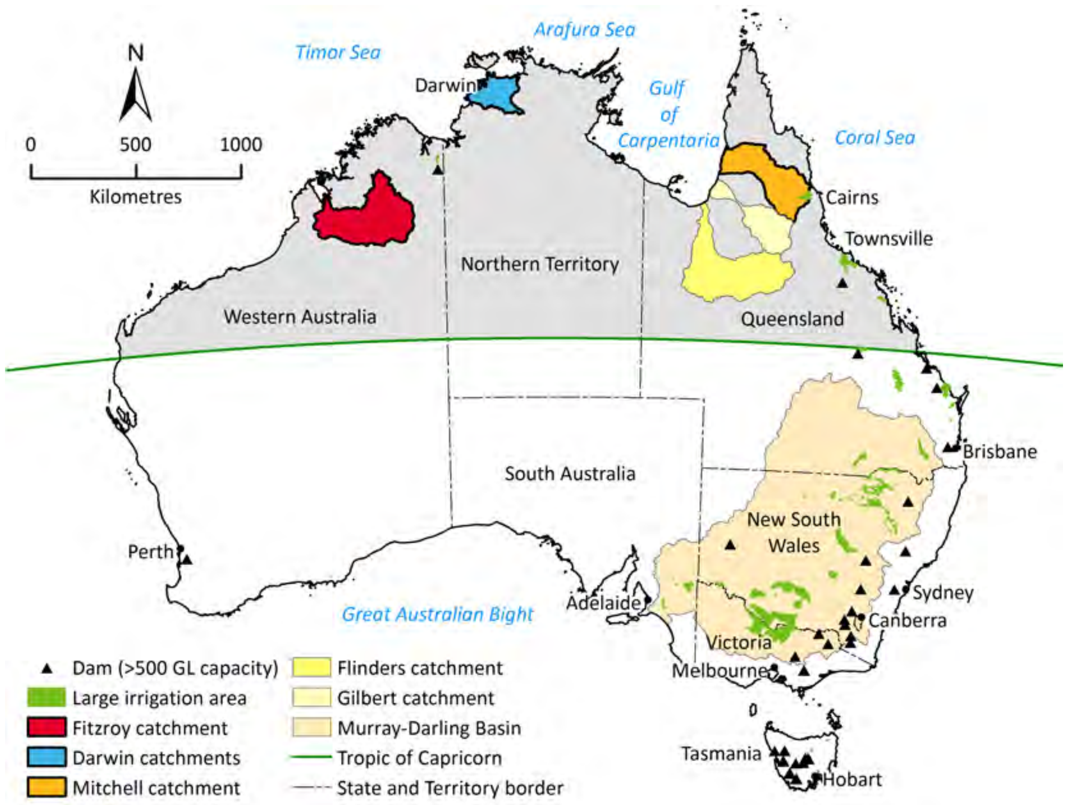

Figure 1-1 Map of Australia showing Assessment area
Northern Australia is defined as the part of Australia north of the Tropic of Capricorn. The Murray–Darling Basin and major irrigation areas and major dams (greater than 500 GL capacity) in Australia are shown for context.

1.2 The Northern Australia Water Resource Assessment

The Northern Australia Water Resource Assessment has undertaken a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water resource development in three priority areas in northern Australia: the Fitzroy catchment, the Darwin catchments and the Mitchell catchment.

The Fitzroy and Mitchell catchments were identified by the Northern Australia White Paper as being suitable candidates for a large-scale assessment of the economics and sustainability of irrigated agriculture because they appear to have large areas of soil suitable for irrigated agriculture and adequate water. The four catchments adjacent to Darwin were chosen because they are relatively close (about one to four hours' drive) to the third largest population centre in northern Australia, Darwin, the capital of the Northern Territory.

The assessment of each of the three study areas aimed to:

- evaluate the climate, soil and water resources
- identify and evaluate water capture and storage options
- identify and test the commercial viability of irrigated agricultural, forestry and aquaculture opportunities
- assess potential environmental, social and economic impacts and risks of water resource, aquaculture and irrigation development.

The techniques and approaches used in the Assessment were specifically tailored to the three study areas.

It is important to note that, although these four key research areas are listed sequentially here, activities in one part of the Assessment often informed (and hence influenced) activities in an earlier part. For example, understanding ecosystem water requirements (the third part of the Assessment, described in Part IV of this report) was particularly important in establishing rules around water extraction and diversion (i.e. how much water can be taken and when it should be taken – the second part of the Assessment, described in Part III of this report). Thus, the procedure of assessing a study area inevitably included iterative steps, rather than a simple linear process.

In covering the key research areas above, the Assessment was designed to:

- explicitly address the needs of and aspirations for local development by providing an objective assessment of resource availability, with consideration of the environmental and cultural issues
- meet the information needs of governments as they assess sustainable and equitable management of public resources, with due consideration of environmental and cultural issues
- address the due diligence requirements of private investors, by exploring questions of profitability and income reliability of agricultural and other developments.

Drawing on the resources of all three tiers of government, the Assessment built on previous studies, drew on existing stores of local knowledge, and employed world-class scientific expertise, with the quality assured through peer-review processes.

The Northern Australia Water Resource Assessment took two and a half years between 16 December 2015 and 30 June 2018.

1.2.1 SCOPE OF WORK

The Assessment comprised several activities that together were designed to explore the scale of the opportunity for irrigated agricultural development in the Fitzroy, Darwin and Mitchell catchments. The full suite of activities is outlined below (Section 1.2.2), and a series of technical reports was produced as part of the Assessment (listed in Appendix A).

In stating what the Assessment did, it is equally instructive to state what it did not do.

The Assessment did not seek to advocate irrigation development or assess or enable any particular development; rather it identified the resources that could be deployed in support of potential irrigation enterprises, evaluated the feasibility of development (at a catchment scale) and considered the scale of the opportunities that might exist.

In doing so, the Assessment examined the monetary and non-monetary values associated with existing use of those resources, to enable a wide range of stakeholders to assess for themselves the costs and benefits of given courses of action. The Assessment is fundamentally a resource evaluation, the results of which can be used to inform planning decisions by citizens, investors, and the different tiers of government – local council, state and territory, and Australian Government. The Assessment does not replace any planning processes, nor does it seek to. It does not recommend changes to existing plans or planning processes.

The Assessment sought to lower barriers to investment in the Assessment area by addressing many of the questions that potential investors would have about production systems and methods, crop yield expectations and benchmarks, and potential profitability and reliability. This information base was established for the Assessment area as a whole, not for individual paddocks or businesses.

The Assessment identified those areas that are most suited for new agricultural or aquaculture developments and industries, and, by inference, those that are not well suited. It did not assume that particular sections of the three study areas were in or out of scope. For example, the Assessment was 'blind' to issues such as land clearing that may exclude land from development now, but might be possible in the future.

The Assessment identified the types and scales of water storage and access arrangements that might be possible, and the likely consequences (both costs and benefits) of pursuing these possibilities. It did not assume particular types or scales of water storage or water access were more preferable than others, nor does it recommend preferred development possibilities.

The Assessment examined resource use unconstrained by legislation or regulations, to allow the results to be applied to the widest range of uses possible, for the longest time frame possible. In doing so, it did not assume a particular future regulatory environment but did consider a range of existing legislation, regulation and policy and the impact of these on development.

It was not the intention – and nor was it possible – for the Assessment to address all topics related to water, irrigation and aquaculture development in northern Australia. Important topics that were not addressed by the Assessment (e.g. impacts of irrigation development on terrestrial ecology) are discussed with reference to, and in the context of, the existing literature.

Functionally, the Assessment adopted an activities-based approach to the work (which is reflected in the content and structure of the outputs and products, as per Section 1.2.2) with the following activity groups: climate, land suitability, surface water hydrology, groundwater hydrology, agriculture and aquaculture viability, water storage, socio-economics, Indigenous water values, rights and development aspirations, and aquatic and marine ecology.

1.2.2 ASSESSMENT PRODUCTS

The Assessment produced written and internet-based products. These are summarised below and written products are listed in full in Appendix A. Downloadable reports and other outputs can be found at:

https://www.csiro.au/en/Research/Major-initiatives/Northern-Australia/Current-work/NAWRA

Written products

The Assessment produced the following documents:

- Technical reports, which present scientific work in sufficient detail for technical and scientific experts to independently verify the work. There is at least one technical report for each of the activities of the Assessment.
- Catchment reports, one for each of the three study areas, which combine key material from the technical reports, providing well-informed but non-scientific readers with the information

required to make decisions about the general opportunities, costs and benefits associated with water and irrigated agricultural or aquaculture development.

- A development example report, which through case studies in each study area, provides examples of how information produced by the Assessment can be assembled to help readers 'answer their own questions'. They are illustrative only, designed to help readers understand the type and scale of opportunity in the catchment.
- Summary reports, one for each of the study areas, are provided for a general public audience.
- Three factsheets provide a summary of key findings for the Fitzroy, Darwin and Mitchell catchments for a general public audience.

Audio-visual products

The following audio-visual products were produced by the Assessment:

- video vignettes summarising key results
- video vignettes demonstrating how to use the Assessment's internet-based products.

Internet-based products

The following internet-based platforms were used to deliver information generated by the Assessment:

- CSIRO Data Access Portal (DAP) enables the user to download key research datasets generated by the Assessment.
- The NAWRA Explorer - a web-based tool that enables the user to visualise and interrogate key spatial datasets generated by the Assessment.
- Internet-based applications that enable the user to run selected models generated by the Assessment.

1.3 Report objectives and structure

This is the catchment report for the Mitchell catchment. It summarises information from the technical reports for each activity and provides tools and information to enable stakeholders to see the opportunities for development and the risks associated with them. Using the establishment of a 'greenfield' (not having had any previous development) irrigation development as an example, Figure 1-2 illustrates many of the complex considerations required for such development – key report sections that inform these considerations are also indicated.

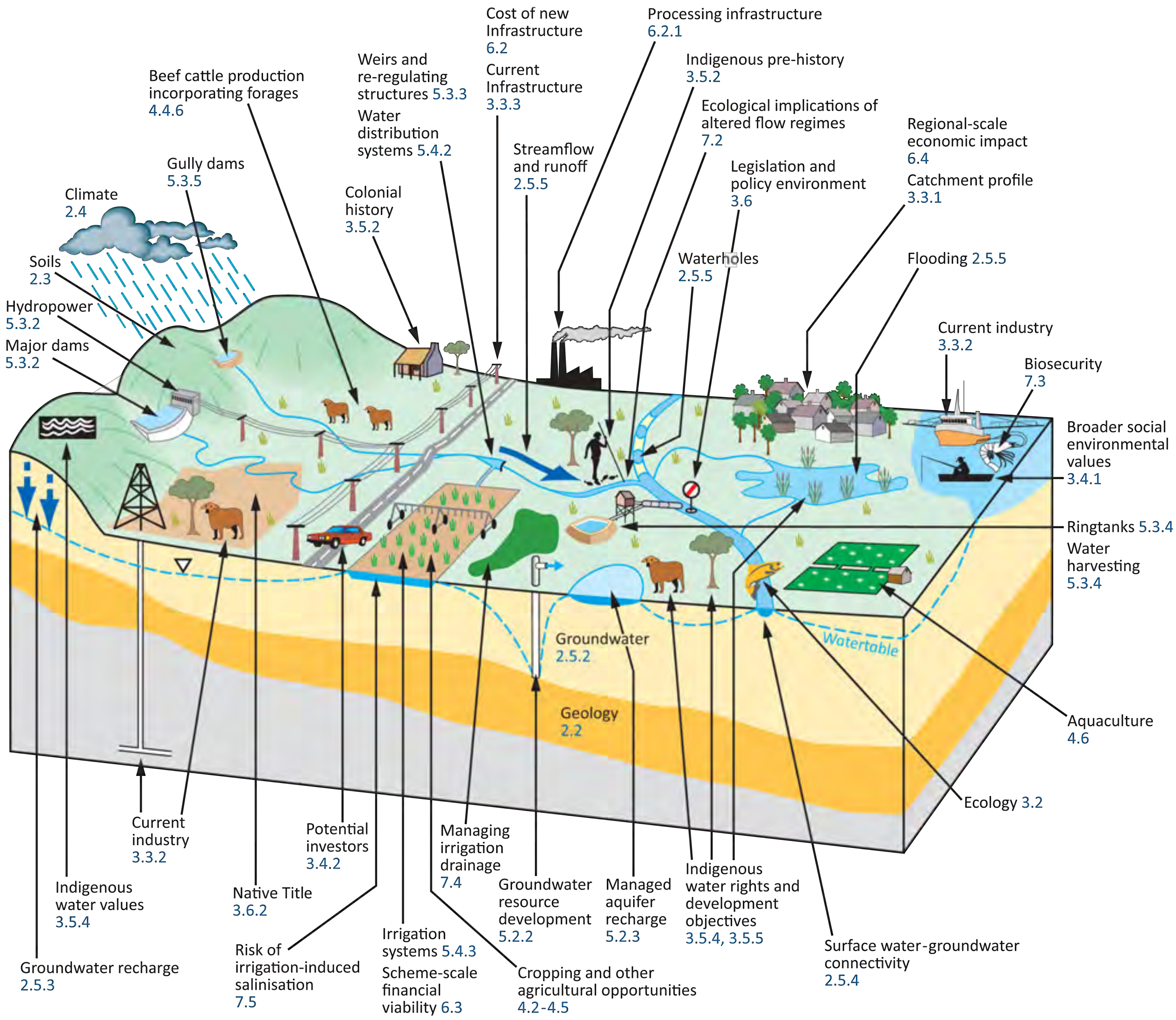

Figure 1-2 Schematic diagram of key components and concepts in the establishment of a greenfield irrigation development

The catchment report addresses questions such as the following:

- What soil and water resources are available for irrigated agriculture?
- What are the existing ecological systems, industries, infrastructure, people and values?
- What are the opportunities for water and irrigation development?
- Is irrigated agriculture economically viable?
- How can water resources be developed and agricultural undertaken sustainably?

Separate catchment reports are provided for the Fitzroy catchment (Petheram et al., 2018a) and the Darwin catchments (Petheram et al., 2018b). The structure of each catchment report is as follows.

- Part I (Chapter 1) provides background, context and a general overview of the Assessment.
- Part II (Chapter 2 and Chapter 3) looks at current resources and conditions within the catchment.
- Part III (Chapter 4 and Chapter 5) considers the opportunities for water and agricultural and aquaculture development based on available resources.

- Part IV (Chapter 6 and Chapter 7) provides information on the economics of development and a range of risks to development, as well as those that might accompany development.

1.3.1 PART I – INTRODUCTION

This provides a general overview of the Assessment. Chapter 1 (this chapter) covers the background and context of the Assessment. Key findings can be found in the front materials of this report.

1.3.2 PART II – RESOURCE INFORMATION FOR ASSESSING POTENTIAL DEVELOPMENT OPPORTUNITIES

Chapter 2 is concerned with the physical environment and seeks to address the question of what soil and water resources are present in the Mitchell catchment, describing:

- geology: focusing on those aspects of geology that are important for understanding the distribution of soils, groundwater flow systems, suitable water storage locations and rocks of economic significance
- soils: covering the soil types within the catchment, the distribution of key soil attributes and their general suitability for irrigated agriculture
- climate: outlining the general circulatory systems affecting the catchment and providing information on key climate parameters of relevance to irrigation under current and future climate
- hydrology: describing and quantifying the surface water and groundwater hydrology of the catchment.

Chapter 3 is concerned with the living and built environment and provides information about the people, the ecology of the catchment and the institutional context of the Mitchell catchment, describing:

- ecology: ecological systems and assets of the Mitchell catchment including the key habitats, key biota and their important interactions and connections
- socio-economic profile: current demographics and existing industries and infrastructure of relevance to water resource development in the Mitchell catchment
- stakeholders: their values and potential engagement strategies and the perspectives of potential investors in the Mitchell catchment
- Indigenous values, rights, interests, and development objectives: generated through direct participation by Mitchell catchment Traditional Owners in the Assessment
- the legal, regulatory and policy environment relevant to water-related development.

1.3.3 PART III – OPPORTUNITIES FOR WATER RESOURCE DEVELOPMENT

Chapter 4 presents information about the opportunities for irrigated agriculture and aquaculture in the Mitchell catchment, describing:

- land suitability for a range of crop × season × irrigation type combinations and for aquaculture, including key soil-related management considerations
- cropping and other agricultural opportunities, including crop yields and water use
- gross margins at the farm scale
- the prospects for integration of forages and crops into existing beef enterprises
- aquaculture opportunities.

Chapter 5 presents information about the opportunities to extract and/or store water for use in the Mitchell catchment, describing:

- water storage opportunities including major dams, large farm-scale dams, natural water bodies and subsurface water storage opportunities in the Mitchell catchment
- estimates of the quantity of water that could be regulated (i.e. made available for irrigation)
- water distribution systems (i.e. conveyance of water from a dam and application to the crop).

1.3.4 PART IV – ECONOMICS OF DEVELOPMENT AND ACCOMPANYING RISKS

Chapter 6 covers economic opportunities and constraints for water resource development, describing:

- regional-scale economic impacts and the costs of infrastructure
- scheme-scale financial viability, including capital costs, farm performance and value adding
- risks due to variability in farm performance, especially during the early years
- learning and staged development as a means of managing risk.

Chapter 7 discusses a range of risks to development, as well as those that might accompany development, describing:

- ecological impacts of altered flow regimes on aquatic, riparian and near-shore marine ecology
- biosecurity risks to agricultural or aquaculture enterprises
- potential off-site impacts due to sediment, nutrients and agro-pollutants to receiving waters in the catchment
- irrigation-induced salinity due to rising watertable.

1.3.5 APPENDICES

This report contains four appendices.

Appendix A – list of information products.

Appendix B – shortened forms, units, data sources, glossary and terms.

Appendix C – list of figures and list of tables.

Appendix D – detailed location map of the Mitchell catchments and surrounds.

1.4 Key background

1.4.1 THE MITCHELL CATCHMENT

The Mitchell catchment covers an area of 72,000 km^2 of north Queensland at the southern end of Cape York Peninsula (Figure 1-3). The Mitchell River has the largest median annual streamflow of any river in northern Australia (Petheram et al., 2014) and flows into the Gulf of Carpentaria near the settlement of Kowanyama, while the headwaters are in the Great Dividing Range on the eastern margin of the catchment. The catchment uplands are drained by a number of major rivers including the Alice, Palmer, Walsh and Lynd rivers. Below the confluence of the Mitchell and Palmer rivers near Dunbar Station is the current delta apex of the Mitchell River Fan Aggregation, at which point the Mitchell River diverges. The Nassau is a large river draining the delta in the south and there are numerous braided stream channels to the north of the delta. Elevation ranges from sea level in the west to around 175 m at Wrotham Park in the centre of the catchment, and reaches the highest point around 1225 m in the Great Dividing Range on the eastern catchment boundary north of Mareeba.

The catchment is characterised by a distinctive wet and dry season due to its location in the Australian summer monsoon with generally more than 90% of rainfall occurring in the wet season (November to April). The mean annual rainfall ranges from approximately 800 mm in the south-east of the catchment to over 1300 mm in the north-west.

The population in the Mitchell catchment is sparse (about 6500), and there are no large urban population centres, although on the eastern boundary, outside of the Mitchell catchment, are the major centres of Mareeba (about 11,000) and Cairns (about 160,000). The largest settlements in the catchment are the towns of Dimbulah, Kowanyama, and Chillagoe, all with populations below 1500 people as at the 2016 census. The road network is limited, comprising largely unsealed roads with the Burke Development Road being the main access across the catchment to Mareeba and Cairns in the east. Access to Kowanyama near the west coast is not possible for extended periods during the wet season and the travel distances to major urban centres are large; Kowanyama to Cairns is 605 km and Cairns to the Queensland state capital of Brisbane is 1670 km.

The Mitchell catchment is spread across four bioregions, the Einasleigh Uplands, the Gulf Plains and Cape York Peninsula. Minor parts of the eastern edge of the catchment occur in the Wet Tropics bioregion. The major land use is pastoralism (95%) on large grazing leases where cattle graze native pastures and shrubs. Conservation reserves are the second largest land use, but only cover 3% of the catchment. Lake Tinaroo in the Barron catchment provides water to the Mareeba–Dimbulah Water Supply Scheme (MDWSS), which straddles the Barron and Mitchell catchments. In the Mitchell catchment the MDWSS is located in the upper Walsh River catchment and irrigated cropping is dominated by sugarcane and horticulture, comprising about 0.3% of the study area.

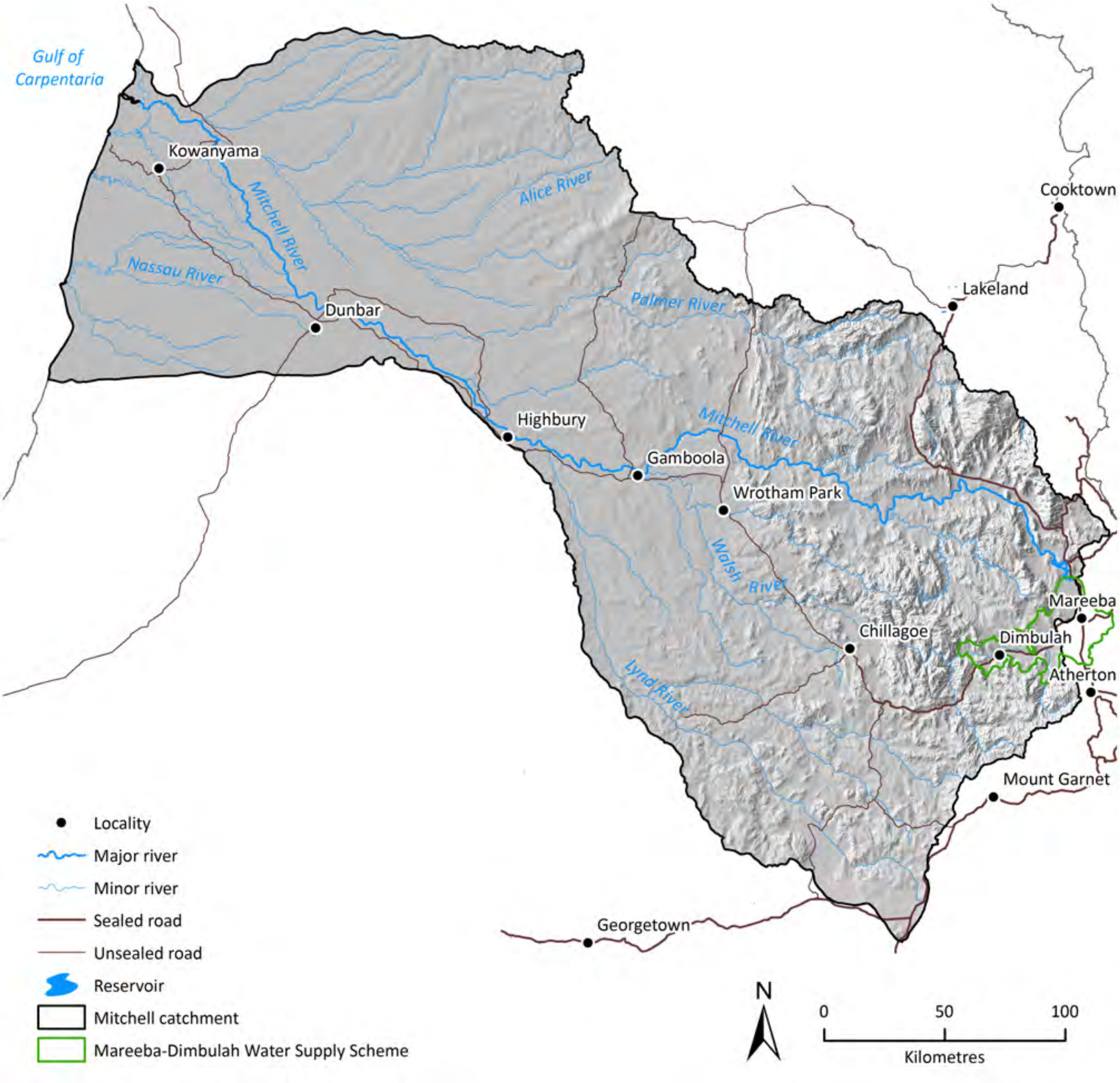

Figure 1-3 The Mitchell catchment
A more detailed map of the Fitzroy catchment can be found on the inside back page of this report.

1.4.2 WET-DRY SEASONAL CYCLE: THE WATER YEAR

Northern Australia experiences a highly seasonal climate, with most rain falling during the 4-month period from December to March. Unless specified otherwise, this Assessment defines the wet season as being the 6-month period from 1 November to 30 April, and the dry season as the 6-month period from 1 May to 31 October. These definitions were chosen because they are the wettest and driest 6-month period respectively for all three study areas. However, it should be noted that the transition from the dry to the wet season typically occurs in October or November and the definition of the northern wet season commonly used by meteorologists is 1 October to 30 April.

All results in the Assessment are reported over the water year, defined as the period 1 September to 31 August, unless specified otherwise. This allows each individual wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons). This is more realistic for reporting climate statistics from a hydrological and agricultural assessment viewpoint.

1.4.3 SCENARIO DEFINITIONS

The Assessment considered four scenarios, reflecting combinations of different levels of development and historical and future climates, much like those used in the Northern Australia Sustainable Yields project (NASY) (CSIRO, 2009a, 2009b, 2009c) and the Flinders and Gilbert Agricultural Resource Assessment (Petheram et al., 2013a, 2013b):

- Scenario A – historical climate and current development
- Scenario B – historical climate and future development
- Scenario C – future climate and current development
- Scenario D – future climate and future development.

Scenario A

Scenario A is historical climate and current development. The historical climate series is defined as the observed climate (rainfall, temperature and potential evaporation for water years from 1 September 1890 to 31 August 2015). All results presented in this report are calculated over this period unless specified otherwise. The current level of surface water, groundwater and economic development was assumed (as of 31 August 2015). Scenario A was used as the baseline against which assessments of relative change were made. Historical tidal data were used to specify downstream boundary conditions for the flood modelling.

Scenario B

Scenario B is historical climate and future development, as generated in the Assessment. Scenario B used the same historical climate series as Scenario A. River inflow, groundwater recharge and flow, and agricultural productivity were modified to reflect potential future development. All price and cost information was indexed to mid-2017. The impacts of changes in flow due to this future development were assessed, including impacts on:

- instream, riparian and near-shore ecosystems
- Indigenous water values
- economic costs and benefits
- opportunity costs of expanding irrigation
- institutional, economic and social considerations that may impede or enable adoption of irrigated agriculture.

Scenario C

Scenario C is future climate and current development. It was based on a 125-year climate series (as in Scenario A) derived from global climate model (GCM) projections for an approximate 2.2 °C global temperature rise relative to the ~1990 climate statistics, which under the Representative Concentration Pathway (RCP) 8.5 socio-economic narrative (i.e. high emissions scenario) was projected to occur in about 2060. The GCM projections were used to modify the observed historical daily climate sequences. The current level of surface water, groundwater and economic development were assumed. Carbon dioxide concentrations were perturbed to reflect projected 2060 carbon dioxide concentrations under RCP 8.5.

Scenario D

Scenario D is future climate and future development. It used the same future climate series as Scenario C. River inflow, groundwater recharge and flow, and agricultural productivity were modified to reflect potential future development, as in Scenario B. Therefore, in this report, the climate data for Scenarios A and B are the same (historical observations from 1 September 1890 to 31 August 2015) and the climate data for Scenarios C and D are the same (the above historical data scaled to reflect a plausible range of future climates).

1.4.4 CASE STUDIES

The case studies in the Assessment are used to show how information produced by the Assessment can be assembled to help readers 'answer their own questions'. They are also used to help readers understand the type and scale of opportunity for irrigated agriculture or aquaculture in selected parts of the Assessment area, and explore some of the nuances associated with greenfield developments in the study area. Case studies examples are provided for each study area.

The case studies are illustrative only. They are not designed to demonstrate, recommend or promote particular development opportunities that may be being currently proposed, nor are they CSIRO's recommendations on how development in the Mitchell catchment should unfold. However, they are designed to be realistic representations. That is, the case studies will be 'located' in specific parts of the Assessment area, and use specific water and land resources, and realistic intensification options.

The case studies are described in full in the companion technical report on case studies (Petheram et al., 2018c).

1.5 References

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Part II Resource information for assessing potential development opportunities

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

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

2 Physical environment of the Mitchell catchment

Authors: Seonaid Philip, Phil Davies, Justin Hughes, Fazlul Karim, Steve Marvanek, Cuan Petheram, Andrew R Taylor, Cate Ticehurst, Jo Vanderzalm, Bill Wang and Ian Watson

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

Based on the Australian Water Resources Council river basins (Geoscience Australia, 1997) the catchment area of the Mitchell catchment was calculated to be 71,529 km^2.

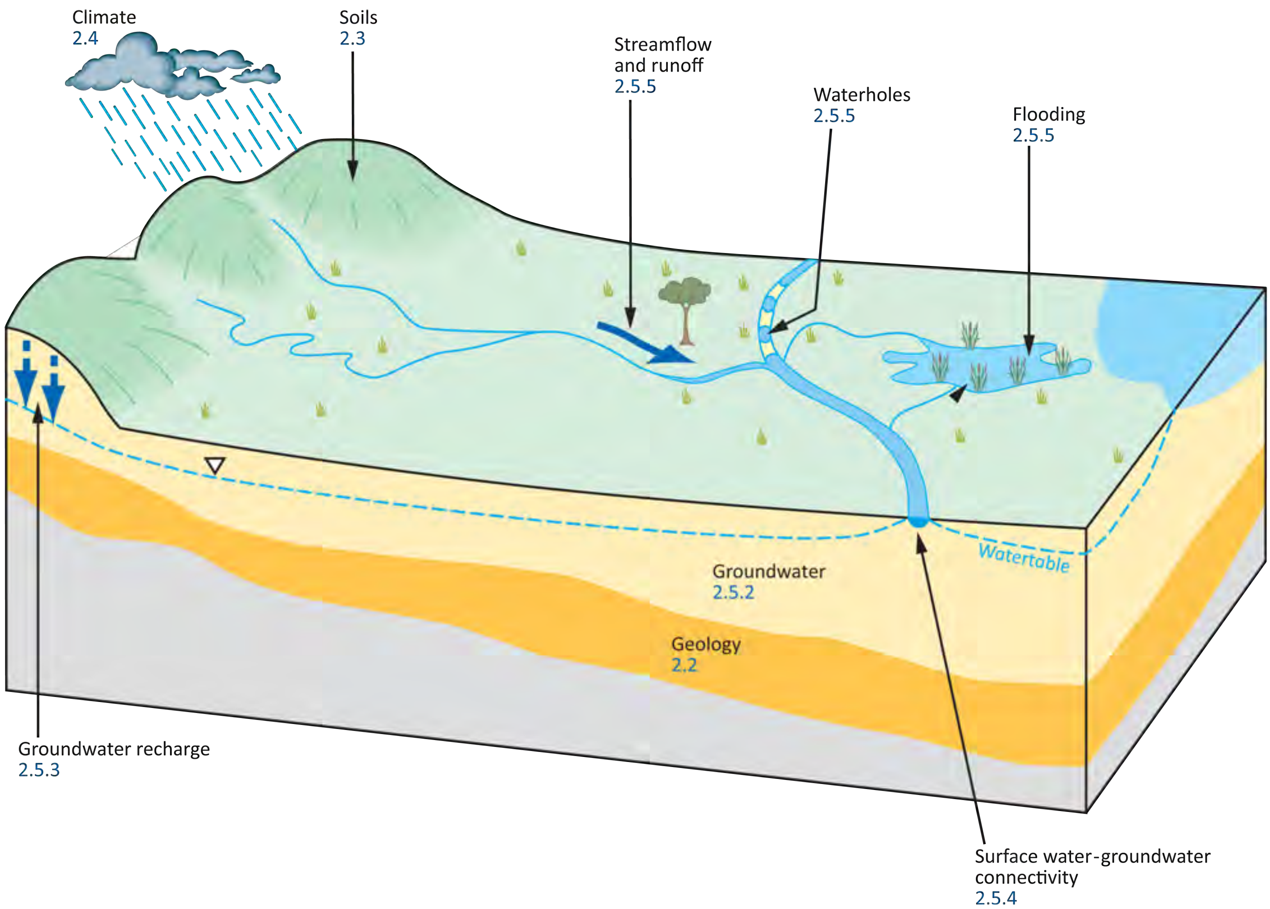


Figure 2-1 Schematic diagram of key natural components and concepts in the establishment of a greenfield irrigation development

2.1 Summary

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

2.1.1 KEY FINDINGS

Soils

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

Climate

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

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

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

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

Hydrology

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

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

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

2.1.2 INTRODUCTION

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

The chapter is structured as follows:

- Section 2.2 examines the geology of the Mitchell catchment, which is important in understanding the distribution of valuable minerals, coal, groundwater, soil and areas of high and low relief, which influences flooding and the deposition of soil.
- Section 2.3 examines the distribution of soils in the Mitchell catchment, their attributes and discusses management considerations.
- Section 2.4 examines the climate of the Mitchell catchment, including historical and future projections of patterns in rainfall.
- Section 2.5 examines the groundwater and surface water hydrology of the Mitchell catchment, including groundwater recharge, streamflow and flooding.

2.2 Geology of the Mitchell catchment

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

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

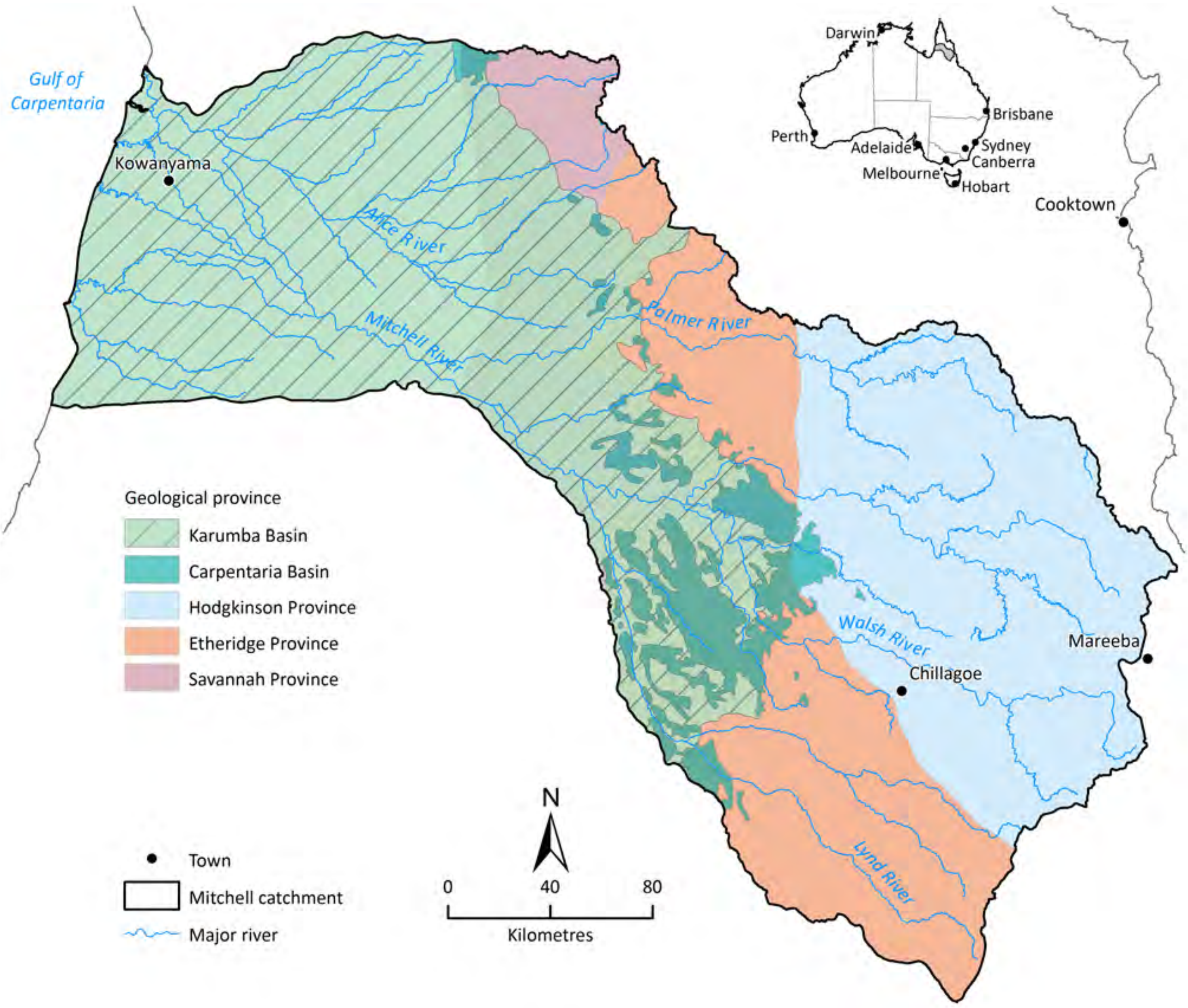


Figure 2-2 Major geological provinces of the Mitchell catchment

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

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

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

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

Major ore bodies in the Mitchell catchment are generally limited to the very old igneous and metamorphic rocks (i.e. older than Permian) of the Hodgkinson and Etheridge provinces, where hot fluids have been transported from great depths and minerals in the fluids precipitated in the faults and fractures of these rocks. The formation of hydrothermal ore bodies (found in this area) is facilitated by deformation of the crust; the older the rock the greater the chance that deformation and mineralisation will occur. For this reason, economically exploitable mineral resources, primarily tin, gold and copper, are mainly located in the eastern third of the catchment around the towns of Chillagoe and Mount Garnet. Tin mineralisation is concentrated around Mount Garnet, while copper and other base metals (e.g. zinc, lead) are mainly focused in the Chillagoe area.

Jurassic- to Cretaceous-age sedimentary rocks of 'clastic' origin occur in the geological Carpentaria Basin in the south-central part of the catchment (Figure 2-3). These sedimentary rocks comprise mostly quartzose sandstone, mudstone and siltstone. The nature of the rocks and gentle rolling topography of the geological Carpentaria Basin has negligible economic potential and presents few opportunities for instream dams. Embankments generally must be very long to provide adequate storage, construction and operation of a spillway to cope with the large flood events that can occur and could pose significant risks. The quartzose sandstone, however, forms a highly porous, high-yielding aquifer, though most of the aquifer west of the outcrop area is too deep to drill for groundwater extraction economically.

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

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

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

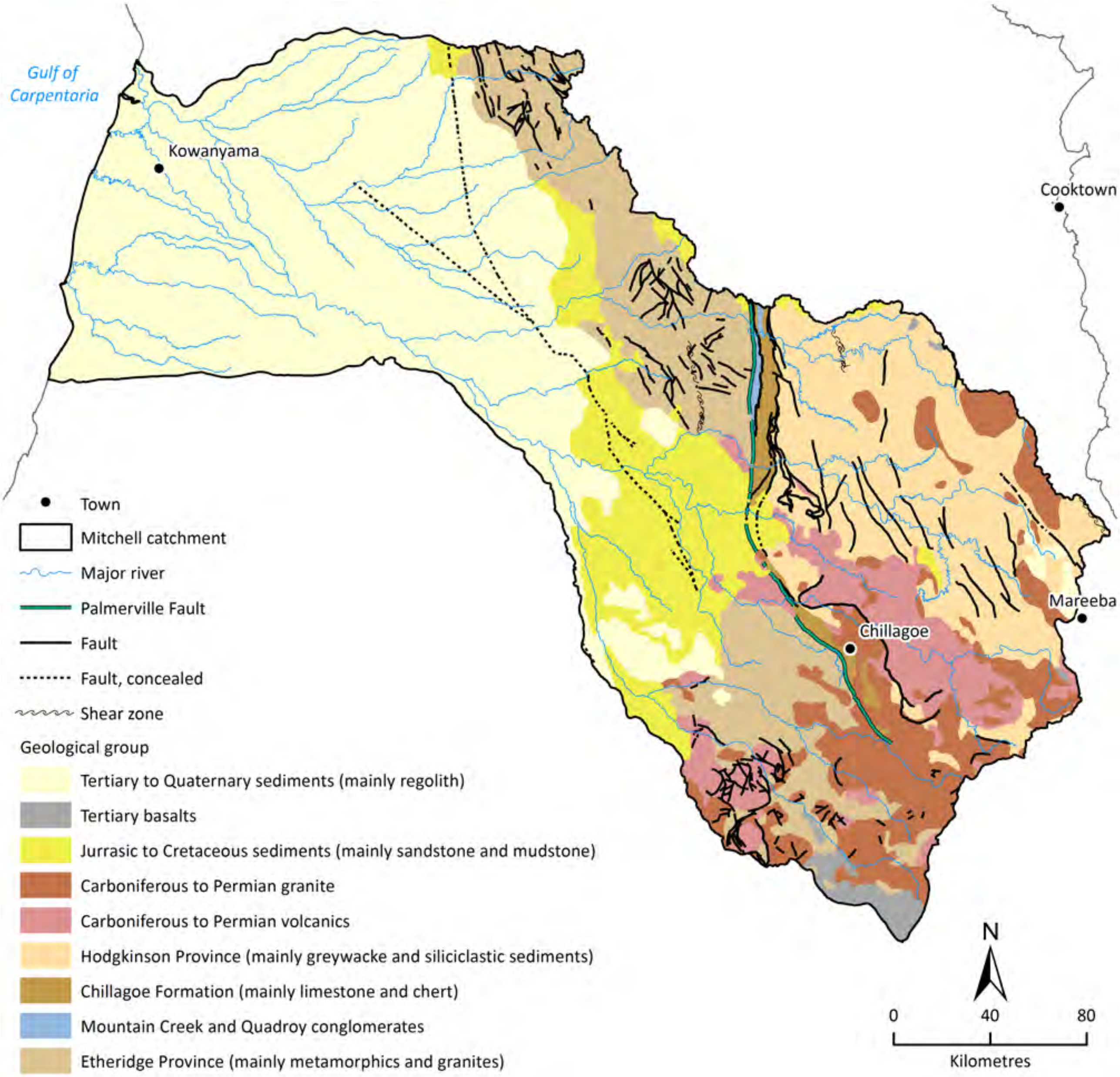


Figure 2-3 Regional geology of the Mitchell catchment

2.3 Soils of the Mitchell catchment

2.3.1 INTRODUCTION

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

This section briefly describes the spatial distribution of soil groups (Section 2.3.2) and soil attributes (Section 2.3.3) in the Mitchell catchment. The management considerations are also summarised. Maps showing the suitability of different crops under different irrigation types are presented in Section 5.5.

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

2.3.2 SOIL CHARACTERISTICS

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

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

Figure 2-4 shows the location of the soil generic groups within the Mitchell catchment.

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

[1] Note that a common set of soil generic groups (SGGs) was developed for the three study areas, but not all groups are found in all areas. In the Mitchell catchment, SGG 5 and SGG 10 soils are not found.

SGG	SGG OVERVIEW AND % OF AREA	GENERAL DESCRIPTION	LANDFORM	MAJOR MANAGEMENT CONSIDERATIONS
4.1	Red loamy soils (8%)	Well-drained, neutral to acid red soils with little or only gradual increase in clay content at depth. Moderately deep to very deep red soils	Level to gently undulating plains and plateaus, and some unconsolidated sediments, usually alluvium	Moderate to high agricultural potential with spray or trickle irrigation due to their good drainage. Low to moderate water-holding capacity, often hard-setting surfaces
4.2	Brown, yellow and grey loamy soils (10%)	As above, but moderately well-drained to imperfectly drained brown, yellow and grey soils	As above, but more common in lower parts of the landscape	As above, but may be restricted by drainage related issues
5	Peaty soils (0%)	Soils high in organic matter	Predominantly swamps	Low agricultural potential due to very poor drainage
6.1	Red sandy soils (<1%)	Moderately deep to very deep red sands, may be gravelly	Sandplains and dunes; Aeolian, fluvial and siliceous parent material	Low agricultural potential due to excessive drainage and poor water-holding capacity. Potential for irrigated agriculture
6.2	Brown, yellow and grey sandy soils (6%)	Moderately deep to very deep brown, yellow and grey sands, may be gravelly	As above, but more common in lower parts of the landscape	Low agricultural potential due to poor water-holding capacity combined with seasonal drainage restrictions. May have potential for irrigated agriculture
7	Shallow and/or rocky soils (37%)	Very shallow to shallow (<0.5 m). Usually sandy or loamy, but may be clayey. Generally weakly developed soils that may contain gravel	Crests and slopes of hilly and dissected plateaus in a wide variety of landscapes	Negligible agricultural potential due to lack of soil depth, poor water-holding capacity and presence of rock
8	Sand or loam over sodic clay subsoils (12%)	Strong texture contrast between the A and B horizons; A horizons usually bleached. Usually alkaline but occasionally neutral to acid subsoils. Moderately deep to deep	Lower slopes and plains in a wide variety of landscapes	Generally low to moderate agricultural potential due to restricted drainage, poor root penetration and susceptibility to gully and tunnel erosion. Those with thick to very thick A horizons are favoured
9	Cracking clay soils (1.5%)	Clay soils with shrink-swell properties that cause cracking when dry. Usually alkaline and moderately deep to very deep	Floodplains and other alluvial plains. Level to gently undulating plains and rises (formed on labile sedimentary rock). Minor occurrences in basalt landscapes	Generally moderate to high agricultural potential. The flooding limitation will need to be assessed locally. Many soils are high in salt (particularly those associated with the treeless plains). Gilgai and coarse structured surfaces may occur
10	Highly calcareous soils (0%)	Moderately deep to deep soils that are calcareous throughout the profile	Plains to hilly areas	Generally moderate to low agricultural potential depending on soil depth and presence of rock

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

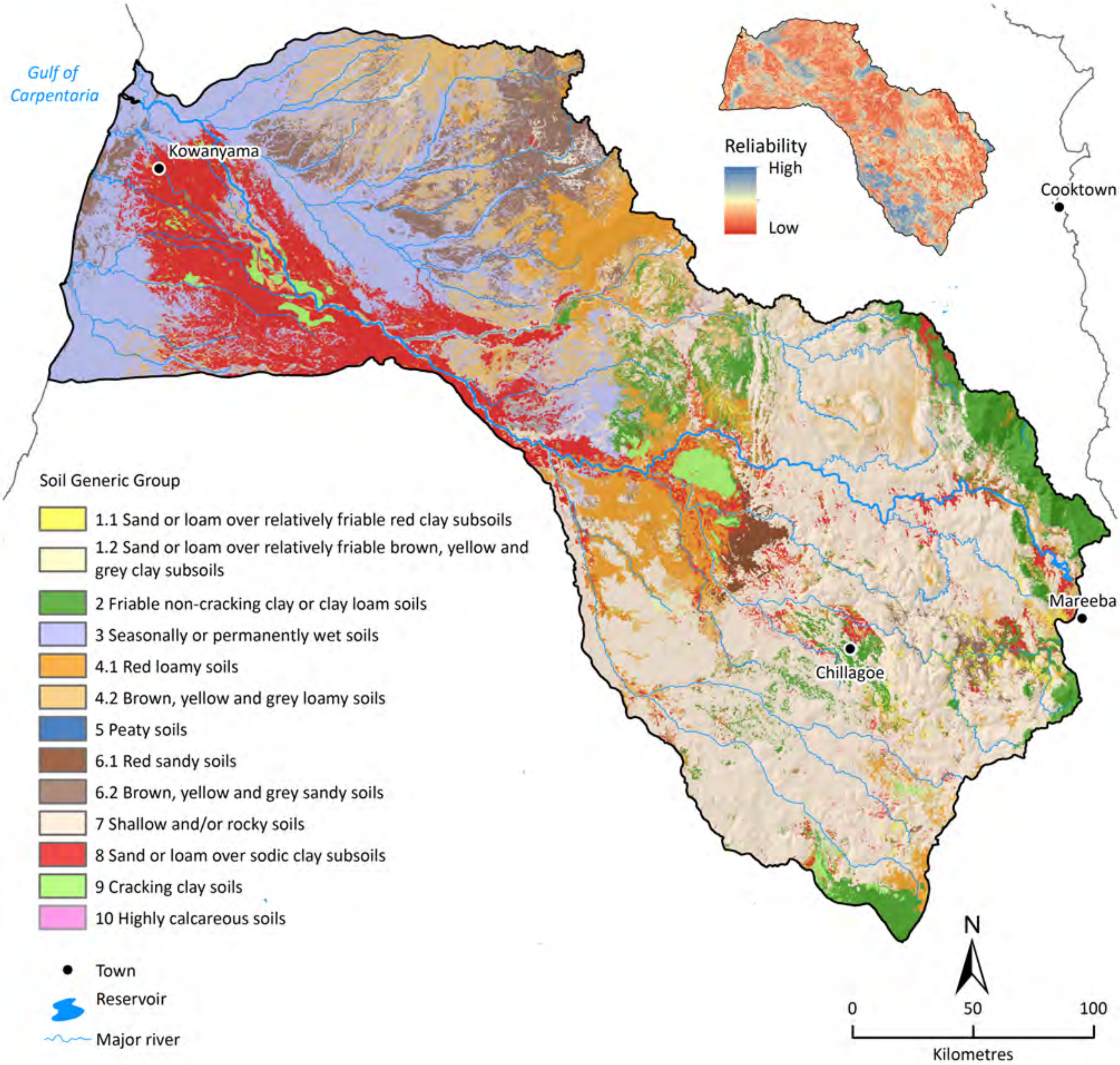


Figure 2-4 Soil generic groups (SGG) of the Mitchell catchment produced by digital soil mapping
The inset map shows the data reliability, which for SGG mapping is based on the confusion index as described in Thomas et al. (2018a).

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

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

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

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

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

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

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

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

2.3.3 SOIL ATTRIBUTE MAPPING

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

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

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

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

Surface soil pH

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

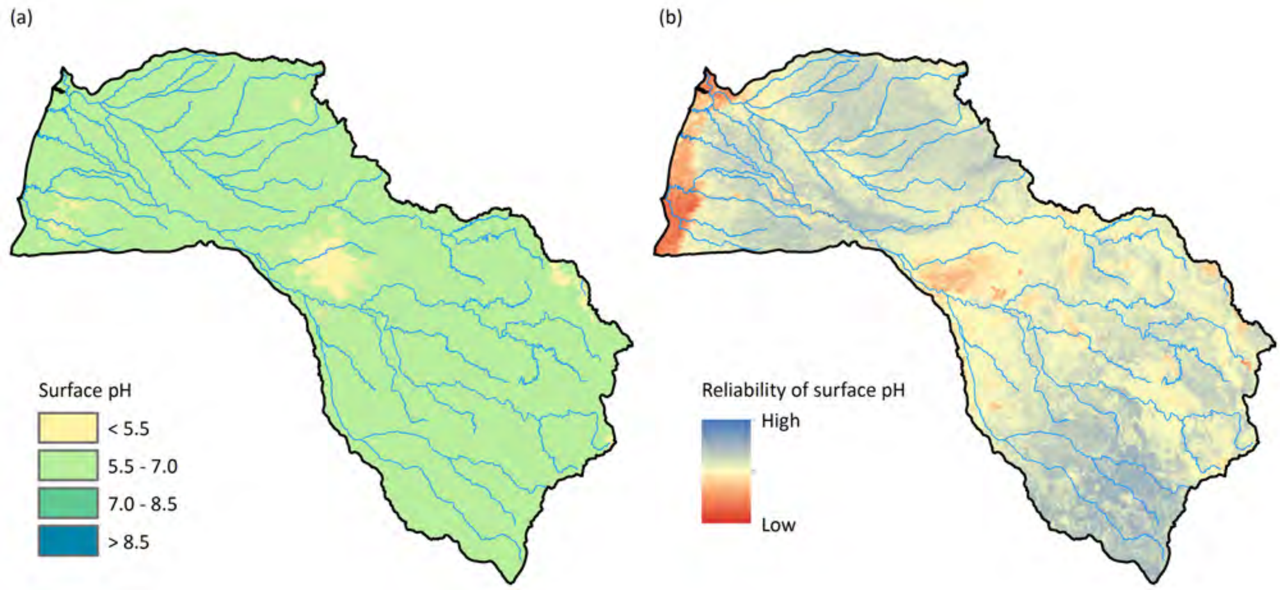


Figure 2-5 Surface soil pH of the Mitchell catchment
(a) Surface soil pH as predicted by digital soil mapping and (b) reliability of the prediction. Surface soil pH is the pH in the top 10 cm.

Minimum soil depth

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

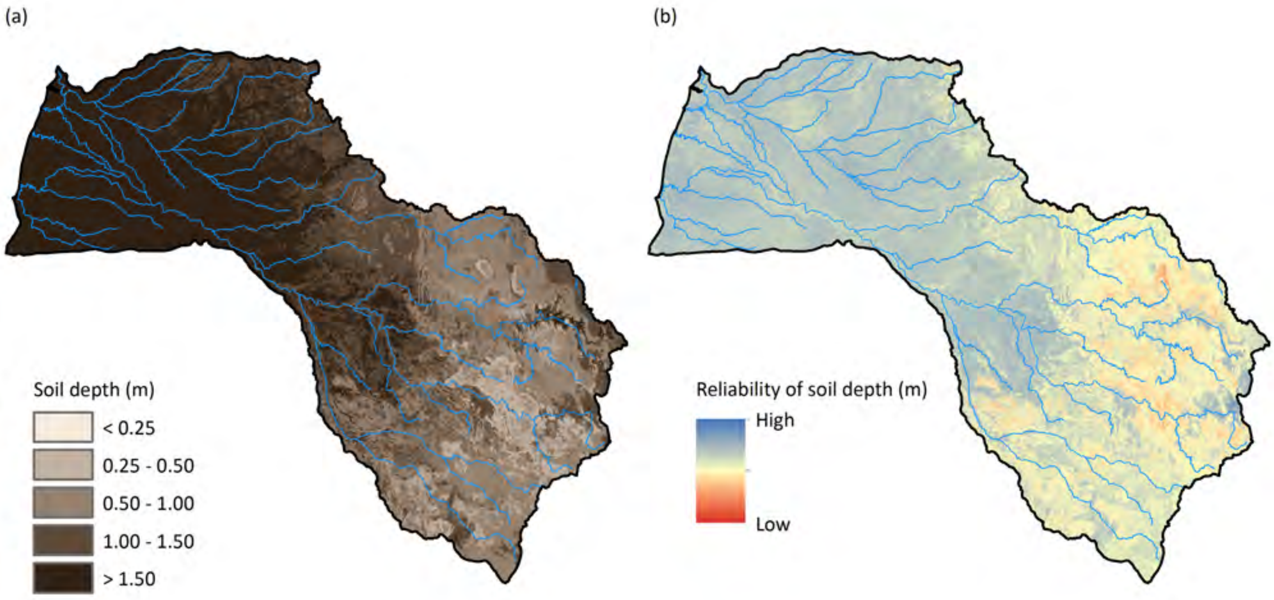


Figure 2-6 Minimum soil depth of the Mitchell catchment
(a) Minimum soil depth as predicted by digital soil mapping and (b) reliability of the prediction.

Soil surface texture

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

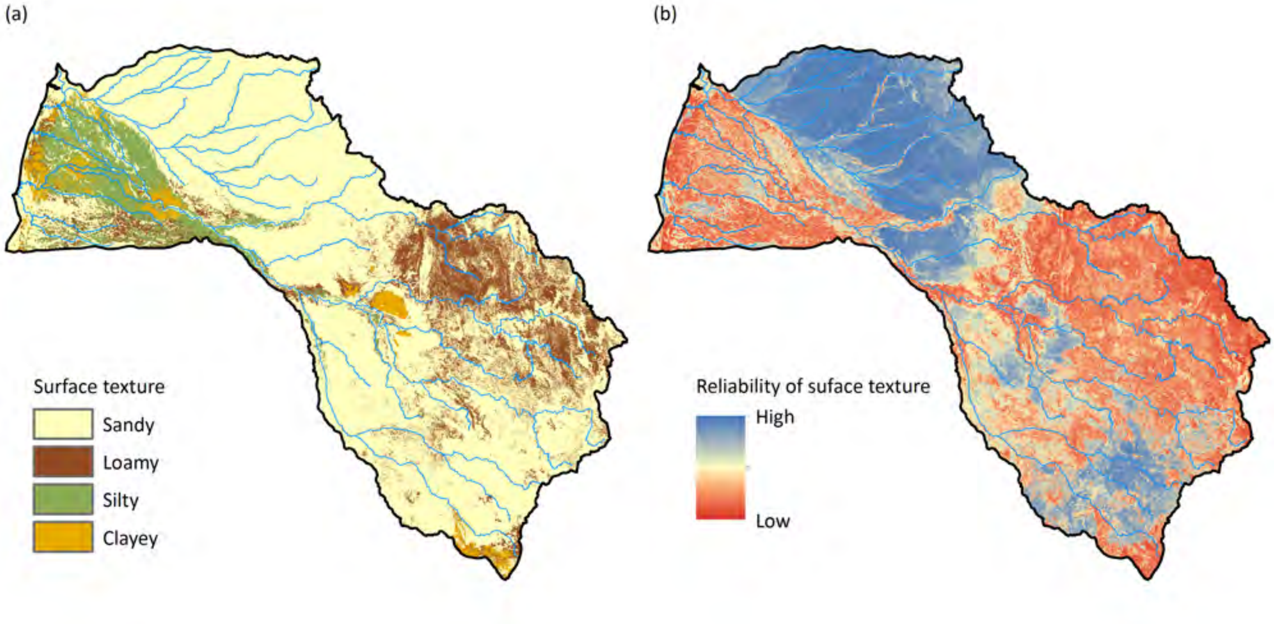


Figure 2-7 Soil surface texture of the Mitchell catchment
(a) Surface texture of soils as predicted by digital soil mapping and (b) reliability of the prediction.

Permeability

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

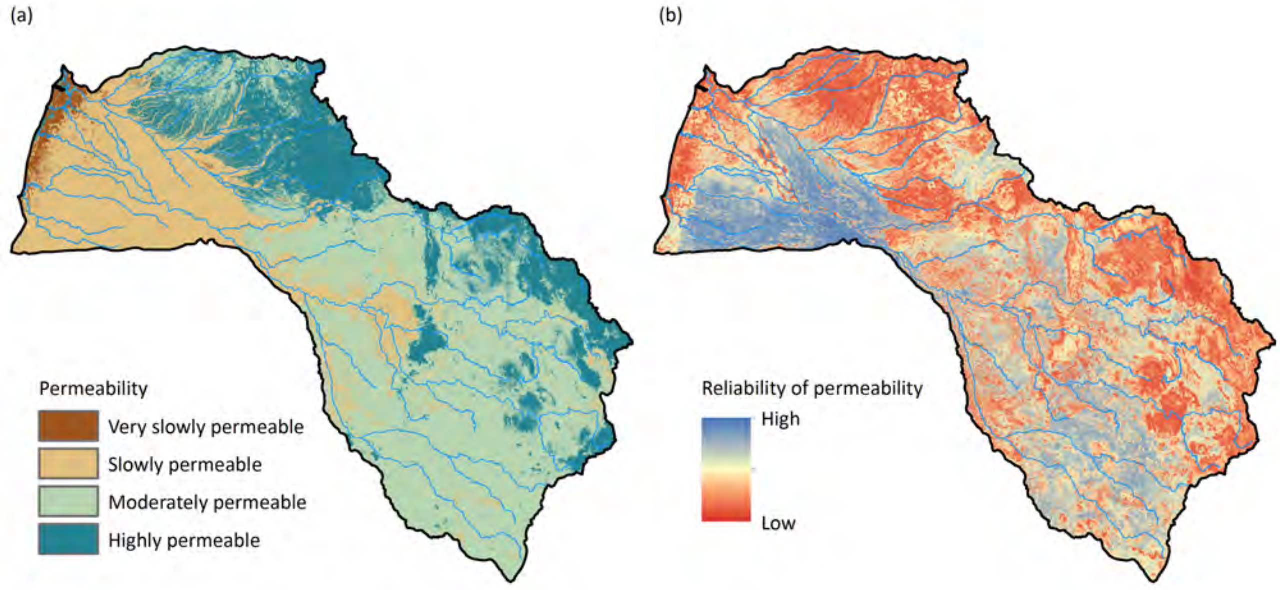


Figure 2-8 Soil permeability of the Mitchell catchment
(a) Soil permeability as predicted by digital soil mapping and (b) reliability of the prediction.

Plant available water capacity to 100 cm

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

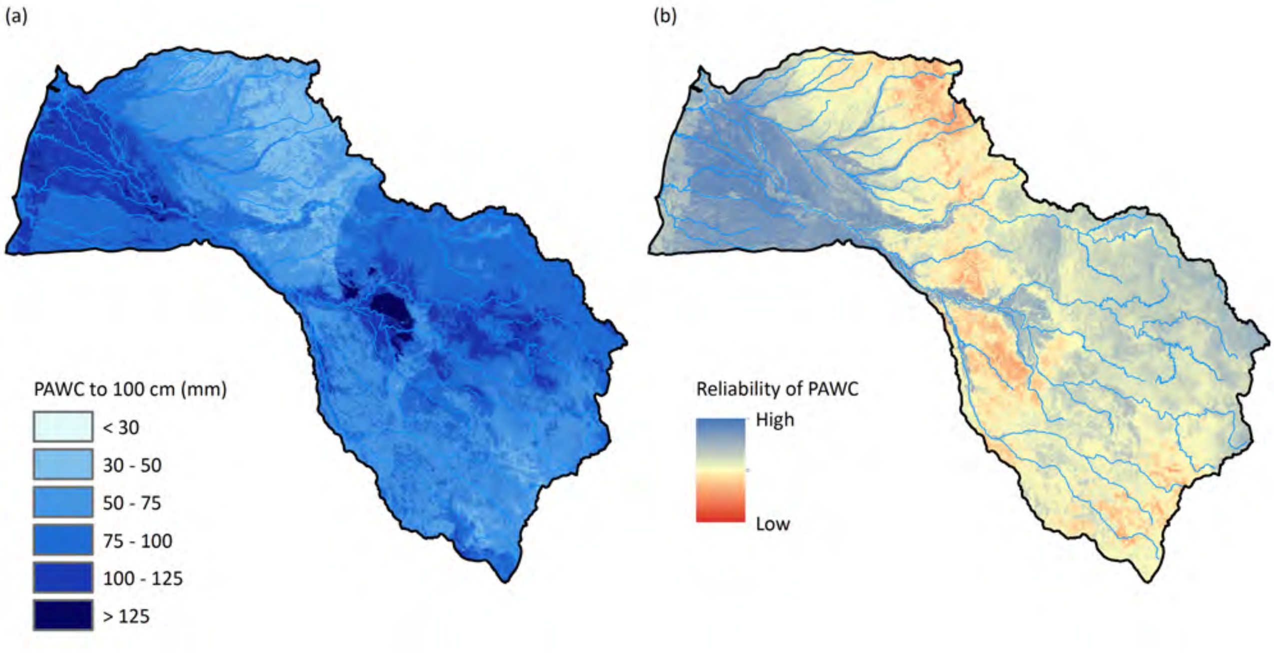


Figure 2-9 Plant available water capacity (PAWC) in the Mitchell catchment
(a) PAWC in the upper 100 cm of the soil profile (PAWC 100) as predicted by digital soil mapping and (b) reliability of the prediction.

Rockiness

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

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

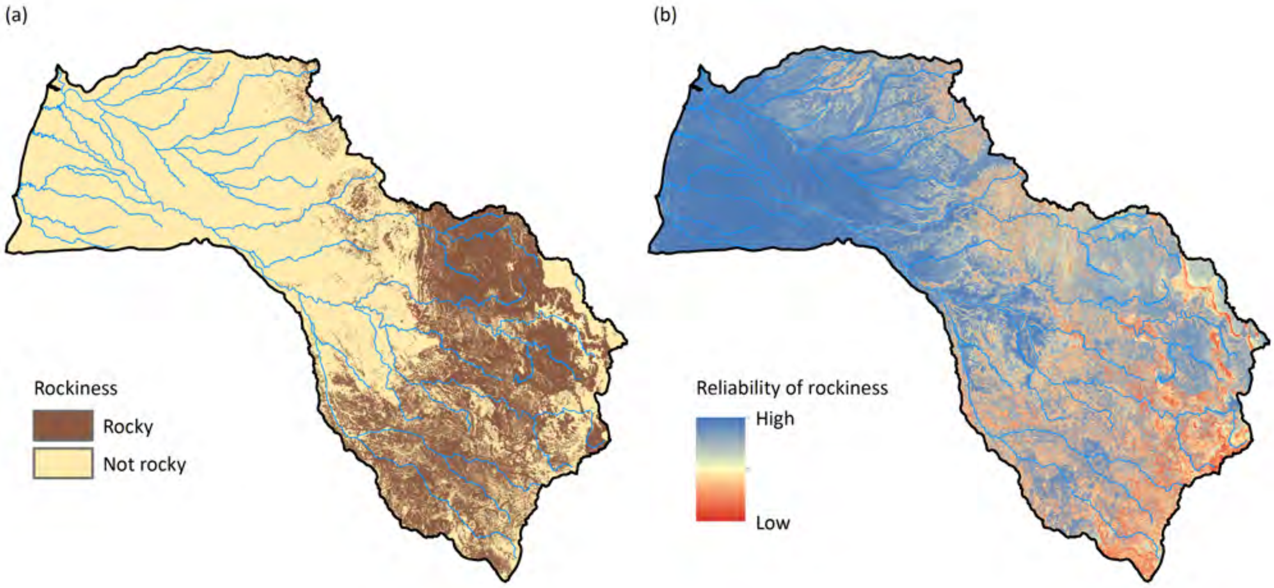


Figure 2-10 Rockiness in soils of the Mitchell catchment
(a) Rockiness represented by presence or absence as predicted by digital soil mapping and (b) reliability of the prediction.

2.4 Climate of the Mitchell catchment

2.4.1 INTRODUCTION

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

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

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

2.4.2 WEATHER PATTERNS OVER THE MITCHELL CATCHMENT

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

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

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

Dividing Ranges, whereas the rest of the catchment receives very little rainfall between May and October.

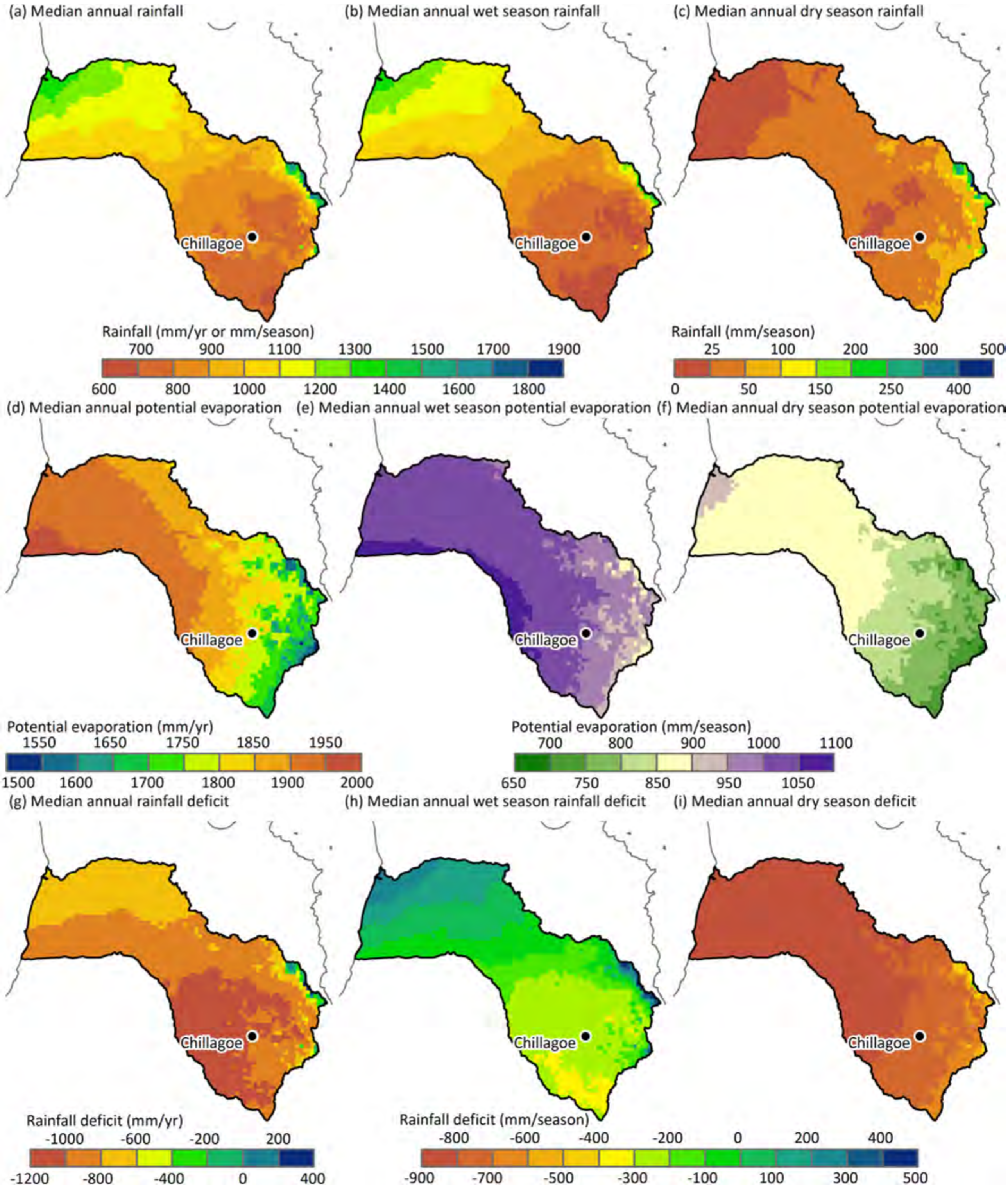


Figure 2-11 Historical rainfall, potential evaporation and rainfall deficit
Median (a) annual, (b) wet-season and (c) dry-season rainfall. Median (d) annual, (e) wet-season and (f) dry-season evaporation and median (g) annual, (h) wet-season and (i) dry-season rainfall deficit in the Mitchell catchment. Rainfall deficit is rainfall minus potential evaporation.

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

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

2.4.3 POTENTIAL EVAPORATION AND POTENTIAL EVAPOTRANSPIRATION

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

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

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

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

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

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

2.4.4 VARIABILITY AND LONG-TERM TRENDS IN RAINFALL AND POTENTIAL EVAPORATION

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

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

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

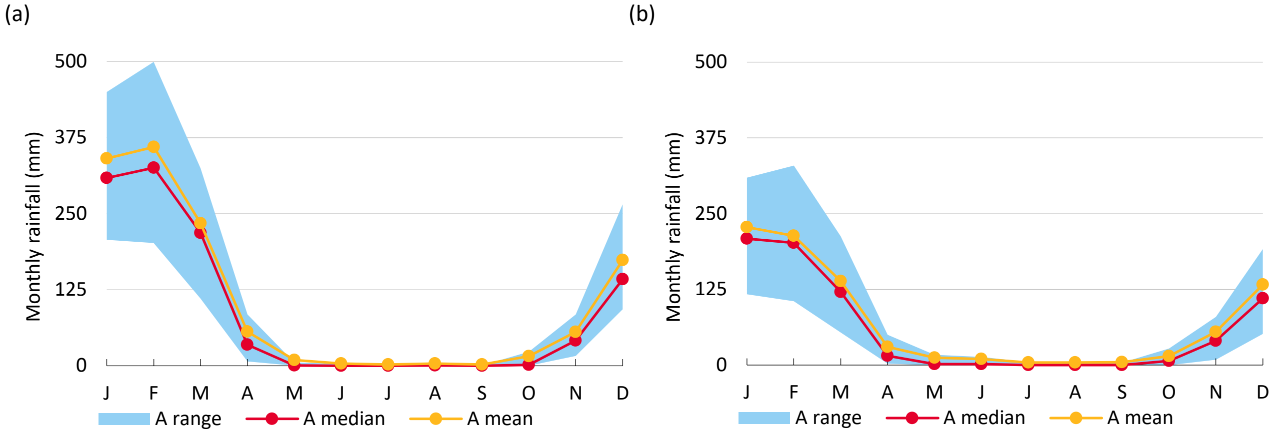


Figure 2-12 Monthly rainfall in the Mitchell catchment at Kowanyama and Chillagoe under Scenario A
(a) Monthly rainfall at Kowanyama and (b) monthly rainfall at Chillagoe. Scenario A is the historical climate (1890 to 2015). A range is the 20th and 80th percentile monthly rainfall.

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

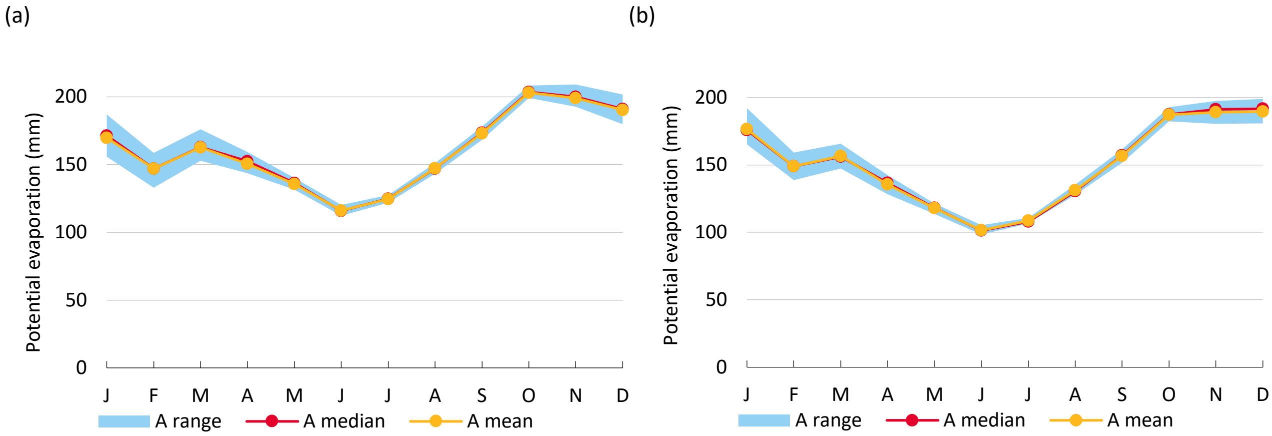


Figure 2-13 Monthly potential evaporation in the Mitchell catchment at Kowanyama and Chillagoe under Scenario A
(a) Monthly potential evaporation at Kowanyama and (b) monthly potential evaporation at Chillagoe. Scenario A is the historical climate (1890 to 2015). A range is the 20th and 80th percentile monthly potential evaporation.

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

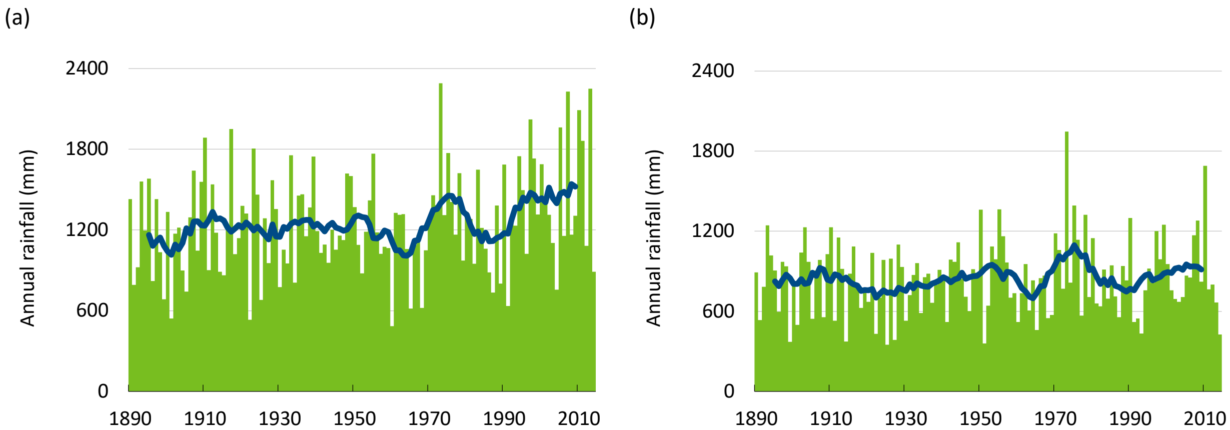
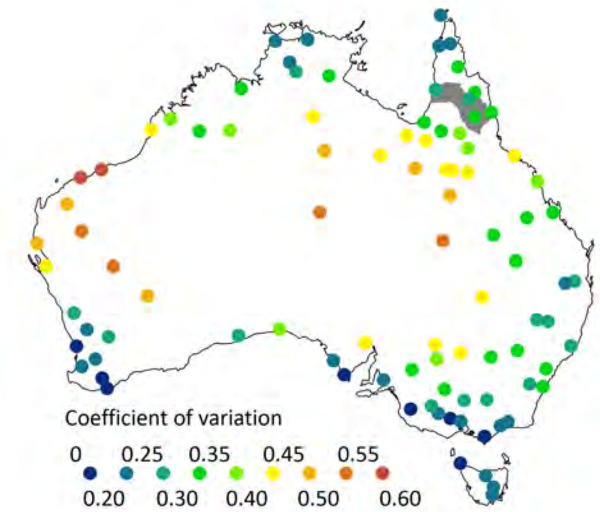


Figure 2-14 Annual rainfall at Kowanyama and Chillagoe under Scenario A
(a) Monthly rainfall at Kowanyama and (b) monthly rainfall at Chillagoe. Scenario A is the historical climate (1890 to 2015). The blue line represents the 10-year running mean.

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

(a)



(b)

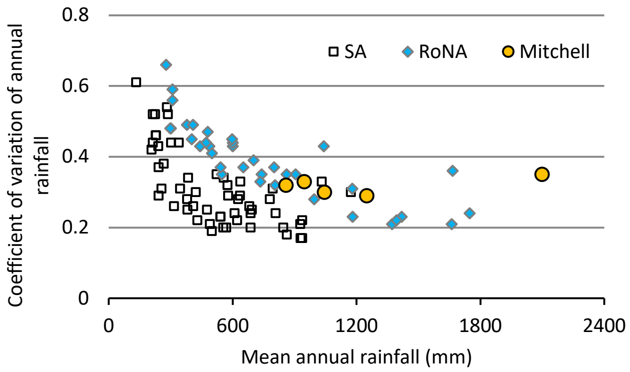


Figure 2-15 (a) Coefficient of variation of annual rainfall and (b) the coefficient of variation of annual rainfall plotted against mean annual rainfall for 96 rainfall stations from around Australia
(a) The grey polygons indicate the extent of the Mitchell catchment. (b) Rainfall stations in the Mitchell catchment are represented by yellow symbols. The light blue diamonds indicate rainfall stations from the rest of northern Australia (RoNA) and hollow squares indicate rainfall stations from southern Australia (SA).

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

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

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

Oscillation Index (SOI), a measure of the strength of ENSO, during spring suggesting that ENSO plays a key role in between-year rainfall variability (McBride and Nicholls, 1983).

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

Trends

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

Runs of wet and dry years

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

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

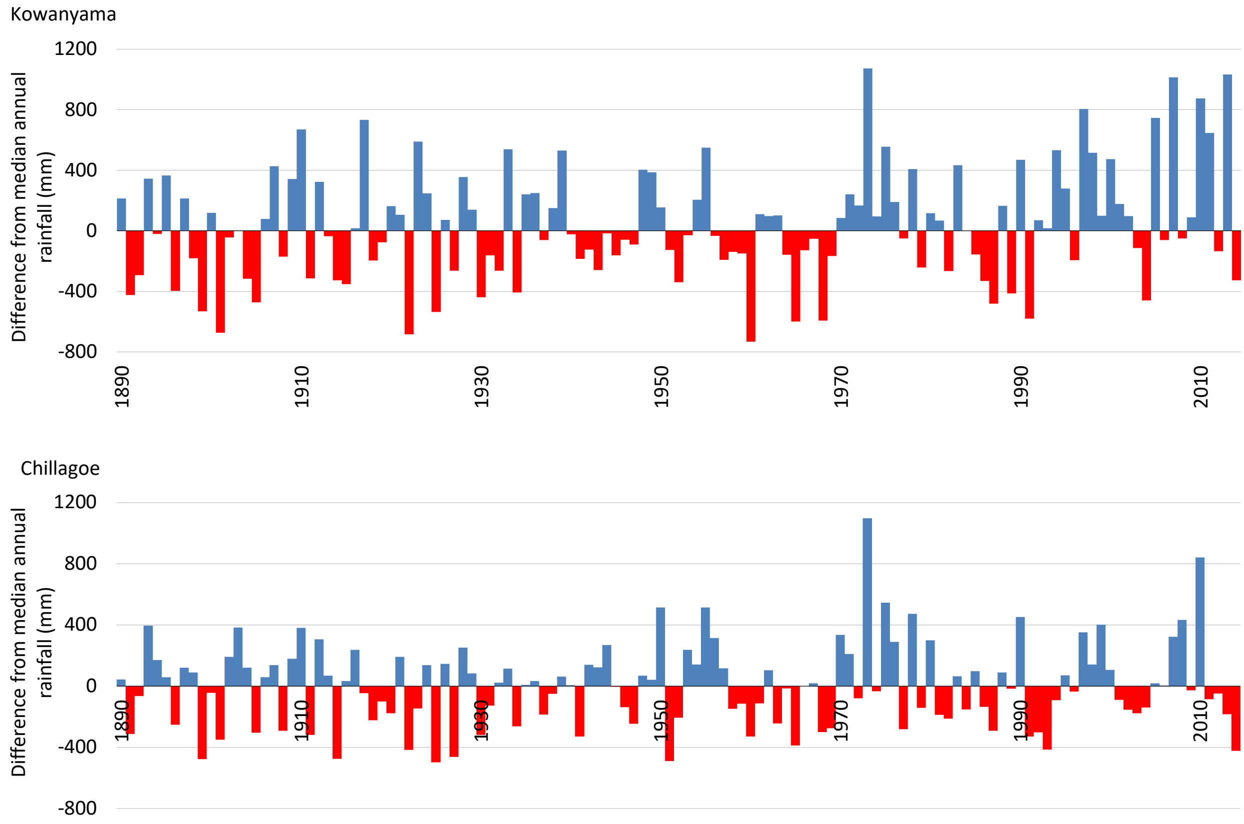


Figure 2-16 Runs of wet and dry years at Kowanyama and Chillagoe under Scenario A
Wet years are shown by the blue columns and dry years by the red columns. Scenario A is the historical climate (1890 to 2015).

Paleo-climate records for northern Australia

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

2.4.5 CHANGES IN RAINFALL AND EVAPORATION UNDER A FUTURE CLIMATE

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

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

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

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

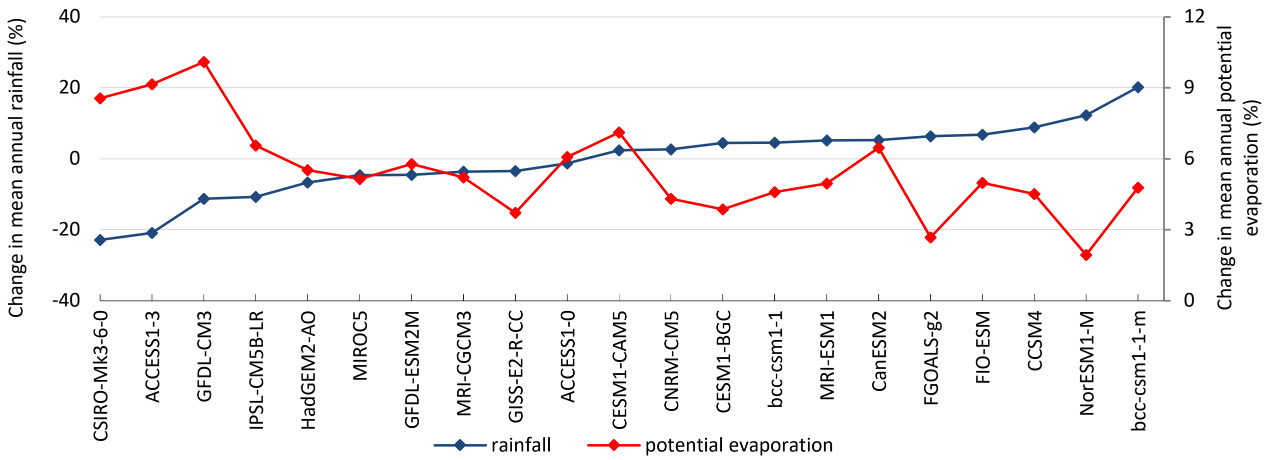


Figure 2-17 Percentage change in mean annual rainfall and potential evaporation under Scenario C relative to under Scenario A

Simple scaling of rainfall and potential evaporation have been applied to global climate model output (GCM-PS). GCM-PSs are ranked by increasing rainfall.

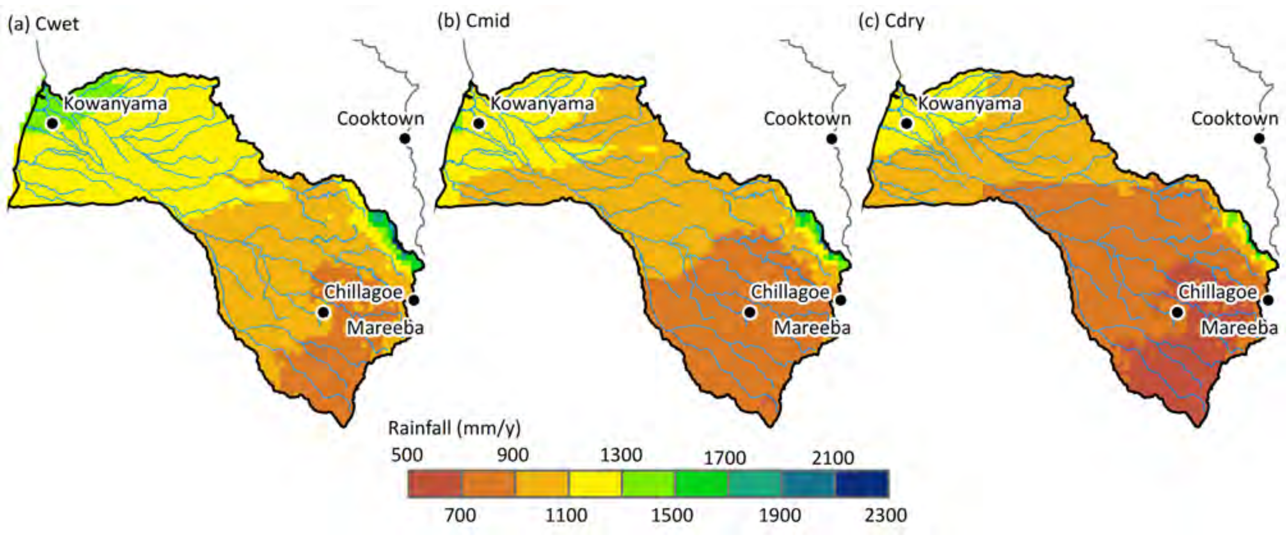


Figure 2-18 Spatial distribution of mean annual rainfall across the Mitchell catchment under scenarios Cwet, Cmid and Cdry

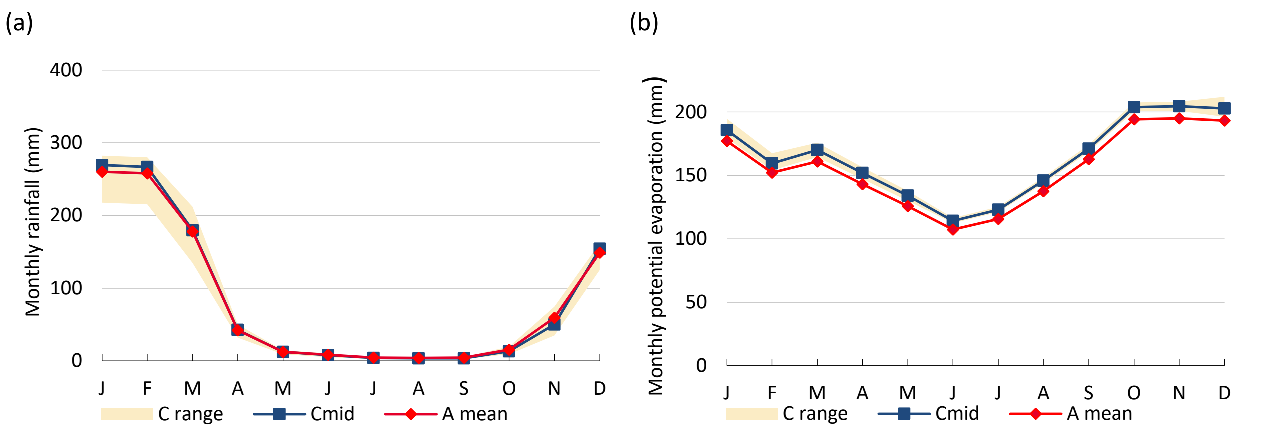


Figure 2-19 Monthly rainfall and potential evaporation for the Mitchell catchment under scenarios A and C
(a) Monthly rainfall and (b) monthly potential evaporation. C range is based on the computation of the 10th and 90th percentile monthly values separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet.

Potential evaporation

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

Sea-level rise and sea surface temperature projections

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

Table 2-2 Projected sea-level rise for the coast of the Mitchell catchment
Values are median of Coupled Model Intercomparison Project (CMIP) Phase 5 GCMs. Numbers in parentheses are the 5 to 95% range of same. Projected sea-level rise values are relative to a mean calculated between 1986 and 2005.

DATE (UNIT)	RCP 4.5	RCP 8.5
2030 (m)	0.12 (0.07–0.15)	0.11 (0.07–0.16)
2050 (m)	0.22 (0.13–0.29)	0.23 (0.15–0.32)
2070 (m)	0.31 (0.19–0.44)	0.39 (0.26–0.54)
2090 (m)	0.43 (0.26–0.62)	0.60 (0.39–0.83)
Rate of change at 2100 (mm/y)	5.9 (3.1–8.8)	10.9 (6.8–15.7)

RCP = Representative Concentration Pathway
Source: CoastAdapt (2017)

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

2.4.6 ESTABLISHMENT OF AN APPROPRIATE HYDROCLIMATE BASELINE

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

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

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

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

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

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

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

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

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

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

2.5 Hydrology of the Mitchell catchment

2.5.1 INTRODUCTION

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

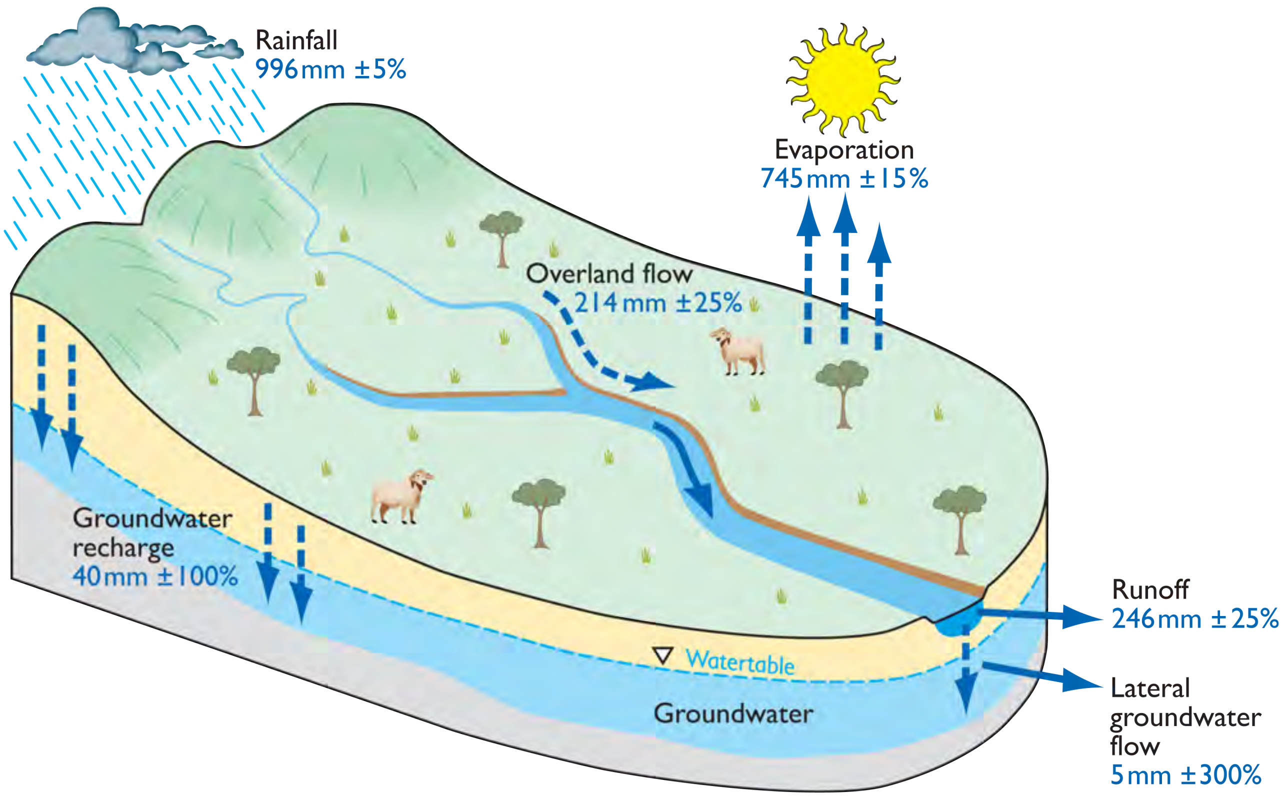


Figure 2-20 Schematic diagram of terrestrial water balance in the Mitchell catchment
Runoff is the mm depth equivalent of streamflow. Overland flow includes shallow subsurface flow. Numbers indicate mean annual values spatially averaged across the catchment under Scenario A. Numbers will vary locally.

Section 2.5 covers the remaining terms of the terrestrial water balance (accounting for water inputs and outputs) of the Mitchell catchment, with particular reference to those processes and terms that are relevant to irrigation at the catchment scale. Information is firstly provided on groundwater, groundwater recharge and surface water – groundwater connectivity. Runoff, streamflow, flooding and persistent waterholes in the Mitchell catchment are then discussed.

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

2.5.2 GROUNDWATER

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

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

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

Hydrogeological units

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

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

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

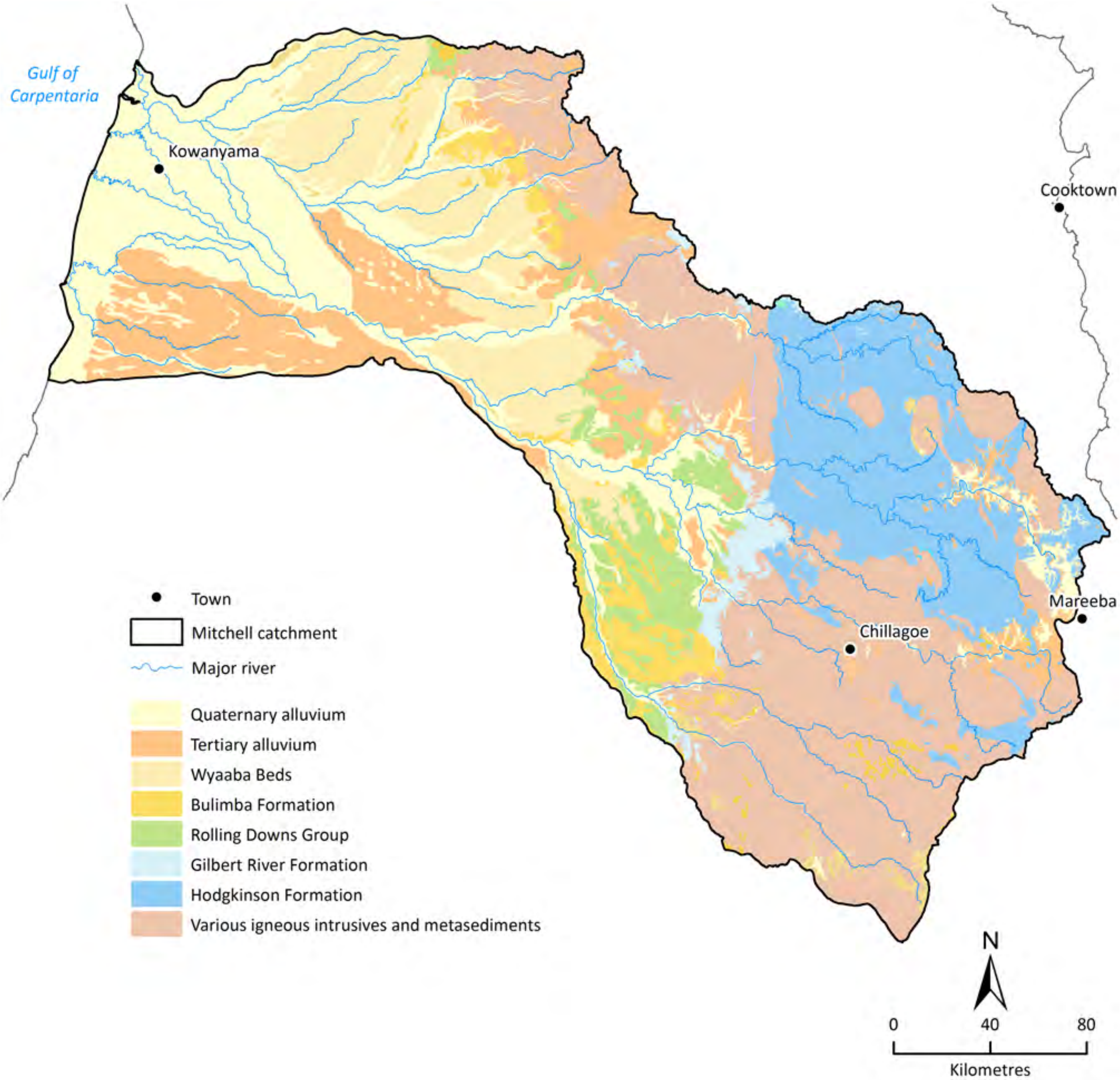


Figure 2-21 Hydrogeological units in the Mitchell catchment
Figure shows units that host aquifers and aquitards. Data source (DNRM, 2016a).

Fractured rock aquifers

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

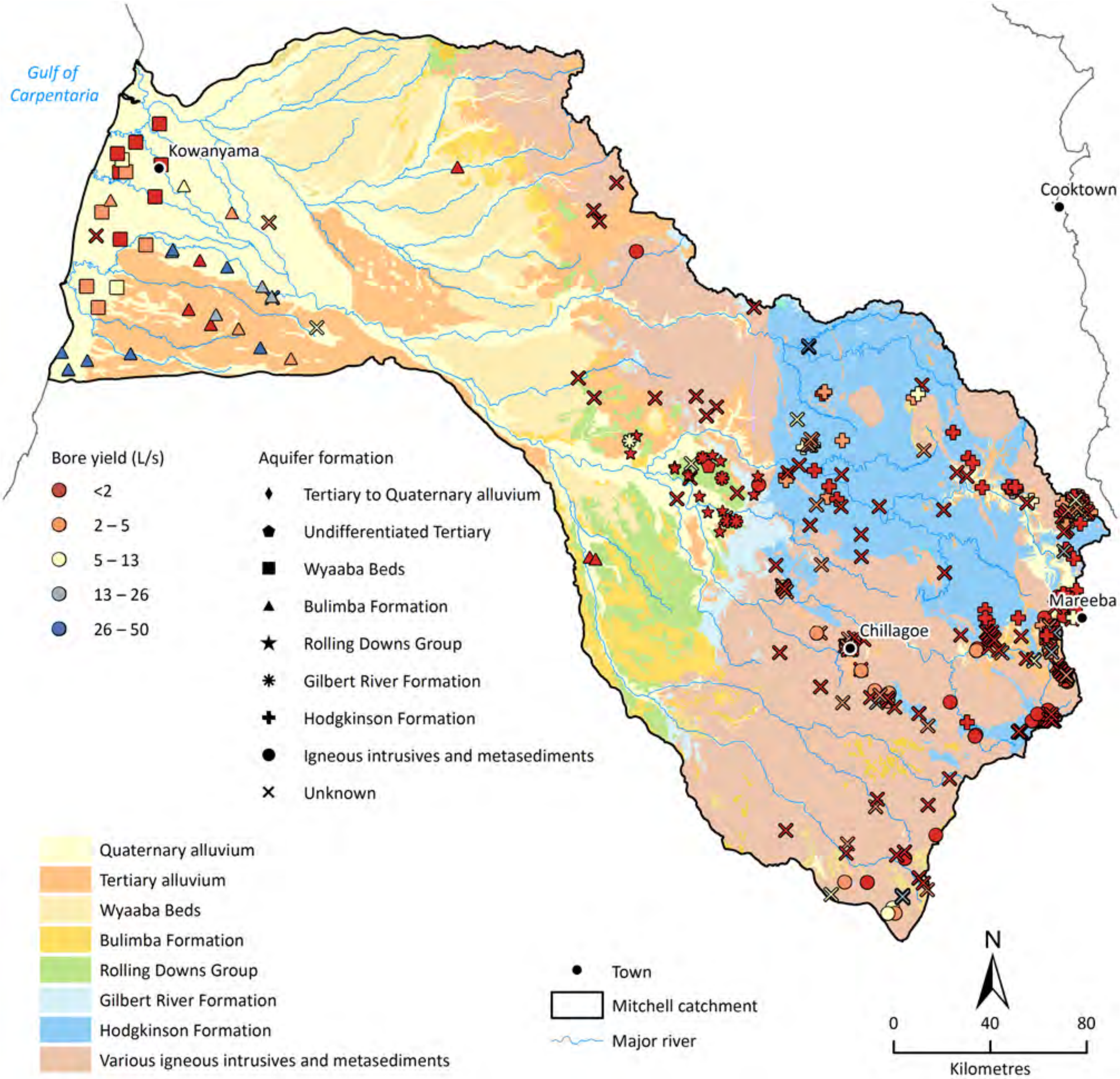


Figure 2-22 Groundwater bore yields for different aquifers in the Mitchell catchment
Data source (DNRM, 2016b)

Sedimentary aquifers of the geological Carpentaria Basin

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

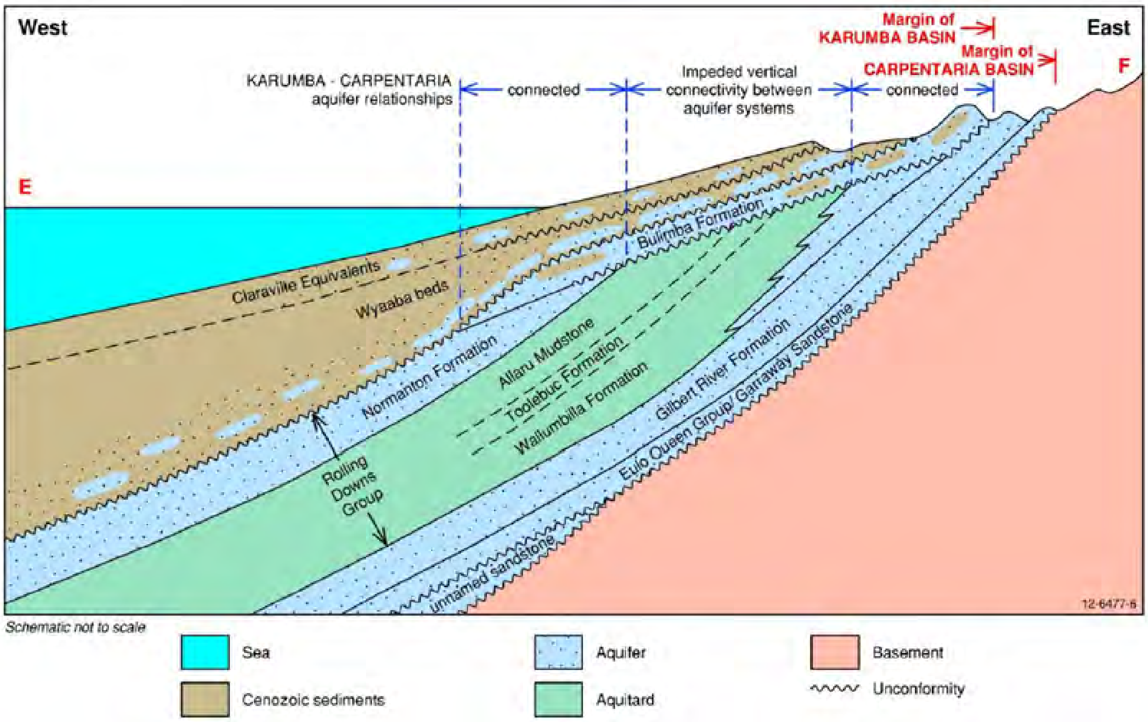


Figure 2-23 Two-dimensional hydrogeological cross-section of the Carpentaria and Karumba basins
Source: Figure 5.14 in Smerdon et al. (2012).

Figure 2-24 Outcropping units of the geological Carpentaria Basin
Photo: CSIRO

Groundwater flow is generally from east to west based on groundwater level data for the entire geological Carpentaria Basin of the Great Artesian Basin (Smerdon et al., 2012), though in the Mitchell catchment only a few bores exist in this aquifer. Bore yields range from 0.04 to 12 L/second (Figure 2-22) and water quality is fresh, ranging from 370 to 900 µS/cm (Figure 2-25).

Some opportunities for future groundwater development exist for the Gilbert River Formation aquifer, though the scale of opportunities is unclear. Only a few bores and accompanying data exist and it is (for most of the catchment) prohibitively deep to warrant investigation by drilling.

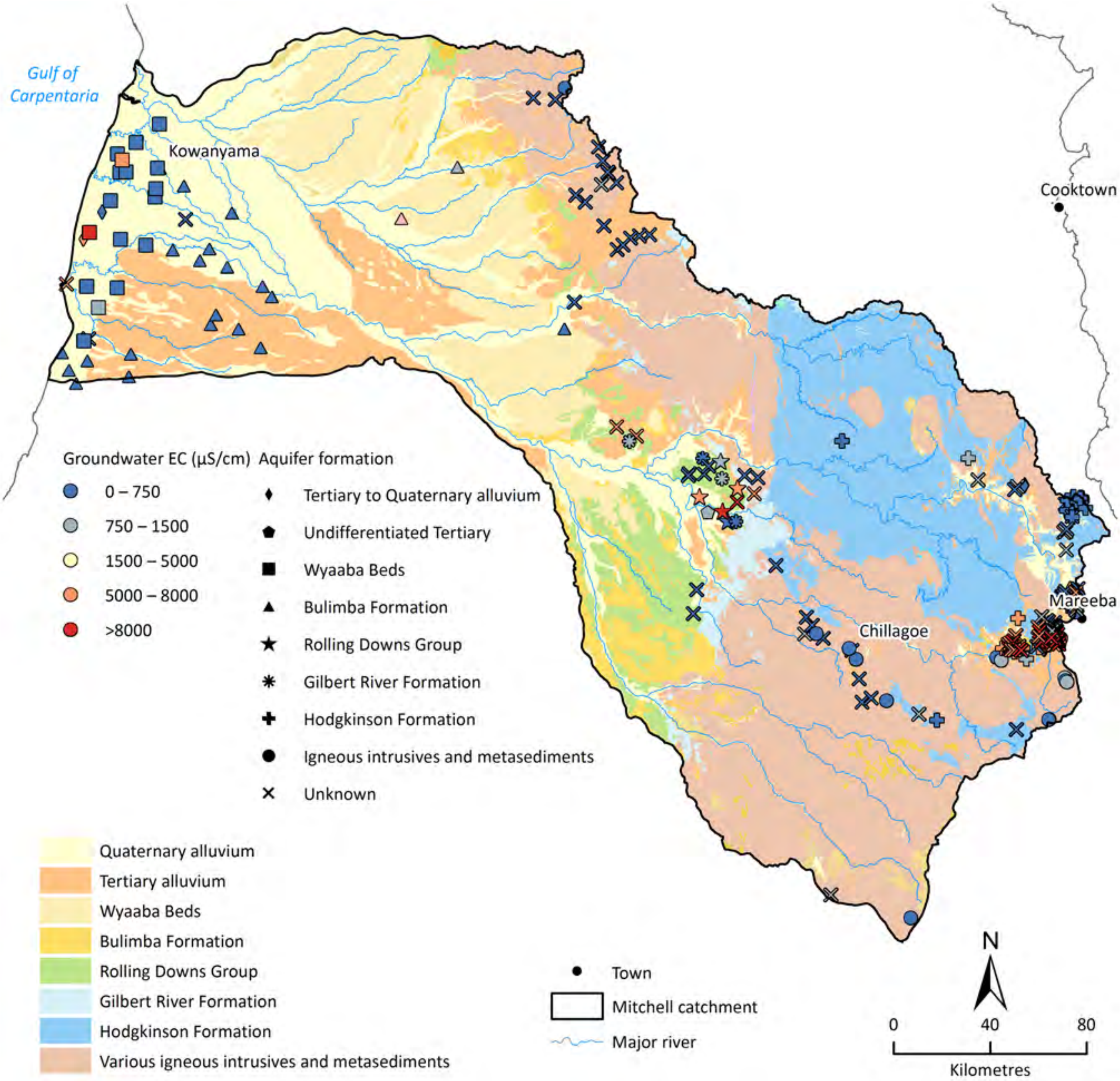


Figure 2-25 Groundwater salinity for different aquifers in the Mitchell catchment
EC = electrical conductivity. Data source (DNRM, 2016b).

Sedimentary aquifers of the Karumba Basin

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

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

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

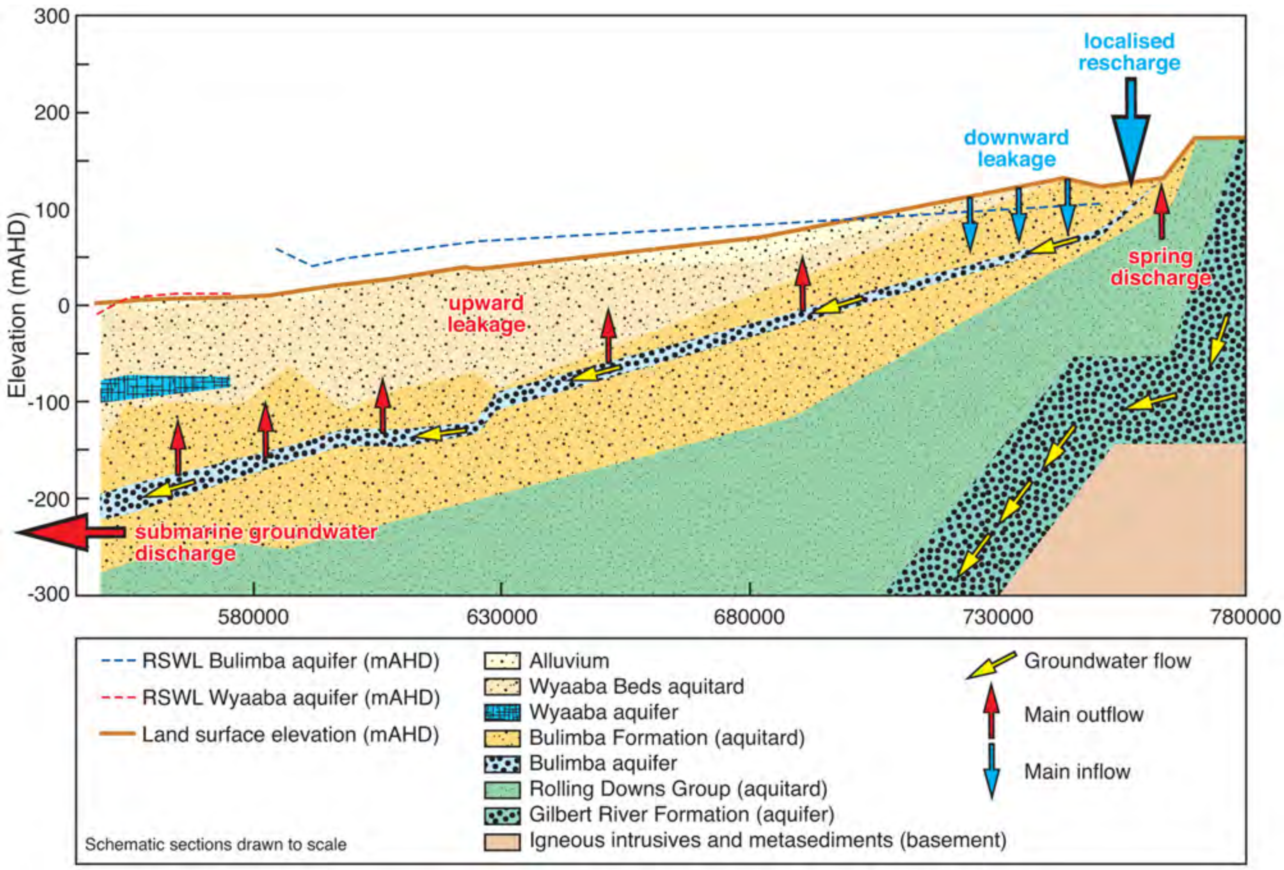


Figure 2-26 Two-dimensional conceptual schematic of key groundwater flow processes in the Bulimba aquifer
Arrows indicate directions and magnitude of flow. Horizontal axis is eastings.

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

Surficial aquifers

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

2.5.3 GROUNDWATER RECHARGE

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

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

For more detail on how these estimates were derived, see the companion technical report on hydrogeological assessment (Taylor et al., 2018).

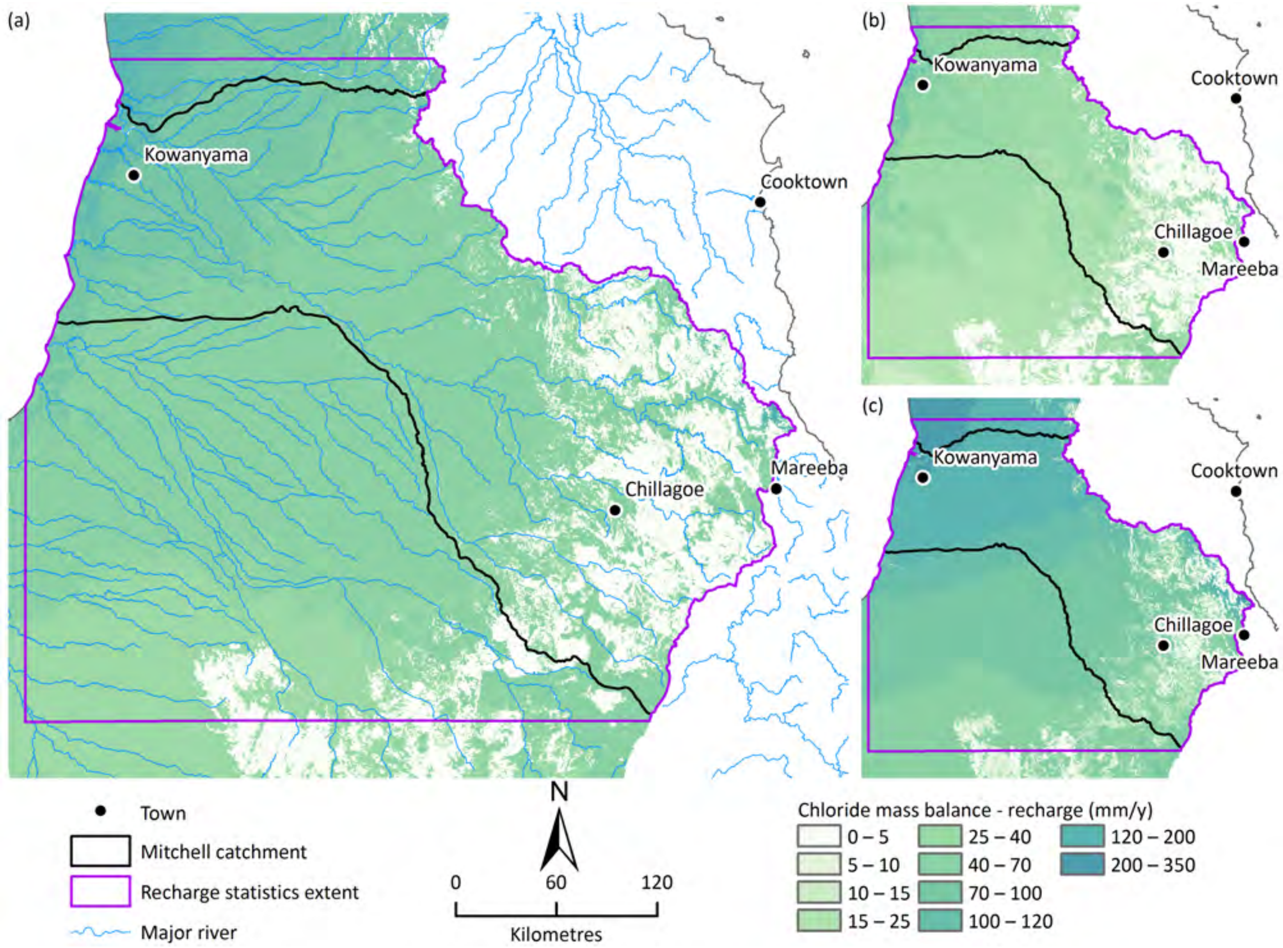


Figure 2-27 Annual recharge estimates for aquifers of the Mitchell catchment

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

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

The estimates of groundwater recharge in the Assessment represent the spatial variability in mean annual recharge across the land surface and are a good starting point for estimating a water balance arithmetically or using a groundwater model. However, none of the methods account for aquifer storage (available space in the aquifer), so it is unclear whether the aquifers can accept these rates of recharge on an annual basis. The methods also do not account for preferential recharge from streamflow or flooding in the landscape, or through sandy palaeochannel features in the outcrop area – as is the case with the Bulimba Formation. Furthermore, in some cases aquifers may not outcrop anywhere at land surface as is the case with the Wyaaba Beds. Therefore, the key features of an aquifer must be carefully conceptualised before simply deriving a recharge volume based on the surface area of an aquifer outcrop and an estimated recharge rate.

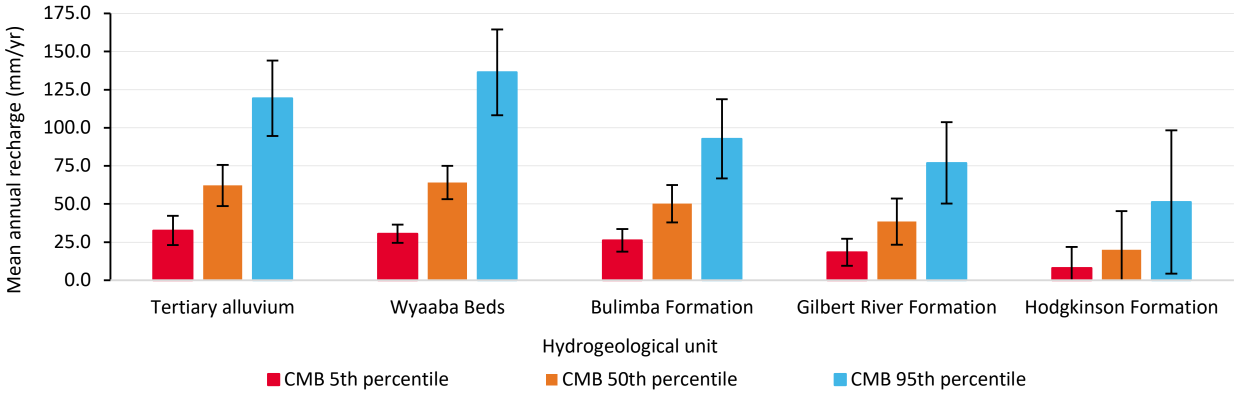


Figure 2-28 Summary of recharge statistics to outcropping areas of key hydrogeological formations
Error bars represent the standard deviation from the mean. CMB is the chloride mass balance method.

2.5.4 SURFACE WATER – GROUNDWATER CONNECTIVITY

Surface water – groundwater interactions occur at various locations in the Mitchell catchment and via a variety of processes. These processes are currently poorly quantified across the catchment due to a lack of groundwater monitoring infrastructure. However, where information does exist, this has been used to classify some river reaches into a likelihood of groundwater inflow (Figure 2-29), based on previous studies described below.

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

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

Surface water – groundwater interactions also occur between the Bulimba aquifer where the Alice, Palmer, Mitchell, Walsh and Lynd rivers and their tributaries traverse the outcropping zone. A component of recharge to the Bulimba aquifer occurs where some of the water in the rivers recharge the underlying aquifer where it is in direct contact with the overlying alluvium. A component of discharge from the Bulimba aquifer occurs as spring discharge (Figure 2-26) in the outcrop zone where the outcropping aquifer becomes full in the wet season (Herbert, 2000).

As discussed above, the alluvium of the major rivers and their tributaries are a common feature connecting groundwater and surface water. The alluvium receives a component of recharge via bank infiltration (river water infiltrating through the riverbank) from streamflow, as well as vertical recharge from overbank flooding. A component of discharge from the alluvium is via bank discharge (groundwater flowing out of the river bank) to rivers when wet-season streamflows reside in the dry season. These processes remain poorly quantified in the Mitchell catchment where bores in the alluvium are almost non-existent.

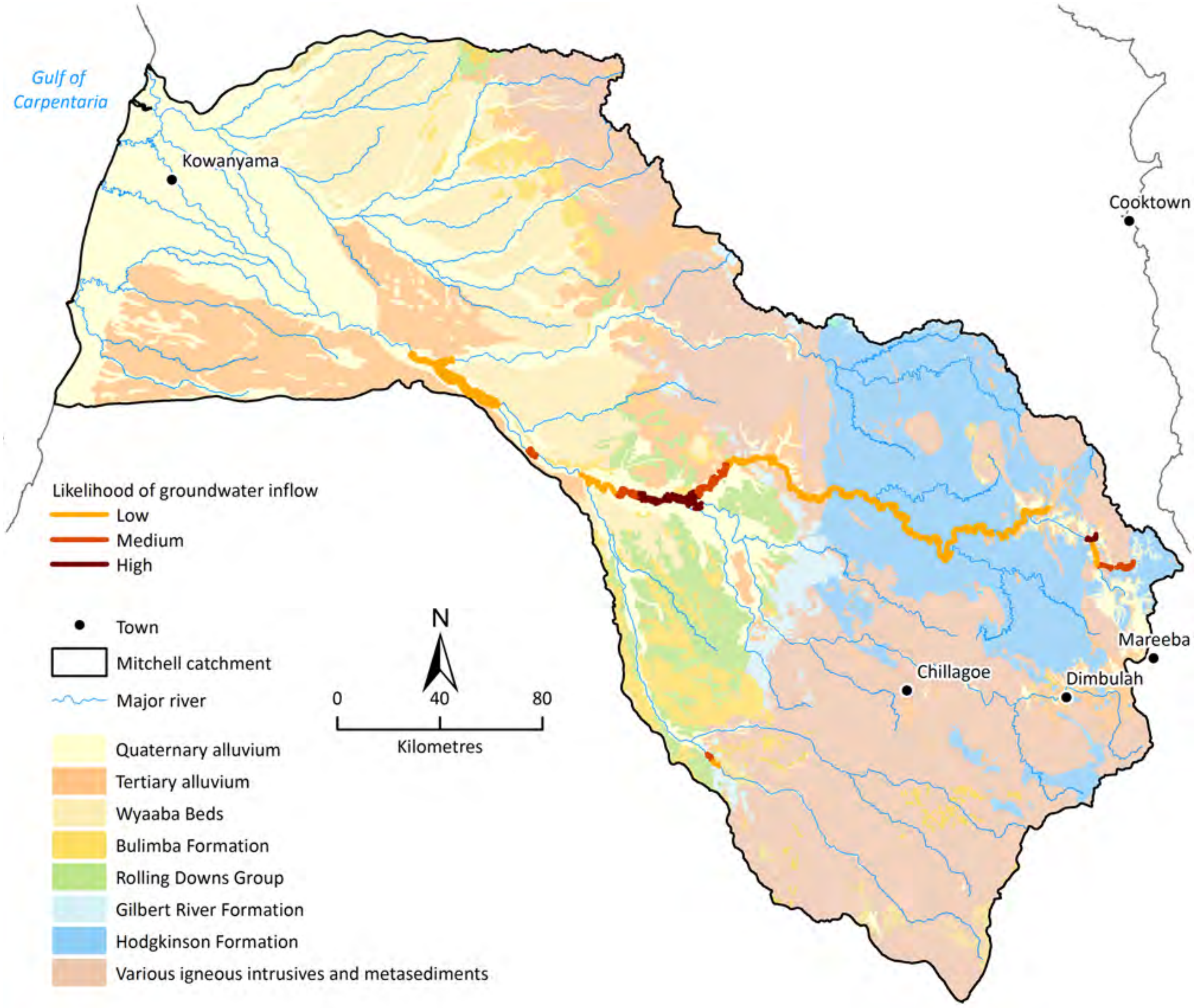


Figure 2-29 Likelihood of groundwater inflow for reaches of the Mitchell and Lynd rivers

2.5.5 SURFACE WATER

Streamflow

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

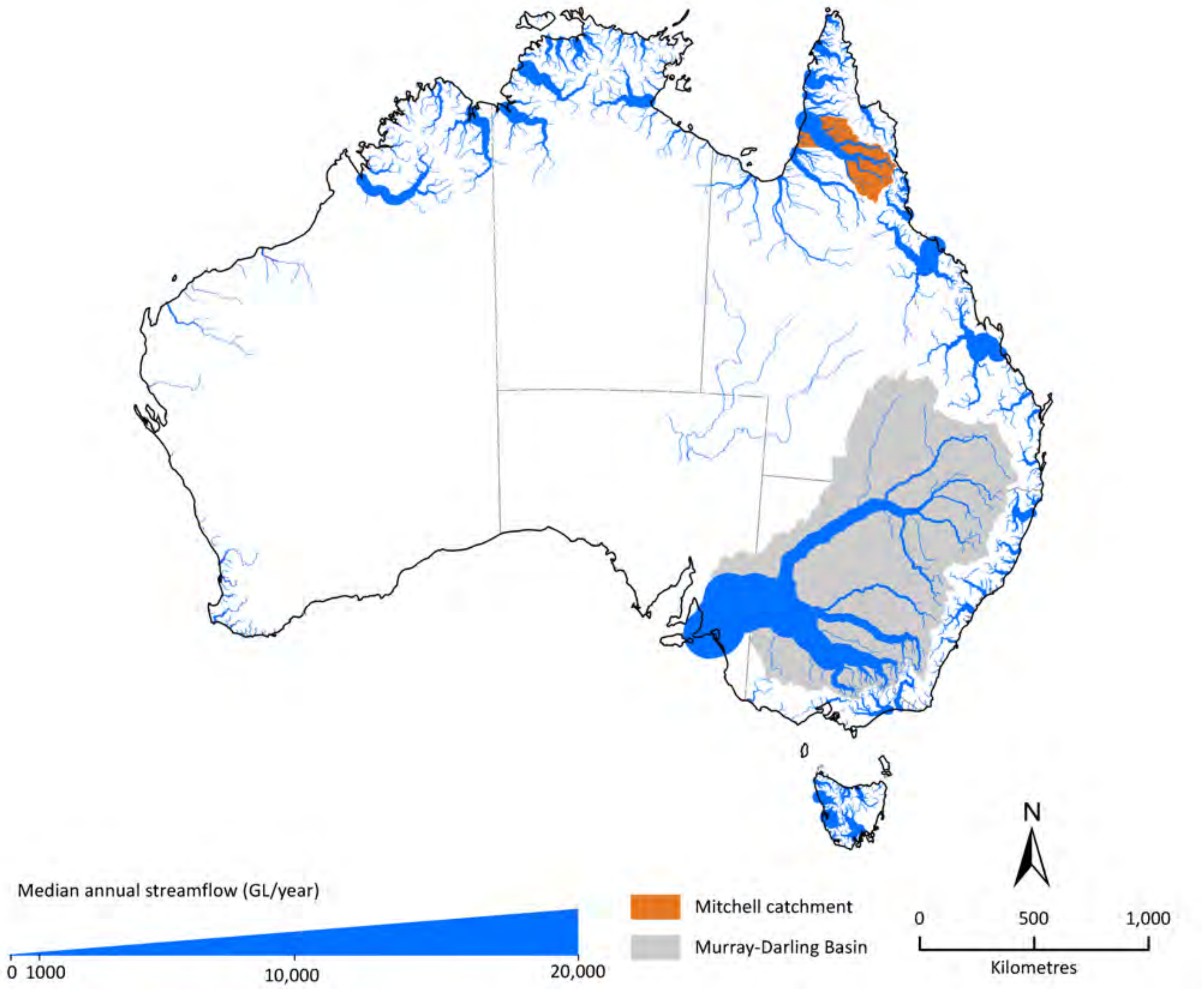


Figure 2-30 Modelled streamflow under natural conditions

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

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

At Dunbar (919009) on the Mitchell River the mean annual streamflow is about 7107 GL. Due to several very wet years 'biasing' the mean, this volume of water is more than 26% higher than the median annual streamflow (5659 GL). The Mitchell River, just before the confluence with the Walsh River, has the highest median annual streamflow (1731 GL), followed by the Palmer River

(1591 GL at 919204), Walsh River (1166 GL at 919309) and Lynd River (1107 GL). The Alice River is ungauged and is estimated to discharge at least 5000 GL into the Gulf of Carpentaria in at least 50% of years. Below Dunbar it is estimated that the median annual discharge from the Mitchell River, its distributary channels and the channels draining the alluvial plains and fans south of the Mitchell River, is 8327 GL. The nature of the connection of the main river with the distributary streams is unknown, and no streamflow gauge data are available downstream of the Dunbar gauge (919009).

As shown in Table 2-3, the upper sections of the Mitchell, Lynd, Palmer and Walsh rivers are perennial most years. Mid-catchment (upstream of gauge 919009), the Palmer and Mitchell rivers remain perennial most years, while the Walsh and Lynd rivers cease to flow for between 20 and 50% of days each year. Below Gamboola (919011) the Mitchell River is perennial.

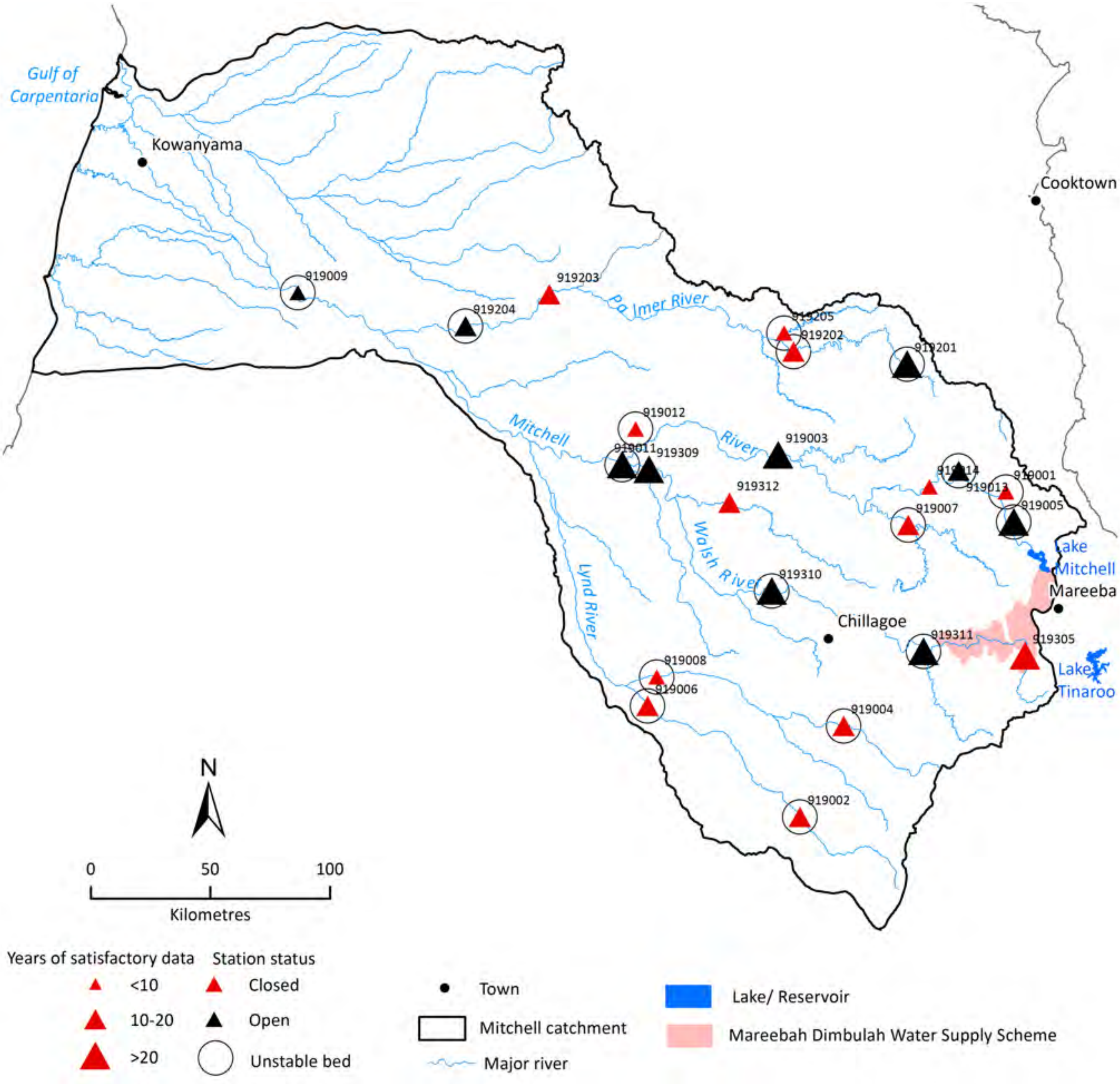


Figure 2-31 Streamflow observation data availability in the Mitchell catchment

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

Table 2-3 Streamflow metrics at gauging stations in the Mitchell catchment

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

STATION ID	STATION NAME	CATCHMENT AREA (km²)	ANNUAL STREAMFLOW (GL)						CEASE-TO-FLOW (%)	BASE-FLOW INDEX
			Max-imum	20th	50th	80th	Min-imum	Mean		
919001	Mary Creek at Mary Farms	86	281	113	88	64	33	91	0	0.59
919002	Lynd River at Lyndbrook	1257	1003	205	100	37	2	135	54	0.18
919003	Mitchell River at O.K. Bridge	7728	9462	2955	1719	620	159	1976	3	0.23
919004	Tate River at Ootann	1618	1690	556	326	125	7	375	48	0.18
919005	Rifle Creek at Fonthill	365	1153	280	187	95	20	207	1	0.27
919006	Lynd River at Torwood	4570	5307	1022	649	347	38	784	15	0.19
919007	Hodgkinson River at Piggy Hut	1693	1892	605	326	118	30	415	49	0.12
919008	Tate River at Torwood	4273	2837	661	374	153	12	453	34	0.25
919009	Mitchell River at Dunbar	45543	33365	10071	5659	2856	805	7107	2	0.30
919011	Mitchell River at Gamboola	20317	15358	5619	3145	1268	318	3697	1	0.24
919012	Galvin Creek at Reid Creek Junction	168	180	95	60	37	12	66	56	0.17
919013	McLeod River at Mulligan Highway	533	1084	339	204	94	25	237	0	0.35
919014	Mitchell River at Cooktown Crossing	2514	5217	1355	799	345	87	915	2	0.28
919201	Palmer River at	531	683	248	139	41	12	157	19	0.17

STATION ID	STATION NAME	CATCHMENT AREA (km²)	ANNUAL STREAMFLOW (GL)						CEASE-TO-FLOW (%)	BASE-FLOW INDEX
	Goldfields									
919202	Palmer River at Maytown	2164	2001	872	458	135	42	535	37	0.15
919203	Palmer River at Strathleven	7062	4243	1920	1214	493	132	1310	1	0.21
919204	Palmer River at Drumduff	7732	5119	2379	1584	718	231	1662	0	0.26
919205	North Palmer River at 4.8 km	422	268	114	65	20	3	72	52	0.26
919305	Walsh River at Nullinga	327	438	162	86	35	3	103	4	0.26
919309	Walsh River at Trimbles Crossing	8649	6886	2043	1161	458	116	1415	23	0.25
919310	Walsh River at Rookwood	4928	5159	1467	810	269	32	971	20	0.22
919311	Walsh River at Flatrock	2792	3098	1083	560	210	21	676	0	0.20
919312	Elizabeth Creek at Greenmantle	623	559	244	147	72	18	169	52	0.17

The Mitchell River during the dry season is pictured Figure 2-32.

Figure 2-32 Mitchell River during the dry season
Photo: CSIRO

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

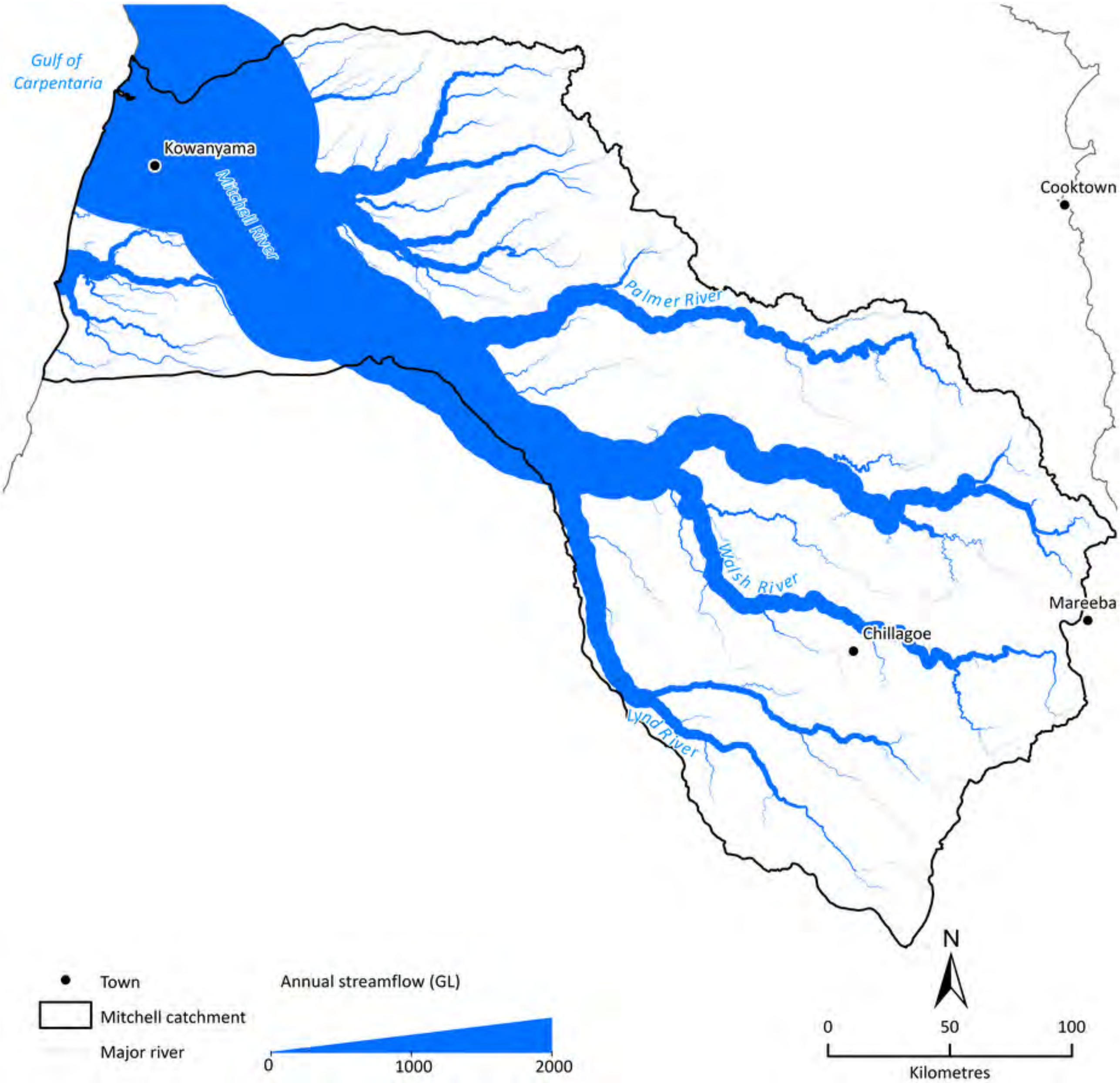


Figure 2-33 Median annual streamflow (50% exceedance) in the Mitchell catchment under Scenario A

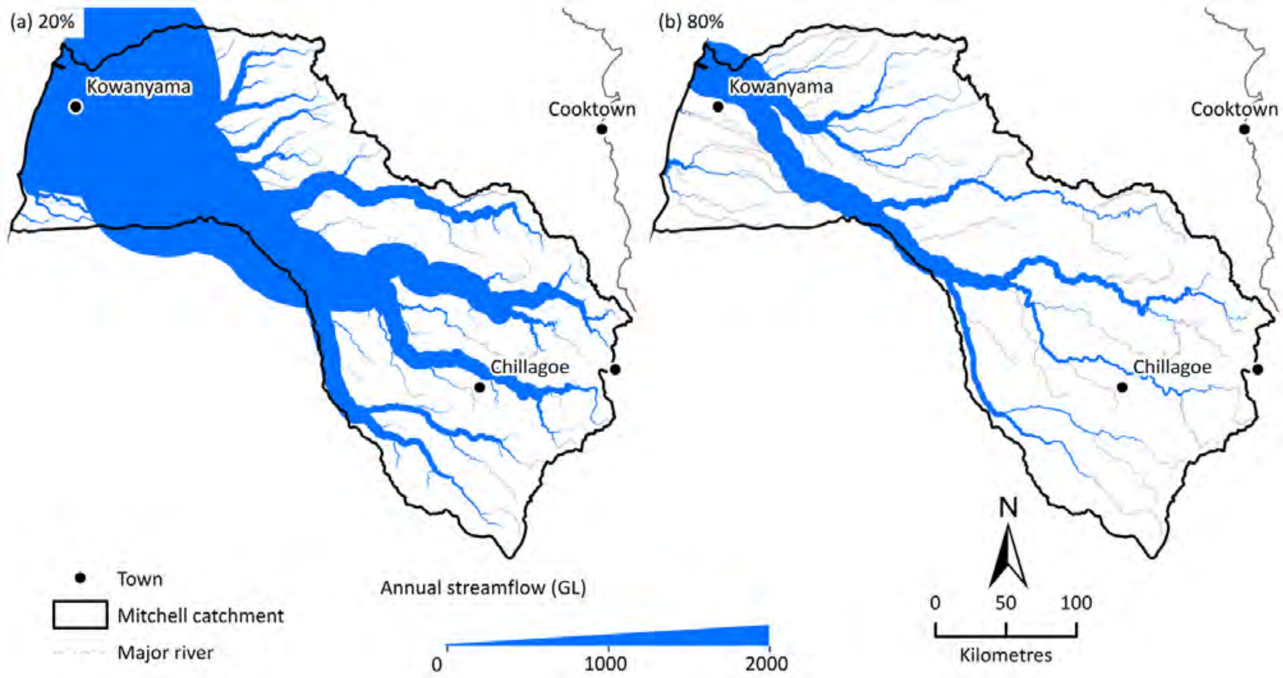


Figure 2-34 20% and 80% exceedances of annual streamflow in the Mitchell catchment under Scenario A

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

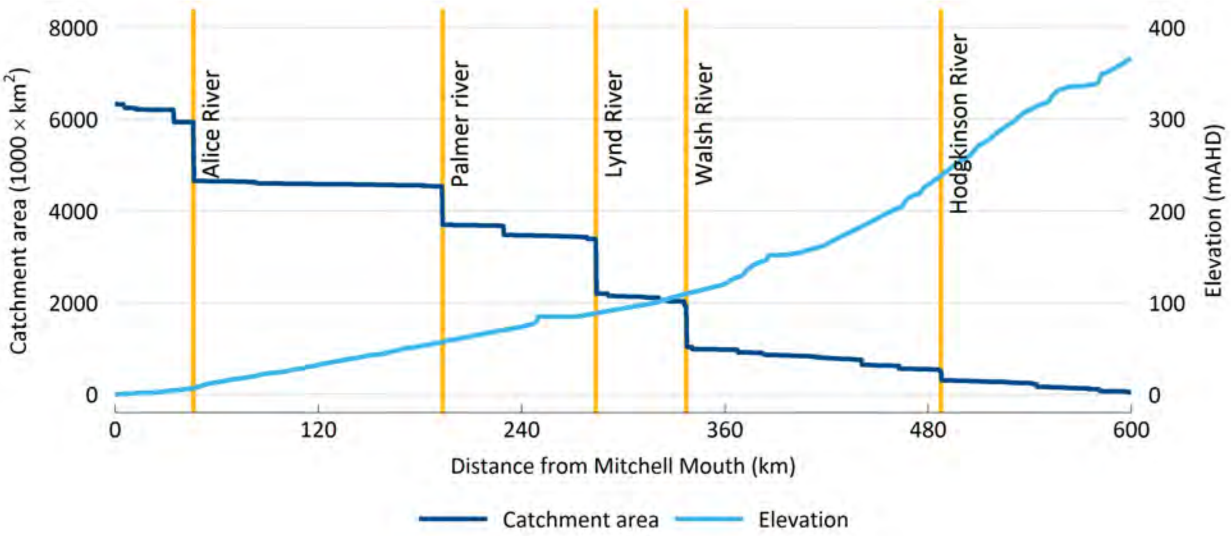


Figure 2-35 Catchment area and elevation profile along the Mitchell River from its mouth to its source

Catchment runoff

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

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

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

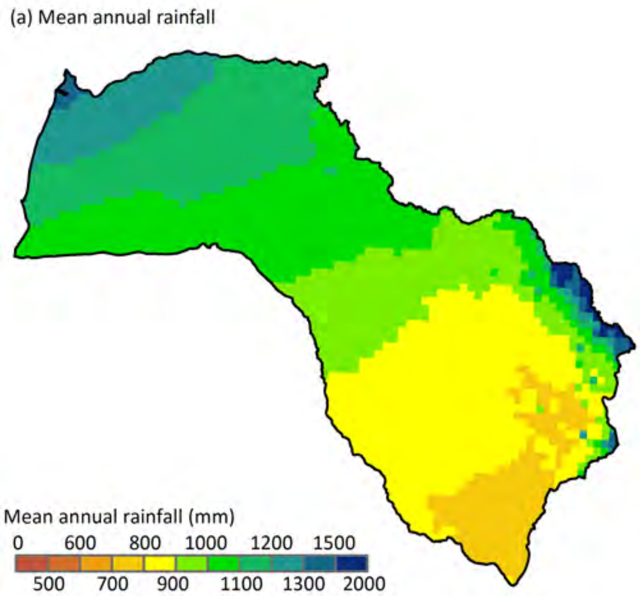


Figure 2-36 Mean annual rainfall and runoff across the Mitchell catchment under Scenario A
Pixel scale variation in mean annual runoff plot is due to modelled variation due to soil type.

Figure 2-37 Walsh River upstream of the junction with the Mitchell River during the dry season

Figure 2-38 Palmer River during the dry season

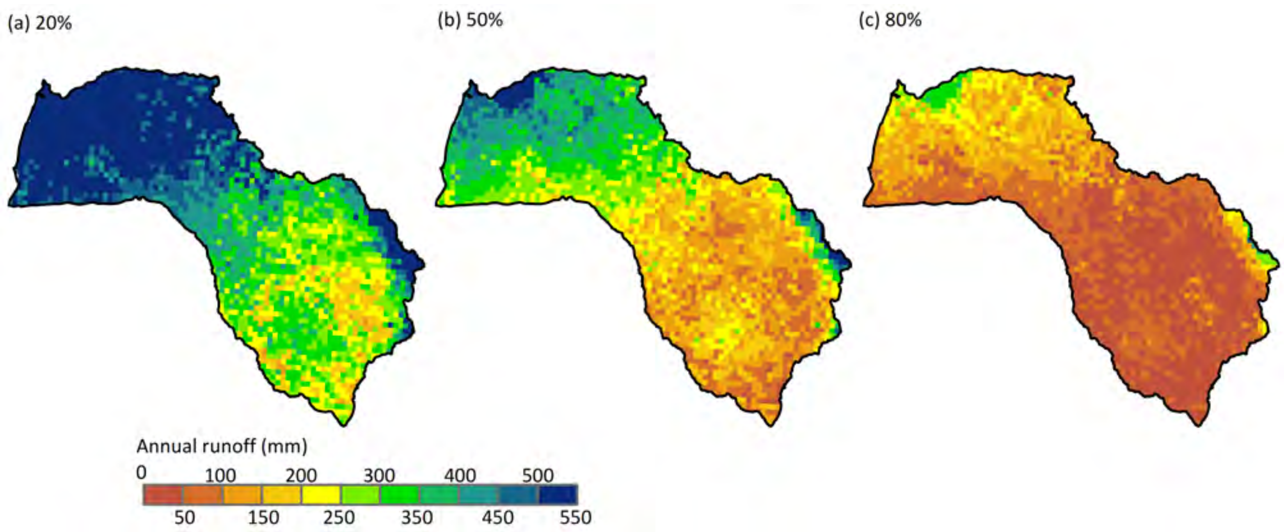


Figure 2-39 Maps showing annual runoff at 20%, 50% and 80% exceedance across the Mitchell catchment under Scenario A

Pixel scale variation in mean annual runoff plot is due to modelled variation due to soil type.

Intra- and inter-annual variability in runoff

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

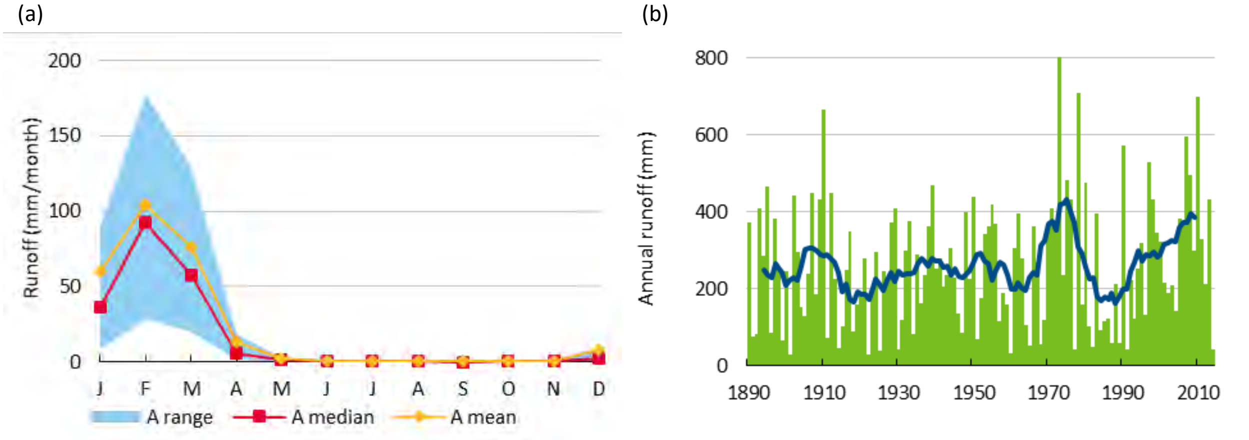


Figure 2-40 Runoff in the Mitchell catchment under Scenario A
(a) Monthly runoff averaged across the Mitchell catchment. (b) Time series of annual runoff averaged across the Mitchell catchment.

Flooding

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

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

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

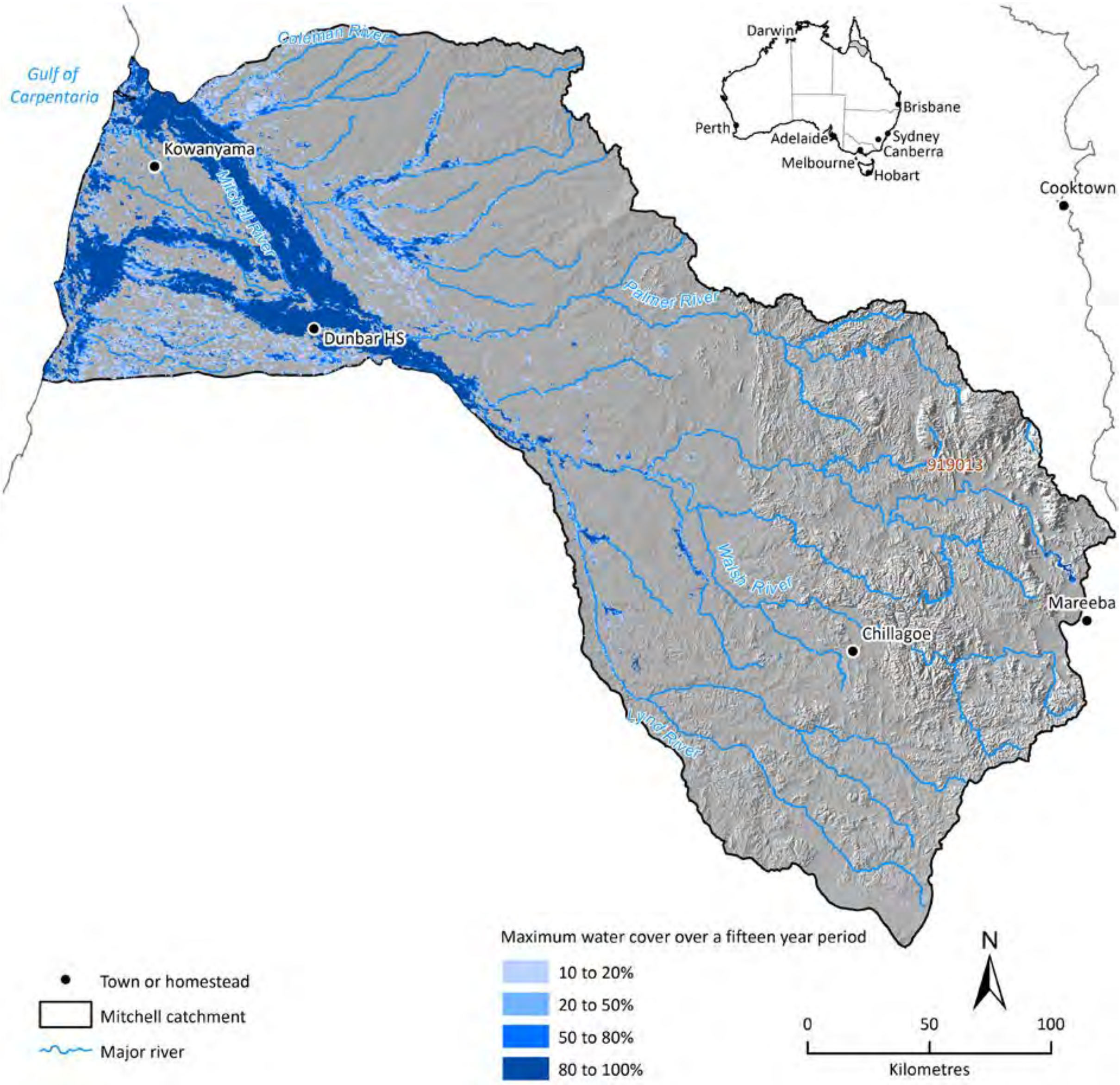


Figure 2-41 Flood inundation map of the Mitchell catchment
Data captured using MODIS satellite imagery. This figure illustrates the maximum percentage of MODIS pixel inundated between 2000 and 2015.

Figure 2-42 indicates the spatial extent and temporal variation in inundation on the coastal floodplains of the Mitchell catchment for selected flood events, based on computer model simulations (see Karim et al., 2018). Where introduced pastures are inundated with stagnant water for a period greater than 5 consecutive days, the above-ground biomass may die; this may extend to 2 weeks if the water is aerated. Where the period of inundation is greater than 20 consecutive days, the entire plant may die. This does, however, vary between pasture species. The largest flood event recorded at streamflow gauging station 919009, the most downstream station in the Mitchell catchment, was in 2011.

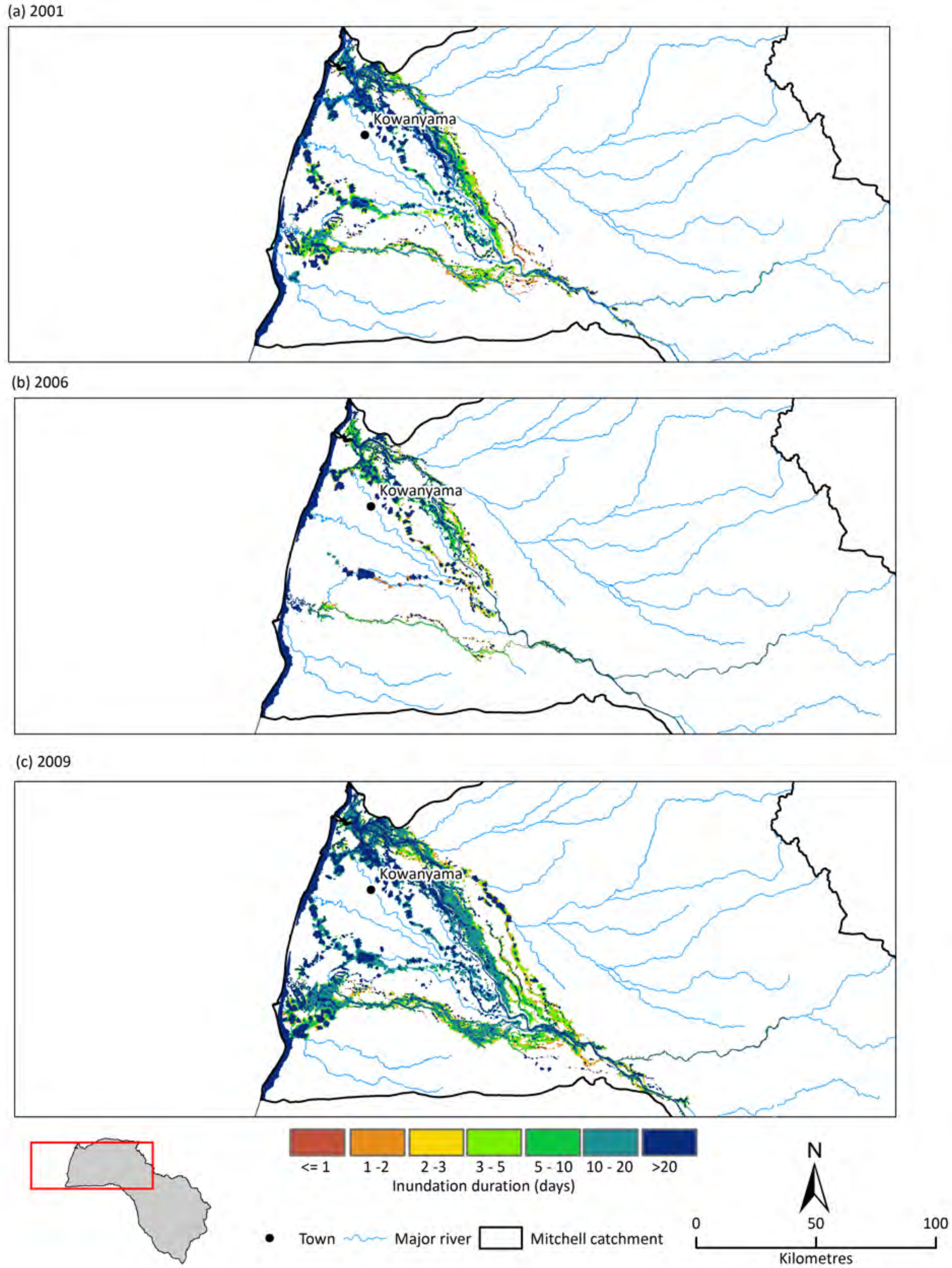


Figure 2-42 Spatial extent and temporal variation of inundation during simulated flood events of (a) 2001 (AEP 1 in 10), (b) 2006 (AEP 1 in 2) and (c) 2009 (AEP 1 in 26)

AEP refers to annual exceedance probability.

Further observations of flooding under the historical climate in the Mitchell catchment are as follows:

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

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

A strong relationship is observed between peak flood discharge at gauge 919009 and maximum inundated area of the Mitchell River floodplain. This relationship enables maximum inundated area to be estimated from streamflow data (Figure 2-43a). Figure 2-43b shows the relationship between peak flood discharge and annual exceedance probability (AEP). These two figures can be used together to estimate the AEP of maximum inundated areas. For example, Figure 2-43a shows the maximum inundated area of 2500 km^2 corresponds to a peak flood discharge of about 4800 m^3/second, which in turn corresponds to an AEP of 20% (or 1 in 5 years) (Figure 2-43). Hence a maximum inundated area of 2500 km^2 is exceeded in 20% of years.

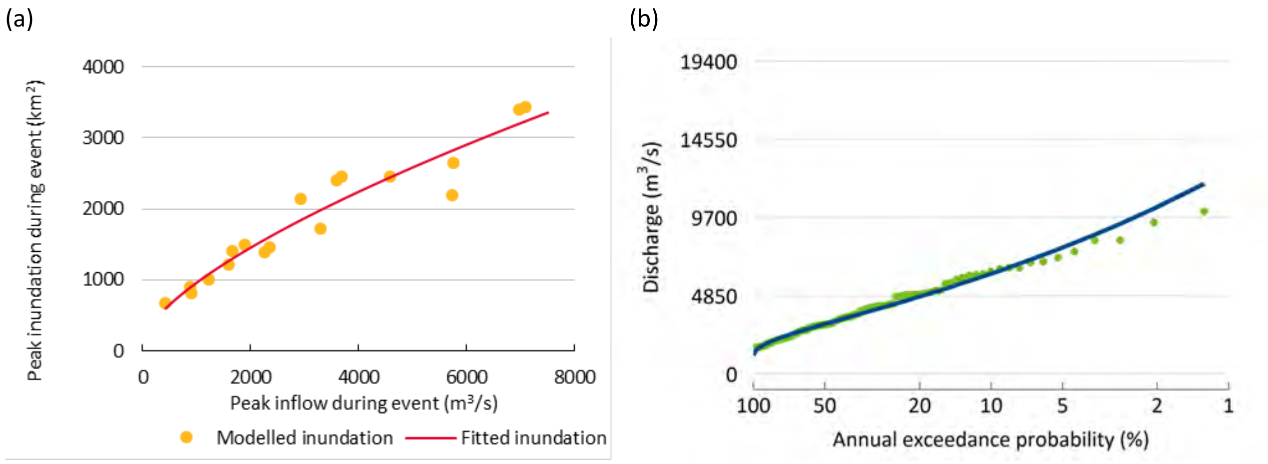


Figure 2-43 Relationships between peak flood discharge, maximum inundated area and annual exceedance probability

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

Streamflow forecasting

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

Instream waterholes during the dry season

The Mitchell River experiences very few no-flow days. However, its major tributaries the Palmer, Walsh and Lynd and their tributaries do experience cease-to-flow periods (Table 2-3). Once streamflow has ceased the rivers break up into a series of waterholes during the dry season. Waterholes that 'persist' from one year to the next are key aquatic 'refugia' and are likely to be sustaining ecosystems in the Mitchell catchment (Section 3.2). Waterholes in the Mitchell catchment are pictured in Figure 2-44 and Figure 2-45.

Figure 2-44 Panoramic view of a persistent waterhole in the Mitchell catchment
Photo: CSIRO

Figure 2-45 Plumed whistling ducks (*Dendrocygna eytoni*) at persistent waterhole in the Mitchell catchment
Photo: CSIRO

In some reaches waterholes may be partly or wholly sustained by groundwater discharge (Section 2.5.4). However, in other reaches there is little evidence that 'persistent' waterholes receive water from groundwater discharge and are likely to be replenished following wet-season flows.

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

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

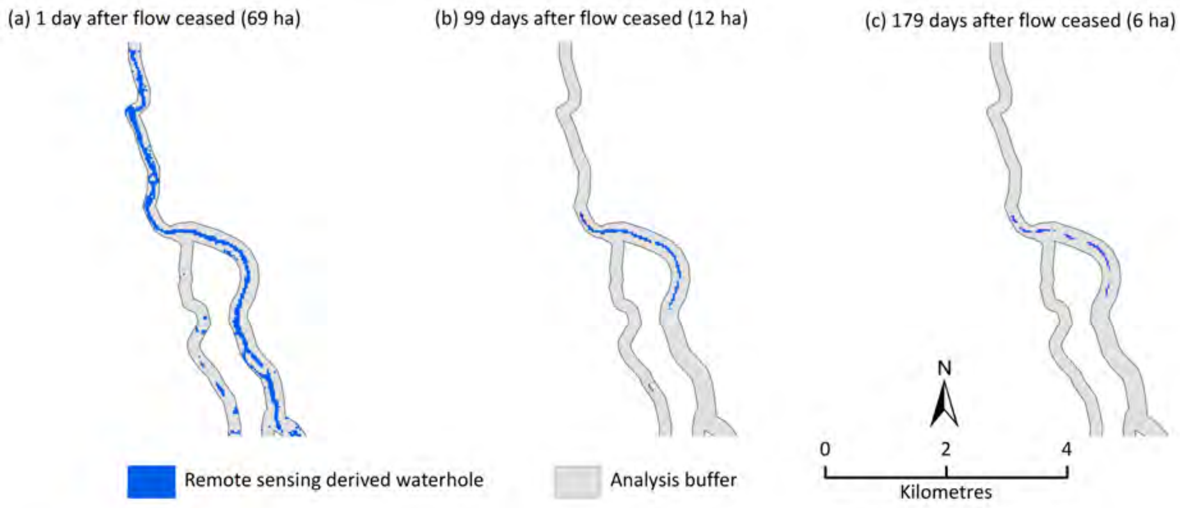


Figure 2-46 Instream waterhole evolution
This figure shows the area of waterholes at a given time after flow ceased and the ability of the water index threshold to track the change in waterhole area and distribution.

As shown in Figure 2-44 and Figure 2-45 persistent waterholes can have variable characteristics, e.g. levels of turbidity and adjacent riparian vegetation. These differences can result in waterholes having varying degrees of ecological importance and different ecological responses arising from a development (Section 3.2).

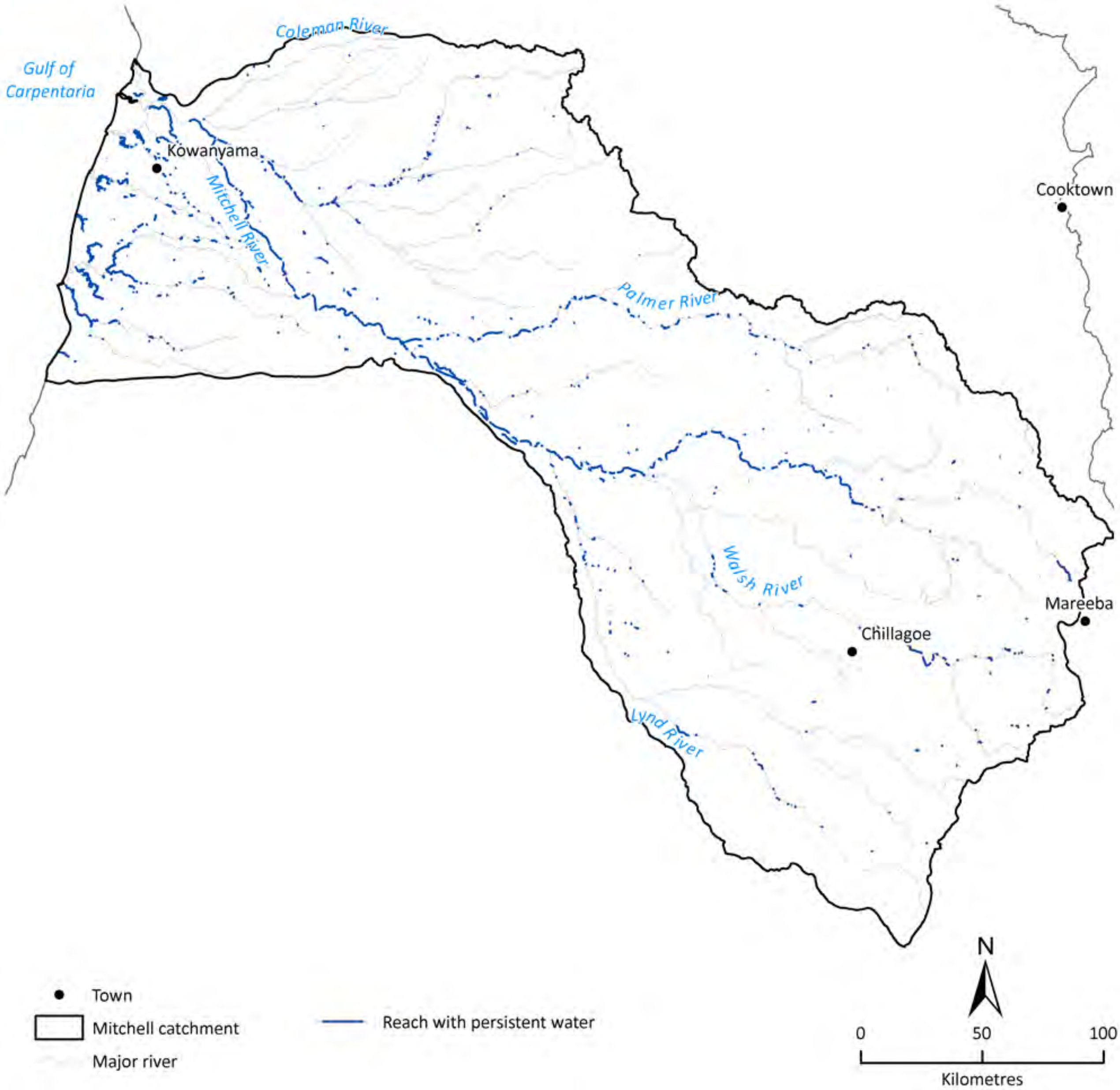


Figure 2-47 Location of river reaches containing permanent water in the Mitchell catchment and water quality sample locations

Persistent river reaches are defined as 1-km river reaches where water was identified in greater than 90% of the dry-season LandSat imagery between 1990 and 2016.

Surface water quality

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

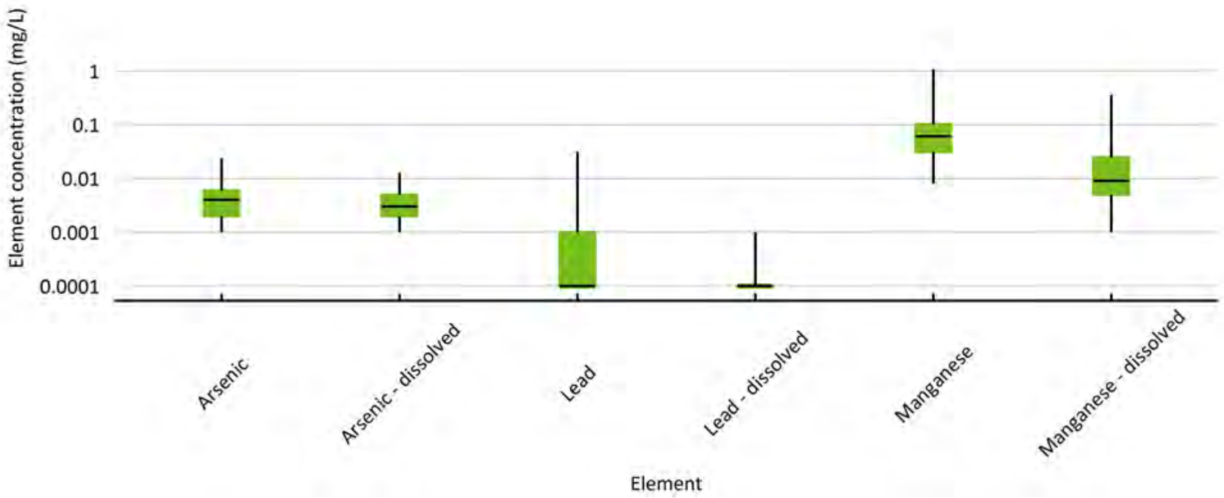


Figure 2-48 Heavy metal concentrations in Mitchell catchment streams sampled in 2017 and 2018

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3 Living and built environment of the Mitchell catchment

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Chapter 3 discusses a wide range of considerations relating to the living component of the catchment and the environments that support these components, the people who live in the catchment or have strong ties to it, the perspectives of investors, the existing transport, power and water infrastructure and the legal, policy and regulatory environment relating to the development of land and water.

The key components and concepts of Chapter 3 are shown in Figure 3-1.

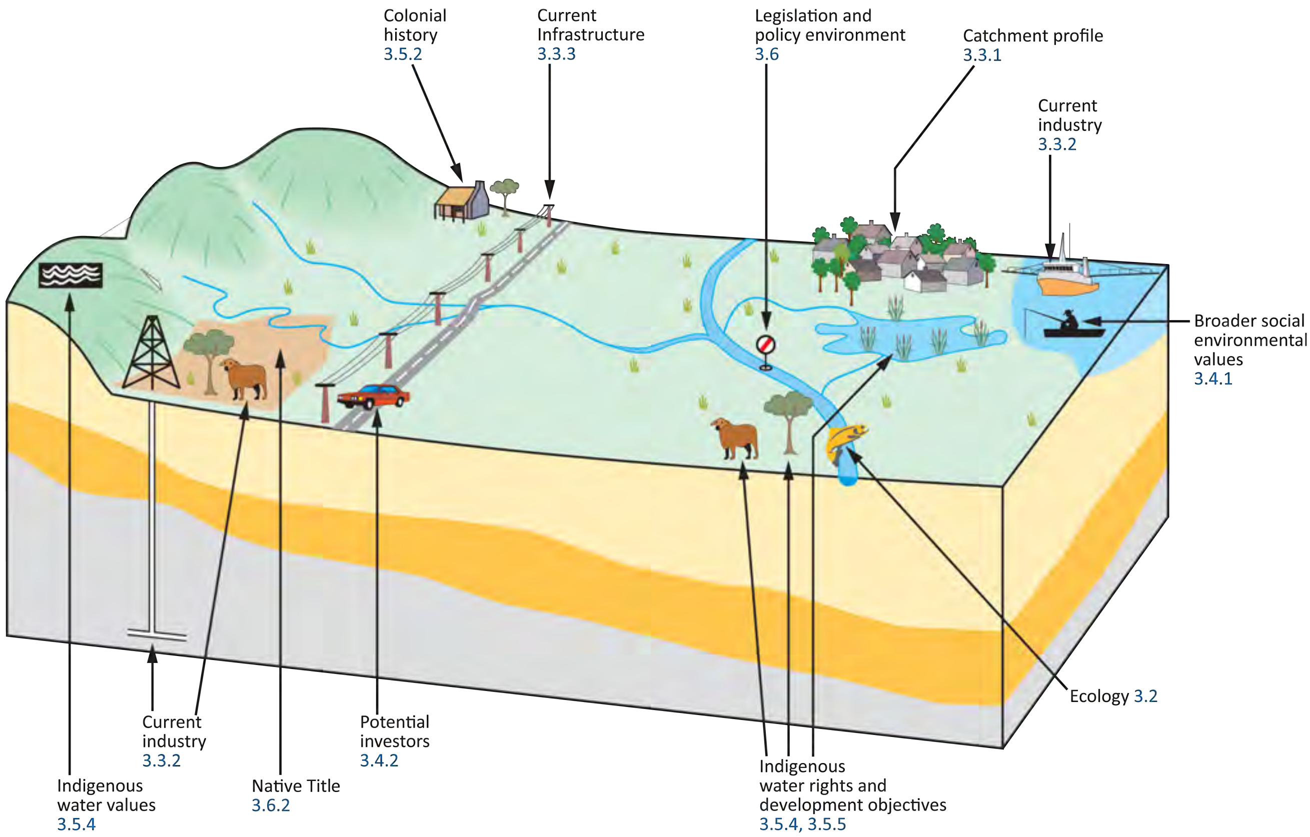

Figure 3-1 Schematic diagram of key components of the living and built environment to be considered in the establishment of a greenfield irrigation development

3.1 Summary

This chapter provides information on the living and built environment including information about the people, the ecology, the infrastructure and the institutional context of the Mitchell catchment. It also examines the values, rights, interests, and development objectives of Indigenous people.

3.1.1 KEY FINDINGS

Ecology

The Mitchell catchment supports a variety of aquatic and terrestrial ecosystems. The Mitchell River connects upland rainforests in the wet tropics through to tropical savanna landscapes and drains into the Gulf of Carpentaria, which has high conservation and economic values. The highly seasonal flows of the Mitchell catchment underpin river-floodplain productivity and provide critical habitats for species. These flows also support a range of fish species, including freshwater sawfish (*Pristis pristis*) (listed as vulnerable under the *Environment, Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act)), a commercial and recreational barramundi (*Lates calcarifer*) fishery and the extensive commercial Northern Prawn Fishery - one of the most valuable fisheries in the country.

The Mitchell catchment has four important bird areas and three wetlands of national significance: the Mitchell River Fan Aggregation (Mitchell River delta), Southeast Karumba Plain Aggregation, and the Spring Tower Complex. Of the four important bird areas the largest is the Southeast Karumba Plan Aggregation. This area provides important waterbird breeding habitat, including the second-largest summer population of wader birds in Australia, and is recognised by Environment Australia (2001) as having high wilderness value.

Given the permanent and unmodified aquatic habitats, the catchment has the second highest fish species richness nationally, with 57 species recorded. Freshwater migratory fishes, which are particularly vulnerable to inchannel barriers, are distributed throughout the Mitchell catchment, with the highest diversity concentrated at the bottom of the catchment. During the dry season, permanent waterholes are critical refugia in an otherwise dry landscape and allow plants and animals to colonise areas during the wet season. The Mitchell catchment also has extensive riparian zones, which are highly fertile and productive when compared to the surrounding terrestrial environment. Towards the end of the catchment, mangroves and salt flats are located along the catchments coastal margin. Salt flats contribute significantly to primary production in coastal areas, releasing high concentrations of nutrients and benthic algae during wetting periods.

While the Mitchell catchment is largely intact it is not pristine. The most widespread agricultural land use is pastoralism, although there has been relatively little clearing within the catchment.

Demographics, industries and infrastructure

The population in the Mitchell catchment is low (about 6500) and sparse with the largest settlement being Dimbulah (population 1050). Unemployment (11%) is high compared with the national average and the population is at a socio-economic disadvantage relative to the rest of the country. The main land use is pastoralism (95%) on large grazing leases where cattle graze native pastures and shrubs. Part of the Mareeba–Dimbulah Water Supply Scheme (MDWSS) extends into the upper reaches of the Mitchell catchment. The gross value of agricultural production is $225 million/year, about half of which is from beef production, with cropping (mangoes, sugarcane and avocados) making up most of the remainder.

The Mitchell catchment is characterised by a sparse road network with the Burke Development Road being the main access to Mareeba and Cairns in the east and to Normanton and Cloncurry in the south. All of the western part of the study area permits Type 2 road trains, which are vehicles up to 53 m in length. There is no rail infrastructure in the Mitchell catchment that can be used for freight transport. In terms of energy supply, the eastern part of the catchment (from near Chillagoe) contains the Tablelands regional distribution network.

Social and investor values

The diverse stakeholders in the Mitchell catchment sometimes have conflicting interests and values relating to the use of water resources and irrigated agricultural development. This has implications for the ability of developers to gain and maintain social licence to operate through the development process. Stakeholder values relate to: the purpose of development; the environmental conditions and ecosystem services that development may alter; how stakeholders are engaged; and to whom benefits accrue. Systematic social impact analysis that investigates stakeholders and their interests will be needed for development at scale. A survey of potential agricultural investors identified institutional certainty, simplicity and bureaucratic speed as the key perceived potential enablers of investment in irrigated agriculture. There was less consistency between investors regarding other enablers of irrigated development.

Indigenous values and development objectives

Indigenous people represent a substantial and growing proportion of the population of the Mitchell catchment, particularly in the lower catchment. They have recognised native title and cultural heritage rights, and control significant natural and cultural resource assets, including land, water, and coastline. Understanding key aspects of pre-colonial and post-colonial patterns of land and natural resource use in the Mitchell catchment is important to understanding both present circumstances and Indigenous responses to future possibilities. Indigenous people have strong expectations for involvement in water, catchment, and development planning. Indigenous people have a range of existing business development plans and objectives that may be impacted by development proposals. They wish to be crucial owners, partners, investors, and stakeholders in future development.

Legal, policy and regulatory environment

Government powers and responsibilities concerning the management of land and water resources in the Mitchell catchment are shared. The Australian Government oversees native title and the implementation of international law obligations. The Queensland Government manages land and water assets. The four local councils are state agencies with responsibilities for land use planning. Land in the catchment is primarily held as Crown leasehold land, national parks, freehold land and Aboriginal land, with much of the catchment also subject to native title, a unique form of property interest that consists of a bundle of rights defined by the laws and customs of the relevant Indigenous community. The rights to the use, flow and control of all water in Queensland are vested in the Queensland Government, who controls the processes for water planning, the regulation of taking and interference with water, and the construction and operation of water infrastructure (e.g. dams, bores, levies and pipes). Land owners' rights to use and develop land are limited by government regulations. The most relevant government regulations are those imposed under federal and state planning, environment and heritage statutes.

3.1.2 INTRODUCTION

This chapter seeks to address the question 'What are the existing: ecological systems; the demographic and economic profile; the land use, industries and infrastructure, stakeholder values and investor perspectives; the values, rights, interests and development objectives of Indigenous people; and the legal, policy and regulatory environment in which development would occur in the Mitchell catchment?'

The chapter is structured as follows:

- Section 3.2 examines the ecological systems and assets of the Mitchell catchment including the key habitats and key biota, and their important interactions and connections.
- Section 3.3 examines the socio-economic profile of the Mitchell catchment including the current demographics and existing industries and infrastructure of relevance to water resource development.
- Section 3.4 examines the stakeholders, their values and potential engagement strategies and the perspectives of potential investors in the Mitchell catchment.
- Section 3.5 examines the Indigenous values, rights, interests, and development objectives generated through direct participation by Mitchell catchment Traditional Owners in the Assessment.
- Section 3.6 examines the legal, regulatory and policy environment relevant to water-related development.

3.2 Ecology of the Mitchell catchment

3.2.1 INTRODUCTION

A catchment as large as that of the Mitchell River inevitably encompasses great ecological diversity. It covers an area of over 72,000 km^2 in the southern part of Cape York Peninsula, extending from the Gulf of Carpentaria to the highlands of the Great Dividing Range, which to the south overlooks the coastal city of Cairns. The Mitchell catchment supports a variety of terrestrial and aquatic ecosystems in a wet-dry tropical climate that, in the west, includes estuarine and coastal systems. Moreover, it is largely intact in terms of the continuity of its plant and animal communities and the ecological processes that underpin them.

The size, diversity and condition of the Mitchell catchment means that it holds important ecological and environmental values, including species and communities listed under the EPBC Act, such as the golden-shouldered parrot (*Psephotus chrysopterygiu*), Gouldian finch (*Erythrura gouldiae*), and northern bettong (*Bettongia tropica*). Its eastern edge is part of the Wet Tropics World Heritage Area. The mouth of the Mitchell River lies within the Gulf Plains Important Bird Area, and the Mitchell River Fan Aggregation (Mitchell River delta), Southeast Karumba Plain Aggregation, and the Spring Tower Complex are on the Directory of Important Wetlands of Australia (DIWA) (Figure 3-2).

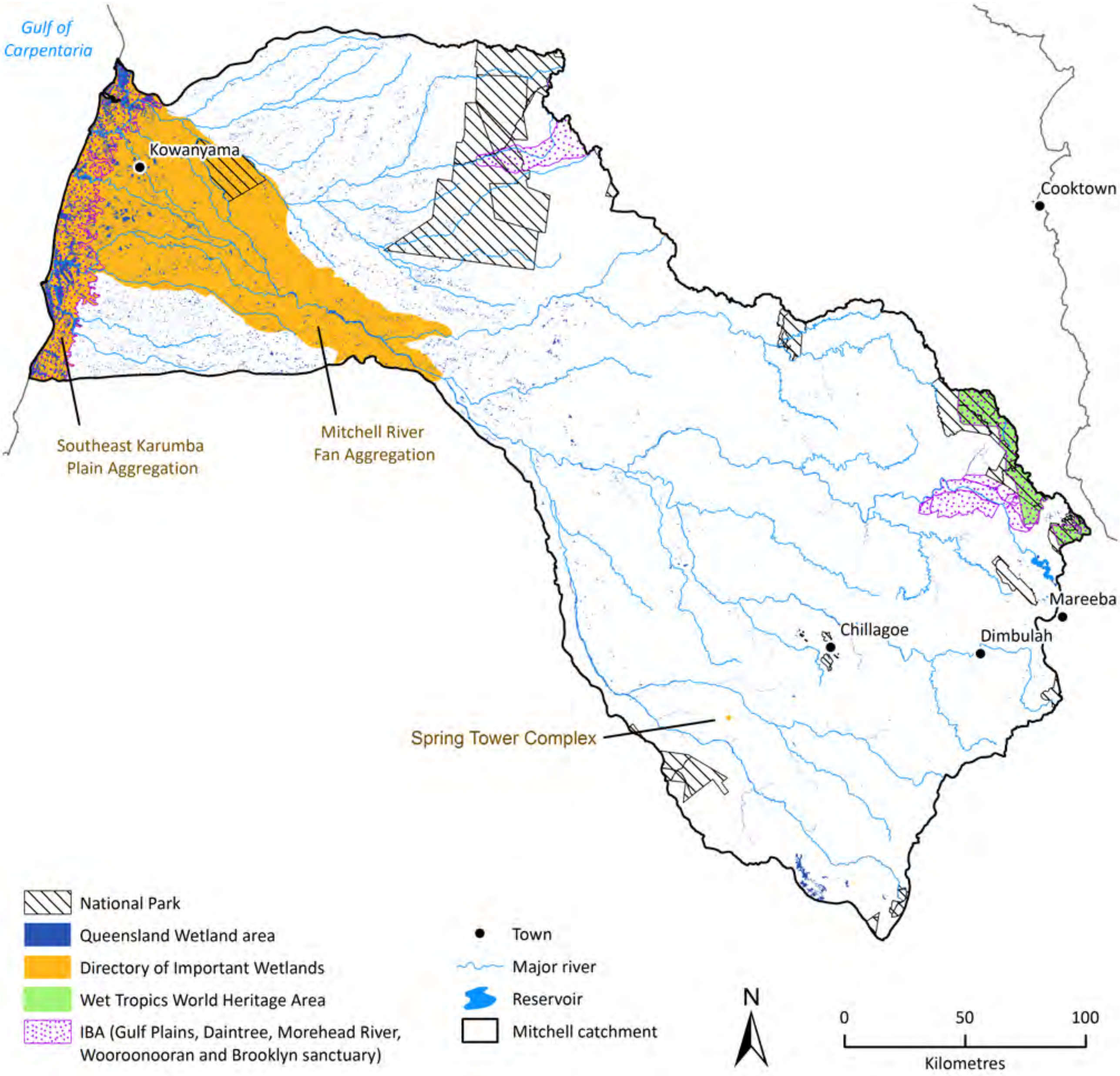

Figure 3-2 Distribution of important wetlands, important bird areas (IBA) and protected areas in the Mitchell catchment

The Mitchell River Fan Aggregation comprises deeply incised stream lines with numerous permanent waterholes and floodplains, and is habitat to a wide range of waterbirds (Environment Australia, 2001). The Southeast Karumba Plain Aggregation contains varied habitats, including tidal flats, stream channels, and ephemeral and permanent wetlands. This provides important waterbird breeding habitat, including the second largest summer population of wader birds in

Australia, and is recognised as having high wilderness value (Environment Australia, 2001). The Spring Tower Complex contains spring-fed freshwater cave systems and is recognised as a good example of a karst wetland, which have restricted distribution in Australia. The Spring Tower Complex contains relic fauna and flora, including vine thickets and blind amphipods (Environment Australia, 2001).

The Mitchell River discharges into the Gulf of Carpentaria and therefore its condition influences the ecological and economic values of that important part of northern Australia's marine environment. The Mitchell catchment also overlies part of the Great Artesian Basin and contributes to its recharge.

The study area contains an extensive network of wetlands and waterholes, which support fish, invertebrates, crocodiles, frogs, turtles and waterbirds. The extensive floodplain of the Mitchell catchment provides an important source of nutrients for a sub-set of fish species, including those feeding on benthic algae (Hunt et al., 2012). Fish, crayfish, prawns and shrimps access carbon from the floodplain as a source of energy. In turn, these animals are an important food source for large predators, particularly in waterholes during the dry season (Hunt et al., 2012). Studies in the catchment have consistently demonstrated the importance of connectivity between the river and floodplains for both large and small fishes and higher level predators, including crocodiles (Hunt et al., 2012; Jardine et al., 2017).

The Mitchell catchment has the second highest fish species richness nationally (Pusey, 2011). This is partly due to its extensive and diverse inland freshwater aquatic habitats, which are permanent and largely undisturbed (Pusey, 2011). Freshwater fishes perform central ecological functions and structure ecological communities within floodplain river ecosystems (Jardine et al., 2012). A sub-set of these fishes are large-bodied diadromous species (species that migrate between freshwater and seawater) which provide the basis for recreational and subsistence fisheries, and are of cultural significance (Close et al., 2014; Ebner et al., 2016). Species such as barramundi, threadfin salmon (*Polydactylus sheridani*) and mud crab (*Scylla serrata*) are particularly important to commercial and cultural fisheries, and they support fishing tourism in the south-eastern Gulf of Carpentaria (Bayliss et al., 2014). The freshwater sawfish is of conservation significance in the catchment. Other significant fauna in the estuarine and coastal waters of the Mitchell catchment include dugongs (*Dugong dugon*), sea snakes (members of the sub-family Hydrophiinae), speartooth sharks (*Glyphis glyphis*), and sea turtles (members of the super family Chelonioidea). Banana prawns (*Fenneropenaeus spp.*) are of considerable value to the Northern Prawn Fishery and are highly dependent on river flow.

To describe the ecology of the Mitchell catchment and discuss the likely impacts of future water resource development on this system, ecological assets have been selected. This chapter considers a key sub-set of assets, as shown in Table 3-1. More information on catchment assets and their distribution is available in the companion technical reports on ecology (Pollino et al., 2018a, 2018b). In Chapter 7, models are used to explore the potential of change to these assets, as a consequence of changes in flow. Figure 3-1 shows the spatial distribution of important areas for conservation (protected areas and important wetlands).

Table 3-1 Asset and asset types in the Mitchell catchment

All assets listed in this table are detailed in the companion technical reports on ecology (Pollino et al., 2018a, 2018b). Assets are water dependent on either surface water flows or groundwater, resulting in either periodic or sustained inundation. Assets consist of species of significance, functional groups, important habitats or ecosystem processes. An asterisk (*) represents assets included in analysis (see Section 7.5). Barramundi and sawfish are considered freshwater assets as the asset analysis only considers the freshwater stage of their life cycle.

CATEGORY	TYPE	ASSET	NOTES
Freshwater	**Important habitats**	Floodplain wetlands*	Critical habitat
		Waterholes-inchannel*	Critical habitat
		Ephemeral habitats	Critical habitat
		Riparian vegetation*	Critical habitat
	Functional groups	Migratory fish*	Commercial/ conservation
		Stable flow spawners*	Commercial/ conservation
		Turtles / Long-necked turtles	Conservation
	Species of significance	Barramundi*	Commercial/ conservation
		Freshwater whipray	Conservation
		Sawfish*	Conservation
	Ecological processes	Fluvial geomorphology	Critical process
		Floodplain and inchannel productivity	Critical process
Marine	**Important habitats**	Mangroves*	Critical habitat
		Seagrass	Critical habitat
		Salt flats*	Critical habitat
		Coral	Critical habitat
	Species of significance	Mullet spp.*	Commercial/ conservation
		Banana prawns*	Commercial
		Mud crabs	Commercial
		Longbums (mangrove whelks)	Commercial
		Snubfin dolphin*	Conservation
		King threadfin*	Commercial/ conservation
		Grunter*	Commercial/ conservation
		Saltwater crocodile*	Conservation

3.2.2 CURRENT CONDITION OF THE CATCHMENT

The Mitchell catchment is largely intact, but areas of the catchment are not in a pristine condition. In the upper parts of the catchment, the ecological composition and structure have been subject to human-induced changes. The most widespread land use has been pastoralism, which influences the environment by changing grazing and burning regimes and increasing rates of soil erosion. There has been relatively little clearing. The eastern portion of the catchment, where there has been more intensive agricultural development, has been subject to more drastic landscape changes, including clearing within the Mareeba–Dimbulah Water Supply Scheme. The catchment has also been subject to deliberate and accidental plant and animal introductions that, despite benefits accruing to particular land users, can have environmental or economic consequences for other stakeholders. The downstream spread of introduced aquatic or terrestrial species from the more highly modified upper parts of the catchment is likely to be a continuing issue.

The hydrology of the Mitchell catchment has been modified, although not to anywhere near the same extent as more southerly catchments. The relatively small Southedge Dam (Lake Mitchell) in the upper catchment was completed in 1987 but there are no other major artificial barriers. The Mitchell catchment is one of the few remaining large catchments in Australia that is essentially unregulated. Exotic fish have been found in the catchment, with the greatest concern being the spotted tilapia. Concerns have been raised over the potential for exotic fish to enter the Mitchell catchment through the irrigation supply systems of the Mareeba–Dimbulah Water Supply Scheme, with recent evidence showing they are in the Mitchell catchment.

Soil erosion is a significant issue in the Mitchell catchment. Widespread gully erosion was initiated after European settlement, particularly in the period 1880 to 1950, and gullying has increased rapidly since 1949 (Shellberg et al., 2016). Dispersal of wet-season flows across the Mitchell catchment floodplains is vital for habitat connectivity. Yet since the removal of riparian vegetation and introduction of grazing cattle, erosion-resisting forces have been altered and floodplain sediment has become increasingly unstable (Brooks et al., 2009). Alluvial gully erosion and channel bank erosion are significant sources of sediment in the Mitchell River, whereas surface soil erosion is a relatively minor component of the total sediment load. Increases in the sediment load of a river such as the Mitchell can impact ecological processes in the river itself as well as beyond its mouth.

3.2.3 KEY HABITATS

Northern Australia contains rivers with highly seasonal flow regimes that support a diversity of habitats. These habitats require flows across the flow regime and are key for breeding, supporting juvenile aquatic animals, foraging and refuge. Habitats of significance in the Mitchell catchment that can potentially be impacted by agricultural and water resource development are described below.

Waterholes and wetlands

During the dry season, many ephemeral rivers of northern Australia cease to flow but retain water in a series of disconnected instream waterholes (McJannet et al., 2014; Waltham et al., 2013). The waterholes that remain during the dry season are an important cultural resource and provide a range of ecosystem functions (Centre of Excellence in Natural Resource Management, 2010; McJannet et al., 2014). For example, at the landscape scale, the number of waterholes and their connectivity allows for movement of biota across the landscape (Department of Environment and Resource Management, 2010). While at the local scale, the size of waterholes confers water-dependent species a refuge in periods without surface flows (Department of Environment and Resource Management, 2010). Permanent waterholes retain water during the dry period, with some being maintained or supported by groundwater inputs. See Section 2.5 (Figure 2-44) for the distribution of permanent waterholes in the Mitchell catchment.

During dry season low-flow or cease-to-flow periods, the size, quality and connectivity of waterholes remaining within the landscape decreases (Department of Environment and Resource

Management, 2010; McJannet et al., 2014). Waterholes are typically surrounded by riparian vegetation, which offer shade and structural diversity, and act as an interface between aquatic and terrestrial ecosystems, supporting high biodiversity. Changes in the flow regime associated with water resource development, surface and groundwater extraction, and climate change have the potential to alter the natural filling and drying cycles of waterholes as well as water quality, including turbidity (McJannet et al., 2014; Waltham et al., 2013). Changes in waterhole permanence could have impacts on the plants and animals at a local scale and on habitats across regional landscapes.

The expansive wetlands of northern Australia are typically extensive and highly productive (see Figure 3-1 for the distribution of wetlands in the Mitchell catchment). Aquatic production in tropical rivers is primarily driven by hydrology and the annual flooding that occurs (Pettit et al., 2017). This cycle influences the availability of nutrients within rivers and the coastal zone (Junk et al., 1989), providing a boost to the overall annual energy budget. In rivers, this supports huge biomasses of fish and invertebrates, and large bird breeding events. Prolonged inundation of wetlands promotes the productivity and biomass of aquatic vegetation (Finlayson, 1991; Pettit et al., 2011; Warfe et al., 2011), which provides important habitat for aquatic fauna. Threats to wetlands are derived from changes in the water regime which can modify connectivity and change the extent and suitability of habitat, and changes to the physical habitat through modification of land use and the introduction of invasive species (plants and animals) (Finlayson and Rea, 1999).

Mangroves and salt flats

Mangrove communities are assemblages of trees and shrubs that are found fringing most of the coastline of mainland Australia, with the most extensive and diverse communities found along the northern coastline. Mangroves support diverse and complex food webs, including crustaceans such as prawns and mud crabs, and a diversity of fish species. While associated with the marine system, mangroves require freshwater input and many mangroves live close to their salinity tolerance levels. Changes in flow regimes can potentially affect mangroves.

Hydrology of mangroves is complex: tidal inundation, rainfall, groundwater seepage and evaporation all influence soil salinity and have a profound effect on mangrove growth and distribution. Freshwater flow into mangroves reduces salinity, creating conditions that are favourable. Extraction of water from rivers and subsequent changes to flow regimes can negatively impact the productivity and extent of mangroves (Röderstein et al., 2014). A reduction in the volume of wet-season flow is likely to reduce the productivity (growth) and composition of mangroves and their extent and connectivity, particularly in the upper reaches of estuaries and the high intertidal zone. Minor reductions in flow regimes have led to massive mortality of mangroves (Blasco et al., 1996).

Coastal salt flats or claypans are shallow coastal basins which are only infrequently tidally inundated. They are often found adjacent to coastal mangrove forests. Tropical northern Australia has extensive areas of these salt flats which remain relatively pristine. These low-lying systems are mostly vegetation-free, and are coated in a thick salt crust for most of the year. During large rainfall events when overbank flow occurs, or during sustained local rainfall, they may be flooded for extensive periods. Wetting of salt flats results in the release of high concentrations of nutrients and benthic algae, which become a food source for animals, including prawns. Salt flats contribute significantly to primary production in coastal areas (Burford et al., 2016). Reduced flows can impact salt flats through reduced inundation, affecting the growth of primary producers that form the base of the food web, with impacts potentially extending into coastal areas (Burford et al., 2016). See Figure 3-3 for a map of the distribution of mangroves and salt flats in the Mitchell catchment.

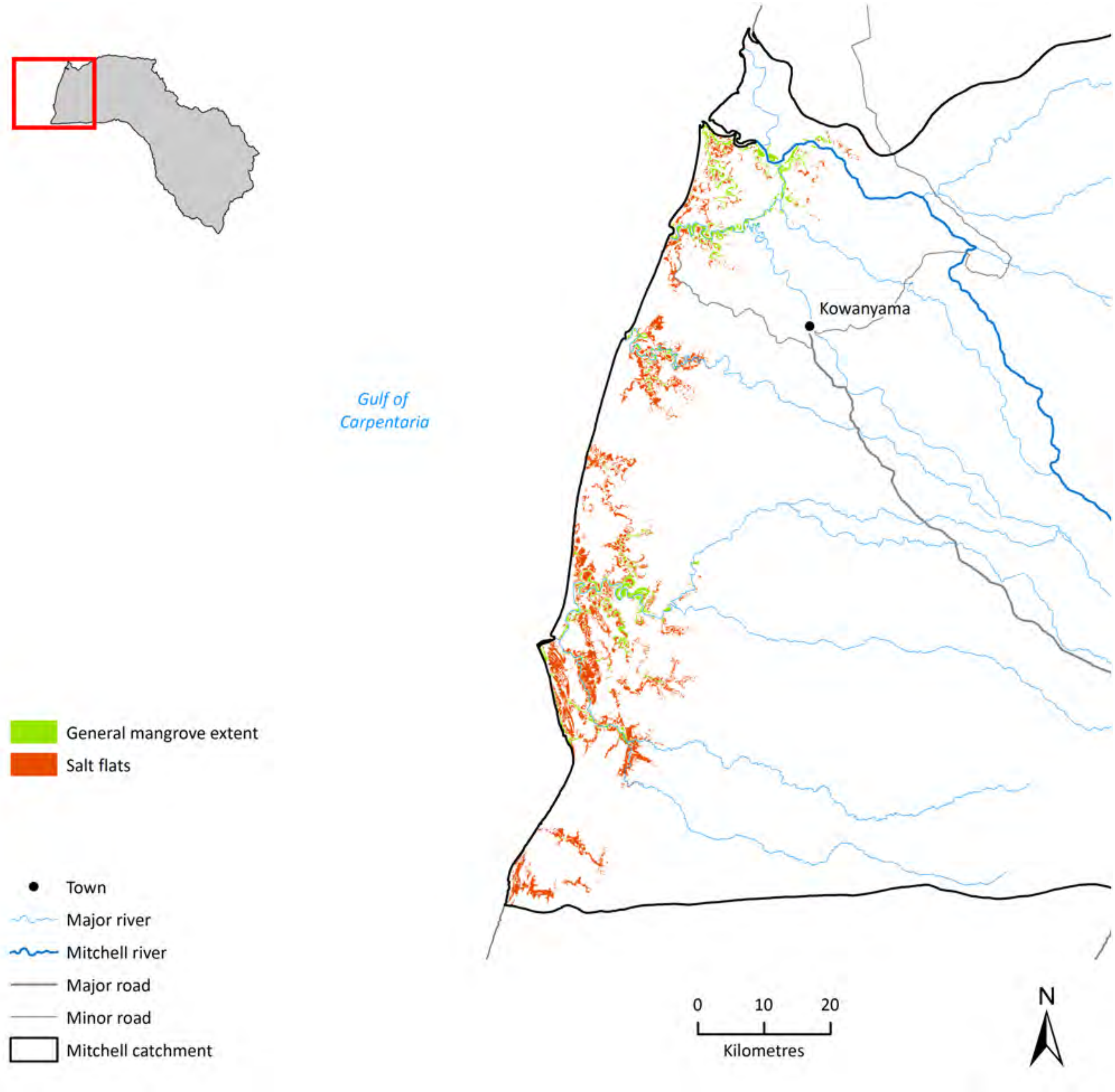

Figure 3-3 Distribution of mangroves and salt flats in the coastal area of the Mitchell catchment

Riparian vegetation

The interface between land and rivers is the riparian zone, which provides an important link between aquatic and terrestrial communities. Riparian zones are regarded as highly diverse, dynamic and complex habitats (Naiman and Decamps, 1997) that act as a thermal buffer to streams. They also influence a number of environmental processes such as instream primary production; nutrient interception, storage and release; enhancement of bank stability; the provision of coarse woody material as habitat and substrate for fish, invertebrates and microalgae; channel morphology and habitat diversity (Pusey and Arthington, 2003). Riparian vegetation is important for providing: bank stability, terrestrial and instream habitat and food resources, as well as acting as corridors for wildlife movement and the movement of sediment, carbon and nutrients into rivers. Riparian zones are often more fertile and productive than surrounding terrestrial vegetation. The timing and quantity of water available to the riparian zone is critical for determining its structure, function and resilience, such that all aspects of the flow regime (i.e. precipitation, runoff and evapotranspiration) exert some control over how riparian vegetation accesses water (Tabacchi et al., 1998).

The ecological integrity of riparian zones across northern Australia is threatened by a range of existing processes, including land clearing, weed invasions and disturbance by livestock (Woinarski et al., 2000). Riparian zones in parts of the Mitchell catchment have become degraded as a consequence of cattle grazing. This has manifested as alluvial gullying (Brooks et al., 2009; Shellberg et al., 2010), which has changed vegetation cover and lead to the establishment of weeds. Management of riparian zones is important for maintaining terrestrial biodiversity as well as instream riverine environments, water quality and biodiversity (Pusey and Arthington, 2003).

Gulf of Carpentaria

The Gulf of Carpentaria is a geologically-recent (~10,000 years) shallow sea (<70 m deep) bounded by topographically-low, nutrient-poor landscapes to the east, south and west and the Arafura Sea and the southern coast of the island of New Guinea to the north (Chivas et al., 2001; Huey et al., 2014). It is roughly 600 km from east to west and 1000 km from south to north, although hydrologically (ignoring national borders) it is a west-opening shallow gulf (<100 m deep) that continues north to the New Guinea coastline (Condie et al., 1999; Condie, 2011). Hydrologically, a seasonal anticlockwise gyre dominates water currents in the Gulf, with a 4 m (approximate) tide range in the south and a 2 m (approximate) tide range in the north (Li et al., 2006). Its benthic sediments are characterised by muds and sandy muds used as habitat by a myriad of epifauna and infauna (Li et al., 2006; Long and Poiner, 1994; Somers and Long, 1994). Water quality is high, with relatively oligotrophic nutrient levels, although not nutrient limited, and a plankton community characteristic of tropical waters (Burford and Rothlisberg, 1999; Rothlisberg et al., 1994). Terrigenous inputs do not affect offshore Gulf waters; low sediment loads and nutrient re-suspended during rough weather drive plankton productivity (Burford and Rothlisberg, 1999; Rothlisberg et al., 1994).

Gulf of Carpentaria shorelines and littoral zones support mangrove (Duke et al., 2017) and seagrass (Poiner et al., 1987) communities, as well as bare sediments and sandy dune shores. Littoral flora stabilise shorelines and importantly, they support a species-rich faunal community for all or part of their life cycles. Key commercial fish and crustaceans comprise a portion of the coastal fauna and have been harvested commercially for over 50 years. Annual floodflows are pulsed and stochastic; large floods deliver sediments and nutrients to estuarine and nearshore habitats to stabilise depositional environments and enhance coastal productivity (Asbridge et al., 2016; Burford et al., 2012). Despite catchment-to-coast fluvial loads being transported and deposited by monsoon-driven floods, nutrient levels in estuaries and coastal waters are characteristically low due to the low fertility of the geologically-ancient, weathered catchment soils and landscapes (Hutley and Beringer, 2010). Primary productivity in Gulf of Carpentaria estuarine habitats is driven by water column and epibenthic phytoplankton communities, supporting meiofauna and larger epibenthos, which are eventually consumed by fishery species (Burford et al., 2012, 2016; Duggan et al., 2014). Tropical fish and crustaceans have co-evolved with the monsoon-driven climate to respond to environmental cues. Wet-season floods sustain riverine habitats, optimise estuarine environments and cue ontogenetic emigration.

Historically, fishing in the Gulf of Carpentaria was a remote activity centred on the few townships scattered around Gulf shores (Baird, 1970; Pownall, 1994). However, from first exploration, Gulf waters supported iconic market species such as barramundi, mudcrabs, mackerel and prawns (Savage and Hobsbawn, 2015) as abundant stocks from which valuable harvests were irresistible, despite difficult operational conditions. In the 1980s, improved vessel design and construction, and refrigeration, allowed commercial fishers to travel across the Gulf for long periods in search of an abundant catch. A view of the Gulf as an 'un-explored' (hence under-exploited) frontier resulted in an overallocation of fishing licences for many species-groups. This view has necessitated a steady reduction in effort over the last 20 to 30 years for the Gulf to remain sustainable. Today, high-value fish and crustaceans are harvested seasonally from relatively 'self-contained' fishing vessels (Figure 3-4). For a range of fishery species, catch is positively correlated with wet-season floodflow (Halliday et al., 2012; Bayliss et al., 2014). However, compared with fisheries along extensive coastlines in other geologically-distinct eco-regions (e.g. the Malaysian peninsula), the Gulf of Carpentaria supports a modest total catch (Loneragan et al., 2005). In 2015–16, more than $300 million of fishery catch was taken from tropical Australian fisheries with $124 million of wild-caught prawns taken from the Gulf of Carpentaria (Mobsby and Koduah, 2017).

Figure 3-4 A prawn trawler (owned by A. Raptis & Sons) in the Gulf of Carpentaria

Inshore, gillnet and pot fisheries target barramundi, king and blue threadfin, barred javelin, sharks and mudcrabs (Griffiths et al., 2010). Offshore, otter trawl, fish trawl, gillnet and troll-line fisheries target a multi-species prawn fishery, tropical scalefish, sharks and mackerel, respectively (Bayliss et al., 2014; Griffiths et al., 2010). The inshore fisheries are managed by state and territory jurisdictions, while the offshore fisheries are managed by the Australian Government. In addition, over the last 20 years, land-based access to Gulf coastlines has become more achievable and resulted in an increase in recreational fishing in rivers, estuaries and near-coast habitats. Mining infrastructure has opened access to coasts (e.g. the McArthur River Mine road infrastructure in the south-west Gulf of Carpentaria), while improved roads, better engineered off-road vehicles and the opening of coastal pastoral properties to camping and fishing have improved access. In conjunction, improved design of recreational vessels has allowed fishers to travel further, and faster, from their remote camping grounds and access locations.

The remote, lightly-exploited habitats and ecosystems of the Gulf of Carpentaria continue to support iconic species that are vulnerable, endangered or extinct over much of their original geographic range. Sawfish, whiprays, river sharks and dolphin inhabit marine, estuarine and riverine habitats throughout the Gulf of Carpentaria and adjacent catchments. Once these species were widely distributed throughout Asia and the Indo-West Pacific. Today, riverine and estuarine habitats in Gulf of Carpentaria rivers such as the Wenlock, Mitchell, Flinders and Roper rivers, are among the last bastions of populations of a suite of these iconic species (Peverell, 2005; Pillans et al., 2009; Devitt et al., 2015).

3.2.4 KEY BIOTA

Native fish

Freshwater fish are an important component of the aquatic biodiversity in northern Australia (Pusey et al., 2017). Fishes comprise the dominant aquatic-vertebrate group in terms of species richness in tropical freshwater catchments of northern Australia. In a recent synthesis of a range of information sources, Pusey et al. (2017) mapped the distribution of 111 freshwater and 42 estuarine fishes across northern Australia, not including those that are elasmobranchs (sharks, rays and skates). An earlier publication documented 176 species of bony fish and six species of elasmobranch recorded in northern Australia (Pusey, 2011). A total of 86 of these species reside exclusively in freshwaters and 90 out of 176 require access to marine or estuarine waters for part of their life cycle (Pusey, 2011).

The Mitchell River supports a high species richness of freshwater fishes, with 57 species recorded, as well as high endemism for fish (Pusey et al., 2017). Studies have found 45 fish species in the catchment are limited to freshwater habitats while three elasmobranchs with at least one freshwater life cycle stage have also been recorded (Allen et al., 2002; Pusey et al., 2017).

Migratory fish

A fish group vulnerable to inchannel barriers and changes to flows are freshwater migratory fishes. Migratory fish are distributed throughout the Mitchell catchment, with a higher diversity of species concentrated at the bottom of the catchment (Figure 3-5). These include freshwater migratory fish groups with populations or subpopulations which undertake large-scale movement during their life cycle. These migrations may be required for reproductive purposes or exploiting available habitat and food resources. While there are many species in this group, a range of species are distributed throughout freshwater habitats including inchannel and offchannel environments, as well as upper and lower catchment areas, such as the barramundi (*Lates calcarifer*), freshwater sawfish (*Pristis pristis*), bull shark (*Carcharhinus leucas*), black catfish (*Neosilurus ater*) and Hyrtl's tandan (*Neosilurus hyrtlii),* sooty grunter (*Hephaestus fugilinosus* and *H. jenkinsi*), freshwater longtom (*Strongylura kreffti*) and spangled perch (*Leiopotherapon unicolor*).

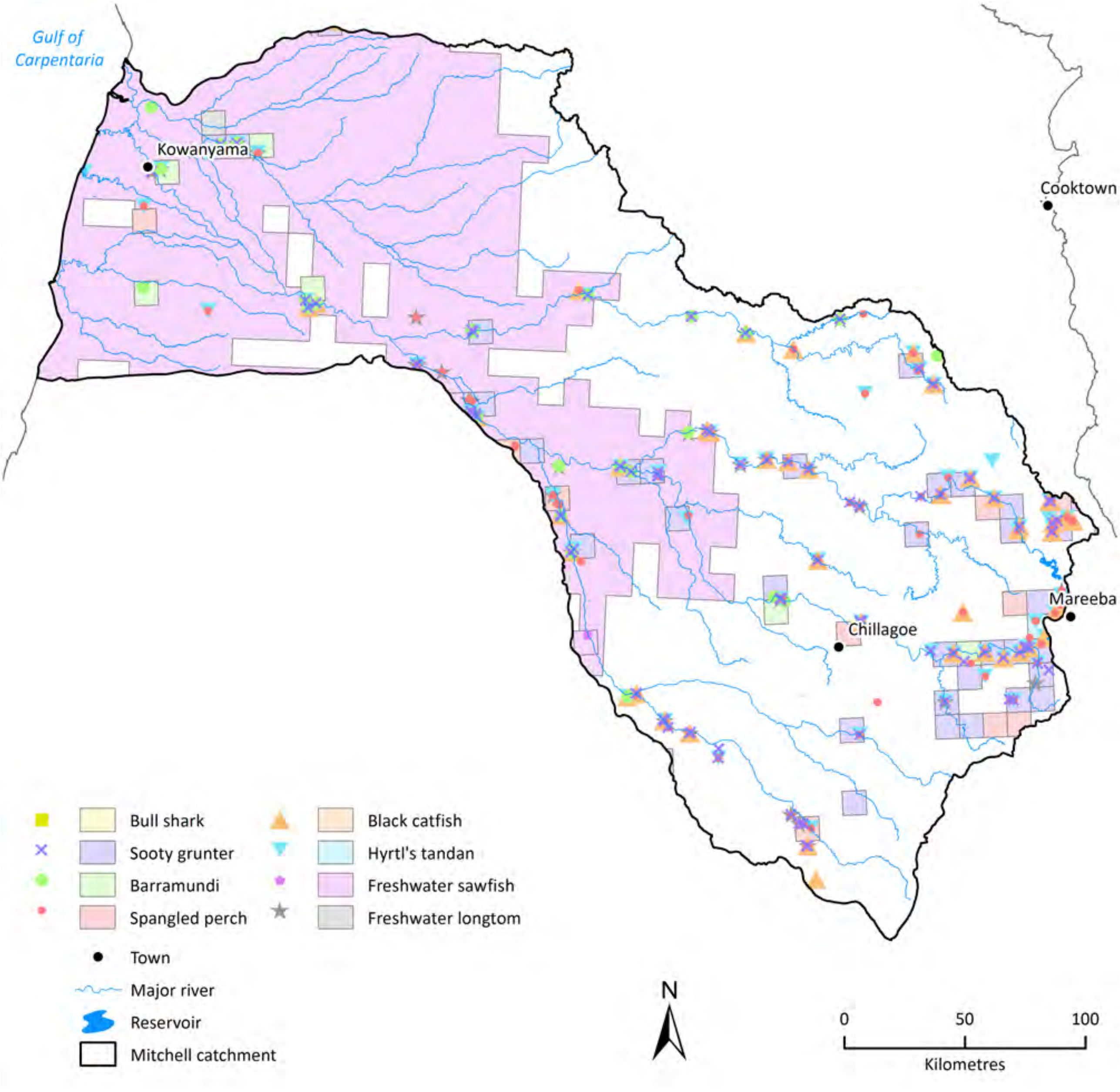

Figure 3-5 Distribution of focal migratory freshwater fishes in the Mitchell catchment
The squares represent the generalised distribution and density of species based on a 10 km grid. Each square may therefore represent one or many occurrence of a species.

Movement and migration of fishes in the Mitchell catchment is critical. Species can move over the Mitchell River floodplain for weeks to months during the wet season, but be confined to the main channel and distributary refugia during the dry season. The distributary refugia are in streams branching off and flowing away from the main stream channel. In the dry season, inundated habitats play a critical role in providing resilience for fish. Infrastructure developments that change connectivity in catchments can impact on this group.

Stable flow spawners

Another important group of fish are the stable flow spawners. While they are distributed throughout the Mitchell catchment, this group is more prominent in the upper areas (Figure 3-6).

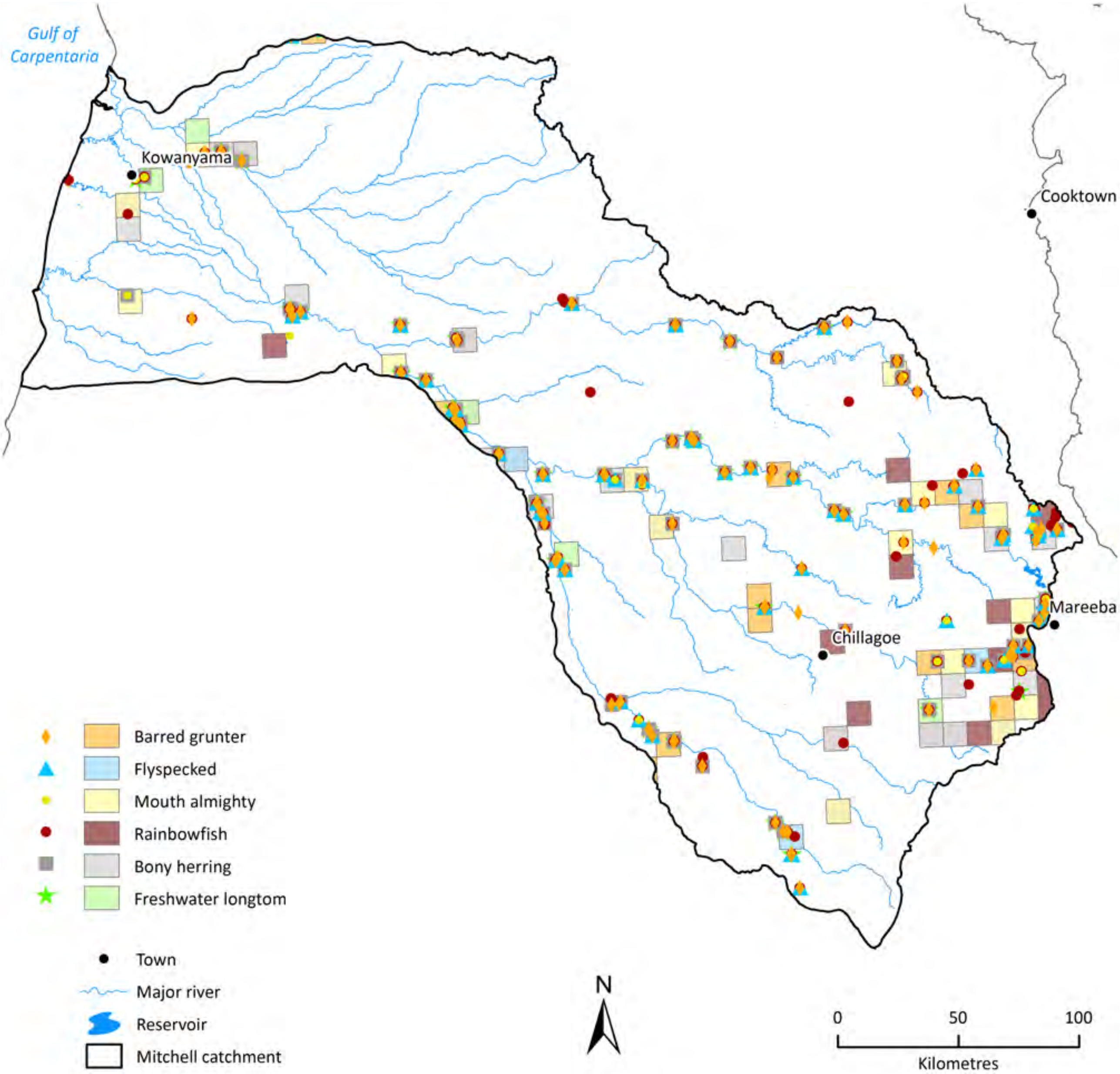

Figure 3-6 Distribution of focal stable flow spawning fishes in the Mitchell catchment
The squares represent the generalised distribution and density of species based on a 10 km grid. Each square may therefore represent one or many occurrence of a species.

This group of fish spawn in association with stable flows (low flow, baseflow and cease to flow) and have the potential to be impacted through flow regulation, due to changes in their habitat (such as availability, structure, size and quality). This group includes a large number of species, including the freshwater longtom, mouth almighty *(Glossamia aprion),* bony bream (*Nematalosa erebi),* barred grunter (*Amniataba percoides*), flyspecked (*Craterocephalus stercusmuscarum stercusmuscarum)* and freckled hardyhead (*Craterocephalus lentiginosus)* and the eastern

(*Melanotaenia splendida splendida)*, chequered (*Melanotaenia splendida inornata)* and western (*Melanotaenia australis)* rainbowfish.

Threatened and endangered fish species

Freshwater sawfish

The threatened freshwater sawfish is found throughout the Mitchell catchment (Peverell, 2005) (Figure 3-7; Figure 3-8). It is listed as vulnerable under the EPBC Act and as critically endangered by the International Union for Conservation of Nature (IUCN). Given the EPBC Act listing, any proposed action that is likely to have a significant impact on their populations or on their habitat may need an environmental impact assessment. Historically the freshwater sawfish occurred on the west coast of Australia, in the Northern Territory and in Queensland, including on the east coast. Currently this species is rarely detected on the east coast of Queensland, but occur as juveniles in the rivers and estuaries of the Gulf of Carpentaria (Morgan et al., 2016; Peverell, 2005).

The prospect of inchannel barriers along migration routes and in the lowlands of the Mitchell catchment poses a threat to the passage of migratory fishes, including the freshwater sawfish. The freshwater sawfish has a marine adult phase while the juvenile phase is in freshwater or saline environments (Morgan et al., 2016; Peverell, 2005). Pupping occurs in estuaries and river mouths (Last and Stevens, 1994), and juveniles and adults occupy large pools and waterholes, mostly in the main channel of larger rivers (Morgan et al., 2004; Peverell, 2005).

Figure 3-7 The freshwater sawfish (*Pristis pristis*)
Photo: James Cook University

Species of sawfishes can attain very large sizes (5 to 7 m total length) and live in tropical and subtropical coastal marine waters as adults (Last and Stevens, 1994). A key feature of the group is the tooth-lined rostrum (or saw) which is a flattened extension of the snout. The saw is important in the specialist, stealth feeding strategies of these species, being used to sense and in some cases strike and impale prey, including prawns and fish (Morgan et al., 2016). Occasionally they are also found in larger offchannel habitat. The freshwater sawfish is a top predator that feeds on fishes and crustaceans (Thorburn et al., 2014).

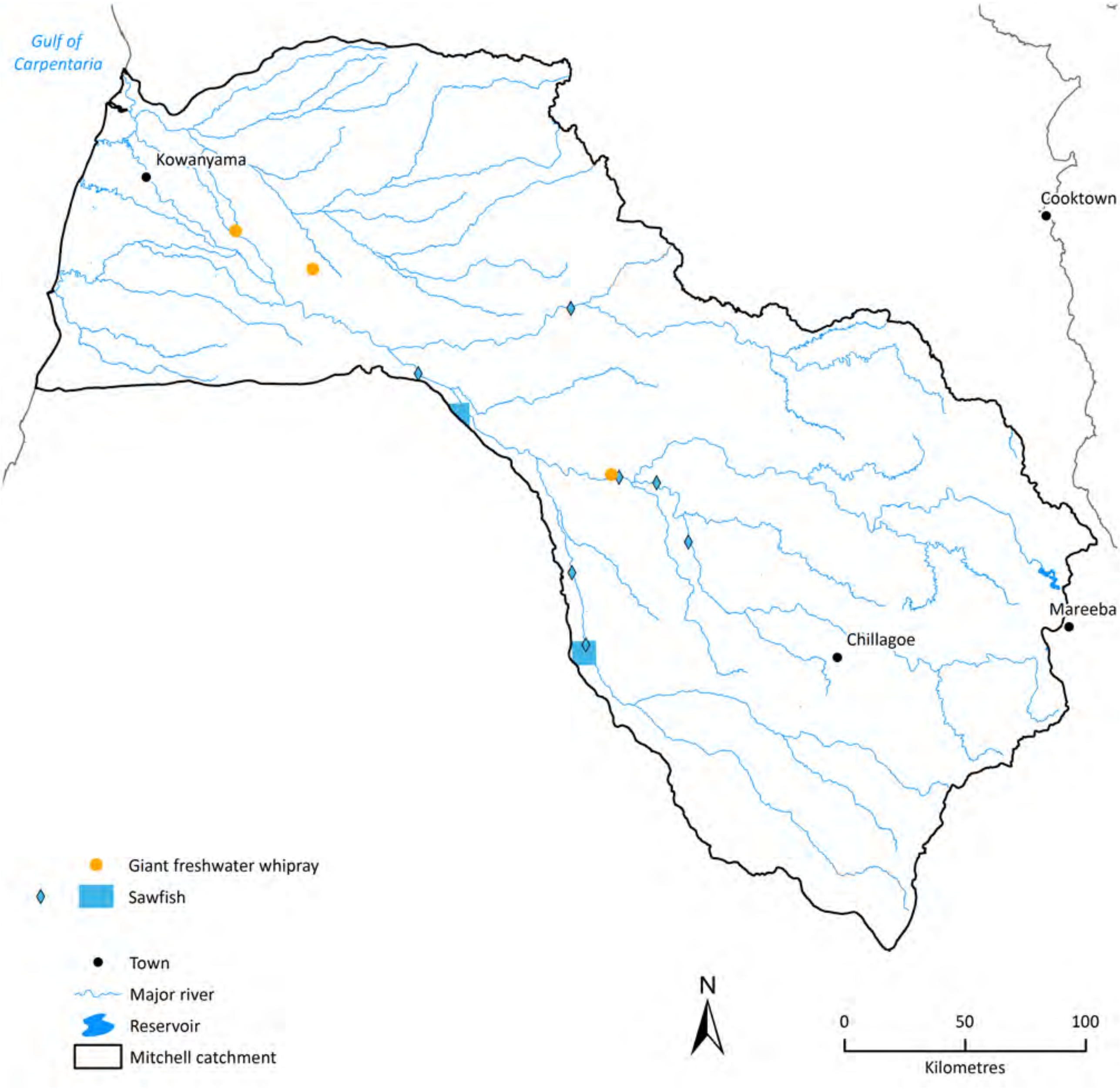

Figure 3-8 Distribution of sawfish (*Pristis pristis*) and giant freshwater whipray (*Urogymnus dalyensis*) in the Mitchell catchment

The limited observations of whiprays are a result of rarity rather than absence of the species.

The squares represent the generalised distribution and density of species based on a 10 km grid. Each square may therefore represent one or many occurrence of a species.

Giant freshwater whipray

The giant freshwater whipray (*Urogymnus dalyensis*) (Last et al., 2016) is a little-known species of stingray, found in a number of large rivers and associated estuaries in northern Australia (Ebner et al., 2016). It is listed as being of least concern on the IUCN Red List, which means that currently it has a lower risk of extinction. There are few observations of the species in the Mitchell catchment (Figure 3-6). The restricted geographic range of the whipray in the Mitchell catchment, the rarity of individuals and the presumed limited interchange between rivers, increases the species' inherent sensitivity to threats (Kyne, 2016). As a large-bodied species with low capability to produce offspring, the freshwater whipray is vulnerable to direct exploitation and deterioration or loss of main channel and floodplain environments.

Whipray are born in estuaries and migrate upstream to spend their first years of life in the freshwater reaches of rivers and tributaries, moving up to 300 km inland (Burrows and Perna, 2006; Thorburn et al., 2003). As they mature, whiprays move down the river and enter the estuarine environment, and consequently can be affected by barriers such as causeways, weirs and dams. The species is a top predator, feeding on fishes and crustaceans (Ebner et al., 2016). Although the ecology and distribution of the species is poorly understood, making it difficult to evaluate the potential direct impact of water resource development, the whiprays are migratory species that can be affected by barriers.

Commercial and recreational species

Barramundi

Barramundi is a large fish that occurs throughout northern Australia in rivers, lagoons, swamps and estuaries. It is a voracious predator and arguably the most important fish species to cultural, recreational and commercial fisheries throughout wet-dry tropical Australia. The species makes up a substantial component of total commercial fish catch in northern Australia (Savage and Hobsbawn, 2015). Barramundi is also a fish of cultural significance, as well as being an important food source for Indigenous populations (Jackson et al., 2012; Toussaint et al., 2005). Barramundi is found extensively throughout the Mitchell catchment (Figure 3-9).

The barramundi is impacted by changes in the flow regimes of rivers and via infrastructure impacting movement of fish. Spawning occurs in the estuary at the beginning of the wet season and young male fish move into floodplain and freshwater habitats when suitable flows provide access (Russell and Garrett, 1985). Recent work has proposed three primary life cycle strategies employed by barramundi (Crook et al., 2017), whereby some male adults return to the estuary to spawn after spending up to several years in freshwater habitats, while some males may delay downstream spawning migrations for several years until they have undergone the transition to females in freshwater habitats. Migrations are thought to be triggered by variation in the flow regime (Crook et al., 2017), making the species particularly vulnerable to water resource development. Barramundi can be caught throughout all four fishing seasons, but higher catch rates occur during the build-up and wet season, as barramundi becomes more active with warmer temperatures.

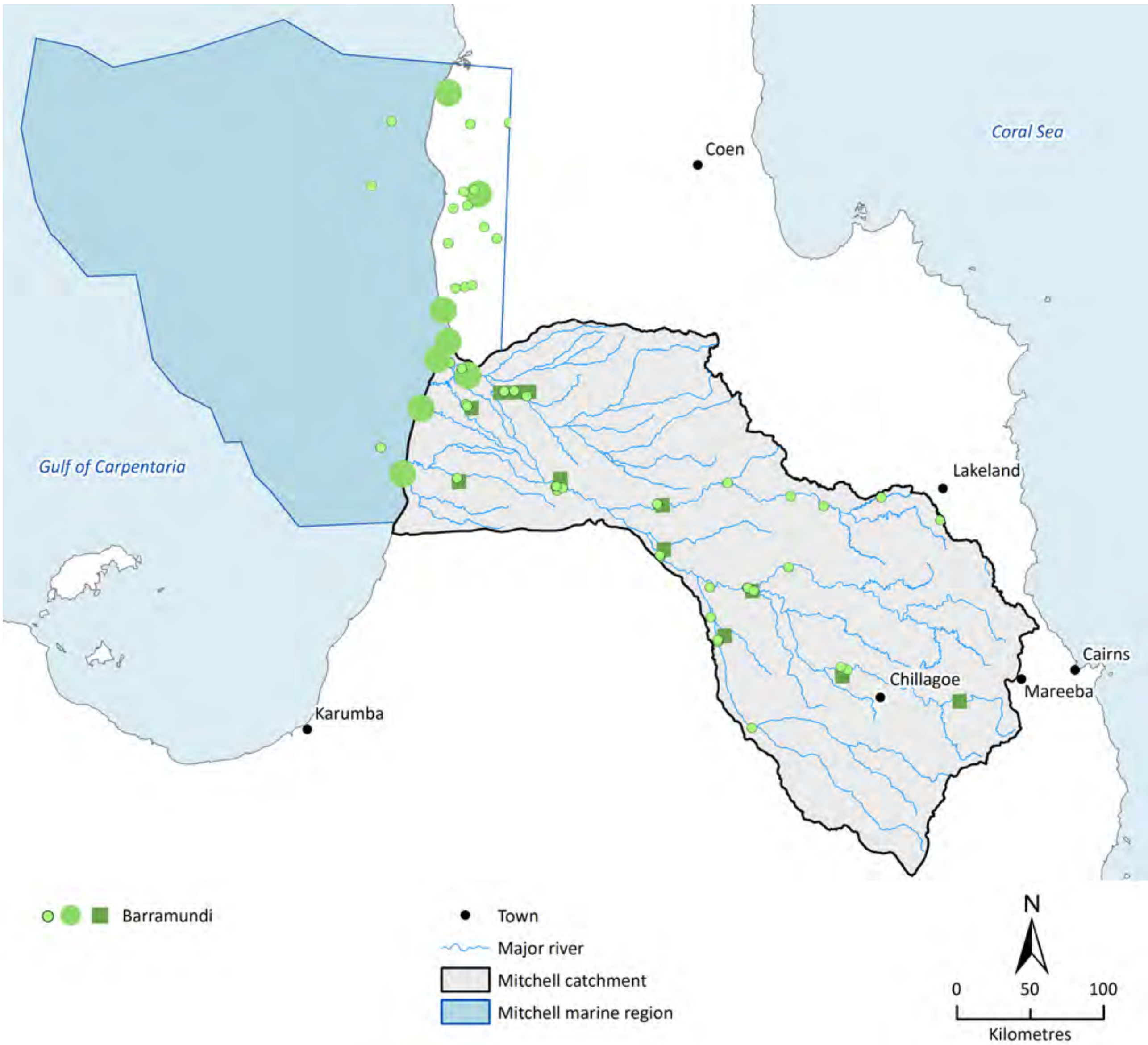

Figure 3-9 Distribution of barramundi (*Lates calcarifer*) in the Mitchell catchment
Square symbols (dark green) are from the species density grid in Queensland WildNet (Department of Science, 2017). The smaller round symbols (light green) are for all other catches collected from other datasets (e.g. Atlas of Living Australia (2016), Northern Australia Fish Atlas (TropWATER, 2017), Jardine et al. (2012) and Pusey et al. (2017)). Larger round symbols (medium green) are 5 nm-buffered records from Queensland Department of Agriculture and Fisheries (recreational fisheries catch).

White banana prawn

The white banana prawn (*Fenneropenaeus merguiensis*), is a short-lived, fast-growing crustacean species that is an important major commercial fishery resource across tropical Australia (see Section 3.3.2; Figure 3-10). White banana prawns complete their life cycle within a year and can be wild-harvested annually. Their stock is tied to key environmental drivers, particularly annual flood flow (Staples and Vance, 1986; Vance et al., 1985). Each year's catch of banana prawns is highly variable, being dependent on temporal cycles of monsoonal rainfall and river flows. In addition to forming a major constituent of a high value fishery, white banana prawns are an important ecological species and a key component of marine and estuarine food webs. They provide a significant food source for a myriad of commercially and recreationally valuable fish species in the coastal ecosystem.

A significant body of research has investigated the life cycle, growth, behaviour, and habitat use of the white banana prawn across multiple life stages to help inform the management of the Northern Prawn Fishery (NPF) (Vance et al., 1996; Wang and Haywood, 1999). The NPF is a very well-managed fishery of high economic value. Larger flow events increase prawn catch through greater juvenile emigration from estuaries to offshore habitats where growth is enhanced and mortality is lower for the sub-adult and adult phases (Robins et al., 2005). Recent studies suggest that nutrients exported during the flood flows support enhanced growth and survival and enhanced food availability through primary and secondary production in near-shore habitats (Burford et al., 2010). Assessing the potential impact of water resource development on the NPF is a critical issue, especially for white banana prawns, whose life cycles are intrinsically linked to natural flow regimes.

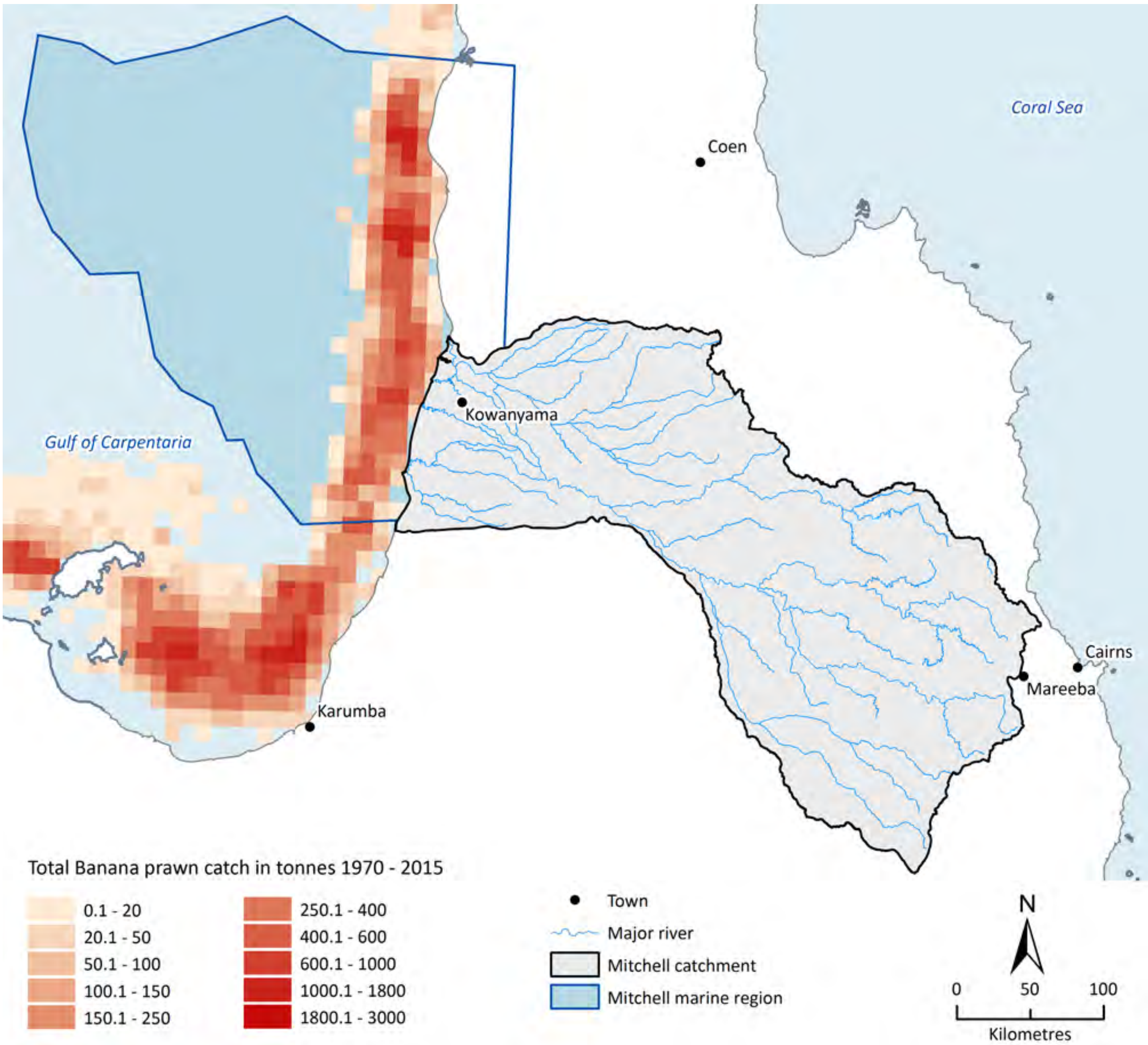

Figure 3-10 White banana prawn (*Fenneropenaeus merguiensis*) catch in the Mitchell catchment

3.2.5 TERRESTRIAL SYSTEMS

Australia's northern terrestrial systems are one of the few remaining mostly intact natural areas on Earth (Kutt et al., 2009). The monsoonal climate controls the ecology of northern Australia's plant and animal species, with annual fluctuations in resources, dictating migration and dispersal patterns, fruiting, seeding and flowering are synchronised with this highly seasonal pattern of rainfall (Woinarski et al., 2005).

Intensive agricultural development can cause habitat fragmentation as a consequence of land clearing but the extent of this is dependent on the scale and type of development and the extent to which it is contiguous or in a mosaic. Habitat fragmentation is a critical issue for biodiversity conservation. Fragment size, isolation and the impact of livestock, feral predators and weeds all affect conservation outcomes (Hobbs, 2001). In developing agricultural landscapes in northern Australia, lessons from fragmentation studies are critical. For savanna species, subtle landscape variations provide critical resources for wildlife, and the loss of this variation can lead to local extinctions (Woinarski et al., 2005).

Fragmented habitats in northern Australia are likely to be under extreme pressure from introduced weeds, altered fire regimes and altered hydrology. Taking those issues into account along with the subtle, complex and largely unknown spatial and temporal fluctuations in critical resources required for many vertebrates presents a considerable challenge.

3.2.6 ENVIRONMENTAL PROTECTION

There are a number of both aquatic and terrestrial species in the Mitchell catchment currently listed as critically endangered, endangered and vulnerable under the EPBC Act and *the Nature Conservation Act 1992* (Qld) (Figure 3-12).

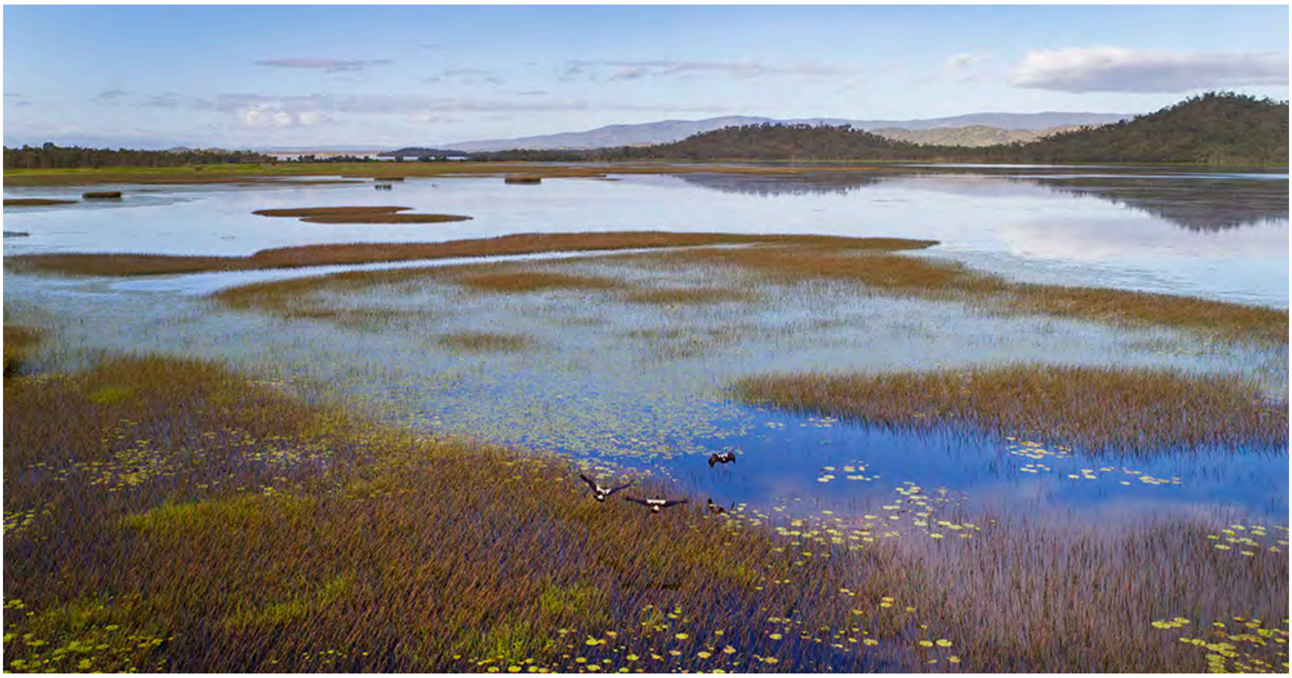

Figure 3-11 Wetlands, critical ecosystems in the Mitchell catchment
Photo: Nathan Dyer

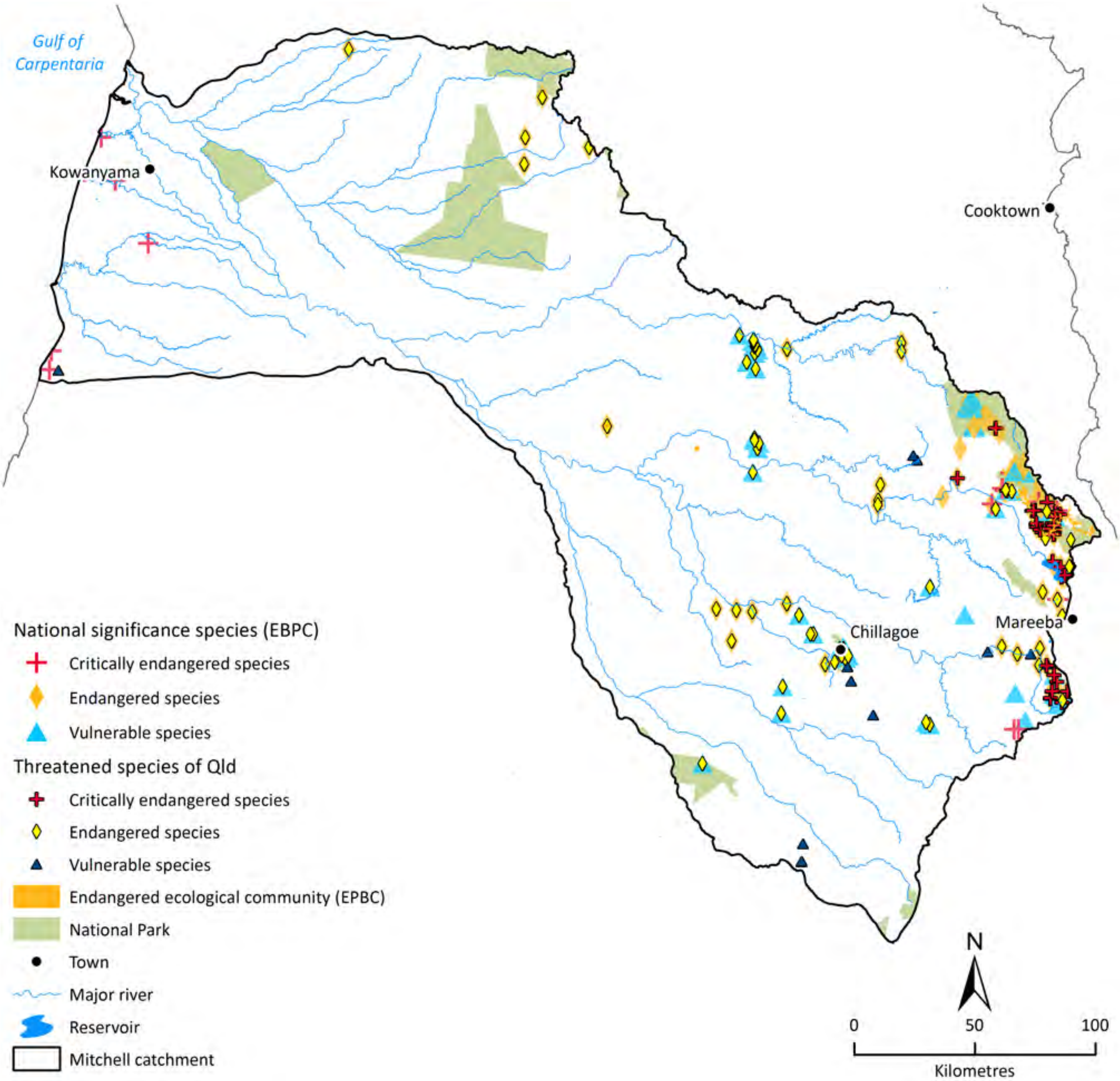

Figure 3-12 Distribution of species listed under the EPBC Act (Cth) and the *Nature Conservation Act 1992* (Qld), in the Mitchell catchment

If a proposed development is predicted to have a significant impact on a matter of national environmental significance (Table 3-2) it would require approval to proceed under the EPBC Act. This approval is required irrespective of local government policies. The *Nature Conservation Act 1992* lists 21 species, most of them mammals, birds and reptiles. This Act requires an approved species management program for any activity that will impact on breeding places of protected animals (Table 3-2).

Table 3-2 Definition of threatened categories under the EPBC Act (Cth) and the *Nature Conservation Act 1992* (Qld)

ACT	CATEGORY	DEFINITION
EPBC Act (Cth)	**Matters of National Environmental Significance**	World heritage properties, national heritage places, wetlands of international importance (listed under the Ramsar Convention), listed threatened species and ecological communities, migratory species protected under international agreements, Commonwealth marine areas, the Great Barrier Reef Marine Park, nuclear actions (including uranium mines), and water resources, in relation to coal seam gas development and large coal mining development.
	Critically endangered species	It has undergone, is suspected to, or is likely to undergo very severe reduction in numbers in the immediate future; its geographic distribution is precarious for the survival of the species and is very restricted. The estimated total number of mature individuals is very low and evidence suggests that the number will continue to decline at a very high rate and the probability of its extinction in the wild is at least 50% in the immediate future.
	Endangered species	It has undergone, is suspected to, or is likely to undergo severe reduction in numbers in the immediate future; its geographic distribution is precarious for the survival of the species and is restricted. The estimated total number of mature individuals is low and evidence suggests that the number will continue to decline at a high rate and the probability of its extinction in the wild is at least 20% in the near future.
	Vulnerable species	It has undergone, is suspected to, or is likely to undergo substantial reduction in numbers in the immediate future; its geographic distribution is precarious for the survival of the species and is limited. The estimated total number of mature individuals is limited and either evidence suggests that the number will continue to decline at a substantial rate and the probability of its extinction in the wild is at least 10% in the medium-term future.
	Critically endangered communities	Extremely high risk of extinction in the next 10 years or three generations of key species.
	Endangered communities	Extremely high risk of extinction in the next 20 years or five generations of key species.
	Vulnerable communities	Extremely high risk of extinction in the next 50 years or ten generations of key species.
Nature Conservation Act 1992 (Qld)	**Endangered**	There have not been thorough searches conducted for the wildlife and the wildlife has not been seen in the wild over a period that is appropriate for the life cycle or form of the wildlife; or the habitat or distribution of the wildlife has been reduced to an extent that the wildlife may be in danger of extinction; or the population size of the wildlife has declined, or is likely to decline, to an extent that the wildlife may be in danger of extinction; or the survival of the wildlife in the wild is unlikely if a threatening process continues.
	Vulnerable	Its population is decreasing because of threatening processes, or its population has been seriously depleted and its protection is not secured, or its population, while abundant, is at risk because of threatening processes, or its population is low or localised or depends on limited habitat that is at risk because of threatening processes.

The highest concentration of threatened species is near the Daintree in the eastern, wetter, higher altitude fringe of the Mitchell catchment (Figure 3-2), however the no-records of species in other areas can be a reflection of a lack of field studies, rather than a true absence of a species. There are four important areas for birds and three important wetlands (Figure 3-2). A previous synthesis report overviewing terrestrial systems of northern Australia found large data gaps exist in the Mitchell catchment, particularly describing plants and animals (Kutt et al., 2009). This lack of data limits any potential analysis of impacts or conservation planning. Queensland Regional Ecosystem mapping (Queensland Herbarium, 2017) which is based on vegetation communities that are associated with a geology, landform or soil, shows that much of the upper Mitchell catchment is characterised as being of no concern, where remnant vegetation is over 30% of pre-clearing extent (Table 3-3; Figure 3-13). Note however, that there are small endangered vegetation communities (less than 10% of remnant vegetation remaining) and of concern vegetation communities (10 to 30% of remnant vegetation remaining) located in areas of the catchment. The lower catchment is largely dominated by communities of concern.

Table 3-3 Categories of regional ecosystem (vegetation) communities

CATEGORY	DEFINITION	SUBCLASS	AREA (ha)	PERCENTAGE OF CATCHMENT (%)
Endangered	Remnant vegetation is less than 10% of its pre-clearing extent across the bioregion; or 10–30% of its pre-clearing extent remains and the remnant vegetation is less than 10,000 ha.	Dominant†	13,902	0.2
		Sub-dominant‡	78	0
Of concern	Remnant vegetation is 10 to 30% of its pre-clearing extent across the bioregion; or more than 30% of its pre-clearing extent remains and the remnant extent is less than 10,000 ha.	Dominant	976,780	13.6
		Sub-dominant	1,005,689	14
No concern at present, least concern	Remnant vegetation is over 30% of its pre-clearing extent across the bioregion, and the remnant area is greater than 10,000 ha.	Dominant	5,044,862	70
Non-remnant	All vegetation that is not mapped as remnant vegetation. May include regrowth, heavily thinned or logged and significantly disturbed vegetation that fails to meet the structural and/ or floristic characteristics of remnant vegetation. It also includes urban and cropping land. Non-remnant vegetation may retain significant biodiversity values.		2,042	1.4
Plantation	Large-scale crops such as cotton and sugarcane.		116	0.0
Water	Large artificial deep-water impoundments (such as Lake Mitchell) and farm dams are mapped as ‘water’ on the remnant coverages, as they do not match any natural regional ecosystem.		2,946	0.1

†‘Dominant’ subclass means that greater than 50% of the polygon contains the regional ecosystem mapping.
‡‘Sub-dominant’ subclass means that less than 50% of the polygon contains the regional ecosystem mapping.

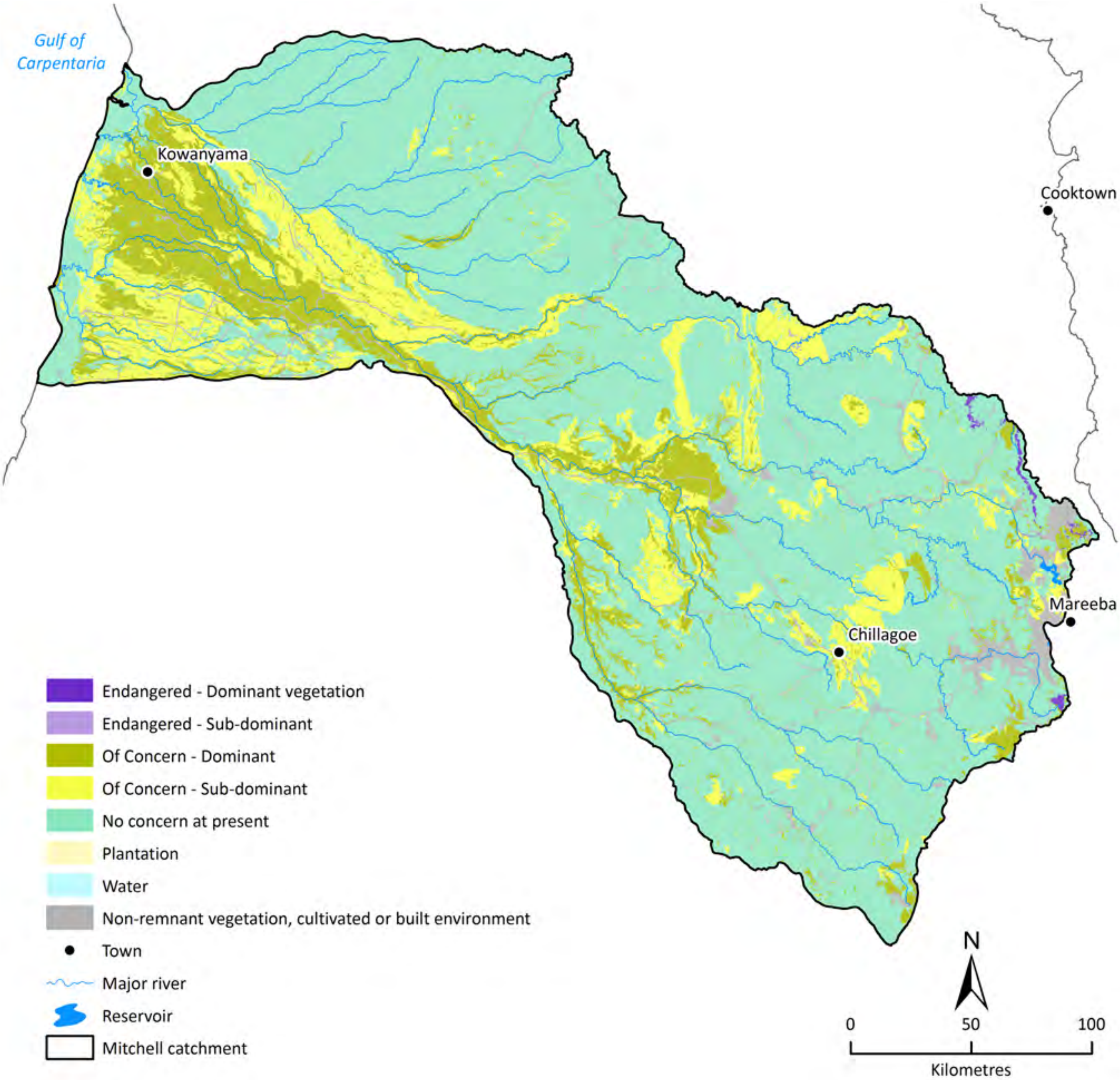

Figure 3-13 Regional ecosystem mapping in the Mitchell catchment
Source: Queensland Regional Ecosystem mapping (Queensland Herbarium, 2017).

3.3 Demographic and economic profile

3.3.1 INTRODUCTION

This section describes the current social and economic characteristics of the Mitchell catchment including the demographics of local communities (Section 3.3.1), current industries and land use (Section 3.3.2), and the existing infrastructure (transport, supply chains, utilities and community infrastructure) on which any new development would build (Section 3.3.3). Unless stated otherwise material for this section was sourced from the companion technical report on socio-economics (Stokes et al., 2017).

3.3.2 DEMOGRAPHICS

The Mitchell catchment encompasses a number of different local government areas, including most of the regions served by Kowanyama Aboriginal Shire Council and Mareeba Shire Council, in addition to the southernmost region of Cook Shire and the northernmost region of the Shire of Carpentaria. The Mitchell catchment is almost entirely contained within the Queensland state electorate of Cook. At the federal level, the northern part of the Mitchell catchment falls within the Leichhardt electorate while the southern part of the study area falls within the Kennedy electorate. The major settlements within the study area are Kowanyama, Chillagoe, Dimbulah, Mount Carbine and Mount Molloy. With the exception of Dimbulah (population 1050), all settlements had populations of less than 1000 as at the 2016 census.

The demographic profile of the Mitchell catchment, based on data from the 2016 and 2011 censuses, is shown in Table 3-4. The catchment is sparsely populated and has a population that predominantly earns lower incomes and is older than the national average. It has a larger proportion of males and a larger proportion of Indigenous people than is typical within the state and the country as a whole. Trends suggest these characteristics are strengthening. The total population of the study area is growing at a slower rate than that of the state and country overall. The median weekly gross household income in 2016 was $986, below the average for the state and only 69% of the average for Australia, although trends indicate this gap may be narrowing.

Table 3-4 Major demographic indicators for the Mitchell catchment

INDICATOR	UNIT	MITCHELL CATCHMENT	QUEENSLAND	AUSTRALIA
Total population, 2016†	number	6,365	4,703,193	23,401,892
Total population, 2011‡	number	6,045	4,332,735	21,507,719
% change in population	%	5.3	8.6	8.8
Indigenous population, 2016, as % of total§	%	25.8	4.0	2.8
Indigenous population, 2011, as % of total*	%	25.6	3.6	2.5
Male population, 2016, as % of total†	%	57.6	49.4	49.3
Male population, 2011, as % of total‡	%	56.0	49.6	49.4
Population density, 2016†	people/km^2	0.1	2.7	3.0
Median age, 2016†	years	42	37	38
Change in median age, from 2011 to 2016‡,†	years	2	1	1
Median weekly gross household income, 2016††	$	$986	$1,402	$1,438
Change in median household income, from 2011 to 2016‡‡,††	%	18.2	13.5	16.5
Average people per household, 2016†	number	2.7	2.6	2.6
Change in average people per household, from 2011 to 2016‡,†	number	–0.3	No change	No change

†Data sourced from ABS (2016c).
‡Data sourced from ABS (2011c).
§Data sourced from ABS (2016a).
*Data sourced from ABS (2011a).

†† Data sourced from ABS (2016b).
‡‡ Data sourced from ABS (2011b).

Socio-Economic Indexes for Areas (SEIFA) scores, which provide measures of socio-economic advantage and disadvantage, indicate that the Mitchell catchment is relatively disadvantaged compared to the rest of the country (Table 3-5). The study area falls within the lowest 30% for three of the SEIFA measures.

Table 3-5 SEIFA scores of relative socio-economic advantage for Mitchell catchment
Scores are relativised to a national mean of 1000, with higher scores (smaller deciles) indicating greater advantage.

INDICATOR	MITCHELL CATCHMENT		QUEENSLAND	
	Score	(Decile)	Score	(Decile)
Index of Relative Socio-economic Advantage and Disadvantage†	928	(3)	996	(5)
Index of Relative Socio-economic Disadvantage‡	938	(3)	1,000	(5)
Index of Economic Resources	951	(3)	1,002	(5)
Index of Education and Occupation	944	(4)	980	(5)

†Based on both the incidence of advantage and disadvantage.
‡Based purely on indicators of disadvantage. Data sourced from ABS (2011e).

3.3.3 CURRENT INDUSTRIES AND LAND USE

New agricultural development could affect current land users and other industries that rely on natural resources. This section describes current agriculture and fisheries industries in the study area, and the other land uses and industries that might be impacted by new development projects.

Employment

The overall unemployment rate in the Mitchell catchment is significantly above that seen in the state, which itself is higher than the rate for the country as a whole (Table 3-6), reinforcing the view that the Mitchell catchment is a region of relative socio-economic disadvantage. According to census data, the rate of unemployment increased considerably from 2011 to 2016. There are noticeable differences in the industries providing the most jobs within the Mitchell catchment compared to both Queensland and Australia as a whole. While 'Education and training', 'Healthcare and social assistance', and 'Construction', are important employers in the study area and nationally, 'Retail trade' and 'Professional, scientific and technical services', which both feature within the top five industries by employment across the nation, are less significant within the Mitchell catchment. Instead, 'Agriculture, forestry and fishing' and 'Accommodation and food services' are far more important, employing almost one-third of the workforce in the catchment. These important differences have a significant impact on the regional economic benefits that can result from development projects initiated within the study area (see Section 6.5).

Table 3-6 Key employment data in the Mitchell catchment in relation to state and national means

EMPLOYMENT STATISTIC	MITCHELL CATCHMENT	QUEENSLAND	AUSTRALIA
Unemployment rate (%), 2016†	11.2	7.6	6.9
Unemployment rate (%), 2011‡	6.3	6.1	5.6
Major industries of employment – top five industries % of employment for each location†			
Agriculture, forestry and fishing	31.8	na	na
Education and training	9.3	9.4	9.1
Public administration and safety	8.6	na	na
Health care and social assistance	8.3	13.5	13.2
Construction	7.5	9.4	8.9
Retail trade	na	10.4	10.3
Accommodation and food services	na	7.7	na
Professional, scientific and technical services	na	na	7.6

†Data sourced from ABS (2016b).
‡Data sourced from ABS (2011b).
na = not applicable (only the top five industries are provided for each location).

Land use

Grazing is the overwhelming dominant land use (95.1%) in the Mitchell catchment (Figure 3-14; Figure 3-15). Approximately 90% of the catchment is under various forms of leasehold tenure, with most being pastoral leasehold. The remainder of the study area is mainly classified as conservation (2.9%), with 1052 km^2 falling within national parks and wetlands (1.6%), which are located in the delta at the bottom of the study area. There are some small areas of dryland (6000 ha) and intensive agriculture (19,000 ha) on the eastern margins of the Mitchell catchment, where it overlaps with the edge of the Mareeba–Dimbulah Water Supply Scheme (MDWSS).

Figure 3-14 Loading cattle onto Type 2 road trains
Photo: CSIRO.

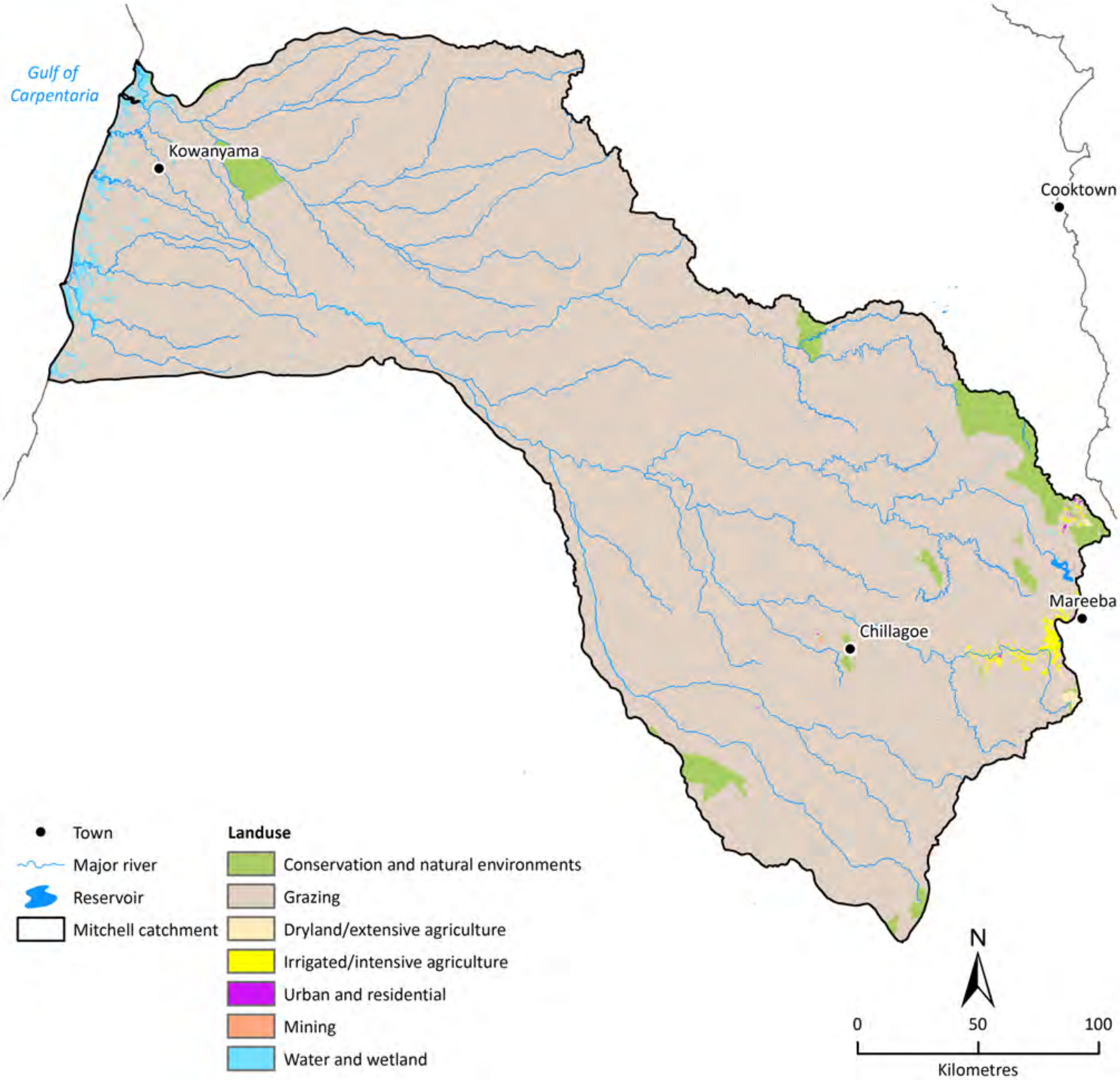

Figure 3-15 Land use classification for the Mitchell catchment
Source: ABARES (2016) Australian Land Use Classification, simplified following Stokes et al. (2017).

Agriculture and fisheries

Agriculture is the largest contributor to the economy of the Mitchell catchment, where the total gross value of agricultural production (GVAP) in 2015–16 was approximately $225 million (ABS, 2017). Livestock commodities ($130 million) account for just over half of the total GVAP, dominated by the beef industry ($117 million), which has been aided by recent large increases in cattle prices. Poultry contributed a further $13 million in 2015–16. Cropping accounted for $95 million, with the largest contributors being mangoes ($29 million), sugarcane ($17 million) and avocados ($14 million) (Note that confidentiality deletions affect subtotals in this GVAP data, so industry values are lower-bound estimates. This is particularly likely to be the case where there are only a few businesses in a category.). Across the Mitchell catchment, agriculture accounts for approximately 32% of employment (Table 3-6).

Grazing industry in the Mitchell catchment

The Mitchell catchment supports a variety of agricultural enterprises but agricultural production is dominated by extensive grazing of beef cattle on leasehold land. Beef production systems are based on dryland native and naturalised pastures that are constrained in quality and quantity by the region's climate and soils. Rainfall is highly seasonal (Section 2.4), there is great variation between years in the amount of rain received and the soils are typically of low fertility. These factors dictate that overall cattle carrying capacity is low (one animal per 10 to 20 ha) and they strongly influence the kinds of beef enterprises that can be conducted within the Mitchell catchment. The relatively remote nature of much of the Mitchell catchment also limits the kinds of markets that can be accessed by the region's beef enterprises. In spite of these constraints, the catchment carries approximately 185,000 head of cattle.

Low productivity per hectare and per animal means that properties need to be reasonably large, ranging from around 10,000 ha in the east of the catchment to over 500,000 ha in the west. Productivity levels and market access dictate that most beef enterprises are centred on cow-calf breeding operations rather than fattening of animals. They typically turn off weaners (120 to 160 kg) or yearling animals (250 to 350 kg) that are sold to operations in more fertile areas further south in Queensland. Yearling animals are also exported live to Asia. While recent cattle prices for livestock have led to optimism in the beef sector, the decade up to 2015 showed cattle properties in the Gulf region of Queensland making regular losses with declining equity (see the companion technical report on agriculture viability in the Mitchell catchment (Ash et al., 2018)).

Pasture production occurs mostly in the December to April period, where plant growth rates can be very high. Almost no pasture production occurs over the remainder of the year. A future irrigation development in the Mitchell catchment could strengthen the northern Australia beef industry by complementing the production of beef cattle, predominantly from extensive dryland grazing, with locally grown irrigated forages (Section 4.4). Greater diversity of markets would assist the industry, and this would be facilitated by the continued supply of higher quality beef for the domestic market (Gleeson et al., 2012).

Existing irrigation in the Mitchell catchment and the Mareeba–Dimbulah Water Supply Scheme

Irrigated agriculture in the Mitchell catchment is at present largely confined to the very east of the catchment in the Upper Walsh River (MDWSS) and in the upper Mitchell catchment, north of Mareeba in the Julatten area. In the late 1800s and early 1900s farming in the Mareeba–Dimbulah area was based on vegetables, maize, fruit and cattle, with tobacco becoming a successful crop some years later in 1928 (SunWater, 2018). Due to the challenges of growing dryland tobacco in the area, the Queensland Irrigation and Water Supply Commission built eight weirs on local rivers in the late 1940s and early 1950s, which permitted limited irrigation development (Griggs, 2002). However, it soon became clear that expansion of the industry would require considerably more water for irrigation. In 1953 construction of Tinaroo Falls Dam (Section 5.3) commenced and was completed in 1958. The primary purpose of the dam was to supply water to the MDWSS, originally known as the Mareeba–Dimbulah Irrigation Area (MDIA), largely to support an expansion of the tobacco industry. With the demise of the tobacco industry, irrigated agriculture in the MDWSS is now dominated by mangoes, bananas, avocados, sugarcane and a range of other tree, field and horticultural crops. The MDWSS currently irrigates an area of about 22,690 ha, around two-thirds of which lies within the Mitchell catchment. This represents about 0.2% of the total area of the Mitchell catchment.

Northern Prawn Fishery

The Northern Prawn Fishery (NPF) spans the northern Australian coast between Cape Londonderry in WA to Cape York in Queensland (Figure 3-16). It is one of the most valuable fisheries in the country and is managed by the Australian Government (via the Australian Fisheries Management Authority) through input controls such as gear restrictions (i.e. number of boats and nets, length of nets) and restricted entry. The two most productive NPF regions – the Mitchell and Karumba NPF regions (Figure 3-12) – are located near the mouth of the Mitchell River and together account for about half of the total annual NPF prawn catch. Like many tropical fisheries, the target species exhibit an inshore/offshore larval life cycle and are dependent on inshore habitats, including estuaries, during the postlarval and juvenile phase (Vance et al., 1998). Monsoon-driven freshwater flood flows cue juvenile prawns to emigrate from estuaries to the fishing grounds and flood magnitude explains 30% to 70% of annual catch variation, depending on catchment region (Buckworth et al., 2014; Vance et al., 2003).

Initially consisting of over 200 vessels in the late 1960s, the number of vessels in the NPF has reduced to just 52 trawlers and 19 licensed operators after management initiatives, including effort reductions and vessel buy-back programs (Dichmont et al., 2008). Fishing activity for banana and tiger prawns, which constitute 80% of the catch, is also limited to two seasons: a shorter banana prawn season between April to June, and a longer tiger prawn season from August to November. The specific dates of each season are adjusted depending on catch rates. Banana prawns generally form the majority of the annual prawn catch by volume. Key target and by-product species are detailed by Woodhams et al. (2011).

The catch is often frozen on-board and sold in domestic and export markets. The catch from the NPF was valued at $106.8 million in 2015 by the Australian Fisheries Management Authority (AFMA, http://www.afma.gov.au/fisheries/northern-prawn-fishery). Given recent efforts to alleviate fishing pressure in the NPF, there is little opportunity for further expansion of the industry.

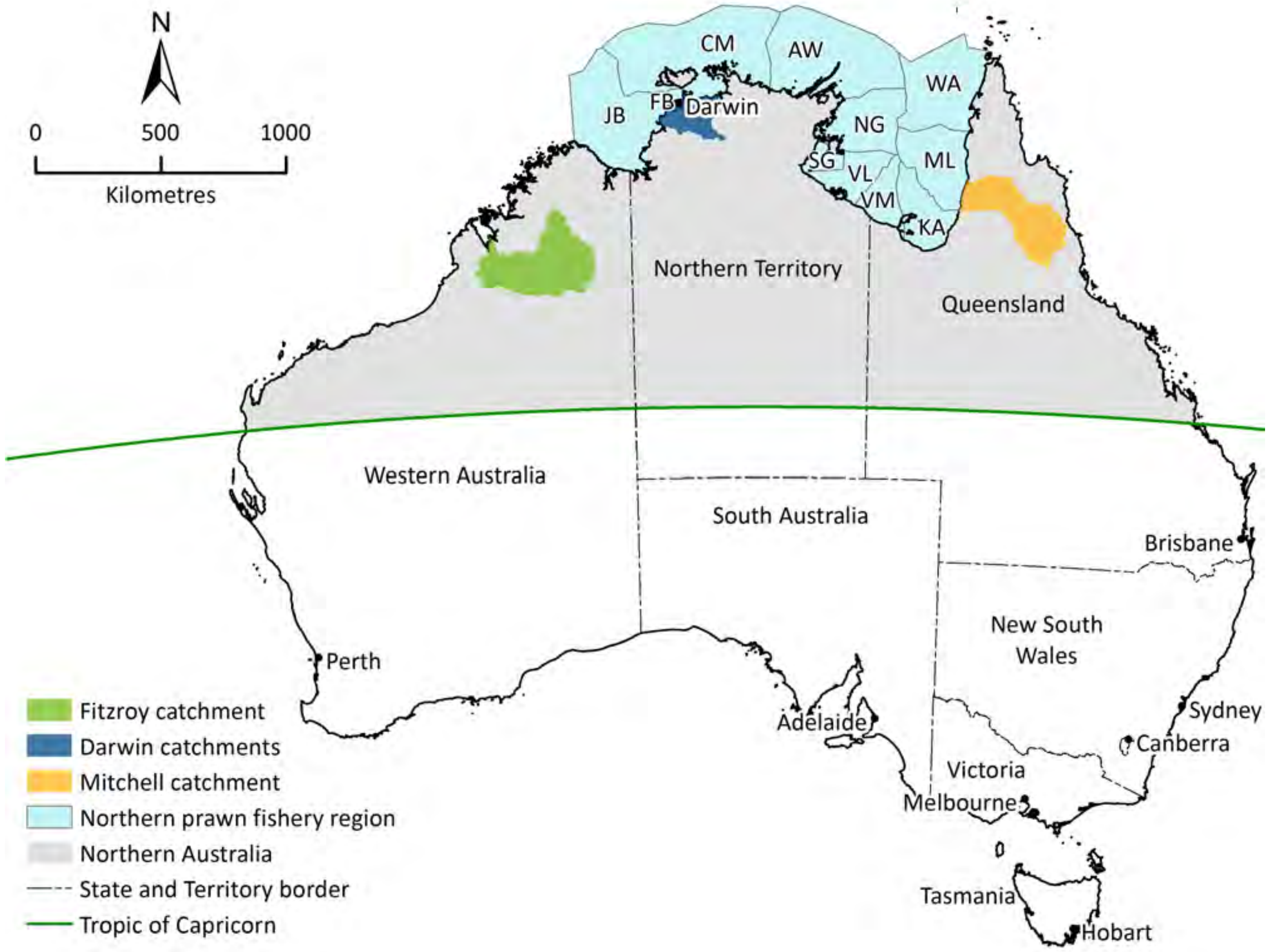

Figure 3-16 Map of regions in the Northern Prawn Fishery (NPF)
The regions in alphabetical order are Arnhem-Wessels (AW), Cobourg-Melville (CM), Fog Bay (FB), Joseph-Bonaparte Gulf (JB), Karumba (KA), Mitchell (ML), North Groote (NG), South Groote (SG), Vanderlins (VL), Weipa (WA), West-Mornington (WM). Source: Dambacher et al. (2015).

Land-based aquaculture in the Mitchell catchment

Land-based aquaculture in the Mitchell catchment is limited (Irvin et al., 2018). Two small red claw (freshwater crayfish) farms are located near Mareeba in the eastern part of the Mitchell catchment. A recent national-scale assessment (Preston et al., 2015) identified 594,000 ha of coastal land that could potentially be suitable for tropical land-based aquaculture in Queensland. Barramundi and tiger prawns were identified as established species suitable for aquaculture in this study area. Potential opportunities for land-based aquaculture in the Mitchell catchment are discussed in Section 4.6.

Tourism

Tourism contributed $52.9 billion (3.2% of GDP) to the Australian economy in 2015–16 (ABS Tourism satellite accounts, 2015–16). International visitors account for 29% of this total contribution to GDP, with the remainder generated by domestic day and overnight stay visitors. The countries providing the largest numbers of international visitors are New Zealand (NZ), China, the United Kingdom (UK) and United States of America (USA).

Of the 76 tourism regions for which Tourism Research Australia collects data, the 'Tropical North Queensland' (TATNQ) tourism region is most relevant to the Mitchell catchment. For some of the data, tourism regions can be further broken down into smaller ABS SA2 regions. The relevant ABS region for the Mitchell catchment is 'Tablelands' which covers approximately half of the Mitchell catchment. Much of the remainder of the Mitchell catchment falls within the 'Kowanyama-Pormpuraaw' SA2 ABS region; however, visitors to that region were not surveyed, so no such data are available. The boundaries of the Mitchell catchment, TATNQ tourism region, and smaller Tablelands SA2 region are shown in Figure 3-17.

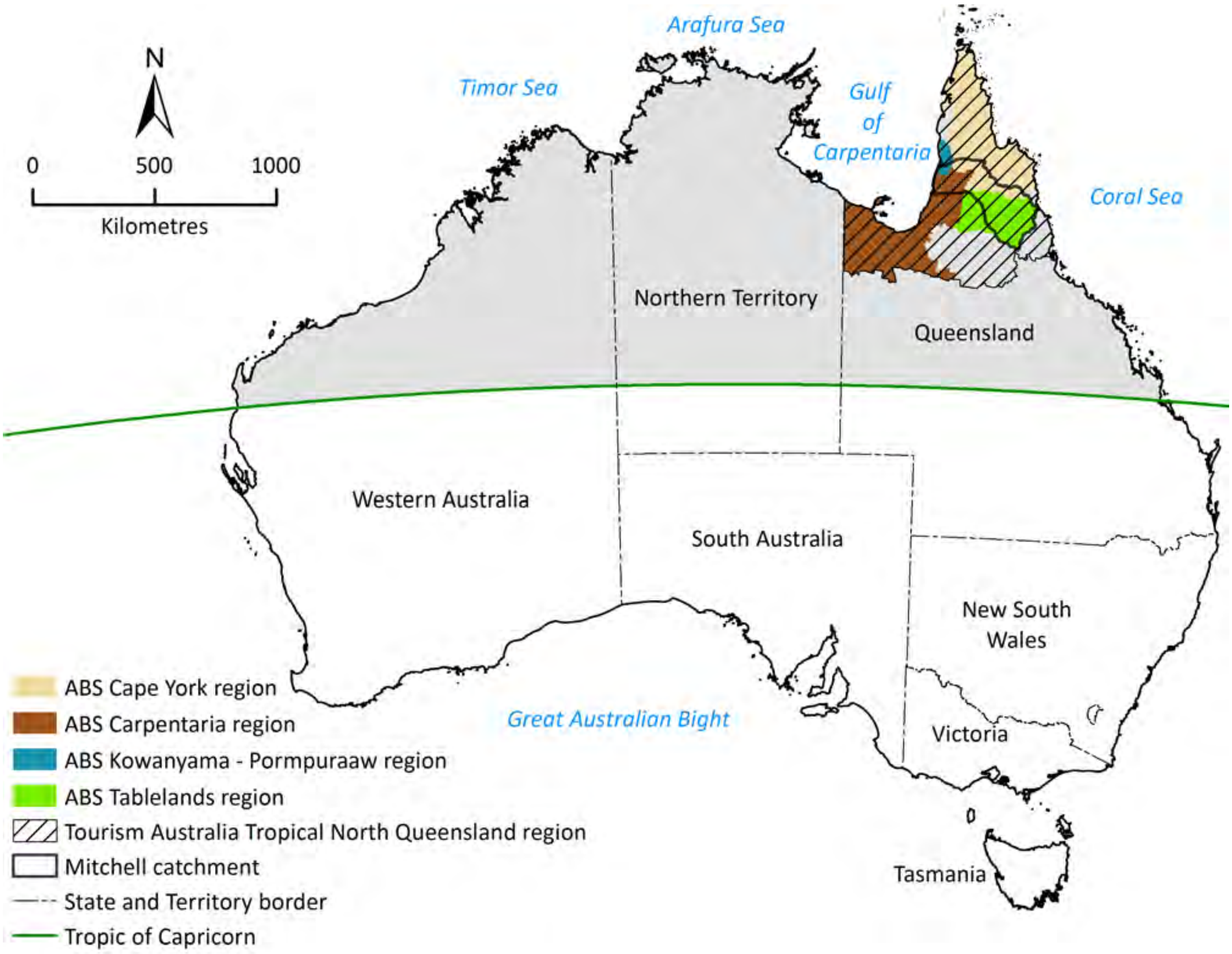

Figure 3-17 Tourism Research Australia and ABS statistical regions relevant to the Mitchell catchment
The smaller ABS Tablelands region falls within the Tropical North Queensland tourism region.

Recognised as one of the key natural tourism regions within the country, over 5 million people visit TATNQ per year (Table 3-7 but see Table 3-7 footnote, §§, for definition of a 'visitor'). However, the prime tourist attractions within the TATNQ tourism region, such as the Great Barrier Reef and rainforests, mainly fall outside the Mitchell catchment. A substantial proportion of the visitors are international, reflecting the major international airport at Cairns, with direct flights to a number of countries, including several regions within China. This is reflected in the top three countries of residence of visitors to the region, with China providing the most, followed by the USA and UK. The TATNQ tourism region also receives many day visitors drawn from elsewhere within Queensland, and the average length of stay for those visitors who stay overnight is around the average for the state and for the country as a whole. However, the average spend per visitor, at $688, is larger than the average for the state or country.

There appears to be substantial capacity for additional visitors within the tourism region as there are fairly low room occupancy rates (Table 3-7). Even during the peak tourism period (July to September) there remains surplus accommodation capacity in the region.

Table 3-7 Key 2015 tourism data relevant to the Mitchell catchment
The extent of the Tropical North Queensland tourism region is shown in Figure 3-13.

TOURISM STATISTIC	TROPICAL NORTH QUEENSLAND	QUEENSLAND	AUSTRALIA
Visitors (thousands)[†,‡,§§]	5,281	58,691	266,874
International visitors (% visitors)[†,‡,§§]	15	4	3
Domestic day visitors (% visitors)[†,‡,§§]	45	62	66
Visitor nights (thousands)[†,‡]	16,930	131,214	560,116
International visitor (% visitor nights)[†,‡]	40	39	43
Average stay per overnight visitor (number of nights)[†,‡]	6	6	6
Spend ($ million)[†,‡]	$3,632	$22,977	$99,086
Average spend per visitor ($)[†,‡]	$688	$392	$371
International visitors (% spend)[†,‡]	28	20	23
Room occupancy rate 2015–16 for hotels, resorts, motels, guest houses and serviced apartments[§,‡‡]	64.6%	62.7%	66.0%
Top three/four countries of origin for international visitors[†,*]	China, USA, UK	NA	NZ, China, UK, USA
Number of tourism businesses in region[†,††]	3,658	51,276	273,512

†Tourism region data sourced from Tourism Region Profiles Demand 2015, https://www.tra.gov.au/tra/2016/Tourism_Region_Profiles/Region_profiles/index.html#.
‡State, territory and national data sourced from International Visitor Survey Results to Sept 2015, https://www.tra.gov.au/Research/International-visitors-to-Australia/international-visitor-survey-results, and from National Visitor Survey Results to Sept 2015, https://www.tra.gov.au/Research/Domestic-tourism-by-Australians/National-Visitor-Survey-results.
§ Region, state and territory data sourced from ABS Tourist Accommodation, Australia, 2015–16, http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8635.02015-16?OpenDocument.
*National data sourced from International Visitor Survey Results to Sept 2015, https://www.tra.gov.au/Research/International-visitors-to-Australia/international-visitor-survey-results.
††State, territory and national data sourced for June 2015 from https://www.tra.gov.au/Research/View-all-publications/All-Publications/Economic-reports/tourism-businesses-in-australia-june-2011-to-june-2015.
‡‡National data sourced from http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/8635.02015-16?OpenDocument.
§§ Domestic 'visitors' represent the number of trips recorded in the National Visitor Survey[†,‡] where trip types include (domestic) overnight trips, (domestic) day trips and outbound (international) trips. Some routine trips, such as same-day journeys to work, are excluded. International 'visitors' represents the number of short term travellers to Australia from overseas[†,‡,*].
NA = no available data.

As a rural and fairly remote area, much of the appeal of the TATNQ tourism region to visitors lies in the natural beauty of the environment and in the associated Indigenous cultural values of the land. The tourism region includes a wide range of protected areas, including nature reserves, conservation areas, and both state-managed and Indigenous co-managed national parks. Surveys of visitors indicate that bush walking and visiting national or state parks are among the most popular tourist activities (Stokes et al., 2017). The key attractions of this tourism region are the Great Barrier Reef and the Wet Tropics World Heritage Areas, listed in 1981 and 1988 respectively. Within the Mitchell catchment there are a number of protected areas that attract tourists, including all or part of the Daintree, Chillagoe–Mungana Caves, Forty Mile Scrub, Hann Tableland, Undara Volcanic, Bulleringa, Mowbray, Kuranda, Mount Windsor, Mount Spurgeon and Mount Lewis National Parks, Kowanyama Indigenous land, and the Errk Oykangand Aboriginal National Park. Eco-cultural tourism based on a combination of natural and cultural values is an important development aspiration for local and regional development agencies.

Mining

Following WA, Queensland is the second-largest contributor to Australian mining industry jobs and revenue. However, the contribution of the Mitchell catchment to the total mining industry jobs and revenue in Queensland is negligible. In terms of employment by industrial sector, the Mitchell catchment supplied less than 0.5% of workers in the Queensland mining sector (ABS, 2011) (Table 3-8). Based on 2011 census data, the mining industry was the eighth most important industry within the study area (out of 19 industries).

Table 3-8 Key statistics relating to the mining industry in the Mitchell catchment

EMPLOYMENT STATISTIC	MITCHELL CATCHMENT	QUEENSLAND	AUSTRALIA
Numbers employed in mining, Census 2016†	66	49,997	177,640
Numbers employed in mining, Census 2011‡	205	52,952	176,560
Sales and service income of mining sector*, 2014–2015§	NA	$37,413 million	$195,519 million
% Employment within mining sector:			
Census 2016†	3.2	2.4	1.7
Census 2011‡	4.3	2.7	1.8

∗Mining sector is defined as coal mining, oil and gas extraction, metal ore mining, non-metallic mineral mining and quarrying; it does not include exploration and other mining support services.
†Data sourced from ABS (2016b).
‡Data sourced from ABS (2011b).
§Data sourced from ABS (2015).
NA = no available data.

The mining industry currently has a footprint covering less than 0.5% of the land within the Mitchell catchment, however, there are a number of mining exploration licenses in place, covering just over 20% of the land area, indicating the potential for further mining operations in the future (Figure 3-18).

The eastern-most third of the Mitchell catchment (around the towns of Chillagoe and Mount Garnet) holds promise for a number of commodities, hosting considerable economically exploitable mineral resources, predominantly tin, gold and copper.

Substantial alluvial tin was mined from the late 1800s to the late 1900s around Mount Garnet, however, current exploration is more focused on locating granite-hosted (‘hard rock’) tin resources. There are still numerous medium-scale tin mining operations in the Mitchell catchment, mainly near Mount Garnet but also south of Chillagoe and near Mount Carbine to the north.

Copper and other base metals (e.g. zinc, lead) are mainly found around Chillagoe. Although the area is past its prime, there are still several mines in operation (e.g. Mungana and Red Dome, north-west of Chillagoe) and exploration is still active. Based on current mining activity it is considered likely that relatively modest discoveries of base metals will be made in the future.

Figure 3-18 shows a considerable number of gold 'occurrences' between Mareeba and the Palmer River. However, the majority of these occurrences are classified as 'very small' and are mostly alluvial deposits. No gold mines are operating at present in the Mitchell catchment and it is likely that the alluvial gold resources have largely been excavated and are currently economically unviable to source (the Palmer River was the site of a gold rush in the late 19th century).

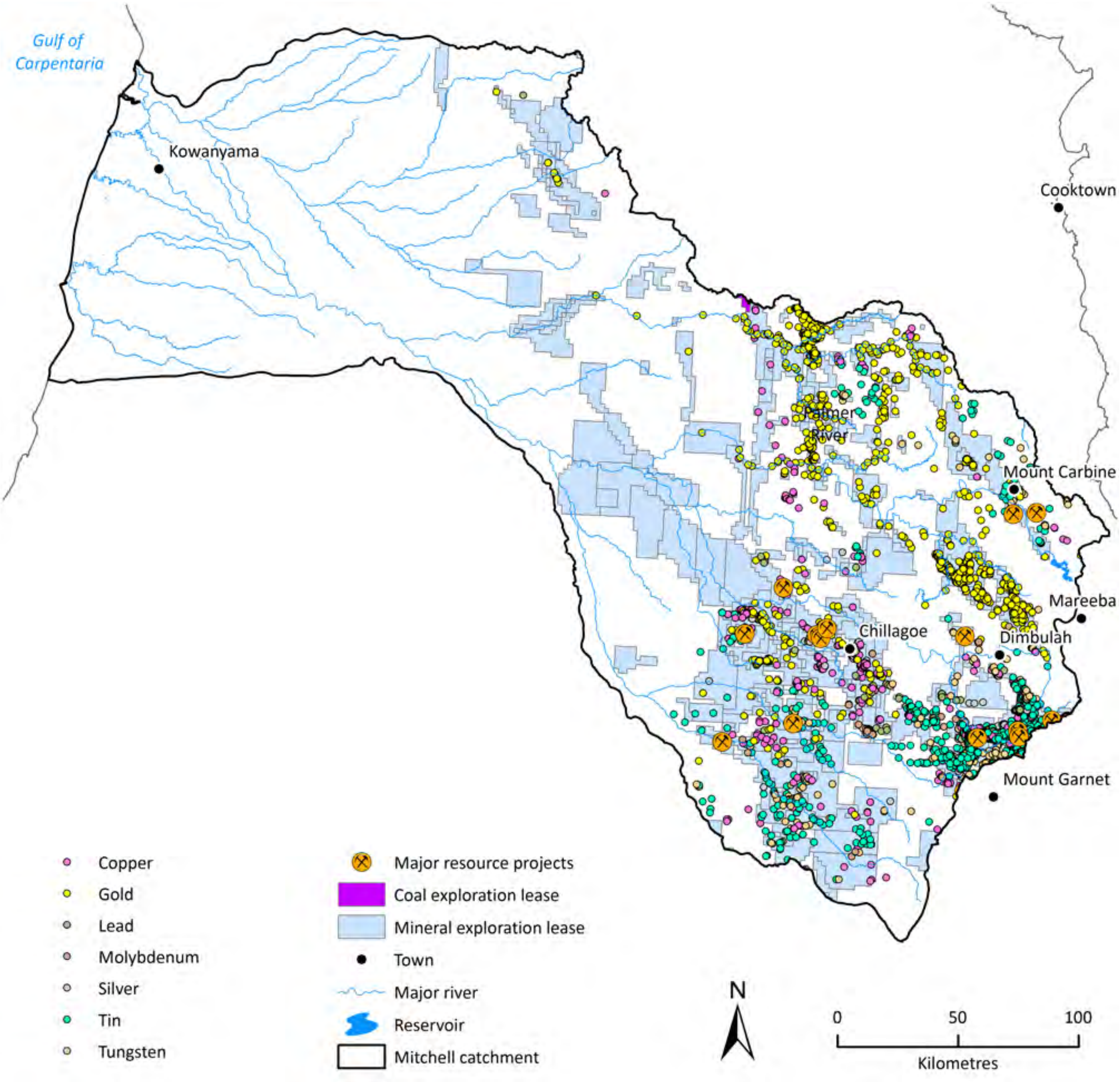

Figure 3-18 Mineral commodities (occurrences), major mines (active medium or larger occurrences) and exploration tenements in the Mitchell catchment

Exploration tenements are parcels of land on which a company has rights to explore for specific resources (e.g. minerals, coal or petroleum (oil and/or gas)).

The western two-thirds of the Mitchell catchment has negligible economic potential for mining.

There are no active hydrocarbon exploration leases in the Mitchell catchment. This is mainly due to the fact that the geological Carpentaria Basin (Figure 2-2) is relatively juvenile and there are no suitable source rocks deposited in the basin (e.g. organic-rich shales) within which hydrocarbons could form over geological time frames. There is one coal exploration lease, which straddles the edge of the north of the catchment, but in general the study area is not prospective for coal.

Furthermore, there are no geothermal leases, mostly likely due to a lack of deep crustal radiogenic rock at depth, coupled with the remoteness of the majority of the catchment.

3.3.4 CURRENT INFRASTRUCTURE

Existing infrastructure in the Mitchell catchment provides a base from which any future development could build. Current infrastructure is described below in terms of transport, supply chains and processing facilities, energy and water services, and community facilities. Costs of new infrastructure are discussed in Section 6.3.

Transport

The Mitchell catchment is characterised by a sparse road network (Figure 3-19; Figure 3-20) with the Burke Development Road being the main access to Mareeba and Cairns in the east and to Normanton and Cloncurry in the south. Burke Development Road is unsealed west of Chillagoe, with the sealed section linking with the Kennedy Highway to the east. All of the roads connecting the north and east of the Mitchell catchment are minor roads. These roads involve several creek crossings with limited or no causeway or bridge infrastructure. As a result, access to Kowanyama is often not possible during the wet-season months of December to February. The travel distances from Kowanyama to the nearest ports are 607 km to Cairns, to the east, and 372 km to the Port of Karumba, to the south. While Karumba has been used for livestock export, it does not have dry bulk storage required for other agriculture exports.

Figure 3-19 Creek crossings often have limited or no causeway and no bridge infrastructure
Photo: Nathan Dyer

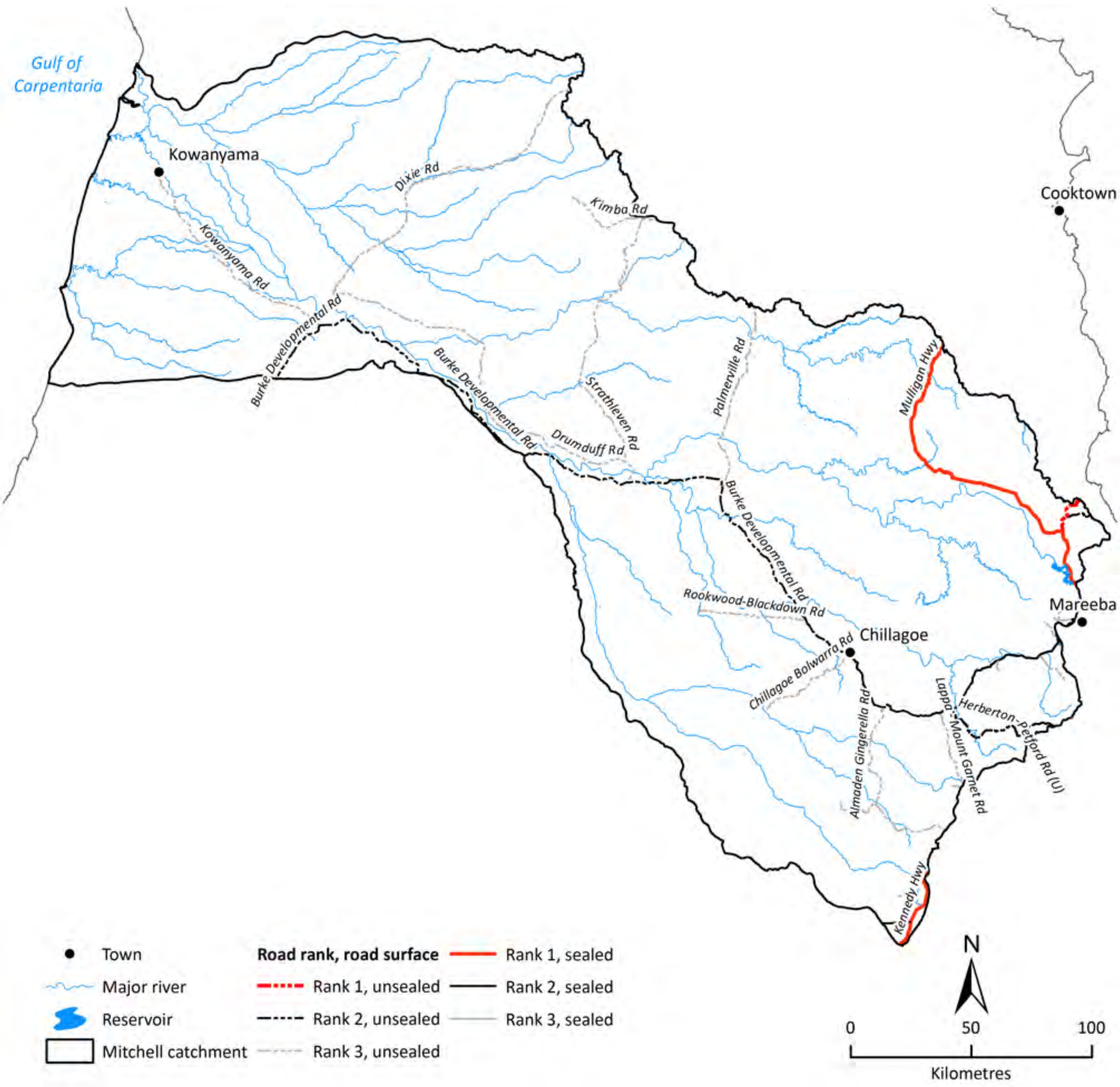

Figure 3-20 Road rankings and conditions for the Mitchell catchment
Rank 1 = well-maintained highways or other major roads, usually sealed; Rank 2 = secondary 'state' roads; Rank 3 = minor routes, usually unsealed local roads.

Figure 3-21 shows the heavy vehicle access restrictions for roads within the Mitchell catchment, as per the National Heavy Vehicle Regulator. All of the western part of the study area permits Type 2 road trains, which are vehicles up to 53 m in length, typically a prime mover pulling three 40-foot trailers (Figure 3-22). Despite the poorer road conditions in the north and west of the Mitchell catchment, these large road trains are permitted due to minimal safety issues from low traffic volumes and minimal road infrastructure restrictions (e.g. bridge limits, intersection turning safety). The sealed roads to the east and near Mareeba are limited to Type 1 road trains (36 m length restriction) and B-doubles (26 m). Transport to Cairns is limited to semitrailer access through the Atherton Tablelands with a detour B-double access via the Palmerston Highway. The Port of Karumba and towns along the Flinders Highway to the south are accessible using Type 2 road trains.

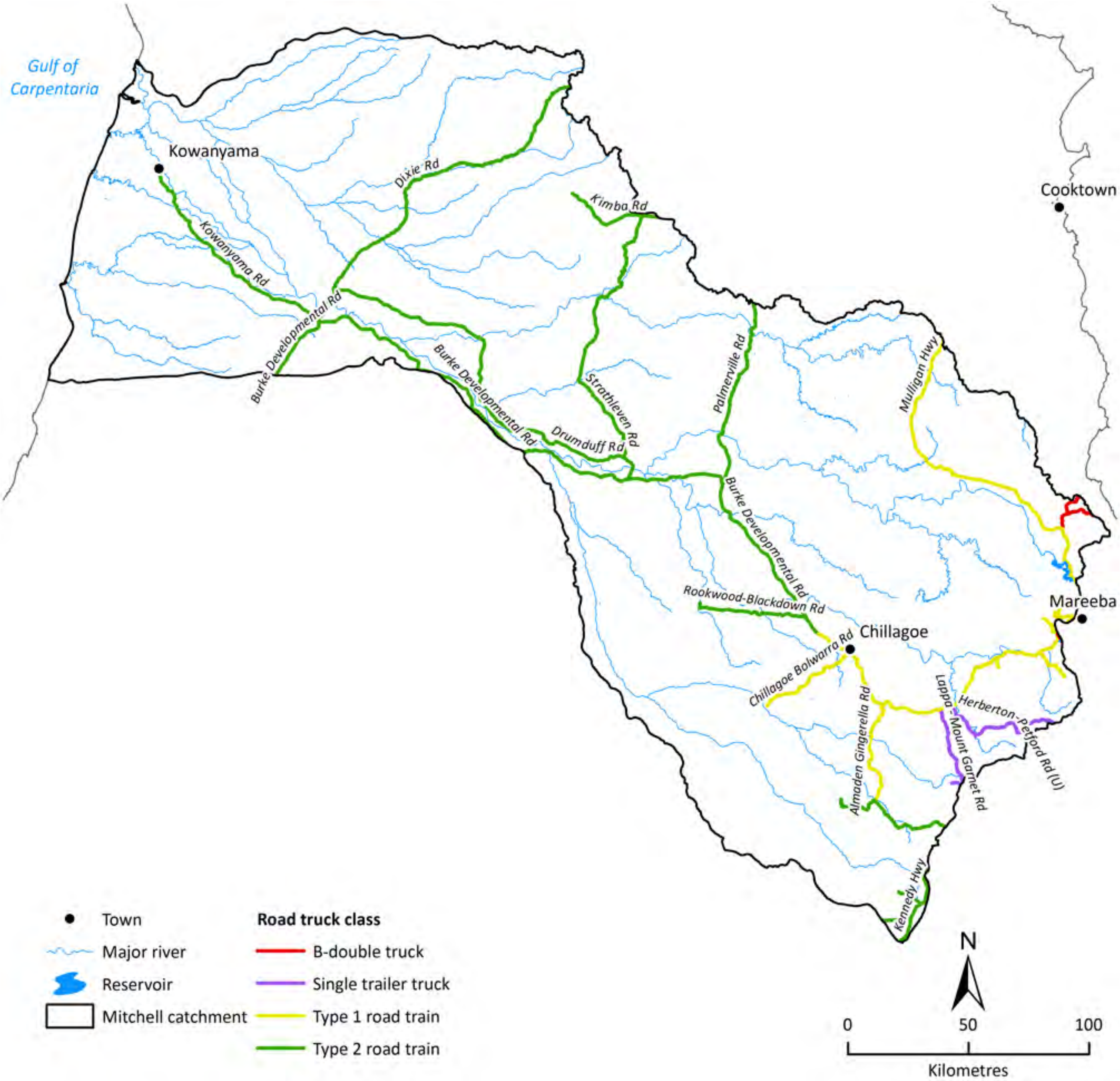

Figure 3-21 Vehicle access restrictions for the Mitchell catchment
Truck classes listed from shortest to longest in legend, as shown in Figure 3-22.

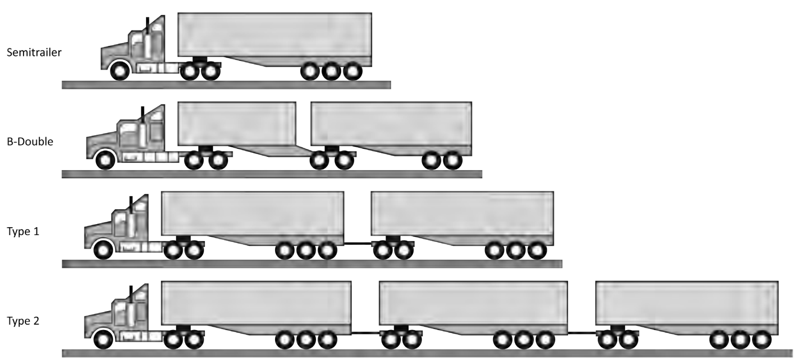

Figure 3-22 Typical vehicle combinations used for agriculture transport in Australia

Figure 3-23 shows the speed limits for the road network within the Mitchell catchment. These speed limits are usually higher than the average speed achieved for freight vehicles, particularly on unsealed Rank 2 and 3 roads. Heavy vehicles using such unsealed roads would usually achieve average speeds of no more than 60 km/hour, often as low as 30 km/hour when transporting livestock. The travel time from Kowanyama to Cairns is about 11 hours.

Kowanyama is often inaccessible from Mareeba between December and February due to the wet season, when the key route (Kowanyama to Dunbar Road) closes due to flooding.

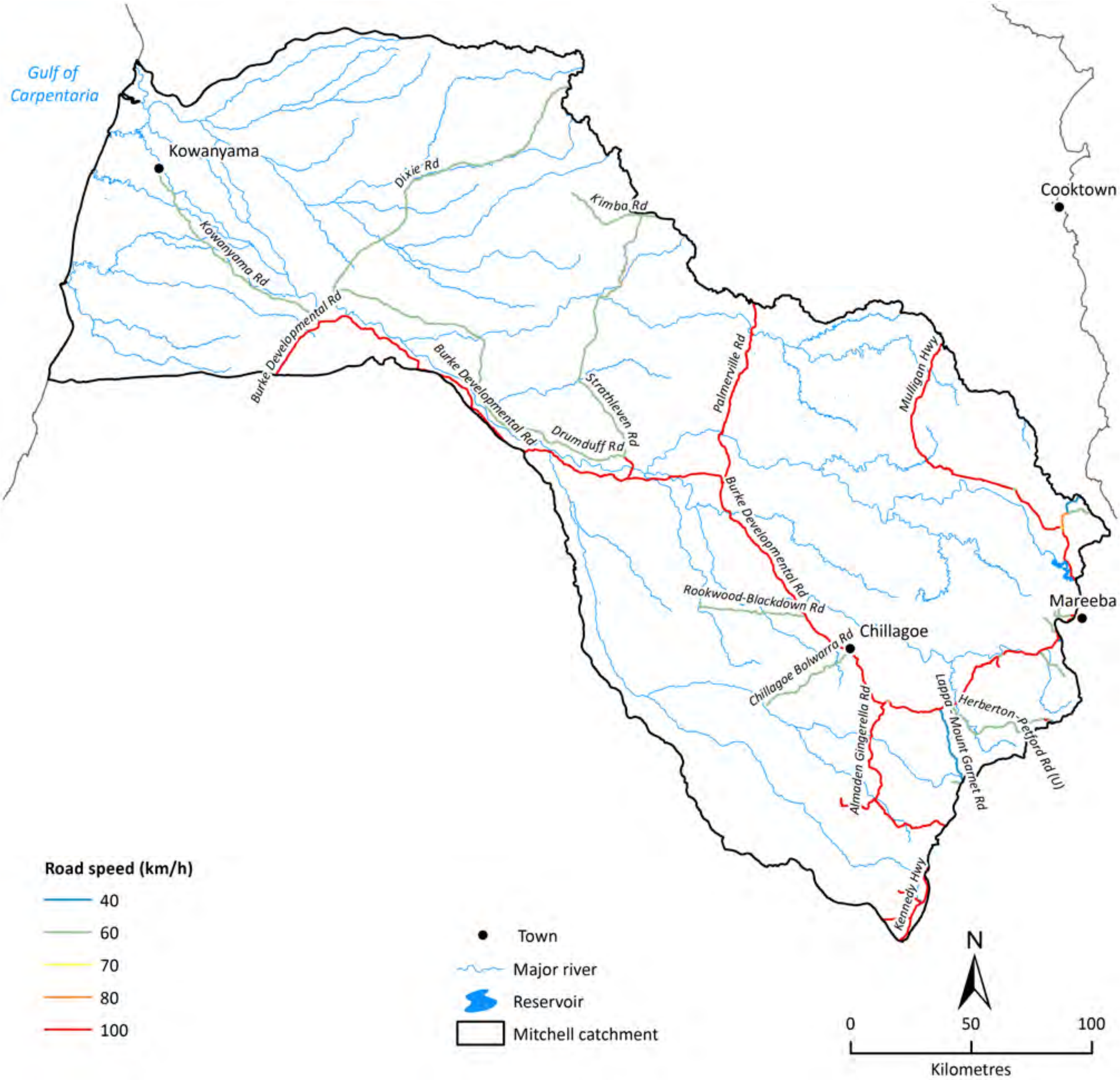

Figure 3-23 Road speed restrictions for the Mitchell catchment

While road closure data was not available, discussions with the Carpentaria Shire Council indicated the road is usually blocked during the wet season from December onwards, but can be cut from November and inaccessible for up to three months. Data on the location of road closures was not available, although roads have usually been inaccessible at creek crossings and causeways.

There is no rail infrastructure in the Mitchell catchment that can be used for freight transport (Figure 3-24), as the Queensland Rail network on the Atherton Tablelands has been progressively closed from 1958 to 2013, with the latest closure between Mareeba and Atherton. The nearest rail links are along the Townsville to Mount Isa rail line, to the south, or the north coast rail line, to the east. These lines have high axle load limits and large crossing loops for efficient rail transport. A tourist train operates from Cairns to Atherton, but is currently unsuitable for heavy or regular freight movements. An alternative is air freight out of Kowanyama (via Skytrans or Hinterland Aviation chartered flights), which may provide backloading capacity to cater for high value agriculture/aquaculture transport to Cairns. However, this capacity is limited to a few tonnes per week given the low frequency of service and use of small planes. It would also require additional cold or dry storage near the airport as well as loading/unloading, which would be low cost given the volumes transported. Airfreight would be an alternative when access from Kowanyama to the Burke Development Road is cut during the wet season.

Supply chains and processing

Outside of the Atherton Tablelands, agricultural production is currently limited to low intensity cattle grazing (Figure 3-25). The road network shows low volumes of annual truck movements in these areas. Beef cattle in the Mitchell catchment are primarily transported to live export and abattoirs, with some transported to feedlots or saleyards in Mareeba. The closest port, the Port of Kurumba, exports fewer than 20,000 head per year, while Townsville exported around 200,000 head in 2015. JBS Swift Australia Meat Works at Stuart is the nearest major meat processing facility, approximately 400 km from Mareeba. There has been some feedlotting on the Atherton Tablelands, although cattle are usually transported south to feedlots closer to the major abattoirs. There is no cotton production in the Mitchell catchment and the nearest cotton gin (Emerald) is 995 km from Mareeba.

Figure 3-24 There is no rail infrastructure in the Mitchell catchment that can be used for freight transport
Photo: CSIRO

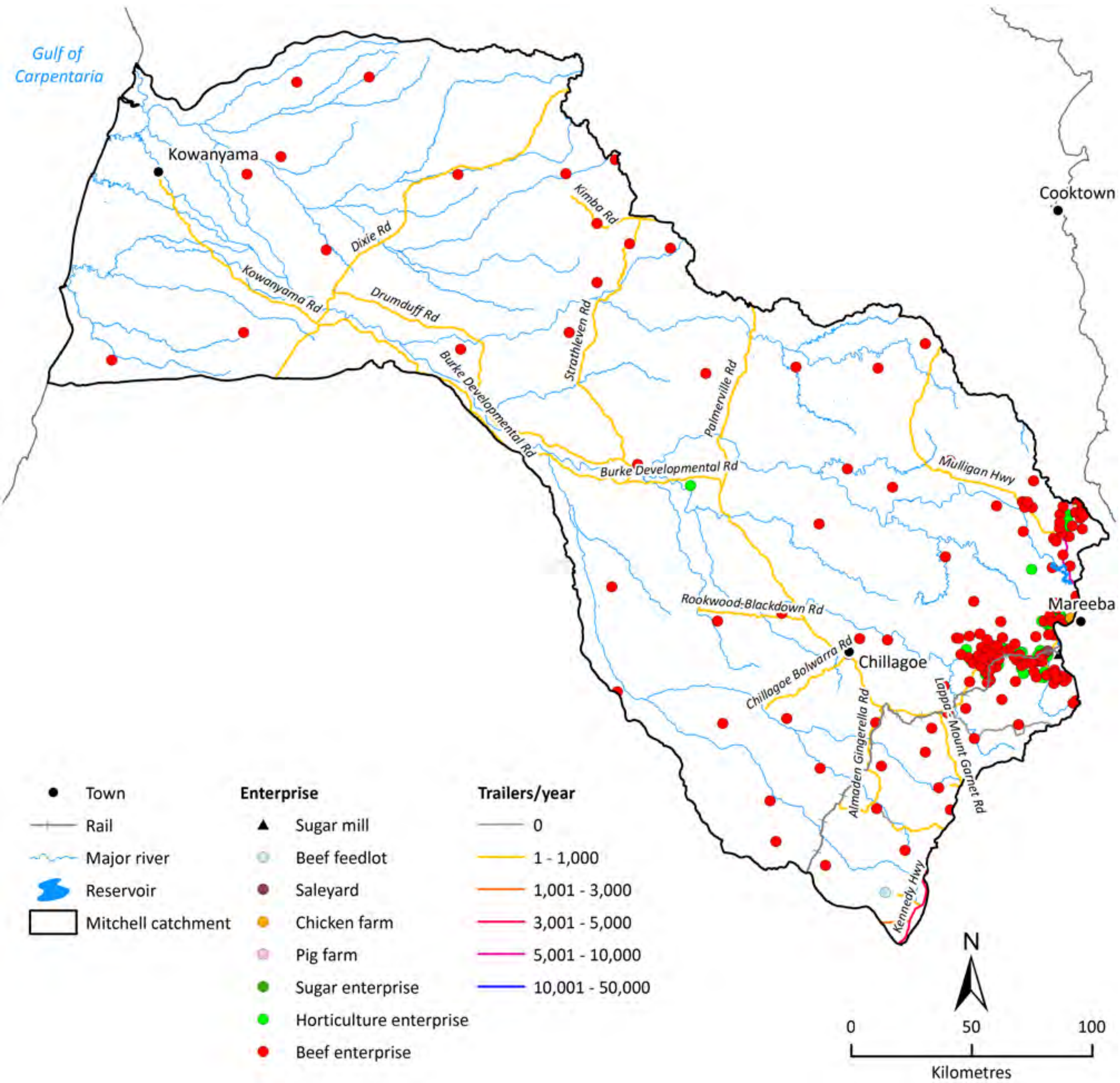

Figure 3-25 Agricultural enterprises in the Mitchell catchment
Roads are colour-coded to show the number of trailers per year of agricultural produce transported along them.

On the eastern border of the catchment on the Atherton Tablelands, annual agricultural produce includes 372,000 chickens (Table 3-9), about 20,000 t of grain, and 800,000 t of sugar transported to Tableland Mill per year. Many of the supply chains are split across the eastern boundary of the Mitchell catchment. For example, the chicken broiler farms are east of the catchment while the processing plant is marginally inside. There is also a diversity of horticultural production on the eastern border of the Mitchell catchment. Cairns is the nearest airport with export air freight capacity, and opportunities for horticulture air freight from these major regional airports is currently being evaluated in a separate project (Hort Innovation AM16012: Study of airfreight capacity for Australian horticulture exports to Asia and the Middle East).

Table 3-9 Overview of agricultural commodities transported into and out of the Mitchell catchment
Prices for horticultural produce can vary substantially over time, which in turn can affect what farmers choose to grow.

COMMODITY	DESTINATION	INBOUND	OUTBOUND	INDICATIVE PRICES ($/kg)
Beef (head)	Live export	0	0	2.70
	Abattoirs	0	2400	2.68
	Property	13,400	21,600	2.15
	Feedlots	1,680	240	2.60
	Other	10,320	9,360	NA
Sugar (t)	Mill	805,000	169,000	0.42
	Export		125,995	0.42
Grains (t)		20,831	0	NA
Chicken (head)		0	372,986	NA
Bananas (t)		0	14,986	1.92
Mango (t)		0	2,962	3.14
Oranges (t)		0	88	NA
Mandarins (t)		0	61	NA
Pumpkins (t)		0	2,454	0.75
Potatoes (t)		0	295	NA
Onions (t)		0	10	0.45
Lettuce (t)		0	43	NA
Pineapples (t)		0	3,592	NA

NA = not available

Energy

In terms of energy supply, the Mitchell catchment is served by the Tablelands regional distribution network (sometimes abbreviated to the Tablelands network/grid) in the 'Far North: Tablelands' Ergon planning area (Figure 3-26) (QDNRM, 2017; EQL, 2016). This distribution network is centred on the major rural towns of Atherton and Mareeba and includes the smaller rural communities of Malanda, Millaa Millaa, Ravenshoe, Mount Molloy, Dimbulah and Chillagoe. The coastal communities of Mossman, Port Douglas and Cooktown are also supplied from the Tablelands network. The network is served from the one 132/66 kV connection point to the National Electricity Market (NEM: the wholesale market of the major national transmission network covering the east of Australia), the T55 Turkinje substation located about 8 km south of Mareeba. The Tablelands system consists of a 66 kV sub-transmission network, a dual circuit 132 kV transmission line from Turkinje to the Craiglie 132/22 kV zone substation near Port Douglas, and a single circuit 132 kV line to the Lakeland 132/66/22 kV substation that supplies the Cooktown area (Ergon Energy, 2017). Energy Queensland Limited (EQL, formerly Ergon Energy and Energex), the state-owned energy utility company, manages this regional electricity distribution network, as well as most of the energy grid for Queensland (EQL, 2016).

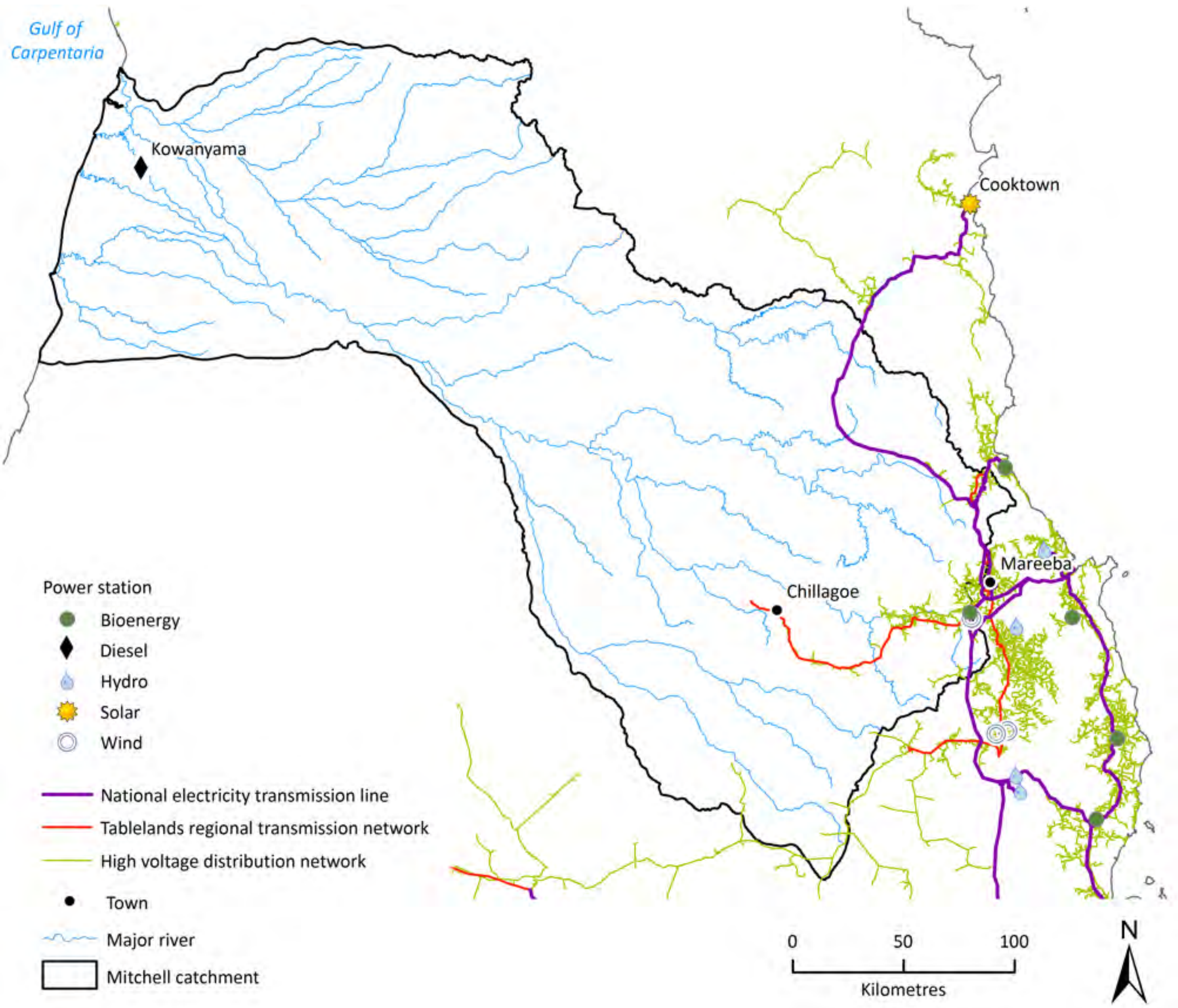

Figure 3-26 Tablelands regional transmission and distribution network and connected energy generation facilities
Source: QDNRM (2017)

A number of commercial-scale energy generation facilities lie within the Mitchell catchment or just beyond its eastern boundary, and supply energy directly to the NEM grid (Figure 3-26 and Table 3-10). This includes two bioenergy (sugarcane bagasse/fibre combustion) facilities; the 11 MW Mossman Mill just outside the Mitchell catchment, and the 7 MW Tablelands Mill within it, and two hydro-electric power facilities to the east of the Mitchell catchment; the 60 MW Barron Gorge and the 1.6 MW Tinnaroo Hydro schemes (QDNRM, 2017). Currently under construction is the $380 million 180 MW Mount Emerald Wind farm, near Mount Emerald between Atherton and Mareeba (QDNRM, 2017; RAC, 2016). The facility is anticipated to be commissioned in late 2018, and will connect to the northernmost point of the 275 kW NEM Powerlink Transmission line that runs north-south along the Mulligan Highway (RAC, 2016). Energy generation in the western portion of the Mitchell catchment, where it exists, is off-grid, small (<1 MW), isolated diesel power systems in the townships of Kowanyama and Pompuraaw, and are also managed by EQL (EQL, 2016). Ergon owns and manages 33 such isolated power systems in remote Indigenous communities across Queensland (EQL, 2016).

Table 3-10 Energy generation facilities in or near the Mitchell catchment

ID	POWER STATION FACILITY NAME	CAPACITY (MW)	ANNUAL ELECTRICITY PRODUCTION (MWh)	GRID	PRIMARY FUEL
A	Mount Emerald Wind Farm†	180	Proposed 500,000 to 600,000	NEM	Wind
B	Barron Gorge Hydro†	60	106,884	NEM	Hydro
C	Mossman Mill†	11	NA	NEM	Bagasse
D	Tableland Mill†	7	NA	NEM	Bagasse
E	Tinaroo Hydro†	1.6	NA	NEM	Hydro
F	Kowanyama	<1	NA	Off-grid	Diesel
G	Pompuraaw	<1	NA	Off-grid	Diesel
	Total	259.6		na	na

†Denotes power station just outside the Mitchell catchment boundary.
NEM = National Electricity Market, NA = no available data, na = not applicable .
Source: Clean Energy Regulator (2017)

Within the Mitchell catchment, potential renewable energy generation opportunities include bioenergy, solar, wind, hydro and pumped hydro. There is likely sufficient electricity demand on the Tablelands network for small new renewable generators to connect directly to this network.

Water

Water provision to the towns in the Mitchell catchment is primarily by local government or a designated service provider under authority from the Queensland Department of Energy and Water Supply (QDEWS). Mareeba Shire Council provides water sourced from Lake Tinaroo to Chillagoe, Dimbulah, Mount Carbine, Kuranda and Mount Molloy, and maintains water infrastructure, including restrictions and billing, across the local government area (MSC, 2017). Kowanyama Aboriginal Shire Council provides water supplies to Kowanyama's 260 connections.

Before investigating the potential for new dams in the Mitchell catchment it is prudent to first examine existing dams and the extent of regulation and quantities of general and strategic reserves in river systems. Table 3-11 lists existing large dams (>10 GL capacity and >10m wall height) in the Mitchell catchment and the adjacent upper Barron catchment.

Table 3-11 Constructed large dams in the Mitchell catchment
Locations in parentheses indicate catchment.

NAME OF DAM	NEAREST TOWN	ORIGINAL OWNER	YEAR CONSTRUCTED	HEIGHT ABOVE BED LEVEL (m)	STORAGE CAPACITY AT FSL (GL)	PRIMARY INTENDED PURPOSE	TYPE OF DAM
Lake Mitchell Dam (Mitchell)	Mareeba	Southedge Daintree Pastoral Pty Ltd	1987	17	190	Residential/ peri-urban†	Earth embankment
Tinaroo Falls‡ (Barron)	Atherton	SunWater	1958	42	439	Irrigation	Concrete gravity

‡Not in study area but adjacent to the Mitchell catchment and supplies water for irrigation in the Mareeba–Dimbulah Water Supply Scheme, some of which is located in the upper Mitchell catchment.
†ANCOLD Register of Large Dams lists the intended primary use as irrigation.
Source: ANCOLD Register of Large Dams (https://www.ancold.org.au/)

One large dam has been constructed in the Mitchell catchment, the privately funded Lake Mitchell Dam. Tinaroo Falls Dam in the adjacent Barron catchment is also listed in Table 3-11 because it supplies water to the MDWSS, part of which lies within the Mitchell catchment.

Lake Mitchell Dam

Lake Mitchell Dam (also known as Southedge Dam and as Quaid's Dam) is a privately developed dam located approximately 27 km north north-west of Mareeba (Figure 3-27). Originally intended to support commercial and residential development with associated recreation, the dam has never been used. There are small areas of soil downstream that could be used for irrigation development.

Figure 3-27 Main cross-river embankment of the Lake Mitchell Dam and spillways
Photo taken looking downstream. Two spillways are located on the left bank abutment.
Photo: CSIRO

If the Lake Mitchell Dam owners agreed to supply water at a price comparable to that charged by SunWater it is technically feasible that water could be pumped from Lake Mitchell to parts of the MDWSS near Mareeba. The existing water plan provides for a general reserve volume of 20 GL/year in the Mitchell River section upstream of the Rifle Creek junction, which includes the Lake Mitchell Dam. A further dam on the Mitchell River - Northedge Dam with a capacity of 275 GL - has been previously proposed. If developed, the reservoir associated with this dam would back up close to the toe of Lake Mitchell Dam.

Tinaroo Falls Dam

Tinaroo Falls Dam is a concrete gravity dam on the Barron River (Figure 3-28). The Tinaroo Falls Dam reservoir supplies water to the MDWSS, of which about 16,000 ha lies in the upper Mitchell catchment. The site was ultimately adopted over the Nullinga dam site (Section 5.3) because of its more suitable location and elevation to service the irrigation area.

Figure 3-28 Tinaroo Falls Dam in the Baron catchment
The Barron catchment is adjacent to the Mitchell catchment. Tinaroo Falls Dam is a concrete gravity dam that supplies water to the Mareeba–Dimbulah Water Supply Scheme.
Photo: CSIRO

Tinaroo Falls Dam has a stated annual water yield of 205 GL for irrigation and an assured water yield of 72 GL for power generation at the Barron Gorge power station (66 MW). Between 2007–08 and 2015–16 water use from Tinaroo Falls Dam reservoir increased from about 50% to 79%. The Tinaroo hydro-electric power station on the irrigation release channel has a capacity of 1.6 MW and became operational in 2004. Water released from the Tinaroo Falls Dam is subject to the Mareeba–Dimbulah Water Supply Scheme Resource Operations Licence (DNRM, 2017), which requires the licence holder to make releases from the Tinaroo Falls Dam to meet minimum Barron River flows.

Current surface water use and allocation

A total of 45 surface water licences exist in the Mitchell River catchment. The total allocation of these licences is 5.4 GL/year. These are classified predominately as 'rural' and include water used for irrigation from the Walsh River above Leafgold Weir and water for the town of Chillagoe. A strategic reserve of 5 GL/year for Indigenous landholders in the Kowanyama area is stipulated in the Mitchell Water Resources Plan.

Current groundwater use and allocation

Groundwater use is prominent across the Mitchell catchment, although the main use is for stock and domestic purposes which is authorised, but not licensed and does not include a volumetric allocation. This is particularly prevalent in the east of the catchment where many bores (>100) are drilled in the fractured rock aquifer of the Hodgkinson Formation (see Section 2.2) and extract small amounts of water over a large area. In total, 14 licensed groundwater allocations exist in the Mitchell catchment, 13 licenses are for stock and domestic use with no volumetric allocation, only one licence has a volumetric allocation. Eight allocations are for groundwater from the Bulimba Formation aquifer, two from the Gilbert River Formation aquifer and the Wyaaba Beds aquifer and one for the Rolling Downs Group aquifer. The only licensed volumetric allocation is an allocation of 500 ML/year for Kowanyama's town water supply which is sourced from the Bulimba Formation aquifer. None of the authorised or licensed groundwater extraction is metered, therefore current estimates of groundwater use do not exist.

Projected urban and industrial water demand

The reticulated network currently meets Cairn's urban and industrial needs of approximately 25 GL/year by supplying water from Copperlode Falls Dam and Behanna Creek. By 2030, the demands on Cairn's reticulated network is expected to increase to about 33 GL/year under a medium growth projection or 44 GL/year under a medium water demand growth projection plus additional demand from a 'special' project, such as the $8 billion Aquis Integrated Resort being constructed at Yorkeys Knob (DEWS, 2014).

Some stakeholders have proposed that a dam at the Nullinga dam site on the Walsh River in the Mitchell catchment could be used to service a portion of the future urban demand in Cairns (Advance Cairns, 2016). A dam at the Nullinga site could provide for an expansion of irrigated production of riparian lands to the Walsh River downstream as far as the Leafgold Weir area. With a delivery pipeline to the West Barron Main Channel, it could supply areas currently supplied from Tinaroo Falls Dam. This would potentially free up supply from the dam which then could be used to supplement supply to Cairns and to the Barron Gorge hydro-electric power station. However, the Cairns Regional Council has indicated that access water from a future regional dam (e.g. Nullinga dam site) is only considered as a potential long-term proposition (CRC, 2015). Short and medium-term initiatives involve demand management, developing the Mulgrave River (increase in system water yield of 8.5 GL/year) and access to a supplemented reserve of the Barron River (an increase in system water yield of 5.5. GL/year). Other options being investigated to augment water supply for agricultural use in the MDWSS include changes to bulk storage rules and operations and modernising existing distribution infrastructure to reduce system losses (Building Queensland, 2017).

Community infrastructure

The availability of community services and facilities can play an important role in attracting or deterring people from living in newly-developed areas in the Mitchell catchment. The Mitchell catchment is served by 24 schools and total student numbers have risen between 2012 and 2016 from 7010 to 7367 (Stokes et al., 2017).

There are no hospitals in the Mitchell catchment but there are primary health care centres in Chillagoe and Kowanyama, and an outpatient clinic at Dimbulah. There are three hospitals just outside the eastern border of the study area (Table 3-12). Each 1000 people in Australia require 4.0 hospital beds served by 28 fulltime equivalent hospital staff and $4.0 million/year funding to maintain current mean national levels of hospital service (AIHW, 2017a).

Table 3-12 Healthcare centres and hospitals in or near (distance in km from boundary) the Mitchell catchment

HOSPITAL NAME	URBAN CENTRE	BEDS	PUBLIC/ PRIVATE	EMERGENCY	OTHER SERVICES	PEER GROUP CLASSIFICATION†
Chillagoe Primary Health Centre	Chillagoe	<50	Public	Yes	Yes	Outpatient hospitals
Kowanyama Primary Health Care Centre	Kowanyama	<50	Public	Yes	Yes	Very small hospitals
Dimbulah Outpatients Clinic	Dimbulah	<50	Public	Yes	Yes	Unpeered and other hospitals
Mareeba Hospital (3 km)	Mareeba	52	Public	Yes	Yes	Public acute group C
Atherton Hospital (6 km)	Atherton	<50	Public	Yes	Yes	Public acute group C
Herberton Hospital (2 km)	Herberton	38	Public	Yes	No	Mixed subacute and non-acute

†Data sourced from AIHW (2015).
Sources: AIHW (2017b); MyHospitals website; Queensland Health (2017).

Recent census data showed that approximately 12% of private dwellings were unoccupied in the Mitchell catchment, a larger proportion than the state and national average (Table 3-13). This suggests that the current pool of housing may be able to absorb some increase in population.

Table 3-13 Number and percentage of unoccupied dwellings and population for the Mitchell catchment

INDICATOR	UNIT	MITCHELL CATCHMENT	QUEENSLAND	AUSTRALIA
Total population, 2016†	number	6,365	4,703,193	23,401,892
Total unoccupied private dwellings, 2016‡	number	336	195,570	1,039,874
% private dwellings that are unoccupied‡	%	12.3	10.6	11.2

†Data sourced from ABS (2016a).
‡Data sourced from ABS (2016c).

3.4 Stakeholder and investor values

3.4.1 INTRODUCTION

There are a diverse set of stakeholders with different and sometimes conflicting interests and values relating to the use of water resources and irrigated agricultural development across the Mitchell catchment. If greenfield developments were to proceed, the diversity of stakeholder perspectives has implications for the ability of developers to gain and maintain social licence to operate throughout the development process.

3.4.2 STAKEHOLDERS, THEIR VALUES AND POTENTIAL ENGAGEMENT STRATEGIES

Stakeholder analysis and a literature review suggests that northern Australia is highly valued, with the extent and nature of these values shifting through time and between stakeholder groups. For example, from about the late 20th century, northern Australia has become increasingly valued for the environmental, aesthetic, cultural and recreational services it provides, alongside its ability to produce agricultural commodities. The rainbow diagram in Figure 3-29 illustrates the diversity of local, regional and national stakeholders in the Mitchell catchment, and their likely support for greenfield development of irrigated agriculture in their catchment. It is important to note that many context-specific factors are missed in this top-down process, and that factors such as the scale of the benefits and to whom benefits may flow may impact support.

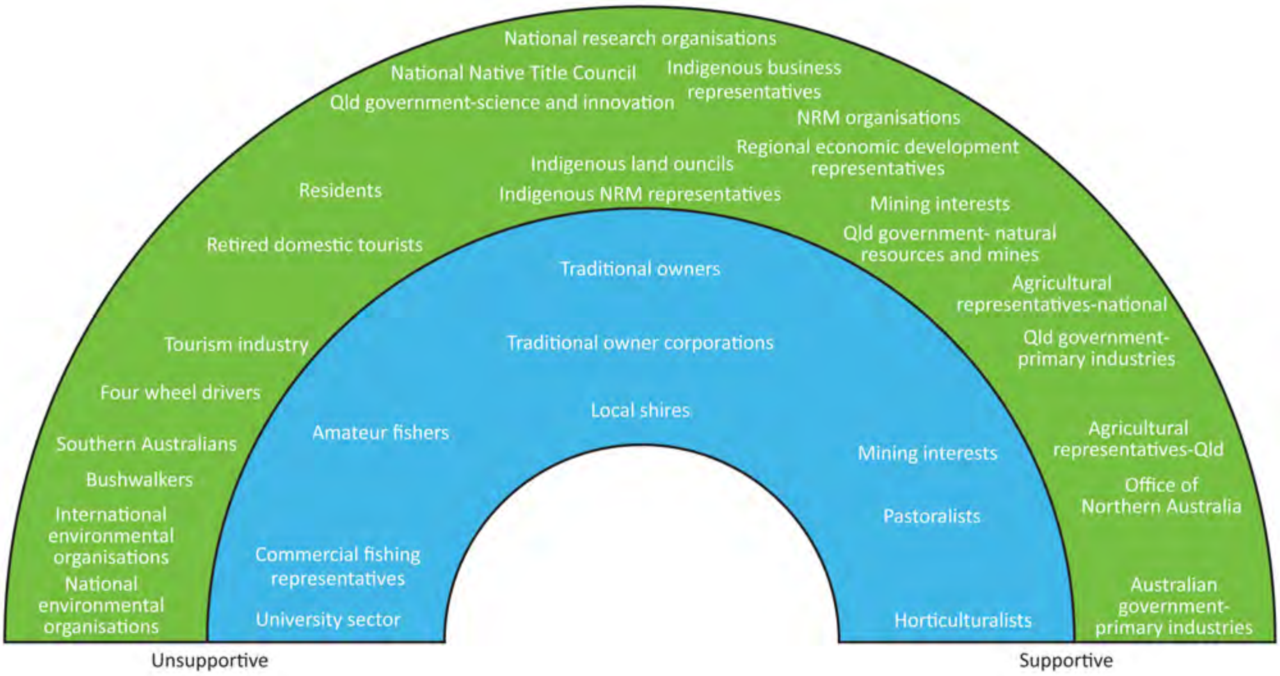

Figure 3-29 Rainbow diagram classifying stakeholders according to their likely support of irrigated agriculture in a greenfield site in the Mitchell catchment

Stakeholders towards the right of the diagram are more likely to be supportive. Internal ring = local stakeholders, external ring = regional, national and international stakeholders, NRM = natural resource management.
Based on stakeholder analysis and literature review (see Stokes et al., 2017).

Underpinning the likely support, or lack thereof, of stakeholder or interest groups for the potential development of greenfield irrigated agriculture in northern Australia are a set of social values, beliefs, attitudes and norms that are often shared within each group. In general, demographers and commentators note a shift from productivist values (see Irving, 2014) centred around the belief that economic productivity and growth are desirable outcomes, towards consumptive (for amenity) and protectionist values in northern Australia (Holmes, 2012). Table 3-14 summarises key stakeholder values that may impact the social licence to operate of development initiatives such as greenfield agriculture. Indigenous-specific values are summarised in Section 3.5.

Table 3-14 Summary of published stakeholder and interest group values relevant to the development of greenfield irrigated agriculture in northern Australia

Ordered least likely to support development through to most likely to support development (as per Figure 3-23). Stakeholder groups who broadly share values related to potential development are combined.

STAKEHOLDER	VALUES, ATTITUDES, BELIEFS AND NORMS
(Inter)national environmental organisations Four-wheel drivers, retired domestic tourists, international tourists, bushwalkers, safari hunters	Want natural environment protected, Indigenous culture valued, sustainability maintained. The 'real Australia', utopia, setting for psychological challenges, a 'proving ground'. Current human geography valued (e.g. few people, poor roads/lack of 2WD access). Valued for nature-based activities, large fish populations, scenic areas and secluded locations. Concern about land clearing, threats to Indigenous values, river diversion, irrigated agriculture, water as a public asset, rivers not dammed, no inter-basin transfer of water or groundwater extraction.
Southern Australians	High value placed upon condition of floodplains, quality of recreational fishing, condition of waterholes. High willingness to pay for rivers to be managed for recreation, cultural and environmental services. Small proportion consider irrigated agriculture important, or wish it to increase significantly.
Residents Amateur fishers and their representatives	Passion for rivers, camping, fishing, strong place attachment to rivers and related recreation. Strongly value perceived easy lifestyle (current human geography). Environment and recreation more important than new commercial/retail business and primary industries. Low value placed on income from irrigation agriculture, high value on environmental and cultural assets. Less willing to pay for management of cultural services than southern Australians. Lack of trust in government driven planning.
Local shires Regional economic development representatives	Vision: highly productive, innovative, resilient, commercially exciting economy, culturally diverse, dynamic, inclusive communities, relaxed. Value developments that leverage and consider social, economic and environmental assets, impacts. Interest in carbon trading, arts and culture sector, nature and culture based tourism. Infrastructure, institutions and social capital cited as higher concerns to development than lack of water.
Pastoralists Agricultural representatives	Occupation as a lifestyle choice and for identity. Environmental stewardship goals and lifestyle goals more important than economic goals Low ability to adapt to change. Free trade, open markets, property rights and private enterprise. Want institutions and infrastructure (largely road networks, but also soft infrastructure) for development.
Horticulturalists	Self-identify as innovators, high adaptive capacity, strong motivations towards profitability. Express concern about the environment (including water quality) but not the rhetoric of wilderness.

Stakeholders are also differentiated in terms of their level of interest in, and influence over, an action or change. These differences can help guide engagement strategies, especially when combined with an understanding of stakeholder values like those highlighted in Table 3-14. Interest/influence matrices were generated by the Assessment's stakeholder analysis, a literature review and the research informing Section 3.5. The matrices mapped stakeholders into four broad types of appropriate engagement: (i) partner, (ii) involve/engage, (iii) consult, and (iv) inform

(Table 3-15). It is important to note that this approach is indicative: a bottom-up stakeholder identification process is a more intensive, rigorous and best-practice approach (Reed et al., 2009) for understanding stakeholders.

Table 3-15 Stakeholder engagement typology for the Mitchell catchment, as determined via influence/interest matrices related to the development of irrigated agriculture in a greenfield site

Partner = High interest, high influence. Involve/engage = Low or moderate interest, high influence. Consult = High interest, low or moderate influence. Inform = Low interest, low influence.

SCALE	PARTNER	INVOLVE/ ENGAGE	CONSULT	INFORM
Local	Traditional Owners Traditional Owner corporations	–	Commercial fishers Horticulturalists Pastoralists Residents	–
Regional	Australian Government – primary industries – water Queensland Government – natural resources – primary industries – water – natural resources and mines	Office of Northern Australia Southern Australians	Commercial fishing representatives Environmental organisations (international and national) Indigenous business representatives Indigenous land councils Indigenous natural resource management organisations Queensland government – state development – science and innovation Regional economic development representatives (regional and national)	Agricultural representatives – national level Bushwalkers Creative industry Four-wheel drivers Mining interests Retired domestic tourists Safari Hunters Tourism industry

Stakeholders in the 'partner' section are likely to have a high level of interest and influence related to potential developments in the Mitchell catchment. Early, intensive, iterative engagement with these groups, resulting in the co-design of development initiatives, may be most appropriate for these groups. Regular discussions are likely to be appropriate with involve/engage/consult stakeholders. Stakeholders in the 'inform' section may accept occasional one-way communication about development in the Mitchell catchment.

The results of this analysis suggest that careful thought is needed as to the purpose of development, which ecosystem services may change through the development, how stakeholders are engaged and to whom benefits are intended, as key stakeholder values relate to all of these factors. At scale, development planning and implementation is likely to require a systematic and robust social impact analysis, including an investigation of, and ongoing engagement with, stakeholders and their interests.

3.4.3 POTENTIAL INVESTORS IN IRRIGATED AGRICULTURE

Very little is known about pre-existing or potential investors based on published literature. To help address this gap, this section contains an initial exploration of potential investors in irrigated agriculture in northern Australia. An initial typology of potential investors across northern Australia highlighted the variety of potential groups and their disparate investor potential, indicated by access to natural and human/financial/social capital. For example, Indigenous landholding/leaseholding corporations have potential access to a significant level of natural capital for development, whereas family trusts may have high levels of human/financial/social capital but little access to natural capital. From this typology, six groups were interviewed (see Section 3.5 for the results of interviews with native title holders, Indigenous Land Use Agreement groups, and Indigenous landholding/leaseholding corporations). Investors or potential investors from the international agribusiness, large companies with agricultural interests and small-scale owner operator horticulturalist types were also interviewed across northern Australia, with two from the Mitchell catchment. Mitchell catchment investors perceived similar constraints as investors across northern Australia, and there was no difference between investor perspectives and investor type. In order of importance, these perceived constraints were: i) institutional uncertainty, ii) institutional complexity, iii) economy of scale issues, iv) poor infrastructure, and v) training and retaining a skilled workforce. Investor concern about institutional uncertainty is illustrated by the following:

'*There is no grandfathering of laws at the moment. For projects of significant size, there should be a permanent agreement between government and the operator around approvals. Banks want to fund over a 15-year period but between state and federal government lifespans there is a change in government every two years. Big projects are long-term investments, two to three generations. So there is a major business change every two years. We need to know that once an approval is in, it cannot be changed.*' (Queensland participant)

Institutional certainty, simplicity and bureaucratic speed were the key perceived potential enablers of investment in irrigated agriculture. There was less consistency between investors regarding other enablers of irrigated development. Regardless, government support was the most consistently cited enabler of further investment.

The data represents a preliminary sample that acts as a marker of the additional information required to secure investor potential. This is particularly so for small- to medium-scale investors (including local landowners and leaseholders) whose views may not be so effectively represented at higher levels of decision making.

3.5 Indigenous values, rights, interests and development objectives

3.5.1 INTRODUCTION AND RESEARCH SCOPE

Indigenous people represent a substantial and growing proportion of the population across northern Australia and control significant natural and cultural resource assets, including land, water, and coastlines. They will be crucial owners, partners, investors, and stakeholders in future development. Understanding the past is important to understanding present circumstances and future possibilities. Section 3.5 provides some key background information about the Indigenous Australians of the Mitchell catchment and their specific values, rights, interests and objectives in relation to water and irrigated agricultural development. Section 3.5.2 reviews some key evidence of past habitation by Indigenous people, the significance of water in past patterns of habitation and the impact of exploration and colonisation processes. Section 3.5.3 reviews the contemporary situation with respect to Indigenous residence, land ownership and access. Section 3.5.4 outlines Indigenous water values and responses to development, and Section 3.5.5 describes Indigenous-generated development objectives.

The material provided here represents a short summary of the research undertaken, and further details regarding this component of the Assessment are contained in the companion technical report on Indigenous values, rights and objectives for the Mitchell catchment (Lyons and Barber, 2018) and for the other two study areas of the Assessment (Barber, 2018; Barber and Woodward, 2018). There has been some previous information about Indigenous water values in the Mitchell catchment, but far less consideration of Indigenous perspectives on general water development and associated irrigated agricultural development more specifically. The work undertaken here directly addresses these data needs.

Engagement with Indigenous people is a strong aspiration across governments and key industries but models of engagement can vary considerably and competing understandings of what 'engagement' means (consultation, involvement, partnership, etc.) can substantially affect successful outcomes. Standard stakeholder models can also marginalise Indigenous interests, reducing what Indigenous people understand as prior and inalienable ownership rights to a single 'stake' equivalent to all others at the table. The Assessment interviewed an overall majority of the board members of Indigenous Traditional Owner organisations and board-nominated senior Indigenous decision makers from within the Mitchell catchment to establish a representative range of Indigenous leadership views. The companion technical report (Lyons and Barber, 2018) provides details of this data. A small number of comments are replicated in the following sections to show the type of data obtained, complemented by key themes emerging from the data analysis. The Assessment does not provide formal Indigenous group positions about any of the issues raised and does not substitute for formal processes required by cultural heritage, environmental impact assessment or water planning legislation. Nevertheless, the research undertaken for this component of the Assessment identifies key principles, important issues and potential pathways to provide effective guidance for future planning and for formal negotiations with Indigenous groups.

3.5.2 PRE-COLONIAL AND COLONIAL HISTORY

Pre-colonial Indigenous society

Pre-colonial Indigenous society is distinguished by four primary characteristics: long residence times; detailed knowledge of ecology and food gathering techniques; complex systems of kinship and territorial organisation; and a sophisticated set of religious beliefs, often known as Dreamings (Cole, 2004; Strang, 1997). The Mitchell catchment contains archaeological evidence of Indigenous habitation stretching back many thousands of years, but the published archaeological record for many locations is relatively sparse. Resource-rich riverine habitats were central to Aboriginal economies based on seasonally-organised hunting, gathering and fishing (Cole, 2004; Strang, 1997). Rivers were also major corridors for social interaction, containing many sites of cultural importance (Cole, 2004; Strang, 2002). Indigenous religious cosmologies provided a source of spiritual and emotional connection as well as guidance on identity, language, law, territorial boundaries, and economic relationships (Williams, 1986). The connection between spirit, language, country and water is explained by a Kowanyama Traditional Owner:

'The other old fellers talk to you in language when you die, they'll… send your spirit back to your own homeland… they can't send you anywhere else to a drier spot, your spirit will have to go back

to a well water or a big waterhole – and no salty water, got to be fresh water… ‘ (Winstone Gilbert, p. 251 in Strang (1997)).

From an Indigenous perspective, ancestral powers are present in the landscape in an ongoing way, intimately connected to people, country, and culture. Those powers must be considered in any action that takes place on the country.

Colonisation

European colonisation resulted in very significant levels of violence towards Indigenous Australians, with consequent negative effects on the structure and function of existing Indigenous societies across the continent. Avoidance, armed defensiveness, and overt violence were all evident in colonial relationships as hostilities arose as a result of competition for food and water resources, colonial attitudes and cultural misunderstandings. The establishment of pastoralism was a focus for conflict as pastoral homesteads and outstations were sited close to permanent water and the animals grazed fertile plains and river valleys used by Indigenous people for food and other resources (McGrath, 1987). As a consequence, Indigenous attacks on colonial pastoral operations were made both in retaliation for past attacks by colonists and as a response to shortages of food and other resources.

The discovery of gold in the Palmer River in the late 19th century established the mining industry in the Mitchell catchment (Kirkman, 1980). The gold rush led to the development of roads and settlements, and industries such as pastoralism that could provide provisions to miners (Cole, 2004; Kirkman, 1982). The gold rush was short-lived, but left a significant legacy of social and environmental damage, and pastoralism became firmly entrenched in the aftermath of the boom. By the 1940s, starvation, the threat of further violence and inconsistent access to water forced the remaining Indigenous inhabitants of the Mitchell catchment to settle on pastoral stations or on the fringes of towns. The use of Indigenous labour for domestic and stock work for much of the 20th century was crucial to the industry, and also meant that some Indigenous people were able to access traditional areas, albeit in a different way.

3.5.3 CONTEMPORARY INDIGENOUS OWNERSHIP, MANAGEMENT, RESIDENCE AND REPRESENTATION

The pressures of colonial violence and forced relocations meant that previously important residential sites were no longer inhabited and in a significant number of cases rarely visited. However, such areas remain crucial to people’s lives, sustaining a distinct individual and group identity as well as connections to past ancestors and future descendants. People are connected to places through a combination of genealogical, traditional and residential ties, only some of which are formally recognised.

Indigenous ownership

Indigenous interests are currently formally recognised by the Australian legal system over at least 60% of the Mitchell catchment. There are three major forms of Indigenous-specific interest: native title, Indigenous land use agreements (ILUAs) connected with native title, and Deed of Grant in Trust land (DOGIT). Indigenous people also hold a range of lands under pastoral lease and freehold title. Native title provides a series of rights (such as access) determined through a legal process.

ILUAs are voluntary registered agreements between native title claimants or holders and other interested parties for the use and management of land and resources. DOGIT land is primarily land that was a former Indigenous mission or reserve. Figure 3-30 shows the current situation with respect to native title claims and determinations. Further discussion of Indigenous land tenure and native title appears at Section 3.6 below.

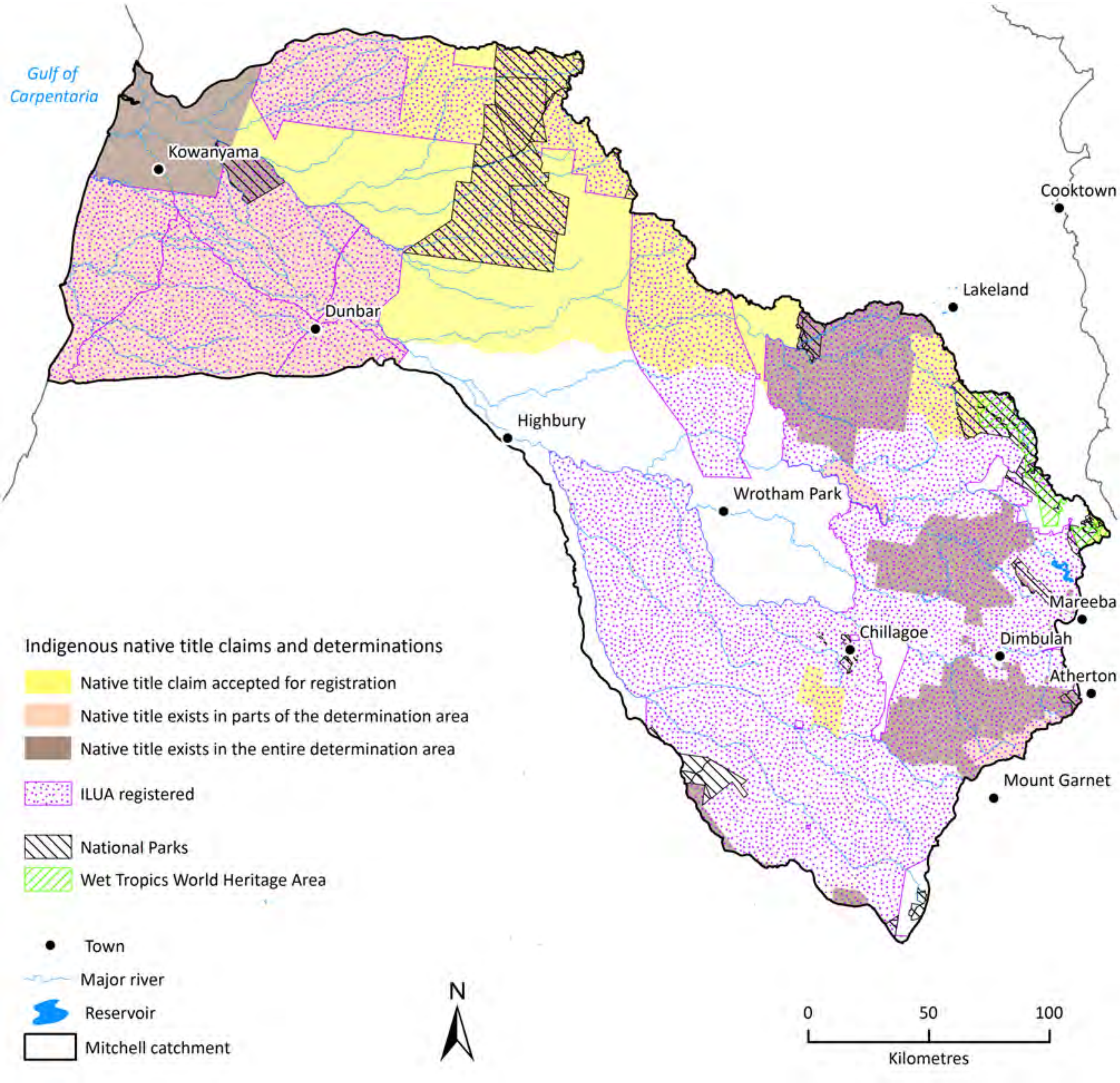

Figure 3-30 Indigenous native title claims and determinations in the Mitchell River catchment as at July 2017
Data source: National Native Title Tribunal

Indigenous residence

Australian Bureau of Statistics census data shows a significant Indigenous population of 26% in the Mitchell catchment (Table 3-4). This includes Indigenous people who are part of recognised local ownership groups, as well as residents who identify as Indigenous but have their origins elsewhere. Indigenous owners of the Mitchell catchment are concentrated in the regional towns of Kowanyama, Chillagoe, Dimbulah, Mareeba, Atherton, and Cairns. This concentration of owners means that residential location differs from the group and tenure boundaries; for many owners (including the Western Yalanji, Wakamin, Kuku Djungan, and Mbabaram peoples) primary residential locations may be outside the catchment. These patterns of residence and dispersal reflect a combination of historical involuntary relocation, voluntary movement to seek jobs and other opportunities, and kinship and family links. Research participants from many groups expressed a strong desire for conditions that would enable more of their people to reside on their own traditional lands.

Indigenous governance and representation

Indigenous organisational and political structures within the Mitchell catchment are quite diverse. Three levels of organisation are particularly relevant to this study: local Indigenous corporations based on recognised Traditional Owner groups; regional Indigenous land councils; and Indigenous representation in catchment management organisations. Group-based local Indigenous corporations are increasingly significant representative structures and were crucial in enabling the current study. Table 3-16 summarises the existing situation in terms of Indigenous ownership, residence, management, and representation in the Mitchell catchment. It shows significant variations in existing capacity, resourcing, and ability to participate in natural resource management decision making. This shapes Indigenous development priorities. Planning processes need to be grounded in the specificities of local groups as well as to be coordinated at catchment and regional levels.

Key regional Indigenous land councils for the Mitchell catchment are the Cape York Land Council (representing Kowanyama and Olkola interests) and the North Queensland Land Council (NQLC) (representing a larger set of groups from the middle and upper catchment). Natural resource management in the Mitchell catchment is jointly overseen by the Northern Gulf Resource Management Group and the Mitchell River Watershed Catchment Management Group. These have previously been guided by Indigenous input through the Alliance of the Northern Gulf Indigenous Corporation and the Mitchell River Traditional Custodian Advisory Group. During the Assessment, a new body was established by Mitchell catchment Traditional Owners, supported by the NQLC to oversee Indigenous catchment management and engagement with future development initiatives.

Table 3-16 Summary of current Indigenous group tenure, residence and natural resource management arrangements in the Mitchell catchment
ILUA = Indigenous Land Use Agreement

GROUP FEATURE	MBABARAM	MULURIDJI	WAKAMIN	KUKU DJUNGAN	WESTERN YALANJI	KOWANYAMA
Key townships	Irvinebank	Mareeba	Chillagoe	Dimbulah	Mount Carbine	Kowanyama
Significant number of people identifying primarily as group member	Yes	Yes	Yes	Yes	Yes	Yes
Group ownership of town land on traditional country	Yes	Yes	Yes	Yes	Yes	Yes
Infrastructure on town land	Yes	Yes	Yes	Yes	Yes	Yes
Local Indigenous corporation with paid staff and office	Yes	Yes	No	No	Yes	Yes
Ownership of significant rural land	Yes	No	Yes	Yes	Yes	Yes
Significant residential presence on traditional lands	No	Yes	No	No	No	Yes
Indigenous ranger program operating on traditional lands	No	No	No	No	Yes	Yes
Native title application currently registered	No	No	Yes	No	No	No
Native Title claim determined	Yes	Yes	No	Yes	Yes	Yes
Current ILUAs	Yes	Yes	Yes	Yes	Yes	Yes
Native Title representation/assistance from Land Council	Yes	Yes	Yes	Yes	Yes	Yes
Formal Indigenous catchment and natural resource management entity	No	No	No	No	No	Yes
Indigenous representation in water planning	No	No	No	No	No	No

3.5.4 INDIGENOUS WATER VALUES AND RESPONSES TO DEVELOPMENT

Introduction: attachment, ownership, protection

Indigenous values in relation to their country encompass principles of attachment, ownership, and the responsibility to protect it. These are manifested in practical terms through:

- The assumption of Indigenous ownership of land and water resources.
- The need for formal external recognition of that ownership.
- The role of local histories in establishing local Indigenous connections and authority.

- The ongoing role of religious and spiritual beliefs (known as the Dreaming).
- The existence of ongoing knowledge of group and language boundaries and identities.
- The importance of hunting and fishing activity to Indigenous cultures.
- Inter-generational obligations to both ancestors and descendants to care for the country.
- Regional responsibilities to near neighbours and downstream groups to maintain the integrity of the country.
- Ongoing access and resource use issues to large tracts of traditional country subject to various forms of non-Indigenous tenure.

These principles also apply to Indigenous attitudes to non-Indigenous activities on Indigenous lands. Development proponents will need to ensure that they follow four frequently highlighted principles:

- consultation with the relevant owners
- their consent for development
- compliance with the terms of policies and agreements, including Traditional Owner employment
- compensation for the access and use of resources.

These principles have clear implications for native title, cultural heritage and environmental impact assessment, as well as for broader issues of sustainable development.

Cultural heritage

Indigenous cultural heritage is a crucial manifestation of the principles of attachment, ownership, and protection. Cultural heritage itself has a number of components: archaeological sites; places associated with traditional stories or traditional knowledge; and places of historical or contemporary importance. Cultural heritage is strongly correlated with permanent water, meaning that riverine and aquatic areas that are the focus of development interest are also likely to contain significant cultural heritage. Three major cultural heritage issues were identified by research participants in this study: ongoing damage to known existing sites; a lack of documented heritage knowledge that hampers Indigenous responses to current development proposals; and potential development impacts on Indigenous abilities to fulfil cultural responsibilities. One participant described how poor consultation by the mining industry had significant implications for water-related cultural heritage and created concerns for him as a senior custodian:

'*I'm really worried about those miners. They never employed a Traditional Owner from Chillagoe, man or woman ... I asked them 'where you getting your water from?' They said 'from the lagoon from out the back'. I was mad they were getting water from my country, where they were pumping that water it was sacred site*.'

Wakamin elder

The Queensland *Aboriginal Cultural Heritage Act 2003* protects heritage sites regardless of the tenure status of the land and protects areas whether or not they actually contain physical evidence of the past. Figure 3-31 shows the general concentration of cultural heritage listed in the state records collated through the Act. This record is known to be very incomplete – the map demonstrates the presence of a layer, not its extent. Consultations between development proponents and Traditional Owners will be significantly aided by early stage field scoping of cultural heritage issues and requirements.

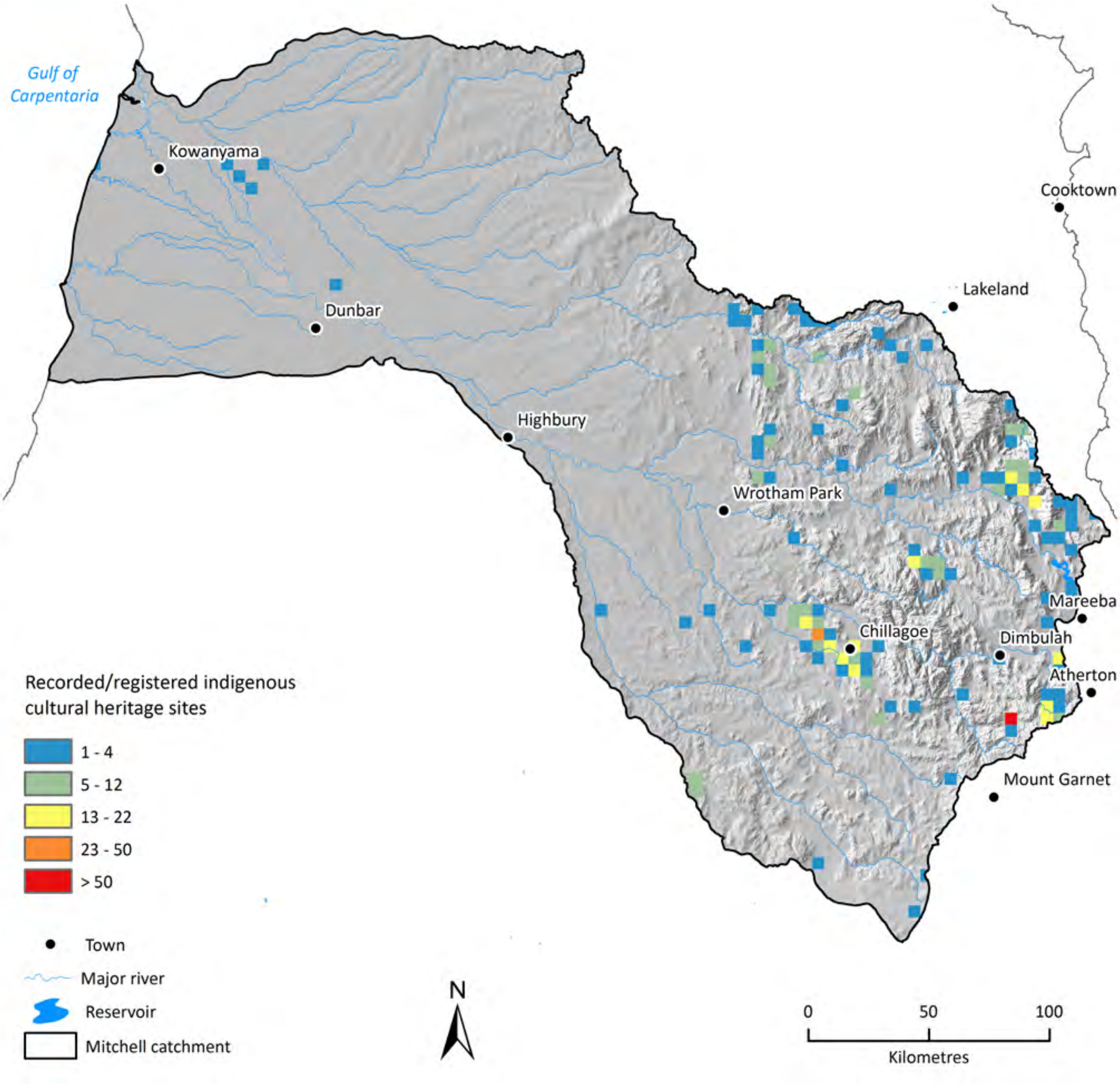

Figure 3-31 Registered Indigenous cultural heritage sites in the Mitchell catchment as at July 2017
Data source: DATSIP, Queensland Government

Contemporary Indigenous water values

Internationally, Indigenous water rights, values and interests have been outlined in a number of significant forums and documents (World Water Council, 2003) including some produced in Australia (NAILSMA, 2009; NAILSMA and UNU-IAS TKI, 2008). During the Assessment, Traditional Owners from across the Mitchell catchment began generating a declaration outlining the importance of protecting the cultural and environmental heritage values of the Mitchell River. Data from research participants in the Assessment clearly demonstrates the overall importance of water to Indigenous people across the Mitchell catchment:

Water is associated with a lot of cultural values. That's why we regard it not only as sacred but also [have] protocols for how you approach that place…in places you can't even swim in that waterhole.

That groundwater you're referring to - soaks and springs - they've all got stories to it because it preserves life [and] anything that preserves life must be held in high value. So we have the result of water [being] in that category.

Kuku Djungan elder

In general terms, Indigenous water values emphasise securing sufficient water to maintain healthy landscapes and to support Indigenous needs. Those needs can be defined in multiple ways, and from an economic perspective encompass such activities as art and cultural production, hunting and gathering, and traditional medicine supply, as well as pastoralism, ecotourism, agriculture and aquaculture. All of these needs depend on natural resources, highlighting the importance of securing and maintaining water supplies for Indigenous people.

Responses to water and irrigation development

In general, large-scale water development was seen as incompatible with contemporary Indigenous values and lifeways. Such development is also interpreted through negative Indigenous perceptions of past development. For example, the past 100 years of mining in the upper catchment has encompassed alluvial mining and the use of cyanide and harmful chemicals. Pastoral development is also seen to have contributed to erosion and degraded water quality. Indigenous concerns about water development noted during the Assessment included the impacts of water extraction, dam scale and location, dam failure, reservoir inundation, effects on animals, the consequences of intensified land use (weeds, erosion, water quality, chemicals, salinity, etc.) and cumulative impacts from other industries, particularly mining. Indigenous research participants also noted particular Indigenous vulnerabilities to negative impacts, largely related to their position as long-term custodians and their marginalised socio-economic and educational status. These issues affected Indigenous assessments of the relative risks and benefits associated with development proposals. From an Indigenous perspective, development that cannot be managed in accordance with customary beliefs (for example, by polluting water sites) represents an ongoing form of colonial dispossession of land and disruption to valued forms of identity (Strang, 2005).

Noting the above issues, Indigenous participants also recognised that power imbalances may see large-scale development proceed. In this context, some data on preferences for particular kinds of water development were gathered, and the general trend from most to least favourable was:

1. flood harvesting to supply smaller, offstream storages
2. smaller instream dams (e.g. gully dams) constructed in side tributaries or branches which do not restrict all of the flow
3. bore and groundwater extraction
4. large instream dams in major river channels.

Proposals for specific sites may not accord with this general trend, and new information may alter the above order at both local and regional scales. With respect to major water and irrigation development, key Indigenous criteria for evaluation include:

- early and further formal group consultations about options, impacts and preferences

- development that specifically address Indigenous needs (for example, access, education, amenity, and recreational opportunities)
- appropriate cultural heritage surveys of likely areas of impact
- Indigenous employment and other benefits during construction
- the need for ongoing monitoring of impacts that employs Traditional Owners
- support for Indigenous roles in development projects that connect water development with both water planning, wider catchment management and enterprise development.

Water planning

Water planning is understood as one way of managing water development risk, but water planning also has particular challenges. In Australia, the National Water Initiative (Department of Agriculture and Water Resources, 2017) led to intergovernmental agreement that water plans must recognise Indigenous needs in terms of access and management. This encompasses Indigenous representation, incorporation of Indigenous social, spiritual and customary objectives, and recognition of native title needs and uses. However, progress in implementing that recognition has been slow due to a lack of knowledge about those interests, competing water demands and the challenges of accommodating Indigenous perspectives in conventional planning frameworks. Queensland has performed better than some other states, and the Mitchell River water plan has a small water allocation specifically reserved for Indigenous people. However, this allocation remains unused, and participants noted the difficulties in participating in water planning forums:

Planning is always top heavy. It's intimidating when you go to these meetings where you got all these ones talking about water management and they've got more letters after their name. You need to have people with knowledge but you need to have people who are actually sitting on the country too. You need to bring the management level down not up.

Western Yalanji country manager

Based on the data generated during the Assessment, formalising and refining Indigenous water values and water planning issues in the Mitchell catchment may require:

- Formal scoping discussions catchment, land council, and local group levels about how best to support Indigenous involvement in water planning.
- Refinement of Indigenous rights, roles and responsibilities in water planning and resourcing of Indigenous involvement in water planning.
- Indigenous-specific tradeable water allocations.
- Further specification of cultural heritage impacts and current and potential future native title rights.
- Articulating water planning with irrigation development, mining and catchment management processes.
- Addressing continuing Indigenous water research needs and information priorities to inform the ongoing development of water resource plans.

Catchment management

Mitchell catchment Indigenous people have a long history of involvement in catchment management. The original Mitchell River Group was created through the initiative of Traditional Owners at Kowanyama and was the first catchment management group in Queensland. As a result, Indigenous catchment management plans and aspirations have been clearly articulated for the Mitchell catchment over a long period. These include care for the country, the management of tourism impacts on cultural heritage, access, Indigenous ranger program support, cultural knowledge revival, partnerships, and enterprise development. However, resources for catchment management have been increasingly constrained, limiting the ability of groups such as Northern Gulf Resource Management and the Mitchell River Watershed Catchment Management Group to function effectively and limiting the level of engagement between these groups and Traditional Owners.

3.5.5 INDIGENOUS DEVELOPMENT OBJECTIVES

Indigenous people have a strong desire to be understood as development partners and investors in their own right, and have generated their own development objectives. This stance informs responses to development proposals outlined by others. As a group, Indigenous people are socially and economically disadvantaged, but also custodians of ancient landscapes. They therefore seek to balance short- to medium-term social and economic needs with long-term cultural, historical and religious responsibilities to ancestral lands. Past forums have outlined Indigenous development agendas that are consistent with Mitchell catchment Traditional Owner perspectives (NAILSMA, 2012, 2013). These agendas are informed by two primary goals:

1. greater ownership of and/or management control over traditional land and waters
2. the sustainable retention and/or resettlement of Indigenous people on their country.

These goals are interrelated, because retention and/or resettlement relies on employment and income generation, and the majority of business opportunities identified by Indigenous people are land- and natural-resource dependent: conservation services, pastoralism, bush foods and products, horticulture, aquaculture, and ecotourism. All groups have multiple management roles but, based on geography, residence, assets, governance and/or skills, some may more easily be able to sustain multiple business activities, while others may be better off focusing on a single activity. Natural and cultural resource management is an ongoing process for Indigenous custodians, but formal paid roles in this sector are particularly valued and Indigenous ranger programs play a crucial incentivising and seeding role. The creation and/or expansion of such programs is a high priority for the research participants in the Mitchell catchment.

Partnerships and planning

In terms of generating wider business partnerships, a range of options may be useful in improving the opportunities for business to understand and invest in Indigenous people and Indigenous lands in the Mitchell catchment. The development of a full business analysis may include the following key potential actions:

- The production of one or more regional prospectuses to define Indigenous assets and opportunities and to communicate with investors.

- Further information and training for Indigenous people about the opportunities and constraints of partnerships with private industry, including discussion of the effect of changes in Indigenous resource rights (acquisition of land, granting of native title rights, securing of water rights and allocations, etc.).
- Wider regional non-Indigenous community training regarding partnerships with Indigenous people, including models for shared benefit agreements and partnership arrangements, employment and training opportunities, etc.
- Creating incentives for Indigenous involvement, including relocation and resettlement allowances, pathways from training to jobs, employer incentives to hire and retain Indigenous staff, etc.
- Training for younger Indigenous people about career planning as well as formal job skills.

Indigenous development objectives, and Indigenous development partnerships, are best progressed through locally specific, group and community-based planning and prioritisation processes that are nested in a system of regional coordination. Such planning and coordination can greatly increase the success of business development and of the opportunities for Indigenous employment, retention and resettlement that arise from them. Modest but targeted resourcing to appropriate entities (e.g. local corporations, rangers, catchment management groups, land councils,) to coordinate further Indigenous capacity building in local group prioritisation, catchment management, water planning, and enterprise development can provide significant returns on investment for major developers, communities, and government.

3.6 Legal, policy, and regulatory environment

3.6.1 INTRODUCTION

This section provides an overview of the legal and policy institutions relevant to water-related development in the Mitchell catchment. The term 'institutions' is used here to refer to the rules and norms that govern water-related development that stem from international and domestic law and policy. The analysis sheds light on the nature of the rights and interests that are necessary to undertake, and could be affected by, water-related development. Four themes are used to structure the analysis: legal and policy context, interests in land, interests in water, and government approvals.

3.6.2 LEGAL AND POLICY CONTEXT

Government powers and responsibilities concerning the management of land and water resources in the Mitchell catchment are shared between the Australian Government, Queensland Government and four local councils (Kowanyama Aboriginal Shire Council, Carpentaria Shire Council, Mareeba Shire Council and Cook Shire Council). While there is a degree of overlap between the powers and responsibilities of these three levels of government, each perform discrete functions.

Australian Government

The Australian Government performs two key functions: oversight of native title; and the implementation of Australia's obligations under international law. Unlike other types of interests in land, native title is a federal responsibility and is managed under the *Native Title Act 1993* (Cth). Similarly, in relation to international law, the Australian Government is responsible for ensuring Australia meets its international obligations. Under Australian law, international legal obligations have no direct effect on domestic law until and unless they are incorporated into it by an act of parliament. The most relevant federal statutes that give effect to international obligations and responsibilities are the *Racial Discrimination Act 1975* (Cth) and *Australian Human Rights Commission Act 1986* (Cth), which prohibit discriminatory behaviour, and the EPBC Act, which regulates activities that adversely affect 'Matters of National Environmental Significance'.

Queensland Government

The Queensland Government is primarily responsible for the management of land and water resources within the Mitchell catchment. It is the ultimate 'owner' of almost all land in Queensland, is responsible for the system of land title in the state, manages Crown lands, reserves and national parks, regulates access to and the use of surface and groundwater, and manages the positive and negative externalities associated with development through planning, environmental and heritage regulations.

Local councils

Local councils have no status under the Australian or Queensland constitutions. Formally, they are state agencies established under local government legislation. The most important functions the four councils in the Mitchell catchment perform in the current context relate to land use planning. They are responsible for preparing and administering local planning schemes, which guide and regulate land use and development within their municipalities.

3.6.3 INTERESTS IN LAND

Proponents of water-related developments will require legal entitlements to access and use the subject land. This could involve the grant or acquisition of a freehold or leasehold interest in the land or the issuance of a licence for a period of time. Freehold and leasehold interests give the holder a legal interest in the land. In contrast, the holder of a licence obtains no property rights in relation to the land. Depending on the nature of the licence, the licensee will either have personal rights of access that are enforceable under contract or the licence will simply make an act lawful that would otherwise be unlawful. For proponents of water-related developments, licences will typically be used for initial exploratory purposes only. To undertake any material development, proponents will usually need to acquire a freehold or leasehold interest in the land from the current landholder, or have a freehold or leasehold interest granted by the state or territory government. Freehold and leasehold interests provide greater security and control than licences, and enable the holder to exclude most third parties from the land and the benefits that stem from its development and use.

Most of the land in the Mitchell catchment is held as Crown leasehold land, national parks, freehold land and Aboriginal land.

Crown leasehold land

Crown leasehold land is government-owned land held under a lease, typically by a private party. The management of, and issuance of leasehold interests in, Crown land in Queensland is governed by the *Land Act 1994* (Qld). There are three main types of Crown leasehold interests that can be issued under this Act: term leases; perpetual leases; and freeholding leases. Most of the Crown leases in the Mitchell catchment are term leases (leases for a fixed term, usually of up to 50 years), and most of these are 'rolling term leases', where the term of the lease can be extended at any time for the same length as the original term. Four types of pastoral leases that existed under the previous legislative regime (pastoral holdings, pastoral development holdings, preferential pastoral holdings and the stud holdings) are now treated as term leases. All Crown leases can be subject to restrictions on the use, development and transfer of land. For example, unless otherwise authorised, they can only be used for the specific purposes identified in the lease and cannot be transferred or sublet. They are also subject to a 'general duty of care', which explicitly includes obligations to take all reasonable steps to avoid causing dryland salinity, conserve soil, protect riparian vegetation, maintain native grassland free of encroachment from woody vegetation, manage declared pests and conserve biodiversity.

National parks

National parks are generally either government-owned land or Aboriginal land that has been declared a national park under the *Nature Conservation Act 1992* (Qld). National parks are required to be managed for conservation purposes in accordance with statutory management principles. Where they are located on Aboriginal land, they must also be managed, as far as practicable, in a manner consistent with Aboriginal traditions applicable to the area. Generally, people wanting to use a national park must obtain a lease, licence or other authority under the *Nature Conservation Act 1992* to do so and there are restrictions on the circumstances in, and purposes for which these interests and authorisations can be issued.

Freehold land

Freehold land is land in which a freehold estate has been granted. Freehold estates are the most complete legal interest in land under Australian law. While close to absolute ownership, freehold estates do not give the landholder the right to use the land as they please. The estates are almost always subject to reservations and the use and development of the land is regulated under planning, environment and other similar statutes.

Aboriginal land

Aboriginal land is freehold land held on trust by Aboriginal land trusts and so-called 'CATSI corporations' (corporations registered under the federal *Corporations (Aboriginal and Torres Strait Islander) Act 2006* (Cth)) for Indigenous groups or communities under the *Aboriginal Land Act 1991* (Qld). Aboriginal land is subject to special restrictions, including that trustees cannot sell or mortgage it. Use and development of Aboriginal land can be facilitated through leases, which are subject to specific rules under the *Aboriginal Land Act 1991*.

In addition to the need for a freehold or leasehold interest, or a licence, any water-related development must be consistent with the native title arrangements that apply to the land. A substantial proportion of the Mitchell catchment is subject to native title and registered native title claims. Native title is a unique form of property interest under Australian law consisting of a bundle of rights defined by the laws and customs of the relevant Indigenous community. Reflecting its unique status, native title has its own system of determination (through the Federal Court of Australia), registration (at the National Native Title Registry, maintained by the National Native Title Tribunal) and protection (under the *Native Title Act 1993*).

Where native title or a native title claim exists over an area of land, proponents of water-related development will be required to engage with relevant Traditional Owners and the federal native title process. Importantly, water-related development in the catchment could involve 'future acts' that could be rendered invalid by the operation of the *Native Title Act 1993*, or trigger a right to compensation. In this context, relevant 'future acts' could consist of special legislation (or legislative amendments) made to facilitate the development, the issuance of property interests and approvals to support or authorise the development, and the conduct of related public works. There are a number of ways of avoiding invalidity of future acts, one of the most notable being entry into Indigenous land use agreements (ILUAs) with Traditional Owners. ILUAs are agreements between native title parties and others about the use of land and waters subject to native title, or over which native title is claimed. Where a determination is made that native title exists, ILUAs can be used to settle arrangements concerning the area and the treatment of native title. Even when native title has not been determined, ILUAs can be used to proactively settle arrangements concerning native title and the use and development of an area with Traditional Owners.

3.6.4 INTERESTS IN WATER

The 'rights' to the use, flow and control of all water in Queensland are vested in the Queensland Government under the *Water Act 2000* (Qld). This legislation contains processes for water planning and the regulation of taking and interference with water. The regulation of the construction and operation of water infrastructure (e.g. dams, bores, levies and pipes) is done through the *Planning Act 2016* (Qld) and the *Water Act 2000*.

Water planning

The Water Act's planning process involves the preparation of statutory water plans, which provide the basis for 'water entitlements' (water allocations, interim water allocations and water licenses), as well as for the allocations of water for environmental and other public purposes. The implementation of each water plan may be supported by a 'water management protocol' that outlines, for the plan area, volumes, purpose and location of unallocated water and processes for releasing unallocated water, and rules for allocating water as well as rules for assigning seasonal allocations. 'Water entitlement notices' also support the implementation of a water plan by providing rules governing the grant, amendment and cancellation of water entitlements such as water licences or allocations for the plan area. The *Water Plan (Mitchell) 2007* is the primary water plan for the Mitchell catchment. It identifies available water in the Mitchell catchment water plan area and provides a framework for regulating the taking and interference with water in the region. The *Water Plan (Mitchell)* deals with water in a watercourse or lake, springs not connected to Great Artesian Basin (GAB) water, underground water that is not GAB water, and overland flow water, other than GAB spring water. The *Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017* regulates access to and use of GAB water either underground or in springs in the Mitchell catchment area. The *Water Plan (Barron) 2002* is also of relevance to the Mitchell catchment as there is an inter-basin transfer of water from the Barron River into the Walsh River (in the upper Mitchell catchment) to support part of the Mareeba–Dimbulah Water Supply Scheme (MDWSS).

Approvals for taking water

Under the Water Act's regulatory regime, activities involving the taking or interference with water are divided into two categories: those that can occur without an authorisation; and those that can only occur under an authorisation. The Act provides for six main types of authorisations: water licences; water allocations; water permits; resource operations licences; distribution operations licences; and operations licences. Rules for issuing and managing these authorisations are detailed in the *Water Act 2000, Water Regulation 2016* (Qld) and water management protocols (for particular water plan areas).

Water-related works approvals

The regulation of the construction and operation of water-related facilities and infrastructure (e.g. dams, levees and bores) is mainly done through the *Planning Act 2016*). Generally, the construction of water-related facilities and infrastructure require development approval under the *Planning Act 2016*, as well as authorisations under the *Water Act 2000* to engage in the actual taking or interference. The details of the development approval requirements are spread across the *Planning Act 2016* and Parts 19 and 20 of the *Planning Regulation 2017* (Qld), and the *Water Act 2000* and Part 10 and Schedule 9 of the *Water Regulation 2016*.

3.6.5 GOVERNMENT APPROVALS

In addition to holding the requisite rights and interests to access the land, and to take water, proponents of water-related development must have the necessary privileges to undertake the development. Some of these privileges will come with proponents' interests in land. However, ownership of an interest in land does not provide the holder with the legal ability to use and develop the land as they please. Government regulations can control the use and development of land and water resources. The most relevant government regulations are those imposed under federal and state planning, environment and heritage statutes.

Australian Government regulations

The Australian Government does not have planning legislation that applies to the Mitchell catchment. However, it does have both environmental and heritage regulations that could apply to water-related development in the region. The principal federal environmental statute is the EPBC Act, which regulates actions that have significant impacts on 'Matters of National Environmental Significance', the environment on Commonwealth land, and the environment generally where the relevant action is carried out by a Commonwealth agency or on Commonwealth land. There are nine Matters of National Environmental Significance, the most relevant of which are World Heritage areas (Wet Tropics World Heritage Area), National Heritage places (Ngarrabullgan National Heritage Place), listed threatened species and ecological communities, and listed migratory species. Water-related development that could have significant adverse impacts on these matters must be referred under the EPBC Act for assessment and approval. Guidelines have been published by the federal environment department to help proponents determine when projects are likely to have significant impacts on matters protected under the Act. Due to the ambiguity associated with determining the significance of potential impacts, proponents should consult with the federal environment department about the need for referrals before undertaking water-related developments. In addition to the regulatory requirements under the EPBC Act, stakeholders interested in water-related development should be aware of the *Aboriginal and Torres Strait Islander Heritage Protection Act 1984* (Cth) (ATSIHP Act). Declarations can be issued under the ATSIHP Act to protect significant Aboriginal areas and objects from injury or desecration. These declarations are rarely made but they can be powerful, forcing the cessation of projects affecting the relevant area or object. There are a number of other federal regulatory regimes that could apply to proponents involved in water-related development. Foreign investors should take particular note of the federal regulation of foreign investment under the *Foreign Acquisitions and Takeovers Act 1975* (Cth) and *Foreign Acquisitions and Takeovers Fees Imposition Act 2015* (Cth). Under this regulatory regime, the federal Treasurer can impose conditions and even block foreign investment proposals in Australia. Foreign interests in agricultural land are also required to be registered with the Australian Taxation Office under the *Register of Foreign Ownership of Agricultural Land Act 2015* (Cth).

Queensland regulations

Planning

Land use planning in Queensland is mainly governed by the *Planning Act 2016* (Qld). There are four local planning schemes that apply in the Mitchell catchment: Kowanyama Aboriginal Shire Planning Scheme; Shire of Carpentaria Planning Scheme; Cook Shire Planning Scheme; and Mareeba Shire Planning Scheme. The local planning schemes divide development into three categories: prohibited development (the type of development cannot be carried out on the subject land); assessable development (the type of development can only be carried out with development approval); and accepted development (the type of development can be carried out without approval). Where a development is assessable, the relevant planning scheme will designate whether the assessment must be ‘code assessment’ (less intensive) or ‘impact assessment’ (more comprehensive and involves public notification and comment). The *State Development and Public Works Organisation Act 1971* (Qld) operates alongside the *Planning Act 2016* and provides for the coordinated planning, assessment and approval of projects of economic, social and/or environmental significance to the state. For this process to apply, projects must be declared ‘coordinated projects’ under the Act by the Queensland Coordinator-General. To be eligible to be declared a coordinated project, projects must have complex approval requirements (federal or state), strategic significance to a locality, region or the state, significant environmental effects or significant infrastructure requirements. While these factors are considered in making the decision, ultimately, whether projects are declared is at the discretion of the Coordinator-General. If projects are declared a coordinated project, they must undergo an Environment Impact Statement (EIS) or Impact Assessment Report (IAR). In addition to approvals required under the *Planning Act 2016*, water-related developments in the Mitchell catchment involving broadacre cropping or water storage activities may require a regional interests development approval under the *Regional Planning Interests Act 2014* (Qld).

Environment

The main environment protection statute in Queensland is the *Environmental Protection Act 1994* (Qld). Under the Act, it is an offence to carry out an ‘environmentally relevant activity’, or to cause material or serious environmental harm, without an environmental authority. Environmentally relevant activities are defined for these purposes as activities that could contaminate and harm the environment that are prescribed under the regulations. Schedule 2 of the *Environmental Protection Regulation 2008* (Qld) contains a list of prescribed environmentally relevant activities, which includes aquaculture facilities, intensive animal feedlots, poultry farming, piggeries, food processing and beverage production, and waste and water treatment services. Where an environmental authorisation is required, it triggers a four-stage assessment and approval process.

Heritage

There are two main state heritage statutes that apply in the Mitchell catchment: one governing non-Indigenous cultural heritage, the *Queensland Heritage Act 1992* (Qld); and one governing Indigenous cultural heritage, the *Aboriginal Cultural Heritage Act 2003* (Qld). The *Queensland Heritage Act 1992* establishes the Queensland Heritage Register to record places of state cultural heritage significance, with the exception of places of Indigenous heritage significance. Protection of places of state and local heritage significance is afforded through the *Planning Act 2016*. The *Aboriginal Cultural Heritage Act 2003* imposes a general ‘cultural heritage duty of care’ not to harm Aboriginal cultural heritage. This duty of care requires a person who carries out an activity to take ‘all reasonable and practicable measures to ensure the activity does not harm Aboriginal cultural heritage’. There are a number of ways proponents can satisfy their cultural heritage duty of care, including by ensuring they carry out the development in accordance with the cultural heritage duty of care guidelines issued under the Act, or entering into a Cultural Heritage Management Plan or ILUA (under the *Native Title Act 1993*) with relevant Traditional Owners.

Major projects

There are two processes for major projects in Queensland: the *State Development and Public Works Organisation Act 1971* (Qld) (SDPWO Act) process for coordinated projects; and the State Assessment and Referral Agency (SARA) (which forms part of the Queensland Department of Infrastructure, Local Government and Planning) process for projects requiring assessment under the *Planning Act 2016* that affect state interests and require assessment by state agencies against the state development assessment provisions. Both of these processes are intended to lower transaction costs for major project proponents by streamlining state government approval requirements.

3.6.6 DURATION OF GOVERNMENT ASSESSMENT AND APPROVAL TIMES

Proponents of water-related developments should be aware that government assessment and approval processes can be resource intensive and time consuming. To illustrate this, an analysis was undertaken of the length of environmental assessments under the SDPWO Act and the EPBC Act. The state analysis covered all projects assessed under the SDPWO Act since 2004, while the EPBC Act analysis covered all projects located in Queensland that were referred and approved over the period July 2010 to March 2018.

Figure 3-32 shows the median length of each stage of the environmental assessment process for the sampled projects under the SDPWO Act. The results are presented by industry and for the entire sample of 65 projects. There are four main stages in the process (not all of which are mandatory for all projects): i) screening (where the Coordinator-General determines whether the project requires formal assessment), ii) scoping (where the Coordinator-General determines the Terms of Reference for the environmental assessment), iii) assessment documentation (where the proponent prepares the assessment documentation), and iv) Coordinator-General report (where the Coordinator-General prepares its advice on the project).

The aggregate of the median length of each stage was 867 days (Figure 3-32), with the longest part of the process being the preparation of the assessment documentation (532 days). The median total assessment time was 1049 days, with an average of 1185 days. While these results are noteworthy, the length of the process varied considerably between projects and project types. For example, 20% of assessments took under 550 days, while 25% took longer than 1500 days. The variability in assessment times reflects the flexibility of the process and the factors that influence its length, including the size and complexity of the proposals, the nature, magnitude and likelihood of relevant economic, social and environmental impacts, resource constraints within the Office of the Coordinator-General, and the speed with which proponents are able to produce relevant assessment information.

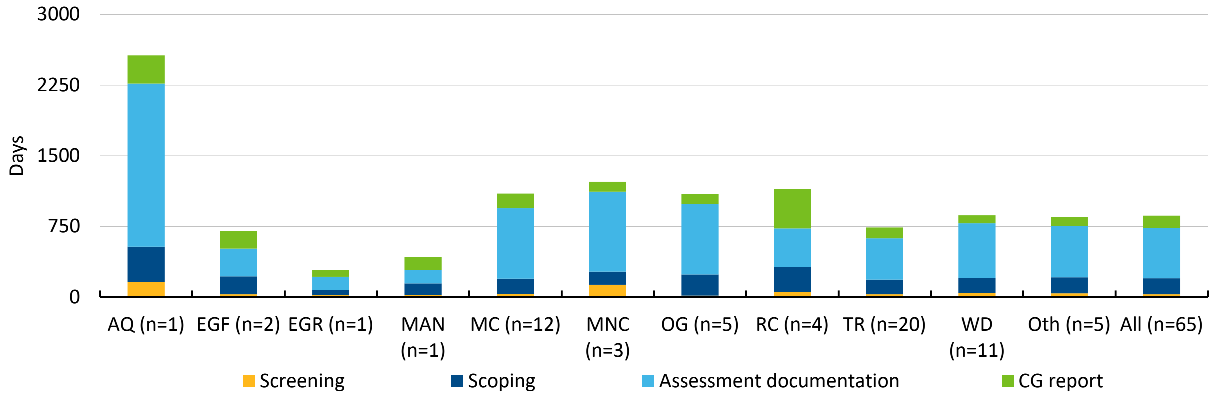

Figure 3-32 Median length of each stage of the assessment process under the *State Development and Public Works Organisation Act 1971* (Qld) (SDPWO Act), 2004–2018

Industry codes: AG = agriculture; AQ = aquaculture; EGF = energy generation (fossil fuels); EGR = energy generation (renewables); MAN = manufacturing; MNC = mining (non-coal); MC = mining (coal); OG = oil and gas; RC = residential and commercial; TR = transport; WD = water resource development; Oth = other. The number of projects in each industry code is provided in parentheses.

Source: Queensland Department of State Development, Manufacturing, Infrastructure and Planning

The federal EPBC Act assessment and approval process often runs in parallel with state processes, meaning it does not necessarily add to project delays. Further, under the EPBC Act, assessments are frequently undertaken through relevant state and territory processes. For example, where a project requires state government approval under the *Planning Act 2016* and Australian Government approval under the EPBC Act, the assessment carried out under the SDPWO Act that guides and informs the *Planning Act 2016* approval will often also cover, and be used for, the federal approval process. While the EPBC Act process has been designed to minimise duplication and delays, it can still be time consuming, particularly where state and federal approvals are sought sequentially.

Figure 3-33 shows the median length of the three main stages of the EPBC Act assessment and approval process (screening, assessment and approval) for the 100 Queensland projects referred and approved over the period July 2010 to March 2018. Again, the results are presented by industry and for the entire sample.

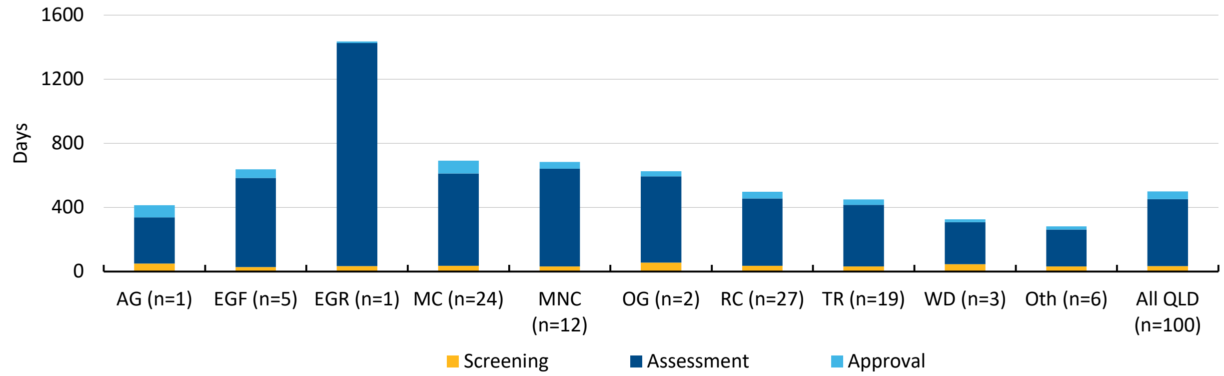

Figure 3-33 Median length of each stage of the assessment and approval process under the EPBC Act, all projects in Queensland over the period July 2010 to March 2018
Source: Department of the Environment and Energy

The aggregate of the median length of each stage was 500 days. The assessment phase accounted for almost 84% of that time, highlighting the importance of proponents ensuring assessment information is provided in a timely manner. Similar to the results from the state analysis, the length of the EPBC Act assessment and approval process was highly variable, ranging from 78 to 2447 days. Just over one third (31%) of approvals took less than 365 days, while 34% took more than 730 days (Figure 3-34).

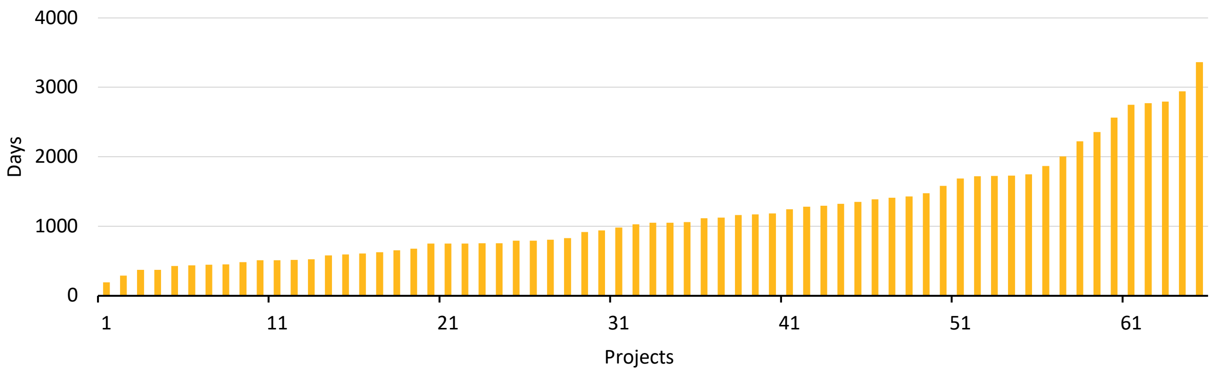

Figure 3-34 Total length of EPBC Act assessment and approval process, Queensland projects from 2010-2018, by length of process
Source: Department of the Environment and Energy.

The potential for government assessment and approval processes to cause delays, and the factors that contribute to them, are illustrated by the two aquaculture and agriculture developments in the SDPWO Act and EPBC Act samples.

The aquaculture development was a prawn farm project at Guthalungra, 40 km north of Bowen in Queensland. The project involved the construction of 259 x 1 ha x 1.5 m deep ponds, which are intended to produce approximately 1600 t of black tiger prawns (*Penaeus monodon*) per year for domestic and international markets. The main environmental concerns associated with the project centred on its potential impacts on water quality and the natural heritage values of the Great

Barrier Reef. The project site is located near the coast and adjacent to the Elliot River, which flows into the reef.

The original proponent of the project, Pacific Reef Fisheries Pty Ltd, submitted an Initial Advice Statement to the Queensland Coordinator-General under the SDPWO Act in January 2001 and referred the project under the EPBC Act in the same month. To reduce duplication, the Australian Government accredited the SDPWO Act assessment process for the purposes of the EPBC Act, meaning the state assessment was used for the final federal approval decision. The assessment was extensive, lasting seven years and ending on 11 January 2008. The EPBC Act approval took a further two years, being finally granted on 4 March 2010.

The length of the state and federal processes highlights the delay risks associated with government approvals. However, it also demonstrates the importance of site selection in project development. The environmental acceptability of aquaculture developments are a function of a number of factors, one of the most important of which is the sensitivity and values associated with the surrounding environment. In this instance, the project site had a number of characteristics that made it appealing from a commercial and production perspective. Yet the site was adjacent to, and would discharge production wastes into, the high profile and highly protected World and national heritage-listed Great Barrier Reef. Siting the project in this location was one of the main contributing factors to the length of the assessment and approval process.

The agriculture development in the EPBC Act sample was a cropping development on the 21,500 ha Meadowbank Station, west of Ravenshoe in north Queensland. The project involved the clearing of 1,365 ha of native vegetation for forage cropping associated with cattle production. Originally, the proposal involved the clearing of over 6,000 ha. This was initially scaled back to 1,470 ha, and later to the final 1,365 ha. The project received state approval under the now repealed *Sustainable Planning Act 2009* (Qld) in November 2016 on the basis of being a high value agriculture development. However, due to potential impacts of the clearing on nationally listed threatened species, including the black-throated finch, the proposal was referred under the EPBC Act in December 2016, after the state approval had been granted. The project was assessed by way of 'preliminary documentation', a low level of assessment that is typically relatively short. Despite this, the EPBC Act approval still took over a year, with final approval granted in early February 2018.

The Meadowbank Station case illustrates the importance of considering government approval timelines when designing projects. By applying for state and federal approvals sequentially, the proponent potentially extended the delays associated with these processes. Where multiple state and federal approvals are required, delays can often be avoided, and costs reduced, by applying for them in parallel.

The SDPWO Act and the EPBC Act will not apply to all water-related developments in the Mitchell catchment. Proponents should seek advice on the government approvals required for their projects well in advance of commencement, including on the likely cost and duration of the processes.

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Part III Opportunities for water resource development

Chapters 4 and 5 provide information on opportunities for agriculture and aquaculture in the Mitchell catchment. This information covers:

- opportunities for irrigated agriculture and aquaculture (Chapter 4)
- opportunities to extract and/or store water for use (Chapter 5).

4 Opportunities for agriculture and aquaculture

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Chapter 4 presents information about the opportunities for irrigated agriculture and aquaculture in the Mitchell catchment, describing:

- land suitability for a range of crop × season × irrigation type combinations and for aquaculture, including key soil-related management considerations
- cropping and other agricultural opportunities, including crop yields and water use
- gross margins at the farm scale
- the prospects for integration of forages and crops into existing beef enterprises
- aquaculture opportunities.

The key components and concepts of Chapter 4 are shown in Figure 4-1.

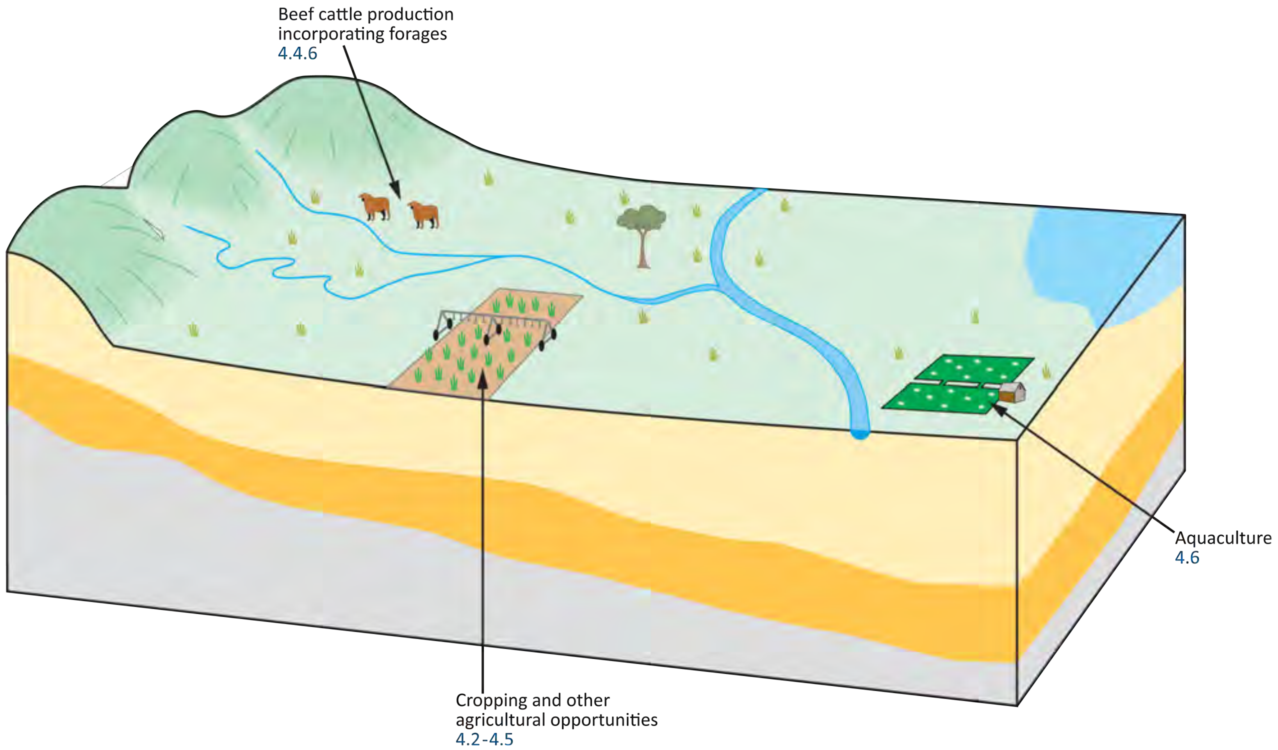

Figure 4-1 Schematic diagram of agriculture and aquaculture enterprises as well as crop and/or forage integration with existing beef enterprises to be considered in the establishment of a greenfield irrigation development

4.1 Summary

This chapter provides information on land suitability and the potential for agriculture and aquaculture in the Mitchell catchment. The approach used to generate the results presented in this chapter involves a mixture of field surveys and desktop analysis. For example, the land suitability results draw on extensive field visits to describe, collect and analyse soils that are integrated with state of the art digital soil mapping. Many of the results are expressed in terms of potential. For example, the area of land suitable for cropping or aquaculture is estimated by considering the set of relevant soil and landscape biophysical attributes at each location and determining the most limiting attribute among them. It does not include water availability, cyclone or flood risk, legislative, regulatory, ecological, social or economic drivers that will inevitably constrain the actual area of land that is developed. Crops and cropping systems and integrated forage–beef system results are based on data analysis and simulation models and assume good agronomic practices producing optimum yields given the soil and climate attributes in the catchment. Likewise, aquaculture is assessed in terms of potential using a combination of land suitability and productive capacity of a range of aquaculture species. Information is presented in a manner to enable the comparison of a variety of agriculture and aquaculture options.

The results from individual components (land suitability, agriculture, aquaculture) are integrated to provide a sense of what is potentially viable in the catchment. This includes providing economic analyses such as gross margins (crops), profit (irrigated forages) and net present value (NPV) (forage–beef); how with the advantage of irrigation more intensive rotational cropping systems might be feasible; options for integrating irrigated forages into extensive beef systems; specific information on a wide range of crop types for agronomy, water use and land suitability for different irrigation types; and integrating agriculture and aquaculture to provide value-add within the catchment.

4.1.1 KEY FINDINGS

Land suitability

A major question for any agricultural resource assessment is how much soil is suitable for a particular land use and the location of that soil. Based on a sample of 14 crop × season of use × irrigation type combinations, the amount of land classified as ‘moderately suitable with considerable limitations’, or better, ranges from about 100,000 ha to a little over 3 million ha before constraints such as water availability, environmental and other legislation and regulations, and a range of biophysical risks are considered. There are reasonable areas of land classed as ‘suitable with minor limitations’ for Rhodes grass, cotton, bananas and mango under specific management practices. There are much greater areas suitable for spray or trickle irrigation than for furrow irrigation.

Dryland cropping

Analysis of cropping opportunities in the Mitchell catchment shows some agronomic potential for dryland cropping with short-season crops such as sorghum, mungbean, maize and peanut producing moderate crop yield potential, given the relatively reliable wet-season rainfall. This provides for positive gross margins consistent with other dryland cropping regions in Queensland.

However, these results are predicated on being able to access the country in January and on being able to sow at the climatically optimum time. In many years the soils would not be trafficable in January or February due to wet conditions, especially the cracking clays (Vertosols), so realising viable crop yields would be challenging. Delaying sowing until March, after the main part of the wet season, dramatically reduces crop yield potential because there would not be enough stored soil water to grow a crop to a successful harvest. It is not feasible to grow most horticultural crops solely on rainfall.

Irrigated cropping

Irrigation provides the opportunity to achieve high yields of broadacre crops, with year to year variation in yield greatly reduced compared with dryland cropping. Water required by crops varies enormously depending on crop type and season of growth; a grain sorghum crop planted during the wet season and reliant only on supplementary irrigation in the final stages of growth can use as little as 2 ML/ha, while a perennial sugarcane crop requires over 10 ML/ha and a high-yielding perennial forage such as Rhodes grass requires up to 15 ML/ha to achieve optimum yields.

The high costs of irrigation, fertiliser and transport mean that gross margins, while positive, may not be sufficient to provide net returns capable of meeting the investment returns required to service the high capital costs of development. In contrast, the industrial crops cotton and sugar, as well as peanut, provide gross margins in excess of $2500/ha, assuming the existence of local processing facilities to reduce transport costs.

Compared with broadacre crops, gross margins of horticultural crops can be considerably higher, especially for the main crops of avocados, bananas, melons and mangoes. This is to be expected because the areas used for horticulture are considerably smaller than for broadacre cropping and the costs of development are usually much higher. Further, risk tends to be higher with horticulture because returns are highly sensitive to prices received. Prices are volatile over short timescales for most horticultural crops because of the relatively small size of the Australian domestic market. Additional risks in horticulture include extreme events (cyclones, disease outbreaks) which can cause a loss of the entire crop.

It may be possible to utilise rotational cropping systems, where more than one crop is grown in a year, in the Mitchell catchment to try to generate higher net returns per year. Given that irrigated broadacre cropping is still not widely practised in northern Australia west of the Great Dividing Range, there has been relatively little experience in implementing rotational cropping systems outside of the Mareeba–Dimbulah Water Supply Scheme. The analysis of cropping systems shows that, for example, a rotation system of cotton and mungbean grown within a year is capable of producing yields similar to individually grown crops and consequently the gross margin for this rotation could achieve a gross margin of $3500/ha/year. However, the design of, and the management skills required to successfully implement intensive cropping rotations in tropical environments should not be underestimated.

Integrating forages and crops into existing beef enterprises

Given the strong dominance of the beef sector in the catchment, a potential use for irrigation is to grow forages that can be incorporated into existing large-scale extensive beef enterprises (i.e. mosaic agriculture). Options included direct grazing of forages using substantial areas of irrigation (200 to 400 ha) to grow animals to reach a marketable weight at a younger age or using much smaller areas (80 to 200 ha) to grow hay crops for feeding calves that are weaned early to improve productivity of breeding cows. Incorporating irrigated forages in this way can increase total beef produced from a property by as much as 50% but net profit increases (excluding the capital costs of development) are considerably less (20 to 40%) because of the high costs (water, fertiliser and hay-making operations) of growing irrigated forages.

Aquaculture

There are considerable opportunities for aquaculture development in northern Australia based on the natural advantages that northern Australia possesses in terms of political stability, proximity to large global markets, and a climate suited to farming of valuable tropical species, and through the large areas identified by the Assessment as suitable for aquaculture in the Mitchell catchment. While challenges to the development and operation of aquaculture enterprises do present in terms of regulatory barriers, global cost competitiveness, and the remoteness of much of the available land area, the potential to exploit the natural advantages of northern Australia and develop modern and sustainable aquaculture industries appears a compelling opportunity.

Candidate species include black tiger prawns, barramundi and red claw. Black tiger prawns require marine water, red claw are a freshwater species and barramundi can be farmed in water ranging from fresh to marine. Marine water temperatures and salinity are suitable for a range of tropical aquaculture species. Pond water temperatures are optimal for most tropical aquaculture species between September and April.

A land suitability analysis was applied to marine ponds, earthen and lined, and to freshwater ponds, earthen and lined. For those species requiring marine water, distance to a marine water source is a key limitation and limits the area of available land to coastal areas. Areas of shallow rocky soils, landscapes where slopes exceed 5% and those areas with high acid sulfate soil potential are generally precluded from aquaculture development. Earthen ponds are restricted to areas of deeper clay (>0.5 m depth) and heavier loam soils where soil compaction and stability properties are suitable for pond construction. Areas with moderate to rapid soil permeability, such as deep sands, are not suitable because loss of pond water and potential contamination of groundwater are major constraints.

There are opportunities for integrating aquaculture production with agriculture but these are not widely practised in northern Australia. Emerging technologies and more locally based feed mills may provide opportunities for agricultural products to be used in manufacturing aquaculture feedstuffs.

4.1.2 INTRODUCTION

This chapter seeks to address these questions for the Mitchell catchment: ‘How much land is suitable for cropping and in which suitability class?’, ‘Is dryland and/or irrigated cropping economically viable?’, ‘Can crops and forages be economically integrated with beef enterprises?’ and ‘What aquaculture production systems might be possible?’.

The chapter is structured as follows:

- Section 4.2 briefly discusses the history of irrigated agriculture development in the catchment and its challenges, existing cropping, recent initiatives and the approach taken in the Assessment to assess derived yields.
- Section 4.3 describes how the land suitability classes are derived from the attributes provided in Chapter 2, with results given for a set of 14 combinations of crop × season × irrigation type. Versatile agricultural land is described and a qualitative evaluation of cropping provided for a set of specific locations within the catchment.
- Section 4.4 provides detailed information on crop and forage opportunities, including dryland and irrigated yields, gross margins and water use. A cropping calendar is provided and information given about the impact of sowing time on production. Four rotational cropping systems are modelled in which two crops per year are planted, as a means of increasing returns in an attempt to meet capital development costs. Finally, the prospects for integrating forages and crops into existing beef enterprises are explored.
- Section 4.5 provides synopses for 11 crop and forage groups, including a focus on specific example species.
- Section 4.6 discusses the candidate species and likely production systems for aquaculture enterprises, including the prospects for integrating aquaculture with agriculture.

4.2 The opportunity for more intensive agriculture in the Mitchell catchment

4.2.1 INTRODUCTION

Aspirations to expand agricultural development in the Mitchell catchment are not new and across northern Australia there have been a number of initiatives to put in place large-scale agricultural developments since World War II. Ash (2014) assessed 13 such agricultural developments, which included both irrigated and dryland developments, to determine factors that affected success and failure.

Key points to emerge from this analysis include the following:

- The natural environment (climate, soils, pests and diseases) makes agriculture in northern Australia challenging, but these inherent environmental factors are not generally the primary reason for a lack of success.
- Management, planning and finances are the most important factors in determining the ongoing viability of agricultural developments.
- Unrealistic expectations of achieving a reasonable return on investment in the first few years brought a number of developments to a premature end. Two factors are key in contributing to the overestimated returns: overly optimistic expectations of the ability to scale up rapidly in area of land developed, and not coming to grips with the operating environment and being able to take time to build experience at smaller scales.
- Supply chains and markets were also important factors in determining the success of developments. For broadacre commodities that require processing facilities, these facilities need to be within a reasonable distance of production sites and at a scale to make them viable in the

long term. In more remote regions, higher value products such as fruit, vegetables and niche crops proved more successful, although high supply chain costs to both domestic and export markets remain as impediments to expansion.

The analysis of Ash (2014) showed that for developments to be successful, all factors relating to climate, soils, agronomy, pests, farm operations, management, planning, supply chains and markets need to be thought through in a comprehensive systems design. Particular attention needs to be paid to scaling up at a considered pace and being prepared for reasonable lags before positive returns on investment are achieved.

4.2.2 QUANTIFYING OPPORTUNITIES FOR FURTHER AGRICULTURAL DEVELOPMENT IN THE MITCHELL CATCHMENT

The Mitchell catchment offers a challenging environment for the development of irrigated agriculture. A brief overview is provided in Chapter 2, with detailed data and analyses available in the companion technical reports on climate (Charles et al., 2016), digital soil mapping (Thomas et al., 2018a), land suitability (Thomas et al., 2018b), river model calibration (Hughes et al., 2018), flood mapping and modelling (Karim et al., 2018) and hydrogeological assessment (Taylor et al., 2018).

Current agricultural activities in the Mareeba–Dimbulah Water Supply Scheme provide good insights into crop growing seasons in the Mitchell catchment as well as agronomic management, yields, and pests and diseases, especially for horticultural crops and broadacre crops such as sugarcane and maize. Potential new areas for dryland and irrigated agriculture are likely to be further west, on different soils and a different climate. Assessing potential yields in these new areas can draw on knowledge from the Mareeba–Dimbulah Water Supply Scheme, complemented by using crop and forage models, which have the capability to predict yields of broadacre crops and forages using local soils, climate and management. A potentially important area for use of irrigation is in fodder crops, which can be incorporated into existing beef systems to lift productivity and profitability of cattle enterprises. Forage crops can be grazed to realise immediate production benefits or harvested for silage or hay to be fed at a later time to manage forage shortages or production feed animals to meet a particular market.

In the Assessment, crop and forage–beef models are used, as described in the companion technical report on agricultural viability (Ash et al., 2018), to assess broadacre crop yields and beef production that incorporates irrigated forage crops. It is important to note that the modelling analysis used in the Assessment estimates potential rather than actual yields. Potential yields are often, but not always, higher than actual yields. It is important to recognise that actual yields are highly dependent on a range of factors associated with management, which means that achieving potential yields can be challenging. For horticulture crops, yield estimates are based on available production data, sourced from production areas in neighbouring regions or from literature sources.

Cropping assessments are provided for four climate locations (Mareeba, Chillagoe, Highbury and Dunbar) with forage–beef assessments undertaken at Chillagoe, Highbury and Dunbar. These locations are shown in Figure 1-3.

4.3 Land suitability assessment

4.3.1 INTRODUCTION

A major question for any agricultural resource assessment is how much soil is suitable for a particular land use and the location of that soil. The overall suitability of a particular land use is determined by a number of attributes. These include climate at that location, slope, drainage, permeability, plant available water capacity, pH, soil depth, surface condition and texture as well as a number of other attributes. Some of these attributes are provided in Section 2.3. From these attributes a set of limitations are derived, which are then considered against each potential land use.

Note that the use of the term suitability in the Assessment refers to the potential of the land for a specific land use such as furrow irrigated cotton, while the term capability (not used in the Assessment) refers to the potential of the land for broadly defined land uses, such as cropping or pastoral (DSITI and DNRM, 2015).

4.3.2 LAND SUITABILITY CLASSES

The overall suitability for a particular land use is calculated by considering the set of relevant attributes at each location and determining the most limiting attribute among them. This most limiting attribute then determines the overall land suitability classification. The classification is on a scale of 1 to 5 from 'Suitable with negligible limitations' (Class 1) to 'Unsuitable with extreme limitations' (Class 5) as shown in Table 4-1.

Table 4-1 Land suitability classification used in the Assessment

CLASS	SUITABILITY	LIMITATIONS	DESCRIPTION
1	Highly suitable land	Negligible	Highly productive land requiring only simple management practices to maintain economic production.
2	Suitable land	Minor	Land with limitations that either constrain production or require more than the simple management practices of Class 1 land to maintain economic production and minimise land degradation.
3	Moderately suitable land	Considerable	Land with limitations that either further constrain production or require more than those management practices of Class 2 land to maintain economic production and minimise land degradation.
4	Currently unsuitable land	Severe	Currently considered unsuitable land due to severe limitations that preclude successful sustained use of the land for the specified land use. In some circumstances, the limitations may be surmountable with changes to knowledge, economics or technology.
5	Unsuitable land	Extreme	The limitations are so extreme that the specified land use is precluded. The benefits would not justify the inputs required to maintain production and prevent land degradation in the long term.

The companion technical report on land suitability (Thomas et al., 2018b) provides a complete description of the land suitability assessment method and the material presented below is taken from that report. Note that for the land suitability maps and figures presented in this section there is no consideration of flooding, risk of secondary salinisation or availability of water as discussed by Thomas et al. (2018b). Consideration of these risks and others, along with further detailed soil physical, chemical and nutrient analyses would be required to plan development at scheme, enterprise or property scale. Caution should therefore be employed when using these data and maps at fine scales.

4.3.3 LAND SUITABILITY FOR CROPS, VERSATILE AGRICULTURAL LAND AND EVALUATION OF SPECIFIC AREAS

Land suitability has been determined for 126 combinations of crop × season × irrigation type within the Assessment (Thomas et al., 2018b). A sample of 14 of these land use combinations is shown in Figure 4-2. Depending on land use, the amount of land classified as Class 3 or better for these sample land uses ranges from about 100,000 ha to a little over 3 million ha in the Mitchell catchment. Almost all of this land is rated as Class 3, and so has considerable limitations, although there is some Class 2 land available for Rhodes grass, cotton, bananas and mango under specific management practices.

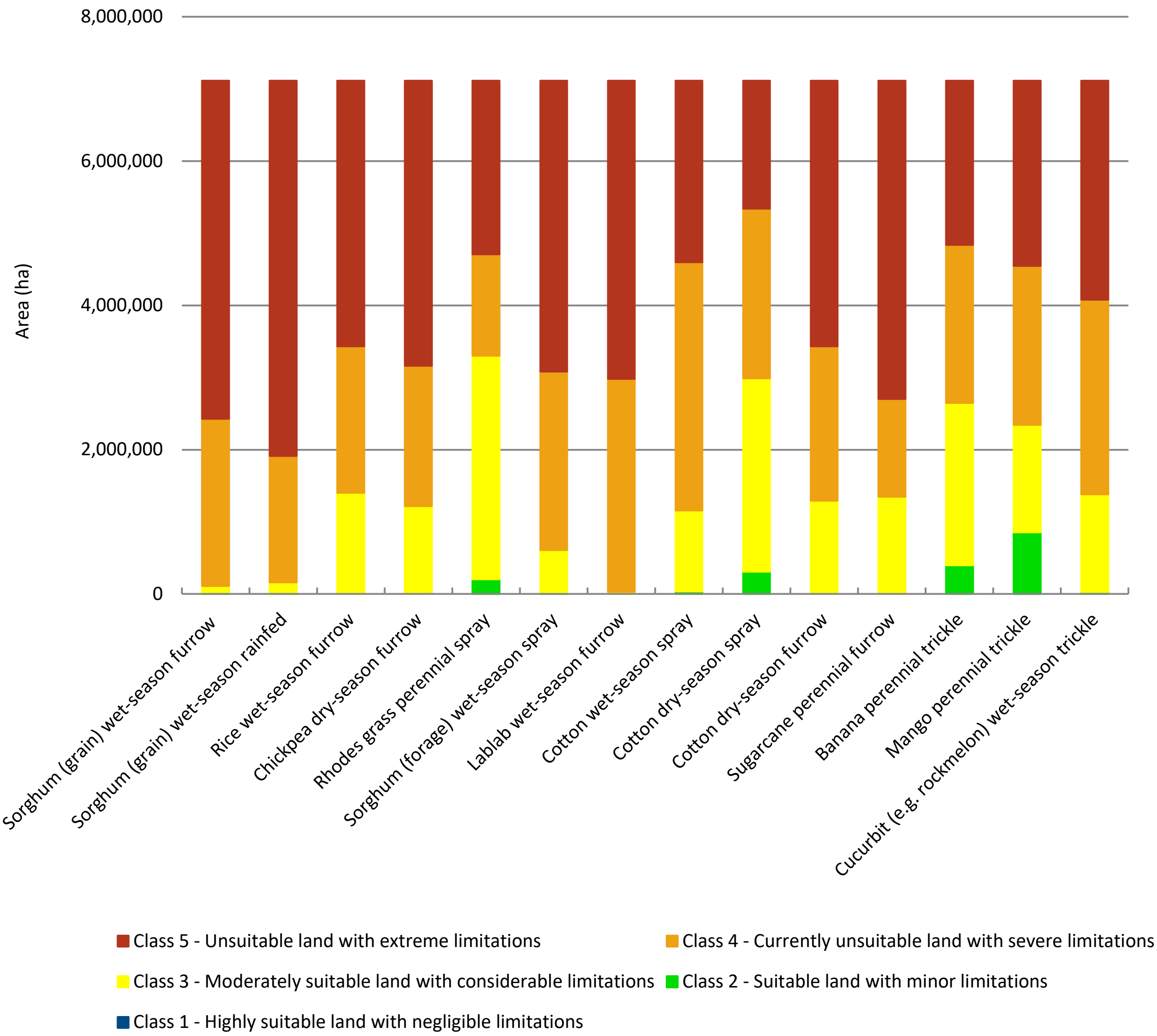

Figure 4-2 Area (ha) associated with each land suitability class in the Mitchell catchment for 14 potential crop land uses
A description of the five classes is provided in Table 4-1.

In order to provide an aggregated summary of the land suitability products, an index of agricultural versatility was derived for the Mitchell catchment (Figure 4-3). Versatile agricultural land was calculated by identifying where the highest number of the 14 selected land use options presented in Figure 4-2 were mapped as being suitable (i.e. suitability classes 1 to 3).

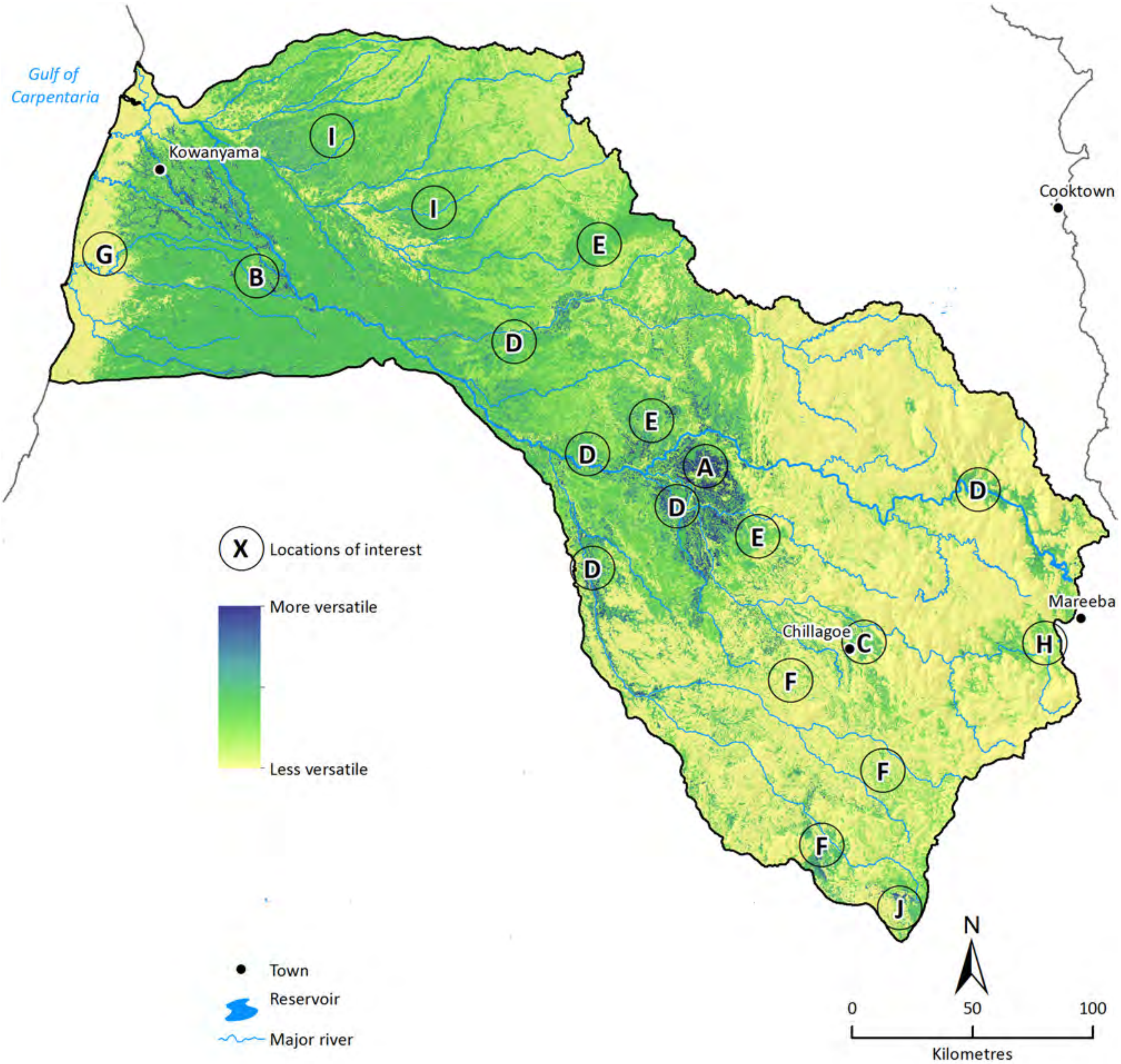

Figure 4-3 Agricultural versatility index map for the Mitchell catchment
High index values denote land that is likely to be suitable for more of the 14 selected land use options. The map also shows areas of interest from a land suitability perspective, discussed in the table below. Note that this map does not take into consideration flooding, risk of secondary salinisation or availability of water.

Qualitative observations on each of the areas mapped as 'A' to 'H' in Figure 4-3 are provided in Table 4-2.

Table 4-2 Qualitative land evaluation observations for locations in the Mitchell catchment shown in Figure 4-3
Further information on each soil generic group (SGG) and a map showing spatial distribution can be found in Section 2.3.

AREA	LOCATION NAME	COMMENT
A	Wrotham Park area	Cracking clay soils (SGG 9) with soft self-mulching surfaces on gently undulating plains and rises derived from mudstone of the Great Artesian Basin. Suitable to moderately suitable for a wide variety of crops including irrigated sugarcane, cotton, grain/forage crops and pulse crops. Requires further investigation to assess the likelihood of salinity issues developing under irrigated cropping. Erosion management required.
B	Lower Mitchell River floodplains and delta	The broad delta comprises floodplains, swamps, prior streams and numerous flood channels with narrow levees. Complex distribution of soils including red, brown and yellow loamy soils (SGG 4.1 and 4.2) on narrow levees, prior streams and channel benches; extensive hard setting seasonally wet loam over brown sodic and intractable clays (SGG 8); and seasonally or permanently wet grey and brown cracking clay soils (SGG 3 and 9) with coarse surface structure. A majority of the delta is subject to flooding. The narrow levees, prior streams and channel benches are moderately suitable for a range of spray-irrigated grain and forage crops and trickle-irrigated horticultural crops, but the generally long thin units restrict irrigation layout and machinery use in most areas. The loam over brown sodic and intractable clays (SGG 8) are suitable for sugarcane, cotton, dry-season grain and pulse crops under furrow irrigation with considerable management required to address seasonal wetness during the wet season, erosion on sloping land adjacent to channels, and restrictions on irrigation water to wet up the soil profile due to impermeable subsoils and sealing surfaces. The cracking clay soils (SGG 9) are suitable for sugarcane, cotton, dry-season grain and pulse crops. The main limitations are flooding on the floodplains during the wet season, coarse surface structure affecting workability and seed germination in some crops, and landscape complexity in the lower delta due to the complex distribution of flood channels and prior streams resulting in small and/or narrow areas limiting paddock size and irrigation infrastructure layout. The management options on lands subject to regular flooding include avoiding cropping during flood prone times and delaying planting until the risk of floods has reduced, growing crops tolerant to flooding and seasonal wetness, removing or protecting equipment from flood damage and avoiding development of flood channels due to high velocity flood waters potentially causing severe erosion. Management of hard setting soils includes maintaining cover crops or pasture cover to reduce surface scalding, and maintaining soil fertility, particularly organic matter, to improve water infiltration in the surface, water holding capacity, soil structure and soil biology to improve seedling emergence and plant establishment.
C	Chillagoe area	Soils are predominantly rocky brown hard setting seasonally wet loam over brown sodic and intractable clays (SGG 8), which are highly erodible with minor rill and gully erosion evident on slopes and adjacent to drainage lines. Minor well-drained red friable loams (SGG 2 and 4.1) and loamy soils with scattered rock outcrop occur on lower slopes of limestone hills and rises on granitic rocks. Approximately 5700 ha are suitable for agricultural development on the red soils but scattered rock outcrop will limit uses mainly to horticulture. The generally long thin units associated with the ridges and lower slopes restricts irrigation layout and machinery use in most areas.
D	Upper Mitchell River, lower Palmer, Lynd and Walsh rivers alluvium	Loam over brown sodic and intractable clays (SGG 8) throughout the alluvial plains in the upper Mitchell River, lower Palmer River and along the Lynd and Walsh rivers. Red, yellow and grey massive loamy soils (SGG 4.2) with sandy surfaces occur on narrow levees and prior streams. Generally deeply incised by the main channel resulting in relatively narrow usable areas. Hard setting sealing surfaces restrict water infiltration and seedling emergence on the soils with loam over brown sodic and intractable clays (SGG 8). Subject to erosion on slopes. Appropriate buffers on rivers should be implemented, particularly in areas subject to gully erosion adjacent to stream channels. Management of hard setting soils includes maintaining cover crops or pasture cover to reduce surface scalding and maintain soil fertility, particularly organic matter, to improve water infiltration in the surface, water holding capacity, soil structure and soil biology to improve seedling emergence and plant establishment. Agricultural potential is moderately suitable mainly for sugarcane and grain/forage crops.
E	Desert	Very deep highly permeable red, brown, yellow and loamy soils (SGG 4.1 and 4.2) with sandy surfaces and very deep red sands (SGG 6.1) on low plateaus in the north-central part of the study area. Seasonally or permanently wet grey soils occur on lower slopes. These loamy soils are moderately suitable for irrigated horticulture and a range of spray-irrigated grain crops.

AREA	LOCATION NAME	COMMENT
F	Uplands	Shallow rocky soils (SGG 7) dominate the uplands. Irrigation potential is generally limited to small areas (<100 ha each) of deeper, gently sloping, well-drained, rock-free soils. The small and/or narrow areas limit paddock size and irrigation infrastructure layout. Erosion management is required.
G	Coastal plains	The lower delta and coastal marine plains are dominated by poorly drained to very poorly drained swampy areas with mainly clay soils (SGG 3) with scattered sandy beach ridges. Acid sulfate soils, regular flooding and storm surge from cyclones require considerable management. The wet clays have negligible potential for irrigated agriculture but are moderately suitable areas for aquaculture. Utilisation of the sandy areas would be constrained by their narrow, isolated occurrences.
H	Mareeba–Dimbulah Water Supply Scheme	A very diverse range of soils developed on metamorphic, granitic and basalt geologies and alluvium. The Mareeba–Dimbulah Water Supply Scheme area has 50,400 ha potentially suitable for irrigating a broad range of crops. Soils on lower landscape positions are subject to seasonal wetness (SGG 3) with some areas of grey sodic soils (SGG 8) at risk from rising saline groundwater. Erosion management is required on sloping lands.

Land suitability and its implications for crop management are discussed in more detail for a selection of crops in Section 4.5. There, land use suitability of a given crop and irrigation combination is mapped, along with information critical to the consideration of the crop in an irrigated farm enterprise. Land suitability maps for all 126 land use combinations are presented in the companion technical report on land suitability (Thomas et al., 2018b).

4.4 Crop and forage opportunities in the Mitchell catchment

4.4.1 INTRODUCTION

Dryland, or rainfed, cropping (farming without irrigation) is not widely practised in the Mitchell catchment with most cropping relying on water for irrigation from the Mareeba–Dimbulah Water Supply Scheme. Dryland cropping is wholly dependent on water stored in the soil and rainfall occurring during crop growth. Although the mean annual rainfall is higher than in many parts of southern Australia that practise dryland cropping, the highly seasonal rainfall and high inter-annual variability of rainfall means that continuous year-on-year dryland cropping is unlikely to be possible every year in the Mitchell catchment. Opportunistic dryland cropping, pursued when conditions are favourable, is likely to provide the most profitable and sustainable approach to dryland cropping. The best opportunities for dryland cropping are on the heavier textured soils (clays) with higher soil water storage capacity on the Mitchell River delta and the undulating plains derived from mudstone in the Wrotham Park area.

When crops are fully irrigated their yield can increase significantly as demonstrated in Table 4-3, where dryland and irrigated modelled yields are shown for cotton, maize and mungbean. The use of 125 seasons of data provides for robust assessments of both median yield and the variability that can be expected about the average due to variations in climate. The 20th percentile exceedance values represent the yield that is exceeded in 20% of all years (i.e. in 20% of years the yield will be higher than this value). The 50th percentile represents the median yield. Similarly, the 80th percentile exceedance values represent the yield that is exceeded in 80% of years (i.e. in 80% of years the yield will be higher than this value). The irrigated yield is highly dependent on the volume of water applied. In essence, more irrigation equals more yield up to the point that the full water needs of the crop are satisfied. The yield response curves can provide insights into the relative response of crops to irrigation and could be used to help guide decisions about which crops and which areas of crop could preferentially receive irrigation water in the event that it is limiting.

There is much more soil suited for irrigated agriculture in the Mitchell catchment than there is water to irrigate it. Whether or not water is limiting in a particular situation will depend on rainfall, the availability and reliability of irrigation water, the area and time for which irrigation water is required and the characteristics of the soil.

Table 4-3 Yields (20th, 50th (median), 80th percentile) of three crops averaged across four locations under dryland and irrigated conditions, using the historical climate record (1890–2015) and a Brown Sodosol soil type

CROP	DRYLAND YIELD			IRRIGATED YIELD		
	20th	50th	80th	20th	50th	80th
Cotton (bales/ha)	4.2	2.8	1.7	10.7	10.5	10.2
Maize (t/ha)	8.3	6.9	4.5	13.6	12.8	12.0
Mungbean (t/ha)	2.0	1.8	1.5	2.4	2.3	2.2

Water storage options are discussed in detail in Chapter 5 but, suffice to say, because there is more moderately suitable soil in the Mitchell catchment than there is water to irrigate it, decisions will need to be made on whether irrigation is economically feasible, and if so, the most efficient and cost-effective use of limited irrigation water. This will require consideration at regional, farm and paddock scales. At the farm and paddock scales, these decisions may need to be made each cropping season.

Eleven crop and forage land use categories were developed by the Assessment and used as a basis for the land suitability analysis. The 11 categories, and a range of the crops that comprise them, are shown in Table 4-4.

Table 4-4 Crop types and crops explored in the Assessment

CROP TYPE	CROP EXAMPLES
Cereals and pseudo-cereals	Chia, maize (grain), millet, quinoa, rice (lowland and upland), sorghum (grain)
Food legumes (pulses)	Chickpea, lentil, mungbean, navy bean
Forage grazing, hay, silage	Rhodes grass, maize (silage), sorghum (forage)
Forage legume	Lablab
Industrial crops	Cotton, sugarcane
Intensive horticulture (vegetables)	Asian vegetables, asparagus, capsicum/chilli, cucurbits (melons), snake bean, sweet corn, tomato
Oilseeds	Poppy, sesame, soybean, sunflower
Root crops	Cassava, peanut, sweet potato
Silviculture (plantation)	African mahogany, Indian sandalwood, teak
Tree crops/horticulture (fruit)	Avocado, banana, citrus (generic), coffee, lychee, mango, papaya
Tree crop (nuts)	Almond, cashew, macadamia

These were based on knowledge of existing or historical cropping in the catchment, knowledge of the crops that have grown well in similar tropical regions, and an understanding of the commercial aspirations of local landholders in the Assessment area.

The 41 crop examples listed in Table 4-4 were subsequently analysed in more detail to identify critical environmental requirements and management considerations. Critical among these is season of growth and sowing time, which determines the conditions in which the crop grows and, consequently, critical factors such as water requirements and yield potential.

By integrating the information on climate, suitable soils, and general agronomic principles for dryland and irrigated crop and forage production it is now possible to undertake a more detailed analysis of the crop and forage–beef opportunities in the Mitchell catchment. This analysis commences with an understanding of optimal times for sowing different crops and forages through development of cropping calendars. It then examines potential crop yields, crop management and gross margins of crops. Given the costly nature of developing land for agriculture and providing irrigation, it is important to examine the potential for cropping systems that involve crop rotations and double cropping that can increase annual revenues. Such cropping systems provide opportunities but also challenges for management; these are addressed in this section.

Forage crop yields and the quality of that forage, which are both important for beef production, are explored, as are the implications for beef enterprise profitability. Finally, the role of pests and diseases is briefly explored. In Section 4.5 a more detailed description of crop types, their suitability to the Mitchell catchment, management and irrigation requirements, and indicative market opportunities is provided.

4.4.2 CROPPING CALENDAR

Cropping calendars identify optimum sowing times and the growing season for different crops. They are an essential crop management tool. Prior to the Assessment no cropping calendar existed for the Mitchell catchment.

The time during which a crop can be reliably and profitably sown is called the sowing window. Sowing windows vary in both timing and length among crops and regions. Figure 4-4 provides a cropping calendar for 38 crops, most of which are likely to be broadly adapted to the Mitchell catchment. Perennial crops are grown throughout the year, and consequently have a less well-defined growing season or planting window. Generally, perennial tree crops are transplanted as small plants (not seeds), and in the tropical north this is usually timed towards the beginning of the wet season to take advantage of wet-season rainfall.

The cropping calendar in Figure 4-4 is based on knowledge of these crops derived from elsewhere in the tropics combined with an understanding of plant physiology, which enables crop response to differences in local climate to be anticipated. The optimum planting window and growing season have been further refined through local experience and through use of the Agricultural Production Systems sIMulator (APSIM) crop model (see companion technical report on agricultural viability (Ash et al., 2018)).

The sowing windows identified in Figure 4-4 correspond with the times of sowing that are likely to maximise potential crop yield in the Mitchell catchment. Sometimes crops can be successfully sown outside of the identified sowing windows and only a small yield penalty would apply. In this analysis, sowing dates between September and November have been avoided because high evaporative demand (see Section 2.4) and low water availability are not conducive to seedling establishment; however, it is possible to sow at this time for many crops. However, wet-season difficulties in access and trafficability may prevent sowing at optimum times.

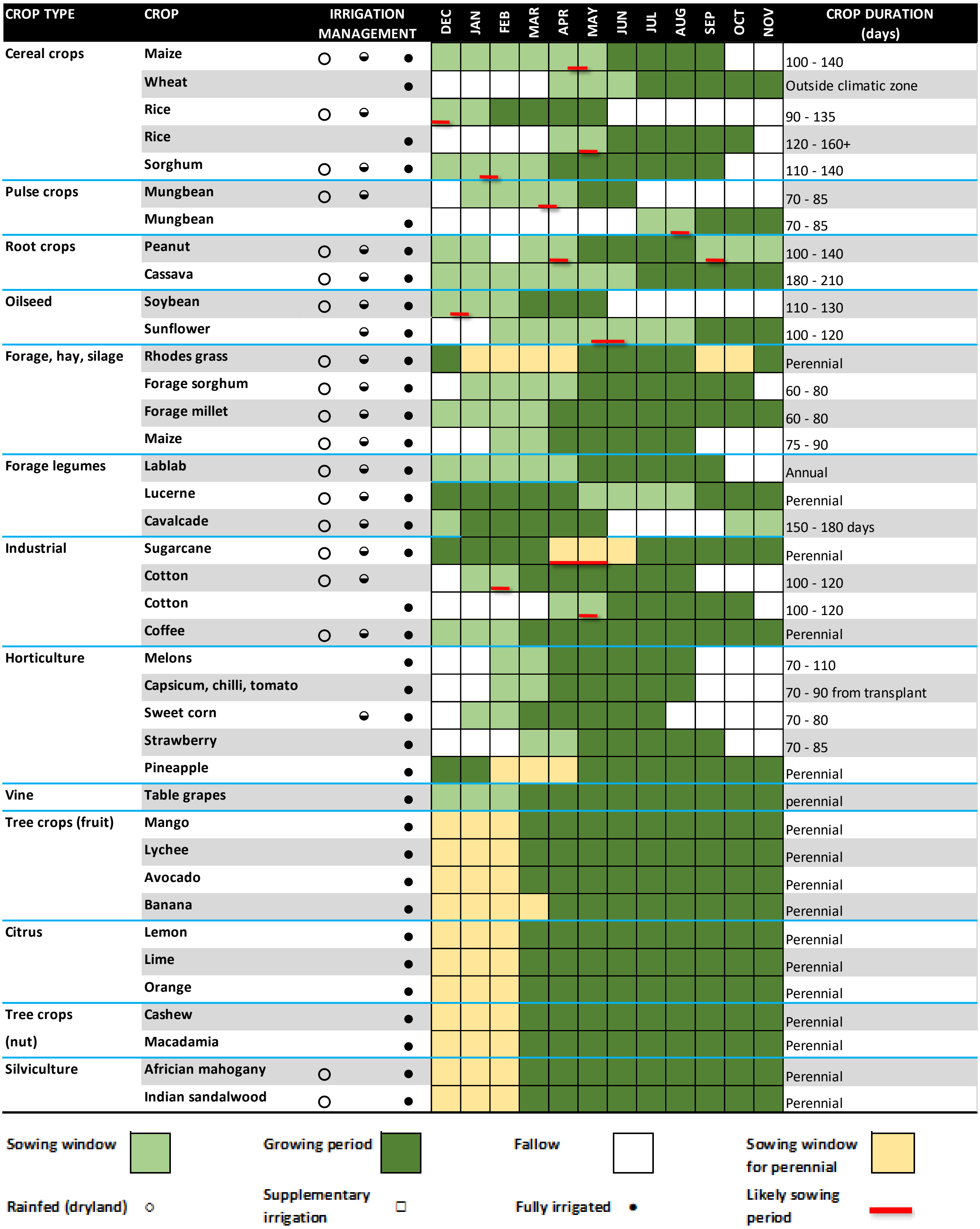

Figure 4-4 Annual cropping calendar for agricultural options in the Mitchell catchment

Sugarcane does not fit into an annual cropping calendar because it is usually established between May and June and harvested over a 6-month window 12 to 18 months later, which is dependent on the operational period of the local processing mill (Figure 4-5). It is not re-planted each year, with the same crop allowed to regrow (ratoon) in subsequent years. Three or four ratoon crops of 12 months' duration each are harvested before the paddock is fallowed or sown to a break crop such as mungbean, cotton, soybean or maize. Cane yields of ratoon crops decline over time and therefore the duration of ratooning usually varies between 3 and 4 years.

Paddock number	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1	Fallow			Plant cane														Harvest	1st ratoon			
2	Plant					Harvest	1st ratoon												2nd ratoon			
3	1st ratoon						2nd ratoon												3rd ratoon			
4	2nd ratoon						3rd ratoon												4th ratoon			
5	3rd ratoon						4th ratoon												Break crop (Mungbean)			
6	4th ratoon						Break crop (Mungbean)				Fallow					Plant cane						

Figure 4-5 Sugarcane crop calendar over 22 months showing growth stages in each of six paddocks

4.4.3 YIELDS AND CROP MANAGEMENT

Dryland cropping

The annual cropping calendar in Figure 4-4 shows that, for many crops, the sowing window includes the month of January. For relatively short-season crops such as sorghum and mungbean, this coincides with both the sowing time that provides close to maximum yield and the time at which the season's rainfall can be most reliably assessed. On average, considerable rainfall is expected in January and February (median of 255 and 187 mm, respectively, spatially averaged across the catchment), and the likely rainfall in a given year can be assessed using seasonal rainfall outlooks, which are currently forecast with a moderate level of skill in the Mitchell catchment at this time of year. Historical analysis of forecast accuracy for the Mitchell catchment suggests that rainfall received is consistent with predictions (above or below median) approximately 60 to 65% of the time.

Table 4-5 shows how soil water content at sowing and subsequent rainfall in the 90 days after each sowing date varies over three different sowing dates. As sowing is delayed from January to March the amount of stored soil water remains reasonably constant. However, there is a significant decrease in rainfall in the 3 months after sowing. Combining the median soil water content at sowing and the median rainfall received in the 90 days following sowing provides totals of 409, 304 and 185 mm for the January, February and March sowing dates, respectively. In 'wetter than average years' (20th percentile exceedance) the amount of soil water at the end of January combined with the rainfall in the following 90 days (over 670 mm) is sufficient to grow a good short-season crop. For 'drier than average years' (80th percentile exceedance), the soil water stored at sowing and the expected rainfall in the ensuing 90 days will result in water stress and comparatively reduced yields.

Table 4-5 Soil water content at sowing and rainfall for the 90-day period following sowing for three sowing dates (Chillagoe), based on a Brown Sodosol soil type

The 20th percentile, 50th percentile (median) and 80th percentile exceedance values are reported, for the 125 years between 1890 and 2015.

SOWING DATE	SOIL WATER CONTENT AT SOWING DATE (mm)			RAINFALL IN 90 DAYS FOLLOWING SOWING DATE (mm)			STORED SOIL WATER + RAINFALL IN SUBSEQUENT 90 DAYS (mm)		
	20th	50th	80th	20th	50th	80th	20th	50th	80th
31 January	152	145	101	527	367	227	676	499	341
28 February	146	140	102	296	164	80	436	302	196
31 March	141	136	98	79	39	10	221	167	126

Figure 4-6 illustrates some of the problems that are likely to be encountered sowing a dryland crop at the end of March where the majority of crop water will come from stored soil water. Median yields of dryland maize declined from around 7 t/ha to 3 t/ha when planting shifted from 1 January to 15 March.

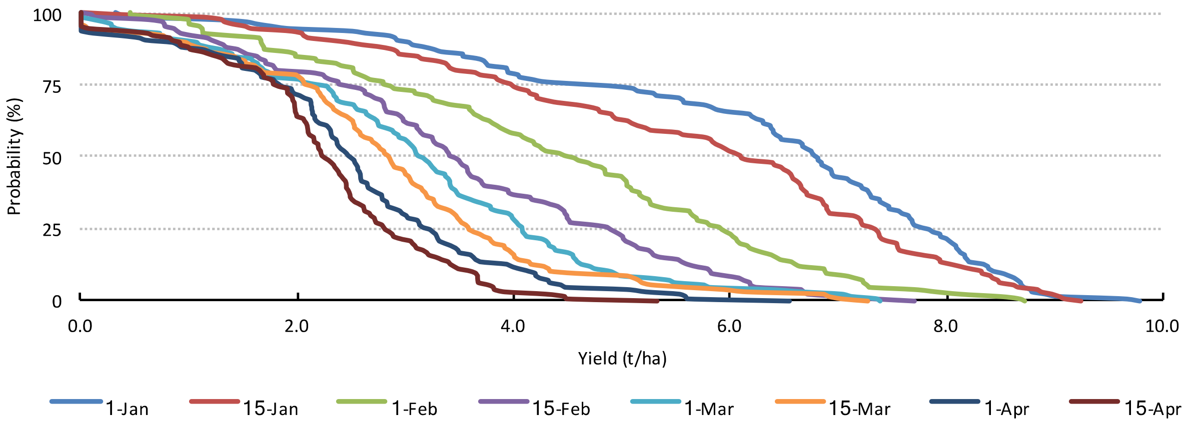

Figure 4-6 Probability of exceedance graph of simulated dryland maize yields (t/ha) for fortnightly sowing dates from January to April for a Brown Sodosol soil type

When planted at an appropriate time, good yields can be obtained with dryland crops of maize, sorghum, mungbean and peanut, especially in the best 20% of years (Table 4-6). As outlined above, opportunistic dryland cropping in the Mitchell catchment is favoured by the fact that the information required to make decisions about cropping opportunity and risk becomes most reliable at precisely the time when decisions about planting most need to be made. For many crops that are well-adapted to the Mitchell catchment (e.g. maize, sorghum, mungbean) the scale of cropping opportunity is clearly distinguishable at the key 'to sow or not to sow' decision point. This is a major enabler of dryland cropping in a highly variable environment, as it permits growers to distinguish the years in which they are most likely to make a profit from the years in which they are least likely to make a profit. Observing the discipline of not planting in less favourable years is likely to be a critical determinant of the economic viability of dryland cropping in the Mitchell catchment. Reliable seasonal forecasts can assist in this decision making but as indicated above, current levels of forecast skill are moderate.

The actual seasons in which growers will find cropping most or least profitable will vary among farms, which vary in physical attributes, management style and cost structures. As a guide, analysis of gross margins (see Section 4.4.4 for description) for dryland crops show that sorghum, maize, mungbean, cotton and peanut are all capable of producing positive gross margins (Table 4-6), and in the case of mungbean, cotton and peanut, this can exceed $1000/ha.

Table 4-6 Sowing date, crop yield, price, variable cost, gross margin and break-even crop yield for dryland crops in the Mitchell catchment, averaged across all four locations, with data shown for two soil types (Sodosol and Vertosol)

The 20th percentile, 50th percentile (median) and 80th percentile exceedance values are reported for the 125 years between 1890 and 2015. Gross margins for the 20th, 50th and 80th percentiles are calculated using the variable costs shown, and the 20th, 50th and 80th percentile yields, respectively. Gross margins for industrial crops (cotton, sugarcane) assume delivery to a (currently non-existent) processing plant.

CROP	SOWING DATE	CROP YIELD (t/ha)			PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)			BREAK-EVEN CROP YIELD (t/ha)
		20th	50th	80th		50th	20th	50th	80th	
Sodosol										
Sorghum	15 Jan to 20 Mar	7.5	5.8	2.9	240/t	892	840	500	−80	3.2
Cotton	1 Jan to 28 Feb	4.2	2.8	1.7	480/bale	1020	975	324	−223	2.6
Mungbean	1 Jan to 15 Feb	2.0	1.8	1.5	1100/t	753	1235	1050	725	0.9
Maize	1 Jan to 15 Feb	8.3	6.9	4.5	280/t	1316	912	597	56	4.7
Peanut	1 Jan to 15 Feb	4.5	3.4	2.2	1000/t	1854	2410	1512	534	1.9
Vertosol										
Sorghum	15 Jan to 20 Mar	8.5	7.7	5.0	240/t	968	1040	880	340	4.0
Cotton	1 Jan to 28 Feb	5.4	4.3	3.2	480/bale	1348	1616	1069	523	2.8
Mungbean	1 Jan to 15 Feb	1.5	1.3	1.1	1100/t	713	774	589	405	0.7
Maize	1 Jan to 15 Feb	8.9	7.9	6.3	280/t	1368	1047	822	462	4.9
Rice	1 Dec to 30 Jan	1.4	2.9	4.2	400/t	1259	356	−50	−517	3.0

While good rainfall and stored soil water enable dryland cropping, the risks associated with timely opportunities to sow a crop during the wet season (January to March) need considering. For example, analysis of the long-term climate for Chillagoe indicates the mean number of rain days experienced in January are in the order of 17, February 18 days, March 14 days and April 7 days. This means that the optimum sowing time of January may not be possible in many years because the soil may be too wet to access and operate machinery. This has significant implications for yields and gross margins. For example, if sowing of maize on a Sodosol is delayed from January until mid-March, yields drop from 6.9 t/ha to 3.0 t/ha and gross margins decline from $597/ha to $347/ha.

While trafficability following a rainfall event is dependent on rainfall amount, soil type and clay content, management options such as laser levelling, controlled traffic and no-till planters can help to facilitate early trafficability on a paddock after rain.

Irrigated cropping

Table 4-7 shows potential irrigated broadacre crop yields at the 20th, 50th and 80th percent exceedance using 125 years of the historical climate record (1890 to 2015) in simulation models. In comparison, Table 4-8 shows crop yield and crop water demand information for horticultural crops based on expert observed data from production, experimental trials and expert opinion.

The modelled yield of irrigated field crops is much less variable than that of dryland crops. Consequently, irrigation provides not only for higher, but also more reliable production compared with dryland crops. In the Mitchell catchment, as elsewhere, it is largely differences in water availability that determine differences in crop yield. The irrigation water required to fully irrigate a crop varies significantly from year to year. The 'applied irrigation water' values in Table 4-7 show that the difference in the volume of water required to fully irrigate a crop can be around twice as much for some crops (e.g. sorghum, sugar) in the 20th percentile years compared with the 80th percentile years. There was less difference between 20th percentile and 80th percentile years on the Vertosol because of the higher water holding capacity of this soil type. This varying demand on irrigation water between years highlights the impact of inter-annual variability of rainfall on irrigation requirements.

In the Mitchell catchment, fully irrigated crops of mungbean and grain sorghum significantly outperform those of dryland crops (Figure 4-7; Figure 4-8) and the between-year yields under irrigation are much less variable than under dryland cropping.

In 50% of years dryland mungbean crops (Figure 4-7) would be expected to yield more than 1.3 t/ha on a Grey Vertosol at Chillagoe and potential crop yields of about 1.5 t/ha could be achieved in 20% of years. The break-even crop for dryland mungbean grown at Chillagoe is estimated to be approximately 0.7 t/ha. This could be expected to be achieved in over at least 75% of years. Under fully irrigated conditions a yield of 2.1 t/ha could be expected in 50% of years.

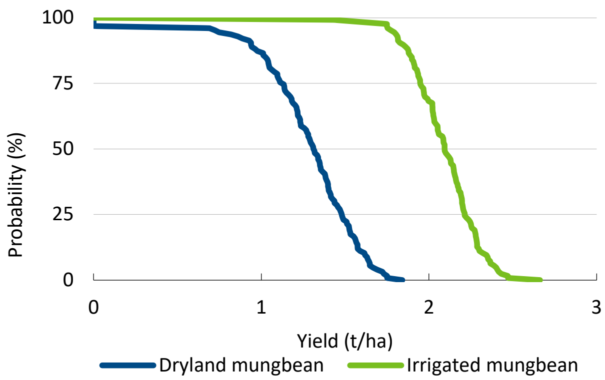

Figure 4-7 Probability of yield potential for dryland and fully irrigated mungbean sown in Chillagoe climate on a Grey Vertosol in January/February (dryland) and August (irrigated)

For sorghum (grain) (Figure 4-8) a yield of 7.6 t/ha could be expected in 50% of years under dryland and 8.8 t/ha under full irrigation on a Grey Vertosol at Chillagoe. Potential crop yields of about 8.4 t/ha and 9.2 t/ha could be expected in approximately 20% of years under dryland and irrigated, respectively. The break-even crop for dryland sorghum grown at Chillagoe is estimated to be approximately 3.2 t/ha. This could be expected to be achieved in at least 75% of years.

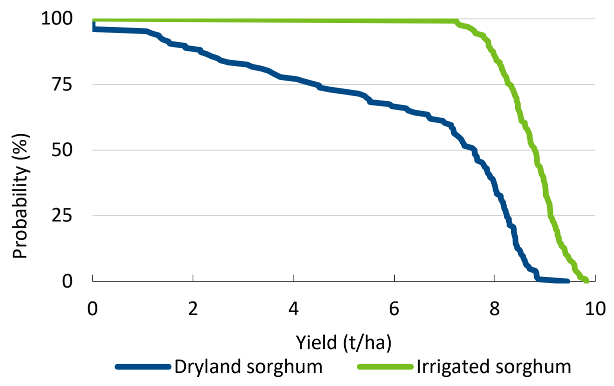

Figure 4-8 Probability of yield potential for dryland and fully irrigated grain sorghum sown in Chillagoe climate on a Grey Vertosol in January to March (dryland) and January (irrigated)

Yields typically increase with increasing irrigation until a point at which the full water needs of the crop are met (Figure 4-9; Figure 4-10). The slope of the rising part of the curve provides an insight into the relative response of crops to irrigation and could be used to help guide decisions about which crops and which areas of crops should preferentially receive irrigation water in the event that it is limiting.

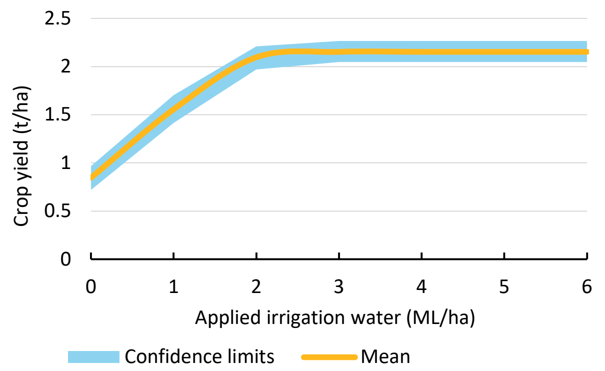

Figure 4-9 Crop yield plotted against applied irrigation water in Highbury Station climate for mungbean planted in April

Modelled confidence limits (20th to 80th percentile) and mean crop yield for mungbean. Representative of the production potential (i.e. assumes no nutrient limitations or pest damage). Assumes perfect timing of irrigation (i.e. no losses).

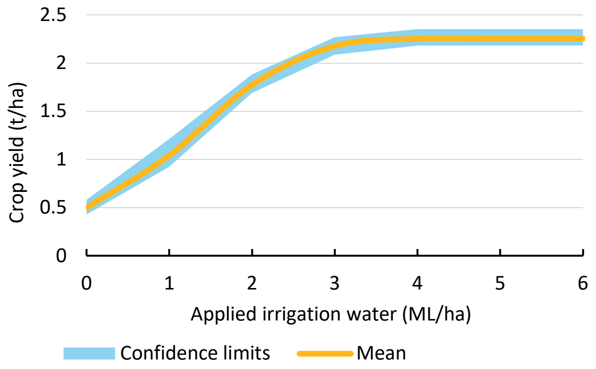

Figure 4-10 Crop yield plotted against applied irrigation water in Highbury Station climate for mungbean planted in July

Modelled confidence limits (20th to 80th percentile) and mean crop yield for mungbean. Representative of the production potential (i.e. assumes no nutrient limitations or pest damage). Assumes perfect timing of irrigation (i.e. no losses).

For horticultural crops, annual crops use considerably less water (around 5 ML/ha) than perennial crops, which can require more than 10 ML/ha (e.g. bananas) (Table 4-8).

The inter-annual variation that can be expected in total irrigation requirement has major implications for the reliability with which crops can be irrigated. Crops sown in the August to November period require the most water; however, this time of year is usually dry, and streams generally have the least flow, and water storages are also likely to be least full, highlighting an additive risk attached to 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 (e.g. dam, offstream storage).

Broadacre crop yields compare favourably with crop yields for other irrigated areas of north Queensland (e.g. the Burdekin). It needs to be reiterated that the simulated yields are potential yields based on good management and don't include potential losses associated with pests and diseases.

Climate change poses a potential risk to agricultural production and viability in future decades (see Section 2.4). To assess the potential impacts of climate change on crop yields climate change scenarios (rainfall, temperature, evaporation) for 2060 were incorporated into crop modelling analyses. In addition to climate variables, increased concentrations of carbon dioxide in the atmosphere affect plant growth and crop yields by increasing photosynthetic and water use efficiencies, which can increase plant growth and may offset negative impacts of decreased rainfall and higher temperatures. Given the importance of carbon dioxide on plant growth this was also assessed in the crop analysis.

Assuming irrigation supplies are not compromised, in simulations of future climate scenarios, broadacre crops such as grain sorghum, sugarcane, and forage sorghum are projected to maintain or even increase yields despite higher temperatures and evaporative demand because of the positive effects of increased carbon dioxide concentrations. This was not the case for mungbean, which shows a decrease in yield under a 2060 climate scenario. Under dryland conditions (no irrigation), the yield of sorghum was significantly reduced under a drier future climate scenario.

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Table 4-7 Cropping season, applied irrigation water, crop yield, price, variable cost, gross margin and break-even crop yield for field crops in the Mitchell catchment, averaged across all four locations, with data shown for two soil types (Sodosol and Vertosol), using 125 years of historical climate data (1890–2015)

Cotton crop yields are given as bales/ha rather than t/ha. All prices are $/t except cotton, which is $/bale. The 20th percentile, 50th percentile (median) and 80th percentile exceedance values are reported, for the 125 years between 1890 and 2015. Gross margins for the 20th, 50th and 80th percentiles are calculated using the variable costs shown, and the 20th, 50th and 80th percentile yields, respectively. Gross margins for industrial crops (cotton, sugarcane) assume delivery to a (currently non-existent) processing plant.

CROP	SEASON	APPLIED IRRIGATION WATER (ML/ha)			CROP YIELD (t/ha)			PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)			BREAK-EVEN CROP YIELD (t/ha)
		20th	50th	80th	20th	50th	80th		50th	20th	50th	80th	50th
Sodosol													
Sorghum	DS†	2.9	1.9	1.2	9.2	8.7	8.0	240	1606	577	481	344	6.7
Maize	DS	6.2	5.4	4.6	13.6	12.8	12.0	280	1914	1811	1620	1451	6.9
Mungbean	DS	3.4	3.2	2.9	2.4	2.3	2.2	1100	1154	1134	1025	916	1.1
Soybean	DS	4.7	3.8	2.8	4.0	3.8	3.6	475	1348	513	426	349	2.9
Chickpea	DS	2.8	2.3	1.8	3.1	2.8	2.6	900	1239	1475	1233	1052	1.4
Cotton	DS	5.9	5.5	5.2	10.7	10.5	10.2	480	2955	3013	2912	2754	6.2
Cotton	WS‡	4.5	4.0	3.4	10.3	9.8	9.5	480	2936	2803	2540	2388	6.1
Sugarcane	P§	15.5	11.9	10.2	195.4	121.9	110.2	42	2098	5453	3020	2664	46.8
Peanut	DS	5.9	5.4	4.8	5.9	5.7	5.3	1000	2438	3388	3172	2901	2.5
Vertosol													
Sorghum	DS	4.3	3.2	2.3	8.4	7.6	3.7	240	1592	376	231	–499	6.6
Maize	DS	6.1	5.2	4.5	13.6	12.9	12.1	280	1926	1788	1636	1476	6.9
Mungbean	DS	4.1	3.7	3.2	2.2	2.1	2.0	1100	1155	966	857	726	1.1
Soybean	DS	5.5	4.3	3.2	4.4	4.1	3.7	475	1392	630	524	391	3.0
Chickpea	DS	2.6	2.2	1.8	3.1	2.8	2.6	900	1237	1458	1257	1092	1.4
Cotton	DS	5.5	5.1	4.7	10.1	10.0	9.9	480	2941	2694	2647	2598	6.2
Cotton	WS	4.1	3.5	3.0	10.2	9.6	9.0	480	2925	2757	2439	2101	6.1
Sugarcane	P	14.3	10.7	9.2	193.7	119.3	107.2	42	2044	5427	2965	2592	45.0

CROP	SEASON	APPLIED IRRIGATION WATER (ML/ha)			CROP YIELD (t/ha)			PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)			BREAK-EVEN CROP YIELD (t/ha)
Rice	DS	8.6	8.1	7.7	10.0	9.9	9.7	400	2148	2008	1969	1908	5.2
Rice	WS	3.5	2.6	1.8	6.2	5.5	4.6	400	1529	960	744	489	3.7

†DS = dry season
‡WS = wet season
§P = perennial

Table 4-8 Cropping season, applied irrigation water, crop yield, price, variable cost, gross margin and break-even crop yield for horticultural and tree crops in the Mitchell catchment, averaged across all four locations

Gross margins (+25%, Average, –25%) reflect price variability. For mangoes, KP is Kensington Pride and PVR refers to plant variety rights mangoes, of which Calypso is an example.

CROP	SEASON	APPLIED IRRIGATION WATER (ML/ha)			CROP YIELD (unit/ha)	UNIT	PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)			BREAK-EVEN CROP YIELD (t/ha)
		20th	**50th**	**80th**				**Average**	**+25%**	**Average**	**–25%**	
Avocado	P[†]	8.9	7.8	7.3	1,243	carton	35	16,685	24,553	16,228	7,903	483
Banana	P	12.8	11.3	10.7	3,400	carton	18	44,398	14,048	2,205	–9,636	2,564
Capsicum	DS[‡]	5.1	4.6	4.4	2,969	carton	17.5	33,543	18,593	8,166	–2,261	1,952
Cashew	P	10.4	9.1	8.7	2,800	kg	2.5	4,675	1,345	140	–1,064	2,366
Lime	P	10.4	9.1	8.7	3,166	carton	14	38,659	8,198	–1,331	–10,861	2,807
Mango (KP)	P	7.5	6.6	6.2	1,000	tray	22	11,724	9,606	5,290	973	542
Mango (PVR)	P	7.5	6.6	6.2	2,500	tray	20	26,014	24,423	14,211	3,998	1,322
Papaya	P	10.4	9.1	8.7	6,600	carton	17	57,455	82,795	54,745	26,695	3,000
Rockmelon	DS	4.7	4.3	4.0	1,900	carton	18	23,998	10,839	3,853	–3,132	1,365
Watermelon	DS	5.4	4.9	4.7	47.5	tonne	900	26,250	14,829	6,098	–2,634	29

†P = perennial
‡DS = dry season

4.4.4 CROP GROSS MARGINS

A key component of determining potential financial viability is gross margin analysis. Gross margins are defined as total sales revenue less the costs of direct production, marketing and transport costs. Gross margin estimates are calculated on a dollar per hectare basis. No specific farm area is used but it is assumed that it is operationally of a commercial size.

Indicative crop gross margins are provided in Table 4-7 and Table 4-8; for several reasons, great care needs to be taken with their use. Gross margins are sensitive to variation in yield and price of outputs, and levels and costs of inputs. These vary from farm to farm, paddock to paddock and year to year.

Perhaps more importantly, gross margins provide no insight into the cost of establishing new enterprises. This requires the use of whole or partial farm budgets which, because of their enterprise specificity, are explored in Chapter 6.

The gross margins are provided merely as an indication of the cash flow that might be generated by established irrigated cropping enterprises in the Mitchell catchment. Gross incomes are based on crop yield values and the yields are also used to calculate tonnage-related variable costs (e.g. cartage, levies, harvesting), which are converted to a dollar per hectare cost and added to other variable costs of production. Pumping costs are calculated using the modelled median applied irrigation water (ML/ha). Costs and prices are obtained from a range of sources and full details are provided in the companion technical report on agricultural viability (Ash et al., 2018).

Gross margins are highly variable between crops, with the industrial crops (sugar and cotton) and peanut returning the highest gross margins. It is assumed in sugar and cotton that processing facilities (sugar mill, cotton gin) are available locally to reduce cartage costs. If these processing facilities are assumed to be unavailable then the gross margins would be negative. The gross margins for sugar and cotton are consistent with other regions in Queensland but it is important to note again that the estimated yields reflect optimum management and no unexpected pest or disease incursions and so are likely to be optimistic. Peanut returns are projected to be very high based on high yields (>5 t/ha) and the current good prices that are received for peanut crops. Maize also shows highly positive gross margins, mostly due to simulated high yields. Sorghum, soybean and wet-season rice produce the lowest returns. Wet-season rice produces low yields, reflecting the low radiation that is experienced over the rainy season.

Gross margins are likewise highly variable between different horticultural crops, with avocado, mango (plant variety rights (PVR) types such as Calypso) and papaya showing the highest gross margins in this analysis. Kensington Pride (KP) mangoes, rockmelon, watermelon and capsicum are all capable of producing positive gross margins, though these are less than $10,000/ha. Gross margins in horticulture are highly sensitive to prices received because of the high input costs of production. This, combined with rapid movements in prices due to supply and demand in local domestic markets, results in gross margins being highly negative when prices drop by 25%.

The inability of most broadacre crops to generate high gross returns as a single annual crop raises the challenge of how gross margins might be improved to better align with required returns for investment. Gross margins can be improved by either reducing variable costs or increasing returns.

In terms of reducing costs, achieving efficiencies in input costs (water, fertiliser, herbicides and pesticides) is usually an ongoing priority for management.

Freight costs make up a significant percentage of variable costs and can represent a significant proportion of gross returns. Freight costs can represent up to 25% of gross returns for broadacre grain costs and are very sensitive to the distance to market, given the relatively low prices received per tonne of product. In contrast, freight costs represent about 10% of gross returns for pulse crops (mungbean, chickpea) even though they need to be transported to cleaning and processing facilities near Townsville. A combination of high prices per tonne and relatively low yields means total tonnage of pulses transported is low compared with coarse grains.

Where local processing facilities are available (cotton gin, sugar mill, peanut drying and shelling facilities) freight costs as a percentage of total returns are generally less than 5%.

High-volume horticulture crops (melons, bananas, papaya) have relatively high transport costs (17 to 25% of gross returns) compared with higher value crops such as avocadoes and mangoes. Ash et al. (2017) identified supply chain costs as a significant challenge for agricultural development in northern Australia. Options for reducing freight costs to market include local processing facilities for high-volume broadacre crops or for horticultural products, establishing lower cost export options through the ports of Townsville or Cairns. Achieving a long-term profitable cropping enterprise will be difficult without a pathway for reducing freight costs as a percentage of the value of product.

Options for increasing gross returns are either through increasing yields or employing more intensive rotational cropping systems (particularly for broadacre crops) that provide more than one crop per year. Significant increases in yield of most crops have been achieved over the last few decades but these increases are over the longer term through improved genetics and farming system technologies. More intensive cropping systems potentially offer more immediate gains in financial returns. However, implementing more intensive rotational systems, including double cropping (two crops per year), is dependent on the interaction between soils, climate and water availability. These issues are explored in the next section on cropping systems.

4.4.5 CROPPING SYSTEMS

As indicated above, new agricultural developments that focus on field cropping may require more than a single crop in a year to generate significant enough revenues to meet development, fixed and variable costs. This can be achieved through rotational cropping systems, where crops are grown sequentially within a year or across years. For example, in double cropping two crops are grown in a 12-month period (e.g. cotton followed by mungbean). The number of different possibilities for cropping systems is very large, given the range of field crops, horticultural crops, forages and rotations that can be grown in northern Australia. The approach adopted in the Assessment focused on examining possible cropping system combinations that could be practically integrated into the climate end environment of the Mitchell catchment. For example, does the pattern of rainfall and soil trafficability permit two crops per year when combined with management resources and capacity to rapidly finish one crop and move into another crop with tightly constrained planting windows?

Two scenarios were explored:

1. Cotton grown from January to June followed by mungbean, grain sorghum or forage (lablab, sorghum or silage maize) grown between July and October.
2. A sugarcane break crop (e.g. mungbean, soybean, maize) rotation.

Cotton–mungbean

Double cropping with cotton followed by either mungbean or lablab shows that good crop yields can be obtained, if the management is sufficiently skilful operationally to harvest one crop and prepare the land and re-plant again with the required timing for both crops (Table 4-9). Based on the gross margins in Table 4-7, annual gross margins with a cotton–mungbean double crop could be in the order of $3500/ha.

Table 4-9 Paddock scale production and irrigation data for cotton–mungbean and cotton–lablab rotations in the Mitchell catchment

	PRODUCTION (bales or t/ha)	APPLIED IRRIGATION (mm)
Cotton	9.5 bales/ha	318
Mungbean	2.3 t/ha	451
Lablab hay	9.3 t/ha	543

Sugarcane break crop rotation

On the higher water holding capacity cracking clay soils in the Mitchell catchment, sugarcane in rotation with break crops such as soybean, mungbean or cotton is possible. For example, a sugarcane system may consist of five paddocks planted to either a cane plant crop, a ratoon crop of 1 to 3 years of age and a break crop (mungbean, soybean, sorghum) or fallow paddock. To maximise supply of cane to a mill, each block of five paddocks is repeated six times to represent six potential harvesting periods (months) from June to November. Cane is planted during May to June and harvested after 13 to 16 months depending on the harvest period June to November. Ratoon crops are harvested in 12 months.

Figure 4-11 shows phases for a May plant crop and June harvest period. A break crop of mungbean is sown following harvest of the 3r ratoon at the end of July. Alternatively, a soybean crop is sown in November and grown over the wet season and harvested in April prior to the establishment of the next plant cane crop. Mungbean yields (t/ha) and crop water demand (ML/ha) to be met by irrigation are presented in Figure 4-11.

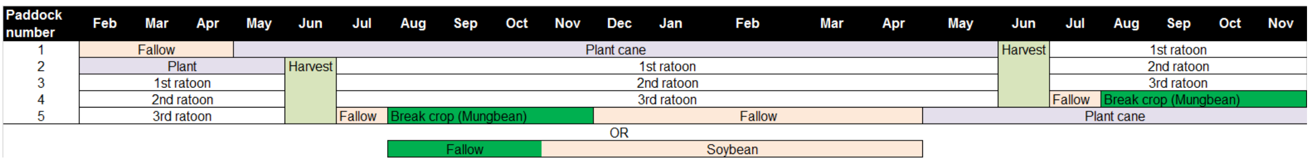

Figure 4-11 Sequence of plant cane, ratoon crops and break crops of soybean/mungbean in a sugarcane crop rotation system

Moderate yields of mungbean can be produced (1.5 to 1.8 t/ha), which are well in excess of break-even yields of 1.1 t/ha (Figure 4-12). In addition, they provide the valuable break that improves soil fertility for subsequent sugarcane crops. The benefits of introducing a legume rotation on subsequent sugarcane yields have been well documented (Garside and Bell, 2011). However, levels of adoption of this crop rotational system in established areas of sugarcane production are not high so this option represents best practice rather than established practice.

More broadly, the design of, and the management skills required to successfully implement either best-practice management for individual crops or intensive cropping rotations in tropical environments should not be underestimated. Throughout this assessment of agriculture in the Mitchell catchment, there is an assumption of good agronomic practice, which provides an optimistic view of potential yield and returns.

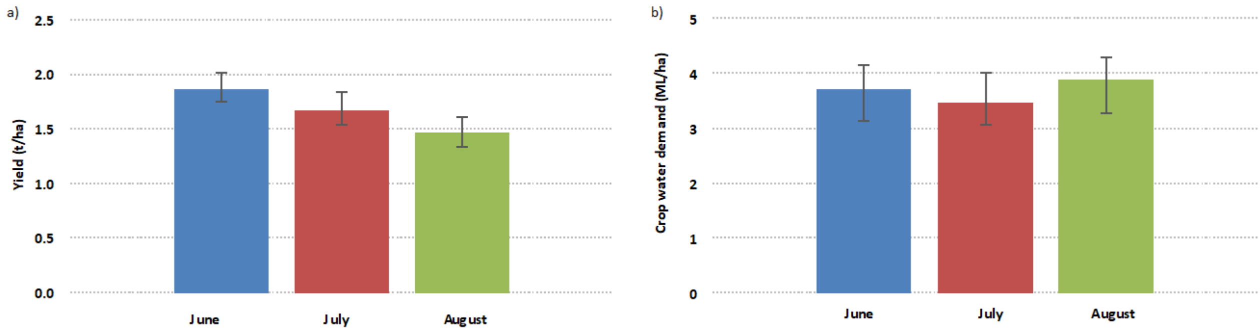

Figure 4-12 (a) Annual mungbean yield (t/ha) following a June, July and August cane harvest. (b) Crop water demand supplied by irrigation (ML/ha) for a mungbean crop following a June, July and August cane harvest

4.4.6 INTEGRATING FORAGES AND CROPS IN BEEF ENTERPRISES

The dominant beef production system that is employed across most of the Mitchell catchment is centred on cow-calf breeding operations with several variations in the post-weaning management and marketing of male animals produced by the breeding herds.

The highly seasonal rainfall and high inter-annual variability coupled with mostly infertile soils means that the stocking rate (animals/ha) that can be sustained in the long term is low (1 animal per 10 to 20 ha). Pasture production occurs mostly in the December to April period, when pasture growth rates can be very high, with almost no pasture production for the remainder of the year. A combination of pasture growth occurring over just a few months in the year and low soil fertility results in forage quality being low. Protein concentrations of forage are around 12% at the start of the wet season but fall to less than 5% late in the dry season, which is below animal maintenance requirements of around 7% crude protein.

Animal production is low as a result of the low carrying capacity and the poor quality of forage for much of the year. Weaning rates in the region are typically low (50 to 60%), as are estimated annual liveweight gains, which can range from 70 to 150 kg, with a mean of around 100 kg/animal/year (Rolfe et al., 2016).

To cope with low productivity per animal, holdings are usually reasonably large although they can range from around 10,000 ha in the more settled areas in the east of the catchment to over 500,000 ha in the west of the catchment. However, scale does not necessarily equate to profitability and until the increase in cattle prices in 2015, many properties in the north Queensland region had been unprofitable over the previous decade (McLean et al., 2014).

One option for overcoming some of the productivity constraints is to utilise improved forages to complement the base forage provided by semi-intact native woodlands and grasslands. Improved forages are species introduced from overseas and specifically bred to suit Australian conditions. Improved forages can be dryland (i.e. rainfed) or irrigated. Given the severe protein deficiency in native pastures during winter and spring, considerable attention has in the past focused on legumes that augment native pasture. This involves oversowing legumes into a native pasture without mechanical intervention, although fire can be used prior to sowing to reduce competition from established native pasture species. Indeed, research was undertaken by CSIRO over many years on Wrotham Park Station, in the central part of the Mitchell catchment, testing the establishment, persistence and productivity of *Stylosanthes* legumes. Productivity gains of animals grazing native grasses augmented with *Stylosanthes* are modest at around 20 to 30 kg/animal/year. While costs of sowing a *Stylosanthes* pasture are low compared with full cultivation and planting, reliability of establishment has resulted in modest levels of adoption.

Use of higher input, higher productivity pastures that are irrigated has been receiving more attention in recent years. On the back of improving cattle markets in the last two years, the general interest in more intensive irrigated developments has been increasing. However, there is currently little use of irrigated forage in the Mitchell catchment.

Irrigated forage options include:

- Perennial grasses (e.g. Rhodes grass)

  Irrigated perennial grasses are currently used across northern Australia, with Rhodes grass (*Chloris gayana*) most widely used, especially in the Pilbara and West Kimberley regions but also in north Queensland and the Douglas–Daly region in the NT. However, the total area of perennial grasses under irrigation across northern Australia is small (<2000 ha).

- Annual grasses (e.g. forage sorghum, maize)

  Annual forage grasses such as forage sorghum (*Sorghum* spp. hybrid) have been widely grown across northern Australia and are recommended by state and territory agencies as suitable forages for the tropics. They are mostly grown under irrigation but opportunistic dryland production is practised. Although forage sorghum is being widely used, it has mostly been for hay production and there is very little data available on animal production under grazing.

- Annual legumes (e.g. lablab, cowpea)

  Given the very low protein content of native tropical grasses over the dry season, irrigated and dryland legumes offer a means of increasing the protein content of diets of cattle in northern Australia. Cowpea (*Vigna unguiculata*) and lablab (*Lablab purpureus*) are both well-suited to the tropics.

Forage production and applied irrigation water data, for native pasture and three commonly used forage crops, Rhodes grass, forage sorghum and lablab are shown in Table 4-10 for three locations in the Mitchell catchment.

Table 4-10 Yields and water requirements for a range of rainfed and irrigated forages in the Mitchell catchment
Yields are expressed on a dry matter (DM) basis rather than fresh forage as this permits a better comparison between forage crops.

CROP	IRRIGATION	CHILLAGOE		HIGHBURY		DUNBAR	
		YIELD (t DM/ha)	WATER USE (ML/ha)	YIELD (t DM/ha)	WATER USE (ML/ha)	YIELD (t DM/ha)	WATER USE (ML/ha)
Native pasture	Dryland	1.3	NA†	1.2	NA	1.3	NA
Forage sorghum	Dryland	5.9	NA	10.8	NA	9.3	NA
Forage sorghum	Irrigated	14.9	4.2	17.0	3.4	20.1	4.5
Rhodes grass	Irrigated	34.8	13.2	35.5	14.5	32.4	14.0
Lablab	Irrigated	9.0	4.2	14.1	6.0	14.0	5.8

†NA = not available

Compared with sown forages, native pasture that relies on rainfall and is growing in nutrient deficient soil has low levels of production. Dryland forage sorghum, sown halfway through the wet season when soil profiles are full with water, can produce quite high amounts of forage, especially on a good clay soil that can store soil water well into the dry season, such as at Highbury. Irrigated forage sorghum produces yields of around 20 t dry matter/ha, which is consistent with measured yields at various sites across northern Australia. Rhodes grass can produce very high forage yields in excess of 30 t dry matter/ha, especially when it is fertilised with large amounts of nitrogen, as is the case for the results shown in Table 4-10. Although Rhodes grass can produce large quantities of biomass it also uses a very large volume of water (13 to 15 ML/ha) since it is irrigated year-round, which can be very costly if water is expensive to apply.

Irrigated forages can be used in a number of ways including grazing, hay, and silage. Most use of irrigated forages in tropical Australia has in recent years been for hay production rather than for grazing. This is because the areas of irrigated forage have been small, with hay being produced for special purpose feeding in yards for short periods (weaning, holding cattle for live export) and excess sold for local production. Irrigation has generally not been on a scale large enough to be used for production grazing of whole cohorts of animals in a large pastoral enterprise. The scale required for this type of enterprise option would be in the hundreds of hectares.

The potential options involving irrigation type, forage species, and use of those forages in a beef enterprise are numerous. For the Mitchell catchment, the three forages described above (Rhodes grass, forage sorghum, lablab) were used in assessing the animal production and economic implications from their incorporation into existing beef operations. Two beef system scenarios were used: (i) grazing of forages by young cattle to increase their weight at sale (from 300 kg to 400 to 450 kg) so that sale options and returns are increased; and (ii) a much smaller area of forage used to produce high-quality hay that is fed to early weaned calves in yards for an extended period. The aim of early weaning is to reduce lactation pressures on cows thereby increasing their body condition and improving subsequent calving percentages.

Using a 60,000-ha cattle operation, and using the climate at Highbury as an example, compared with a baseline property, use of forages can greatly increase growth of young animals in the grazing scenario and employing an early weaning strategy in combination with hay fed to young weaners can significantly increase the number of calves weaned (Table 4-11). In both scenarios the total amount of beef produced per year is markedly increased. Use of irrigated forage crops for grazing increases the growth of young cattle significantly, from 115 kg/head/year in baseline simulations to 272 kg/head/year in the grazed lablab option. Further, allowing young females to use the forage crops boosts their weights, which provides a lifetime benefit in increasing weaning rates by 2 to 3 percentage units.

Table 4-11 Production and financial outcomes from the different irrigated forage and beef production scenarios for a representative 60,000 ha property at Highbury

NPV analysis assumes a discount rate of 5% and an investment period of 15 years.

	BASELINE	GRAZED FORAGE FOR STEER FATTENING			EARLY WEANING STRATEGY USING HAY + EXCESS HAY SOLD LOCALLY		
Forage	None	Forage sorghum	Rhodes grass	Lablab	Forage sorghum	Rhodes grass	Lablab
Area of irrigated forage (ha)	0	250	185	400	110	80	200
Herd size (AE)	3677	3872	3876	3946	3778	3790	3778
Area of irrigated forage (ha)	0	250	185	400	110	80	200
Pasture utilisation (%)	20.6	20.3	20.2	20.1	20.3	20.4	20.3
Weaning rate (%)	55.0	58.0	58.0	59.0	65.0	65.0	65.0
Annual growth (kg/animal)	115	211	235	272	117	117	117
Beef produced per year (t)	406	570	582	619	472	475	472
Gross margin ($/ha)	211	251	240	268	248	245	273
Gross margin ($/AE)	13	16	15	17	15	15	17
Profit (EBIT) ($ m)	0.47	0.61	0.57	0.67	0.58	0.57	0.67
Net present value* ($ m) – $12,000/ha capital cost	NA†	–0.96	–0.85	–1.79	0.58	0.75	0.12
Net present value ($ m) – $20,000/ha capital cost	NA	–2.60	–1.95	–4.17	–0.07	0.28	–.07

†NA = not available

Growing a small area of hay, primarily used to feed early weaned calves (weaned at 4 months), significantly improves herd productivity, with weaning rates increasing by 7 to 10 percentage units.

While the grazed and hay scenarios produce similar net profits, the capital costs required for the hay scenario are considerably lower because of the smaller area of forage crop required. This has implications when the capital costs of development are considered in an investment analysis, using NPV analysis over a 15-year time horizon with a discount rate of 5%. For example, none of the grazed forages could produce a positive NPV when using capital costs of either $12,000 ha or $20,000/ha. This is because the area of cropping required for the grazed forage options is considerable and this demands a high capital cost, which makes it challenging to generate a positive NPV, even where annual profit increases are significant. In contrast, positive NPVs are possible for a number of the hay options when current beef prices of around $3.00 per kg are used (Table 4-11). Apart from hay requiring a lower capital outlay because the area of development is smaller, the benefits flow through the whole breeding herd as a result of the early weaning strategy. This highlights the importance of undertaking a full investment analysis to determine the likely returns on capital from different forage options.

4.5 Crop synopses

4.5.1 INTRODUCTION

Note that the estimates for land suitability in these synopses represent the total areas of the catchment unconstrained by factors such as water availability; land tenure; environmental and other legislation and regulations; and a range of biophysical risks such as cyclones, flooding and secondary salinisation. These are addressed elsewhere by the Assessment. The land suitability maps are designed to be used predominantly at the regional scale. Farm-scale planning would require finer scale, more localised assessment.

4.5.2 CEREAL CROPS

Cereal production is well-established in Australia. Around 20 million ha of land is devoted to grain (wheat, barley, grain, sorghum, oats, triticale, maize, etc.) production each year, yielding over 50 Mt/year with a value in 2016–17 of $26.1 billion (ABARES, 2018). Domestic markets demand all cereals. Significant export markets exist for wheat, barley and sorghum (grain) and there are niche export markets for grains such as maize and oats.

Among the cereals, the 'summer crops' such as sorghum (grain) and maize are the most promising for the Mitchell catchment. These could be grown opportunistically using dryland production or more continually using irrigation.

Assuming unconstrained development, approximately 3 million ha of the Mitchell catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for irrigated cereal cropping using spray irrigation in the dry season. About 1.3 million ha are moderately suitable with considerable limitations (Class 3) for furrow irrigation in the dry season. Inadequate drainage renders wet-season cropping under furrow irrigation to a much reduced area (Figure 4-13a) except for rice. About 100,000 ha are categorised as Class 3 for dryland cropping of sorghum (Figure 4-13b). Very little land is Class 2 (suitable with minor limitations) and there is no Class 1 land. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

The 'winter cereals' such as wheat and barley are not well-adapted to the environment of the Mitchell catchment. If grown during winter, they would require full irrigation.

To grow cereal crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is often a contract operation, and in larger growing regions other activities can also be performed under contract.

Table 4-12 provides summary information relevant to the cultivation of cereals, using sorghum (grain) as an example. The companion technical report on agricultural viability (Ash et al., 2018) provides greater detail for a wider range of crops.

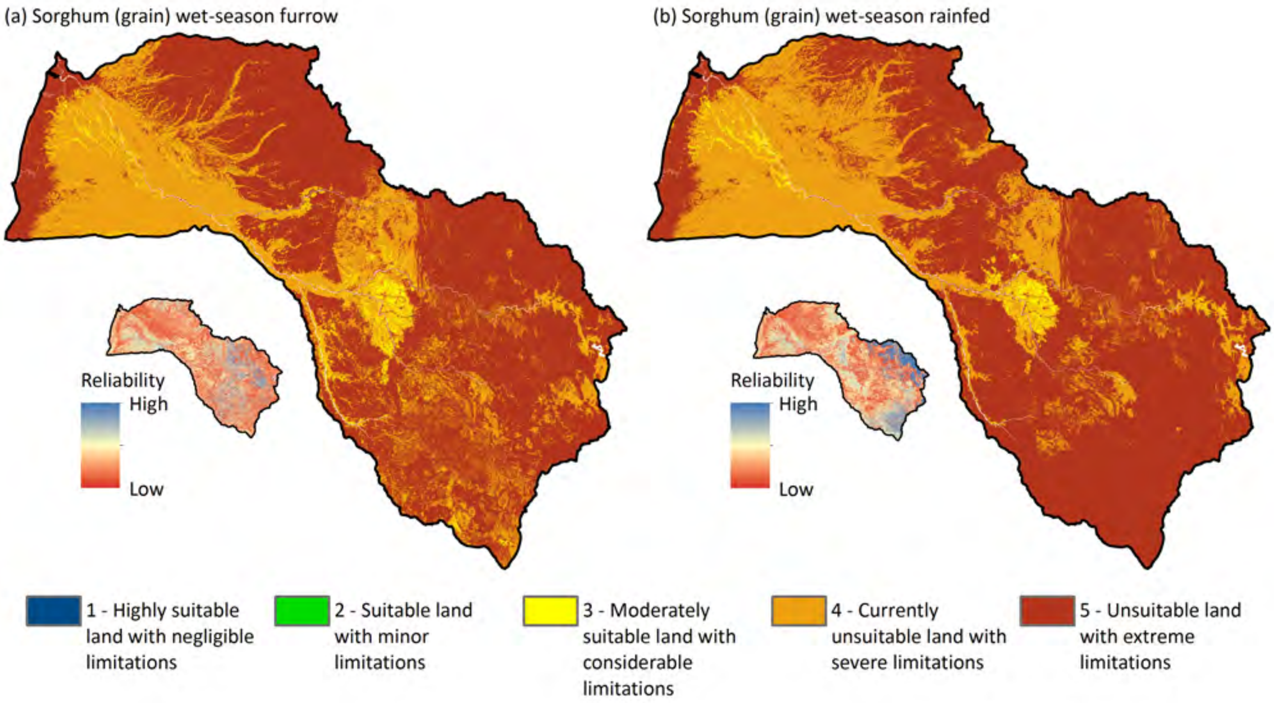

Figure 4-13 Modelled land suitability for grain sorghum grown in the wet season using (a) furrow irrigation and (b) rainfed

Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-14 Sorghum (grain)

Photo: CSIRO

Table 4-12 Sorghum (grain) (*Sorghum bicolor*)

PARAMETER	DESCRIPTION
Summary	Major summer rainfed (dryland) grain crop grown mainly for stock feed. Currently grown extensively in southern and central Queensland (600,000 to 700,000 ha). Sorghum has been a major grain crop in the NT, grown in rotation with pasture legumes such as Cavalcade. It can potentially supply an intensification of the northern Australian cattle industry.
Growing season	Planting window December to July. 120- to 180-day duration of growth. Ranges of sorghum cultivars are available to suit different sowing times and geographic locations.
Land suitability assessment	Land suitability is highly dependent on season of planting and type of irrigation. While 42% of the catchment is Class 3 or Class 2 for spray irrigation of grain sorghum in the dry season, this drops to 18% under furrow irrigation. Wet-season spray irrigation is limited to only 16% of the catchment and wet-season furrow to only 3%. Less than 2% is Class 3 for wet-season rainfed (dryland) although opportunistic use after good wet seasons may allow a greater area in some years. The coastal strip is limited by potential acid sulfate soils, while the uplands are dominated by excessive slope, rockiness and low soil water storage due to shallow and/or lightly textured soils. Wet-season cropping is limited by inadequate drainage of the soil profile on heavier soils. The clay soils in the mid-catchment are most suitable for furrow irrigation but are also at risk of secondary salinisation.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	1 to 4 ML/ha (January sowing). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Dryland: 3 to 8 t/ha (January sowing) Irrigated: 4 to 9 t/ha (January sowing)
Salinity tolerance	Moderately tolerant – EC_e threshold for yield decline 6.8 dS/m
Downstream processing	Available for direct delivery to end user.
By-products	Biomass for stock feed, bio-processing?
Production risks	Frost, heat stress at flower, minimum soil temperature for germination
Rotations	High potential for annual rotation.
Management considerations	Header, row crop planter, spray rig (pest control), fertiliser
Complexity of management practices	Medium
Markets and emerging markets	In Australia sorghum grain is used mostly for stock feed in the cattle, pig and poultry industries. A large amount of grain is exported. Potential emerging market for feedlots supplying local abattoir.
Prices	Generally, $150/t to $300/t
Opportunities and risks under a changing climate	More tolerant of drought and temperature stress than maize.
Further reading	DAFF (2011a)

4.5.3 FOOD LEGUME (PULSE CROPS)

Pulse production is well-established in Australia. Approximately 2 million hectares of pulse crops are grown annually, producing around 5 million tonnes of mainly chickpea, lupin and field pea with a value greater than $3.2 billion (ABARES, 2018). Pulses produced in the Mitchell catchment would most likely be exported.

The pulses, many of which have a short growing season, are often well-suited to opportunistic dryland production or more continuous irrigated production, probably in rotation with cereals or other non-legume crops.

Assuming unconstrained development, nearly 3 million ha of the Mitchell catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for irrigated cropping of pulses using spray irrigation in the dry season (Figure 4-15a, Table 4-1). About 1.3 million ha are moderately suitable with considerable limitations (Class 3) for furrow irrigation in the dry season (Figure 4-15b). About 130,000 ha are categorised as Class 3 for dryland cropping. Only a small proportion of land is Class 2 (suitable with minor limitations) and there is no Class 1 land. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

Not all pulse crops are likely to be suited to the Mitchell catchment. Those that are 'tender' such as field peas and beans may not be well-suited to the highly desiccating environment and periodically high temperatures. Direct field experimentation in the catchment is required to confirm this, for these and other species.

Pulses are often advantageous in rotation with other crops because they provide a disease break and, being legumes, often provide nitrogen for subsequent crops. Even where this is not the case, their ability to meet their own nitrogen needs can be beneficial. This may be a distinct advantage in areas such as the Mitchell catchment where freight costs (for fertiliser, etc.) pose a considerable cost burden on potential growers. Mungbeans are also high value (>$1000/t) and so the freight costs as a percentage of the value of the crop are low compared with cereal grains.

To grow pulse crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is generally a contract operation, and in larger growing regions other activities can also be performed under contract. The equipment required for pulse crops is the same as is required for cereal crops, so farmers intending on a pulse and cereal rotation would not need to purchase extra 'pulse-specific' equipment.

Table 4-13 provides summary information relevant to the cultivation of many pulses, using mungbean as an example. The companion technical report on agricultural viability (Ash et al., 2018) provides greater detail for a wider range of crops.

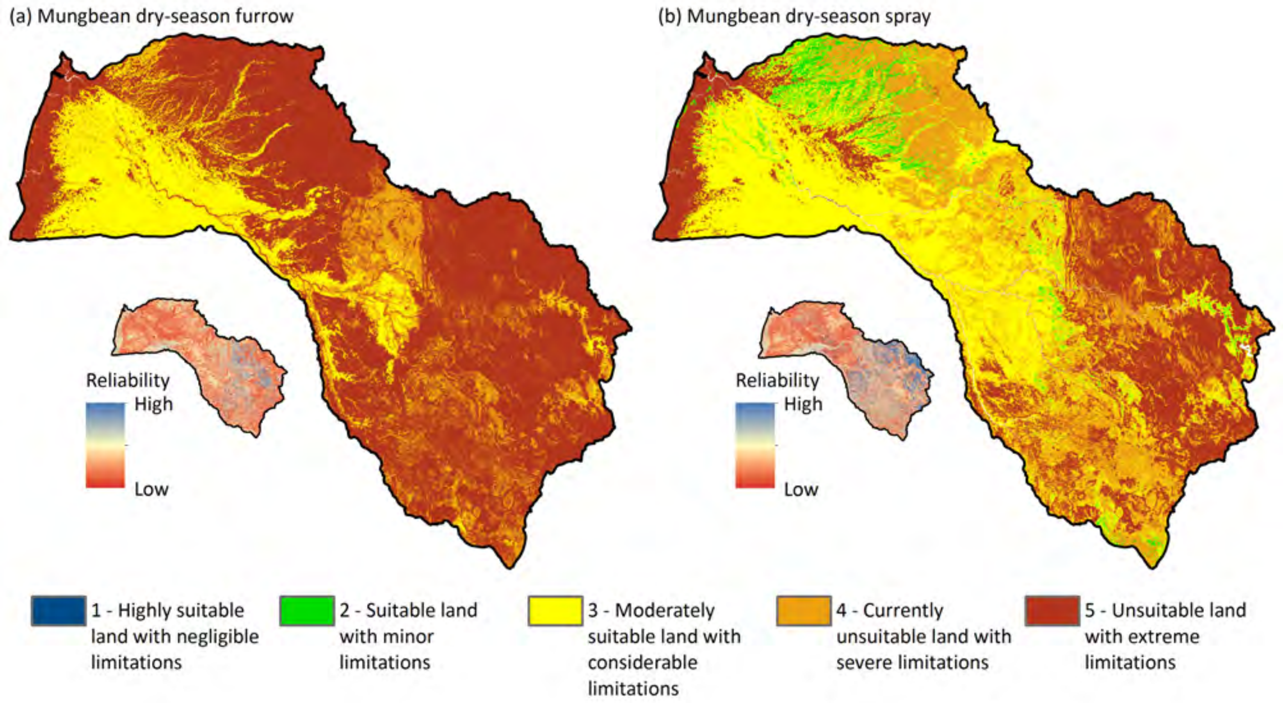

Figure 4-15 Modelled land suitability for mungbean in the dry season using (a) furrow irrigation and (b) spray irrigation

Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-16 Mungbean

Photo: CSIRO

Table 4-13 Mungbean *(Vigna radiata)*

PARAMETER	DESCRIPTION
Summary	Mungbean is a relatively quickly maturing (90 days) grain legume that can be sown in early spring or late summer as part of a planned rotation or as an opportunity crop. Mainly used for human consumption (sprouting and processing) but can be used as green manure and livestock forage. In the northern grains region of Queensland and NSW, 66,000 ha were grown in 2011. Generally reliable production for spring and summer plantings for both rainfed (dryland) and irrigation. Market-driven demand for high-quality product for sprouting.
Growing season	Planting window February to May
Land suitability assessment	While 42% of the catchment is Class 3 or Class 2 for spray irrigation of mungbean in the dry season (including nearly 300,000 ha of Class 2) this drops to 18% under furrow irrigation because the extensive sands north-east of the delta and in the mid- and upper catchment are too permeable. Less than 2% is Class 3 for rainfed (dryland) although opportunistic use after good wet seasons may allow a greater area in some years. The coastal strip is limited by potential acid sulfate soils, while the uplands are dominated by excessive slope, rockiness and low soil water storage due to shallow and/or lightly textured soils. The clay soils in the mid-catchment are most suitable for furrow irrigation but are also at risk of secondary salinisation.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	3 to 5 ML/ha (August sowing). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Dryland: 1 to 2 t/ha (January sowing) Irrigated: 2 to 2.5 t/ha (August sowing)
Salinity tolerance	Sensitive – ECe Threshold for yield decline 1.8 dS/m
Downstream processing	Available for direct delivery to end user.
By-products	Biomass for stock feed
Production risks	Rain periods during late grain fill for spring-sown mungbean. Insect damage resulting in quality downgrades
Rotations	Opportunity crop, annual rotation
Management considerations	Header, row crop planter, spray rig (pest control)
Complexity of management practices	Medium
Markets and emerging markets	Increasing demand for high-quality grain to supply the domestic market. Nearly all (95%) of the Australian mungbean crop is exported (DEEDI, 2010).
Prices	World mungbean prices are largely determined by both the volume and quality of the crops in China and Burma. Price trends usually become obvious in December when the harvest of the Chinese crop nears completion and both the volume and quality of production become apparent. Mungbeans are classified into five grades and price varies accordingly.
Opportunities and risks under a changing climate	Short-season opportunity crop, lower fertiliser requirements, potential for increased insect pest pressure as a result of increased temperatures
Further reading	DEEDI (2010), DAFF (2012c)

4.5.4 OILSEED CROPS

Soybean, canola and sunflowers are oilseed crops used to produce vegetable oils, biodiesel and for supplementary use as high protein meals for intensive animal production (cottonseed is also classified as an oilseed that is used for animal production). Soybean is also used in processed foods such as tofu; it can provide both green manure and soil benefits in crop rotations, with symbiotic nitrogen fixation adding to soil fertility and sustainability in an overall cropping system. Soybean is used commonly as a rotation crop with sugarcane in northern Queensland. Summer oilseed crops such as soybean and sunflower are more suited to tropical environments than winter-grown oilseed crops such as canola.

Soybean is sensitive to photoperiod (day length) and requires careful consideration in selection of the appropriate variety for a particular sowing window. Unlike soybean, sunflower cannot be baled or used for forage and because it is susceptible to many of the same diseases as legumes it should not be used in rotation with legumes.

Australia produces around 5 to 6 million tonnes of oilseed crop annually, about 80% of which is from canola and the remainder primarily from cottonseed (ABARES, 2018), with soybean and sunflowers contributing 3 and 4%, respectively.

Assuming unconstrained development, between 2.5 and 3 million ha of the Mitchell catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for irrigated cropping of oilseeds using spray irrigation in the dry season (Figure 4-17a). Between 800,000 ha and 1.3 million ha are moderately suitable with considerable limitations (Class 3) for furrow irrigation in the dry season (Figure 4-17b). Inadequate drainage renders wet-season cropping under furrow irrigation to a much reduced area. About 700,000 ha are categorised as Class 3 for dryland cropping. Only a small proportion of land is Class 2 (suitable with minor limitations) and there is no Class 1 land. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

To grow oilseed crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is generally a contract operation, and in larger growing regions other activities can also be performed under contract. The equipment required for oilseed crops is the same as is required for cereal crops, so farmers intending on an oilseed and cereal rotation would not need to purchase extra ‘oilseed-specific’ equipment.

Table 4-14 provides summary information relevant to the cultivation of oilseed crops, using soybean as an example. The companion technical report on agricultural viability (Ash et al., 2018) provides greater detail for a wider range of crops.

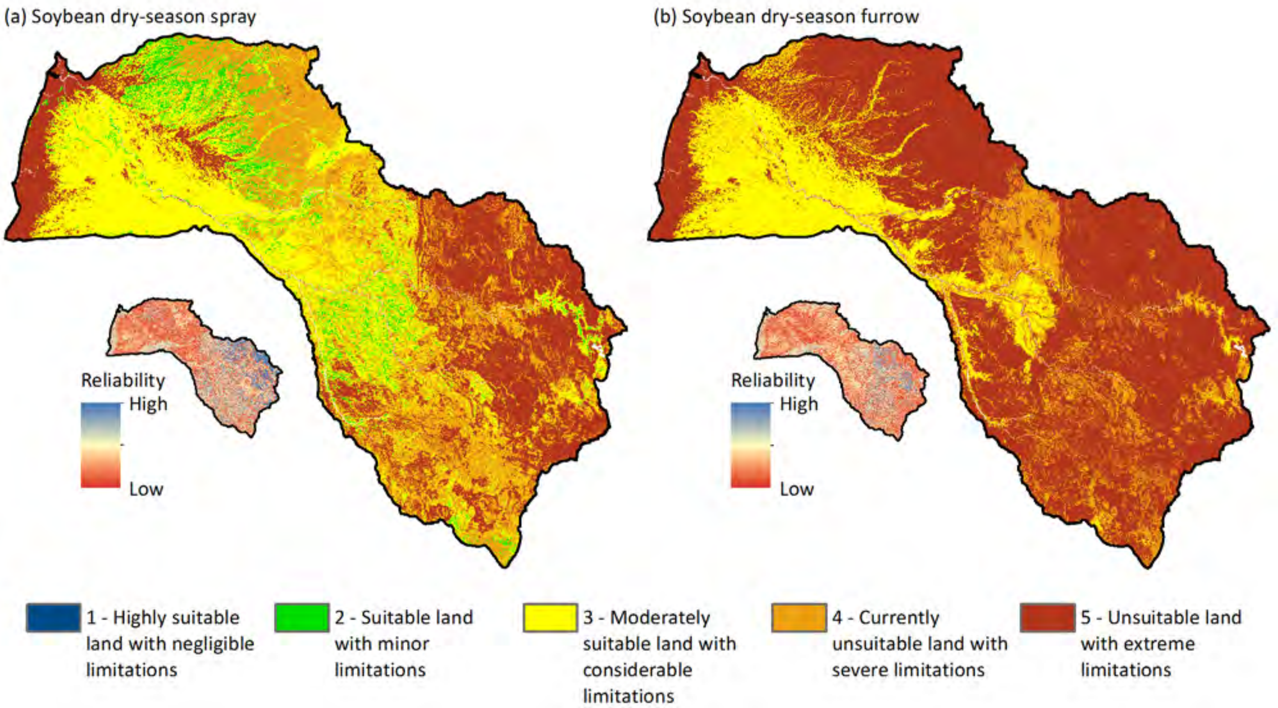

Figure 4-17 Modelled land suitability for soybean in the dry season using (a) spray irrigation and (b) furrow irrigation
Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-18 Soybean
Photo: CSIRO

Table 4-14 Soybean *(Glycine max)*

PARAMETER	DESCRIPTION
Summary	Soybean (*Glycine max*) is a legume with a compact growth habit less than 1 m high. Soybean is the most widely grown oilseed crop, with many varieties available to match a wide range of Australian environments – primarily differentiated by the time taken to maturity. Soybeans flower as day length becomes shorter, so varieties are matched to a combination of latitude and planting time. Longer varieties are planted earlier (November) and shorter maturing varieties can be planted later (January). Soybean is suited to a range of soil types and can be successfully grown without irrigation, relying on wet-season rain, but will yield better with irrigation. It is able to tolerate moderate levels of flooding and soil salinity. It is being increasingly used as an irrigated forage in northern Australia because of its high productivity and ease of establishment.
Growing season	Under irrigation planting from late spring (November) through to January. Sowing time is matched to variety.
Land suitability assessment	Land suitability is highly dependent on season of planting and type of irrigation. While 42% of the catchment is Class 3 or Class 2 for spray irrigation of soybean in the dry season, this drops to 18% under furrow irrigation. Less than 2% is suitable for rainfed (dryland) although opportunistic use after good wet seasons may allow a greater area in some years. The coastal strip is limited by potential acid sulfate soils, while the uplands are dominated by excessive slope, rockiness and low soil water storage due to shallow and/or lightly textured soils. Wet-season cropping is limited by inadequate drainage of the soil profile on heavier soils. The clay soils in the mid-catchment are most suitable for furrow irrigation but are also at risk of secondary salinisation.
Irrigation system requirements	Spray, surface
Applied irrigation water (median)	4 ML/ha. Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Irrigated: 3.5 to 4.0 t/ha
Salinity tolerance	Moderately tolerant
Downstream processing	Either sourced for edible trade (which attracts a premium) or delivered for crushing and oil extraction.
By-products	Crushed by-product is used for stock feed. Oil has potential use in biofuels.
Production risks	Wet conditions at harvest can be detrimental to grain quality. Wet growing conditions can also increase pest and disease pressure, requiring more control.
Rotations	Soybean is commonly used in rotations including sugarcane, cotton, rice and other crops. Soybean is a legume and therefore able to 'fix' atmospheric nitrogen, providing a benefit to the following crop.
Management considerations	Ability to effectively use inoculants and desiccants. Direct seeders and headers. Ability to identify pests and diseases and apply effective control measures appropriately.
Complexity of management practices	Medium
Markets and emerging markets	Primarily domestic market
Prices	\$450 to \$750 per tonne
Opportunities and risks under a changing climate	Under water constraints varieties with shorter times to maturity can be planted to conserve water.

4.5.5 ROOT CROPS, INCLUDING PEANUT

Root crops are those vegetables where the harvested material grows under the ground. The harvesting of root crops involves 'pulling' the material from the ground, prior to either direct harvest or drying prior to harvest. While peanut is technically an oilseed crop, it has been included in the root crop category due to its similar agronomic requirements (i.e. the need for it to be 'pulled' from the ground as part of the harvest operation).

When peanut is included in the root crop category, peanut is by far the most likely root crop that would be grown in the Mitchell catchment. The Australian peanut industry currently produces approximately 20,000 to 25,000 t/year from around 8000 ha, with an on-farm annual value of production of $15 to $20 million. The Australian industry is focused in Queensland, with a major production area just to the south of the Mitchell catchment in Tolga.

Root crops are potentially well-suited to the lighter soil types in the Mitchell catchment. Root crops are not suited to growing on heavier clay soils such as the Vertosols that dominate the lower and central Mitchell because they need to be pulled from the ground for harvest, and the heavy clay soils, such as cracking clays, are not conducive to easy crop pulling.

Assuming unconstrained development, approximately 1.8 million ha of the Mitchell catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for irrigated cropping of root crops using spray irrigation in the dry season (Figure 4-19). In the wet season this area is reduced to around 150,000 ha. Less extensive areas are suited (Class 3) to furrow irrigation with about 160,000 ha in the dry season and less than 10,000 ha in the wet season with wetness on the heavier textured soils being the limitation and the lighter textured soils being too permeable. Given root crops are not suited to heavy soils and these heavier textured soils are most suited to furrow irrigation, the root crops are largely suited to spray irrigation. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

To grow root crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. The harvesting operation requires specialised equipment to 'pull' the crop from the ground, and then to pick it up either immediately or after a drying period.

Table 4-15 provides summary information relevant to the cultivation of root crops, using peanut as an example. The companion technical report on agricultural viability (Ash et al., 2018) provides greater detail for a wider range of crops.

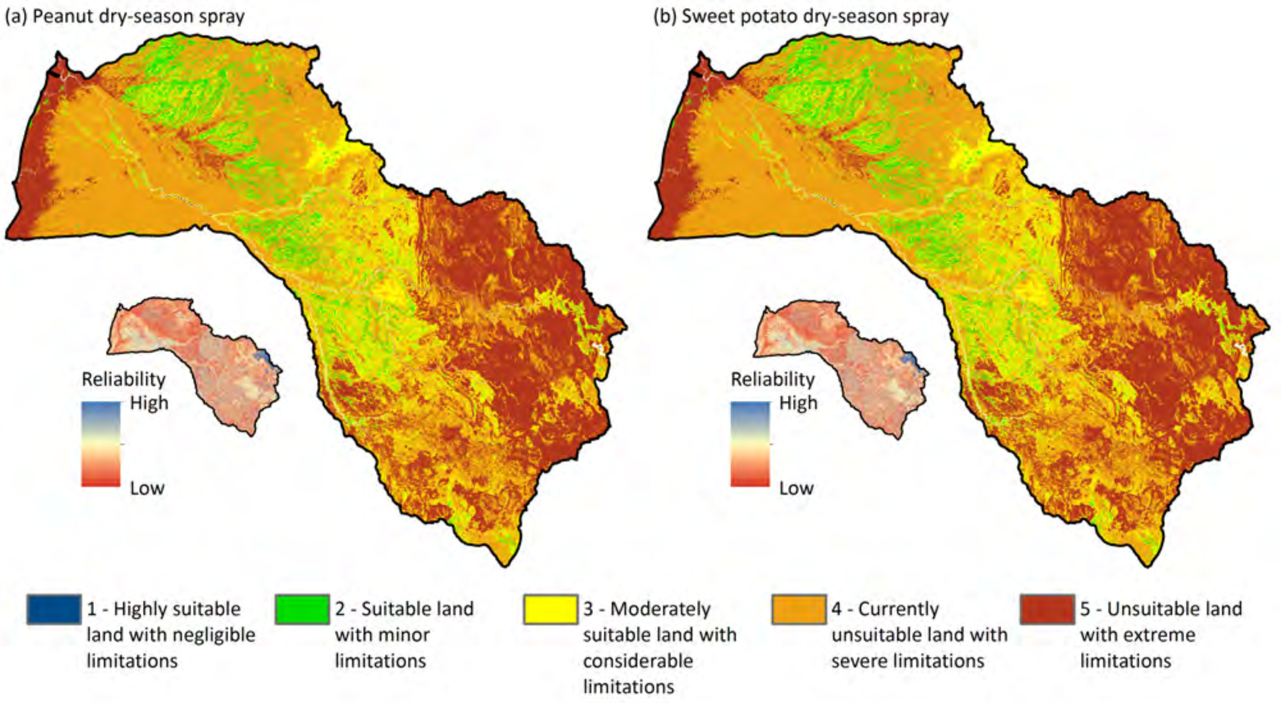

Figure 4-19 Modelled land suitability for (a) dry-season peanut using spray irrigation and (b) dry-season sweet potato using spray irrigation
Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-20 Peanuts
Photo: Shutterstock

Table 4-15 Peanut (*Arachis hypogaea*)

PARAMETER	DESCRIPTION
Summary	Peanut (*Arachis hypogaea*) is a legume with a compact growth habit less than 0.6 m high. Most peanuts grown in Australia are grown in Queensland, primarily around Kingaroy, Bundaberg/Childers, Emerald and the Atherton Tablelands. While technically an oilseed crop, the agronomic requirements of peanut are close to those of root crops. Peanut can be grown under irrigation or dryland where rainfall is suitable. Peanut varieties are either Virginia, runner or Spanish type. Virginia is used in the snack food industry, with runner and Spanish used in the manufacturing industries. Harvesting of peanut is specialised, occurring is two distinct operations requiring specialised equipment. First the crop roots are cut below the pods and the bush is 'pulled' from the ground. In the second stage the pods are removed from the rest of the bush in a process called 'threshing'. Most peanut pods will then need drying prior to being safe for storage.
Growing season	Under irrigation peanut can be grown in the wet season or dry season. Planting for wet-season production is from December to February and planting for dry-season production is from late March to early June.
Land suitability assessment	Land suitability for root crops is highly dependent on soils, preferring the lighter textured soils. Approximately 25% of the catchment is Class 3 or better for peanut under spray irrigation in the dry season, reflecting these lighter textured soils, this drops to only 2% in the wet season. The coastal strip is limited by potential acid sulfate soils, while the uplands are dominated by excessive slope, rockiness and low soil water storage due to shallow and/or lightly textured soils.
Irrigation system requirements	Spray. Peanut is not suited to the heavy soils suited to surface irrigation.
Applied irrigation water (median)	5.2 to 5.5 ML/ha. Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Irrigated: 5.3 to 6.4 t/ha
Salinity tolerance	Moderately sensitive
Downstream processing	Peanuts must be dried prior to storage, which is commonly done in dryers, but under favourable conditions can be done in the field prior to threshing. Peanuts are then transferred to a processing facility (e.g. Kingaroy) where they are shelled and graded, prior to being sent to market either raw or blanched, crushed for oil extraction and used in manufacturing peanut-based products for human consumption.
By-products	Peanut shell is used for mulch or animal feed. Crushed by-product used in stock feed mixes.
Production risks	Dry soil at harvest can damage crop during 'pulling'. Wet conditions after pulling can degrade crop quality. Hot dry conditions reduce yield. High temperatures and high moisture content after harvest increases aflatoxin risk.
Rotations	Peanut is well-suited to crop rotations with cereals such as maize or rice, and can be planted in a sugarcane fallow. Peanut can be wet- or dry-season grown in the Mitchell catchment. Peanut is a legume and therefore able to 'fix' atmospheric nitrogen, providing a benefit to the following crop.
Management considerations	Ability to effectively use inoculants and desiccants. Harvesting and threshing equipment, access to dryers
Complexity of management practices	Medium
Markets and emerging markets	Primarily domestic market
Prices	$1000 per tonne
Opportunities and risks under a changing climate	Hotter and drier dry seasons could limit areas suitable to peanuts.
Further reading	DAFF (2011b)

4.5.6 FORAGES

Forage, hay and silage are crops that are grown for consumption by animals. Forage is consumed in the paddock in which it is grown, which is often referred to as 'stand and graze'. Hay is cut, dried, baled and stored before being fed to animals at a time when natural pasture production is low (generally towards the end of the dry season). Silage use resembles that for hay, but crops are stored wet, in anaerobic conditions where fermentation occurs to preserve the feed's nutritional value.

Dryland and irrigated production of fodder is well-established throughout Australia, with over 20,000 producers, most of whom are not specialist producers. Fodder is grown on approximately 30% of all commercial Australian farms each year, and 70% of fodder is consumed on the farms on which it was produced. Approximately 85% of production is consumed domestically. The largest consumers are the horse, dairy and beef feedlot industries. Fodder is also widely used in horticulture for mulches and for erosion control. There is a significant fodder trade in support of the northern beef industry, though there is room for expansion as fodder costs currently comprise less than 5% of beef production costs (Gleeson et al., 2012).

Non-leguminous forage, hay and silage

The Mitchell catchment is well-suited for dryland or irrigated production of non-leguminous forage, hay and silage. Potential markets exist in the extensive cattle industry of northern Australia, which may comprise among the most promising opportunities for dryland and irrigated agriculture in the Mitchell catchment. There is potential for farmers primarily engaged in extensive cattle production to use irrigated forage, hay and silage to increase the beef turnoff from their enterprises.

Forage crops include grasses, both annual and perennial, such as sorghum, Rhodes grass, maize, and Jarrah grass, with particular cultivars specific for forage. These grass forages require considerable amounts of water and nitrogen as they can be high yielding (20 to 40 t dry matter/ha). Given their rapid growth, crude protein levels can drop very quickly, reducing their value as a feed for livestock. To maintain high nutritive value, high levels of nitrogen need to be applied and in the case of hay, the crop needs to be cut every 40 to 60 days. The rapid growth of forage during the late spring and summer months can make it challenging to match animals to forage growth so that it is kept leafy and nutritious and does not become rank and of low quality. Dryland hay production from perennials gives producers the option of irrigation when required or, if water becomes limiting, allowing the pasture to remain dormant before water again becomes available. Silage can be made from a number of crops, such as grasses, maize and sorghum.

Assuming unconstrained development, up to 3 million ha of the Mitchell catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for irrigated hay, forage or silage production using spray irrigation in the dry season, including Rhodes grass (Figure 4-21a). About 1.3 million ha are moderately suitable with considerable limitations (Class 3) for furrow irrigation in the dry season but the amount of land available for furrow irrigation during the wet season is reduced due to inadequate drainage (Figure 4-21b). Only a small proportion of land is Class 2 (suitable with minor limitations) and there is no Class 1 land. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

Apart from irrigation infrastructure, the equipment needed for forage production is machinery for planting. Fertilising and spraying equipment is also desirable but not necessary. Cutting crops for hay or silage requires more specialised harvesting, cutting, baling and storage equipment.

Table 4-16 describes Rhodes grass production for hay over a 1-year cycle. Rhodes grass was chosen primarily because of the ability to model its production over 125 years. Information similar to that in Table 4-16 for grazed forage crops is presented in the companion technical report on agricultural viability (Ash et al., 2018).

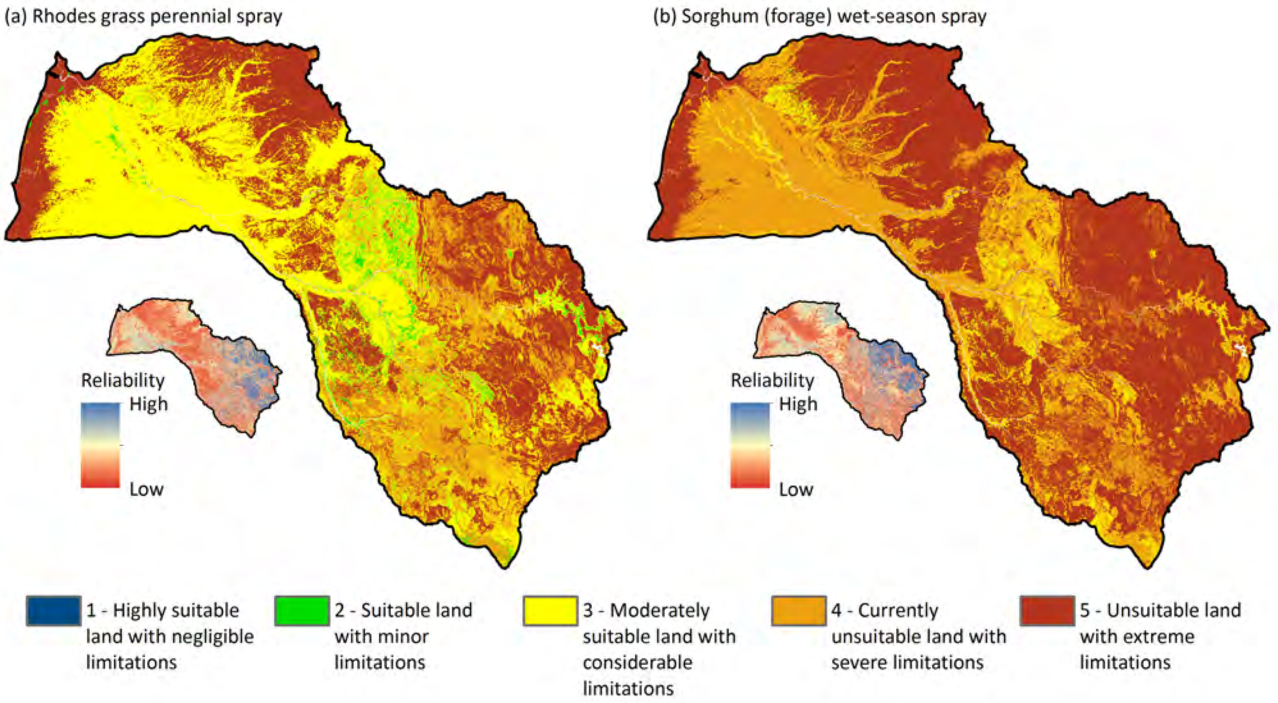

Figure 4-21 Modelled land suitability for (a) Rhodes grass and (b) forage sorghum, both grown using spray irrigation
Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-22 Rhodes grass
Photo: CSIRO

Table 4-16 Rhodes grass *(Chloris gayana)*

PARAMETER	DESCRIPTION
Summary	Rhodes grass (*Chloris gayana*) is a drought tolerant perennial grass with a growth habit of 0.75 to 1.5 m in height. In dryland environments it prefers an annual rainfall of at least 650 mm and it is well-suited to a wide range of soils from light loams to heavy clays. Rhodes grass has a high leaf to stem ratio for a tropical grass but it can quickly go to seed if not cut or grazed regularly. It is able to tolerate moderate levels of flooding and soil salinity. It is being increasingly used as an irrigated forage in northern Australia because of its high productivity and ease of establishment.
Growing season	Under irrigation planting from early spring (September) through to autumn, though growth continues, albeit more slowly, through the cooler dry-season months.
Land suitability assessment	A large proportion of the catchment, 46%, is Class 3 or Class 2 for Rhodes grass under spray irrigation. Under furrow irrigation this drops to 13% principally due to wet-season drainage constraints. The coastal strip is limited by potential acid sulfate soils, while the uplands are dominated by excessive slope, rockiness and low soil water storage due to shallow and/or lightly textured soils. The clay soils in the mid-catchment are most suitable for furrow irrigation but are also at risk of secondary salinisation.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	12 to 16 ML/ha. Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Irrigated: 30 to 40 t/ha
Salinity tolerance	Moderately tolerant
Downstream processing	Available for direct delivery to end user.
By-products	Potential use in biofuels.
Production risks	Slow to establish without adequate water post sowing. Low frost tolerance.
Rotations	Perennial pasture. Potentially a component of a ley farming system, where crops are grown in rotation with grass pastures or legumes to disrupt carry-over pest and disease and improve soil fertility and structure.
Management considerations	Baler, forage cutter. Nitrogen fertiliser may be required to maintain productivity if not sown with legumes. No significant pests or diseases.
Complexity of management practices	Low
Markets and emerging markets	Growing demand from northern Australian livestock industry for good-quality forages.
Prices	Primarily for use on-farm. Price received will depend on drought conditions, with higher prices during dry periods.
Opportunities and risks under a changing climate	Drought tolerant, with some tolerance of moderate soil salinity (when established).
Further reading	DAFF (2013a)

Forage legume

The use of forage legumes is similar to that of forage grasses, described early in Section 4.5.6. They are generally grazed by animals but can also be cut for silage or hay. Some forage legumes are well-suited to the Mitchell catchment, and would be considered among the more promising opportunities for irrigated agriculture (Table 4-17 and Figure 4-23).

Forage legumes are desirable because of their high protein content and their ability to fix atmospheric nitrogen. The nitrogen fixed during a forage legume phase is often in excess of that crop's requirements, which leaves the soil with additional nitrogen. Forage legumes could be used by the northern cattle industry, and farmers primarily engaged in extensive cattle production could use irrigated forage legumes to increase the capacity of their enterprise, turning out more cattle from the same area. Cavalcade and lablab are currently grown in northern Australia and would be well-suited to the Mitchell catchment.

Assuming unconstrained development, nearly 3 million ha of the Mitchell catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for irrigated forage legumes using spray irrigation in the dry season (Figure 4-23a) and about 600,000 ha for spray irrigation in the wet season (Figure 4-23b). About 1.2 million ha are moderately suitable with considerable limitations (Class 3) for furrow irrigation in the dry season but there is less than 50,000 ha considered Class 3 or better for wet-season cropping under furrow irrigation principally due to inadequate drainage. While furrow irrigation is possible it is not the most water-efficient method of irrigation, a potentially important consideration in a strongly water limited environment such as the Mitchell catchment. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

The equipment needed for grazed forage legume production is similar to that for forage grasses, that is, a planting method, with fertilising and spraying equipment being desirable but not essential. Cutting crops for hay or silage requires more specialised harvesting, cutting, baling and storage equipment.

Table 4-17 describes lablab production over a 1-year cycle. The comments could be applied similarly to Cavalcade production.

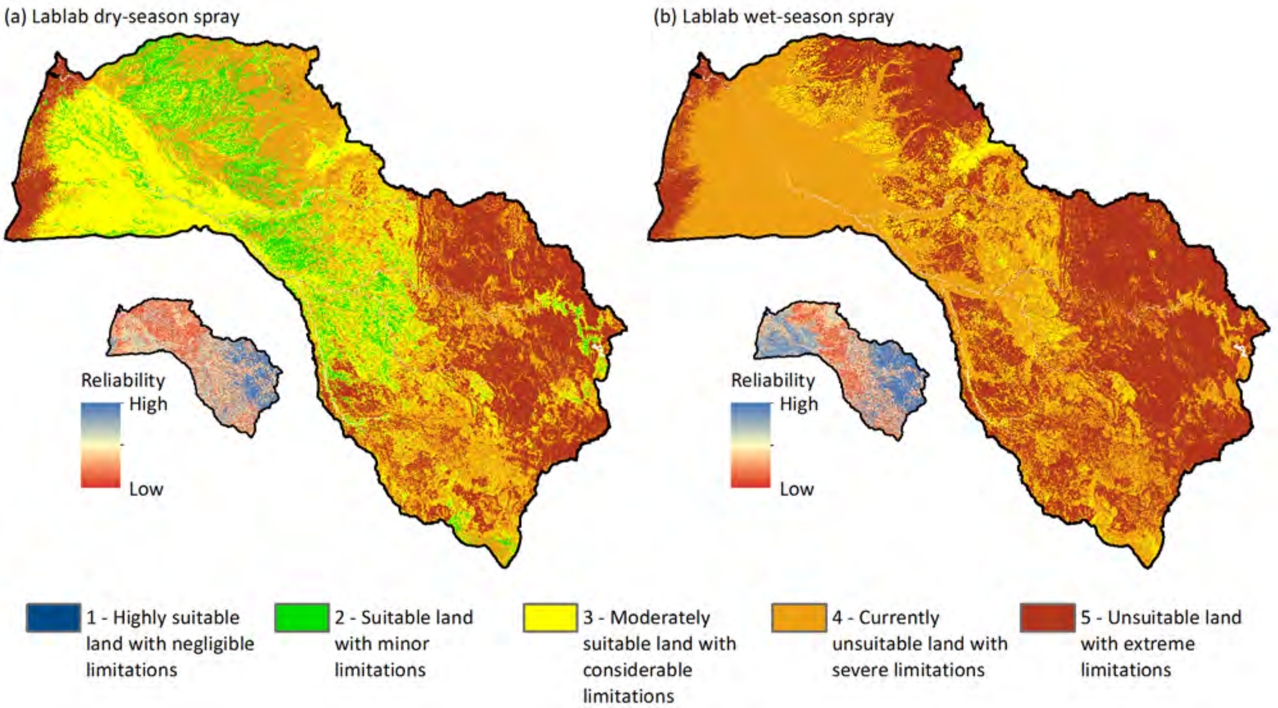

Figure 4-23 Modelled land suitability for lablab using spray irrigation in (a) the dry season and (b) the wet season
Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-24 Lablab
Photo: CSIRO

Table 4-17 Lablab (*Lablab purpureus*)

PARAMETER	DESCRIPTION
Summary	Lablab is a widely adapted forage legume sown for grazing, hay production and green manure. It is used in mixed cropping and livestock systems and sometimes as a legume ley in cropping systems to address soil fertility. It can be grown on the majority of arable soils, from deep sands to heavy clays with adequate drainage. Used in mixed cropping and livestock systems in northern Australia.
Growing season	Under irrigation planting from early spring (September) through to autumn
Land suitability assessment	While 42% of the catchment is Class 3 or Class 2 for spray irrigation of lablab in the dry season (including nearly 700,000 ha of Class 2), this drops to 18% under furrow irrigation because of inadequate drainage limitations. Less than 1% is Class 3 for rainfed (dryland) although opportunistic use after good wet seasons may allow a greater area in some years. The area considered available for wet-season furrow is less than 30,000 ha. The coastal strip is limited by potential acid sulfate soils, while the uplands are dominated by excessive slope, rockiness and low soil water storage due to shallow and/or lightly textured soils. The clay soils in the mid-catchment are most suitable for furrow irrigation but are also at risk of secondary salinisation.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	4 to 6 ML/ha (March sowing). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Dryland: 6 to 13 t/ha (August sowing) Irrigated: 9 to 14 t/ha (March sowing)
Salinity tolerance	Moderately sensitive
Downstream processing	Available for direct delivery to end user.
By-products	Biomass for stock feed, potential use in biofuels.
Production risks	Timing of crop establishment to avoid high temperature stress at flowering and to maximise harvesting outside of major rainfall periods. Does not tolerate heavy grazing.
Rotations	Annual rotation, break crop in cotton or sugar rotation
Management considerations	Baler, forage cutter
Complexity of management practices	Low
Markets and emerging markets	Growing demand from northern Australian livestock industry for good-quality forages.
Prices	Primarily used on-farm.
Opportunities and risks under a changing climate	Drought tolerant (when established). Provides additional soil nitrogen in crop rotation.
Further reading	Cook et al. (2005), Brown and Pengelly (2007)

4.5.7 INDUSTRIAL (COTTON)

Dryland and irrigated cotton production are well-established in Australia. The area of land devoted to cotton production varies widely from year to year, largely in response to availability of water. Approximately 320,000 ha are planted each year, though this has varied from about 70,000 to almost 600,000 ha over the last 20 years. Gross value of production varies greatly; it was $2.5 billion in 2016–17 and $2.95 billion in 2011–12 as a consequence of favourable La Niña crop growing conditions and abundant irrigation supplies (ABARES, 2018). Genetically modified (GM) cotton varieties were introduced in 1996 and accounted for 98% of cotton produced in 2016. Australia was the fourth largest exporter of cotton in 2015. Cottonseed is a by-product of cotton processing and is a valuable cattle feed. Mean lint production in 2015–16 was 2.25 t/ha (ABARES, 2018).

Commercial cotton has had a long but discontinuous history of production in northern Australia, including in Broome, the Fitzroy River and the Ord River Irrigation Area in WA; in Katherine and Douglas–Daly in the NT; and near Richmond and Bowen in northern Queensland. An extensive study undertaken by the Australian Cotton Cooperative Research Centre in 2001 (Yeates, 2001) noted that past ventures suffered from:

- a lack of capital investment
- too rapid movement to commercial production
- a failure to adopt a systems approach to development
- climate variability.

Mistakes in pest control were also a major issue in early projects. Since the introduction of GM cotton in 1996, yields and incomes from cotton crops have increased in most regions of Australia. The key benefits of GM cotton (compared to conventional cotton) are savings in insecticide and herbicide use, and improved tillage management. In addition, farmers are now able to forward-sell their crop as part of a risk management strategy.

Research and commercial test farming have demonstrated that the biophysical challenges are manageable if the growing of cotton is tailored to the climate and biotic conditions of northern Australia (Yeates et al., 2013). In recent years irrigated cotton crops achieving 10 bales/ha have been grown successfully in the Burdekin irrigation region and experimentally in the Gilbert catchment of north Queensland. New GM cotton using CSIRO varieties that are both pest and herbicide resistant is an important component of these northern cotton production systems.

Climatic constraints will continue to limit production potential of northern cotton crops when compared to cotton grown in more favourable climatic regions of northern NSW and southern Queensland. On the other hand, the low risk of rainfall occurring during late crop development favours production in northern Australia, as it minimises the likelihood of late season rainfall that can downgrade fibre quality and price. Demand for Australian cotton exhibiting long and fine attributes is expected to increase by 10 to 20% of the market during the next decade and presents local producers with an opportunity in targeting production of high-quality fibre.

Assuming unconstrained development, nearly 3 million ha of the Mitchell catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for irrigated cotton using spray irrigation in the dry season (Figure 4-25a) and about

1.1 million ha for spray irrigation in the wet season. About 1.3 million ha are moderately suitable with considerable limitations (Class 3) for furrow irrigation in the dry season (Figure 4-25b) but only a little over 200,000 ha for furrow irrigation in the wet season, principally due to inadequate drainage. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

In addition to a normal row planter and spray rig equipment used in cereal production, cotton requires access to suitable picking and module or baling equipment as well as transport to processing facilities. Initial development costs and scale of establishing cotton production in the catchment would need to consider sourcing of external contractors and could provide an opportunity to develop local contract services to support a growing industry.

Cotton production is also highly dependent on access to processing plants (cotton gins). There are no processing facilities in the Mitchell catchment, and the nearest gin is in Emerald, approximately 680 km by road. The absence of a nearby cotton gin is likely to decrease the attractiveness of cotton production in the Mitchell catchment, compared with other cropping options, particularly those that can service a local regional market.

The high oil and protein content of cottonseed, a co-product of the ginning process, is a profitable source of oil for domestic and export markets and local stock feed. Cottonseed contains about 20% crude protein and is a major component in drought feeding when mixed with molasses or grain. Regional processing of cotton could supply local cattle producers with a cost-effective high-quality feed supplement.

Other industrial crops such as tea and coffee are unlikely to yield well in the Mitchell catchment climate, and tobacco and hemp are not currently allowed to be grown in Australia. Niche industrial crops, such as guar and chia, may be feasible for the Mitchell catchment, but there is only limited verified agronomic and market data on these crops. Past research on guar has been conducted in the NT and current trials are underway. These could prove feasible in the future. The companion technical report on agricultural viability (Ash et al., 2018) provides greater detail for a wider range of industrial crops.

Table 4-18 describes some key considerations relating to cotton production.

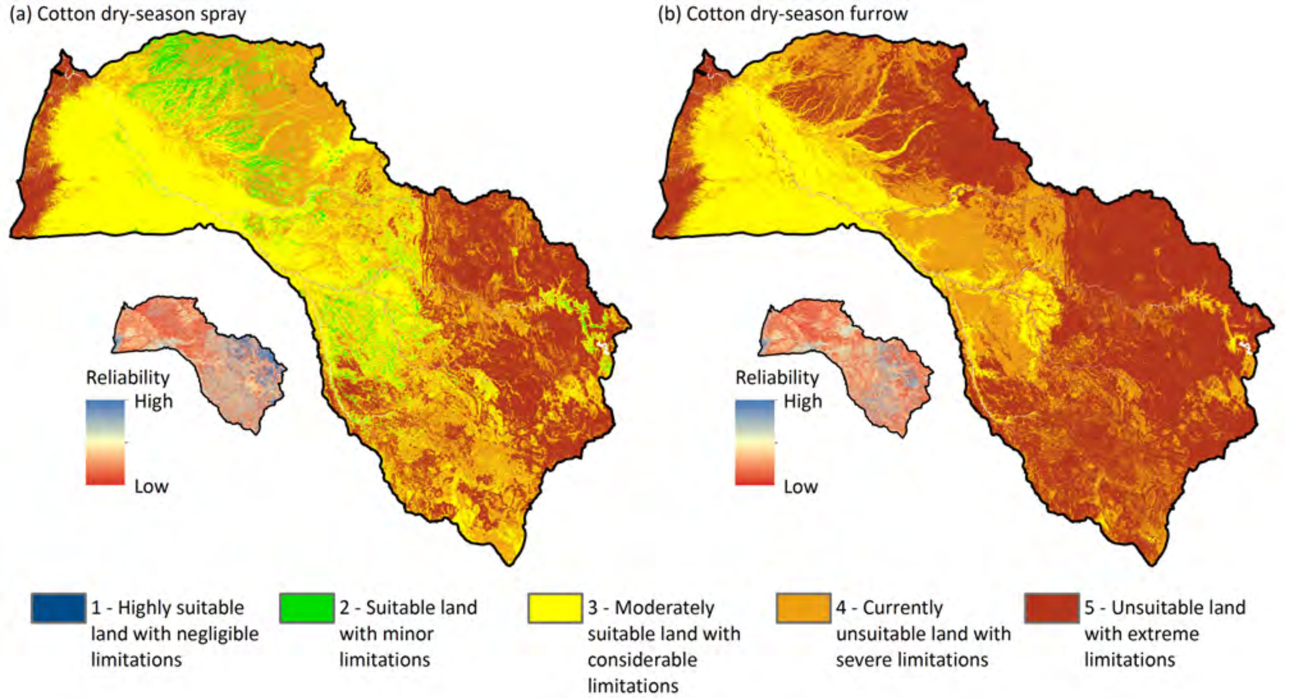

Figure 4-25 Modelled land suitability for cotton grown in the dry season using (a) spray irrigation and (b) furrow irrigation.

Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-26 Cotton
Photo: CSIRO

Table 4-18 Cotton (*Gossypium* spp.)

PARAMETER	DESCRIPTION
Summary	Cotton is a shrub native to some tropical and sub-tropical regions, producing 32% (in 2009) of the world's fibre production. Australian cotton production is small compared with production in the USA and Israel. However, due to a favourable climate during the growing season, Australia is recognised (along with Egypt) as currently producing the world's best cotton. A high proportion of Australian cotton (84% in 2005–06) is produced under irrigation with rainfed (dryland) crops sown into stored soil water resulting from traditional fallowing processes. Cotton is marketed on qualities of grade, colour and fibre length. Cotton can be grown on the majority of deep arable soils with adequate rainfall or supplementary irrigation. CSIRO GM cotton has been successfully grown in the catchment of the Gilbert River and is currently grown in the catchment of the Burdekin River.
Growing season	Planting window December to February, maturity May to July
Land suitability assessment	While 42% of the catchment is Class 3 or Class 2 for spray irrigation of cotton in the dry season (including about 300,000 ha of Class 2) this drops to 18% under furrow irrigation because of inadequate drainage limitations. About 2% is Class 3 for rainfed (dryland) although opportunistic use after good wet seasons may allow a greater area in some years. The area considered available for wet-season furrow is a little over 200,000 ha. The coastal strip is limited by potential acid sulfate soils, while the uplands are dominated by excessive slope, rockiness and low soil water storage due to shallow and/or lightly textured soils. The clay soils in the mid-catchment are most suitable for furrow irrigation but are also at risk of secondary salinisation.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	3 to 5 ML/ha (wet-season crop); 4–6 ML/ha (dry-season crop). Assumes perfect timing of irrigation (i.e. no losses). The water balance component of the APSIM cotton model has not been validated for northern Australia and the model outputs are likely to be underestimated. For this reason, the applied irrigation water values for cotton have been based on similar summer-grown crops (sorghum (grain)). More work is required for validating the cotton model in the tropics.
Crop yield (median)	Dryland: 1 to 4 bales/ha (February sowing) Irrigated: 9 to 10 bales/ha (wet-season crop); 10 to 11 bales/ha (dry-season crop)
Salinity tolerance	Tolerant – EC_e Threshold for yield decline 7.7 dS/m
Downstream processing	Cotton gin
By-products	Cottonseed for stock feed
Production risks	Early frost, prolonged water logging, reduced radiation due to cloud cover
Rotations	High potential for annual rotation
Management considerations	Picker, row crop planter, spray rig (pest control), fertiliser
Complexity of management practices	High
Markets and emerging markets	Price is influenced by international commodity markets. Australia is one of the world's largest exporters of raw cotton, with more than 90% of production exported, mainly to Asian spinning mill customers. China, Indonesia, Thailand, South Korea, Japan, Taiwan, Pakistan and Italy are the main buyers. Cotton growers have the option of delivering their cotton directly to a processor or having it marketed by an independent merchant. There are several pricing options available, including forward contracts.
Prices	Currently approx. $450/bale
Opportunities and risks under a changing climate	Seasonal climate variability, water availability for irrigation
Further reading	DAFF (2012a)

4.5.8 INDUSTRIAL (SUGARCANE)

Sugar production is well-established in Queensland, which produces approximately 95% of the Australian crop. There are approximately 370,000 ha of cane grown annually in Australia, supplying 24 mills that produce approximately 4.4 Mt of sugar. The gross value of production is approximately $1.8 billion (ABARES, 2018).

Sugarcane is classified as an industrial crop in the Assessment because it requires a local processing facility. It is estimated that at least 12,000 ha are required for a sugar mill to be economically viable. As a consequence, sugarcane is considered to be a promising crop only where large areas of suitable irrigable land are available. There is a sugar mill very close to the Mitchell catchment, servicing sugarcane production in the Mareeba–Dimbulah Water Supply Scheme. Given the high costs of transport of harvested cane per unit of sugar produced, it can only be economically transported relatively short distances. If a production area was to be established distant from Mareeba then local processing facilities would be required.

Assuming unconstrained development, about 3 million ha of the Mitchell catchment is considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for irrigated sugarcane using spray irrigation (Figure 4-27a) but only about 1.3 million ha are moderately suitable with considerable limitations (Class 3) for furrow irrigation (Figure 4-27b) due to inadequate drainage. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

The relatively large diurnal temperature variation in the Mitchell catchment through the May to September months, and lack of rainfall during this time could render sugar content of cane grown in the Mitchell catchment among the highest in the Australian industry.

Equipment required for growing sugarcane is mostly industry-specific, with only tillage, spraying and some fertiliser equipment, such as used on other crops. Specialised planting, row formation, and harvesting equipment is required, but most farmers use contract harvesting, and many also use contract planters. At least 10 to 12 contract harvesters would be needed to service the minimum 12,000 ha of sugarcane required to support a viable sugar mill.

Table 4-19 describes some key considerations relating to sugarcane production.

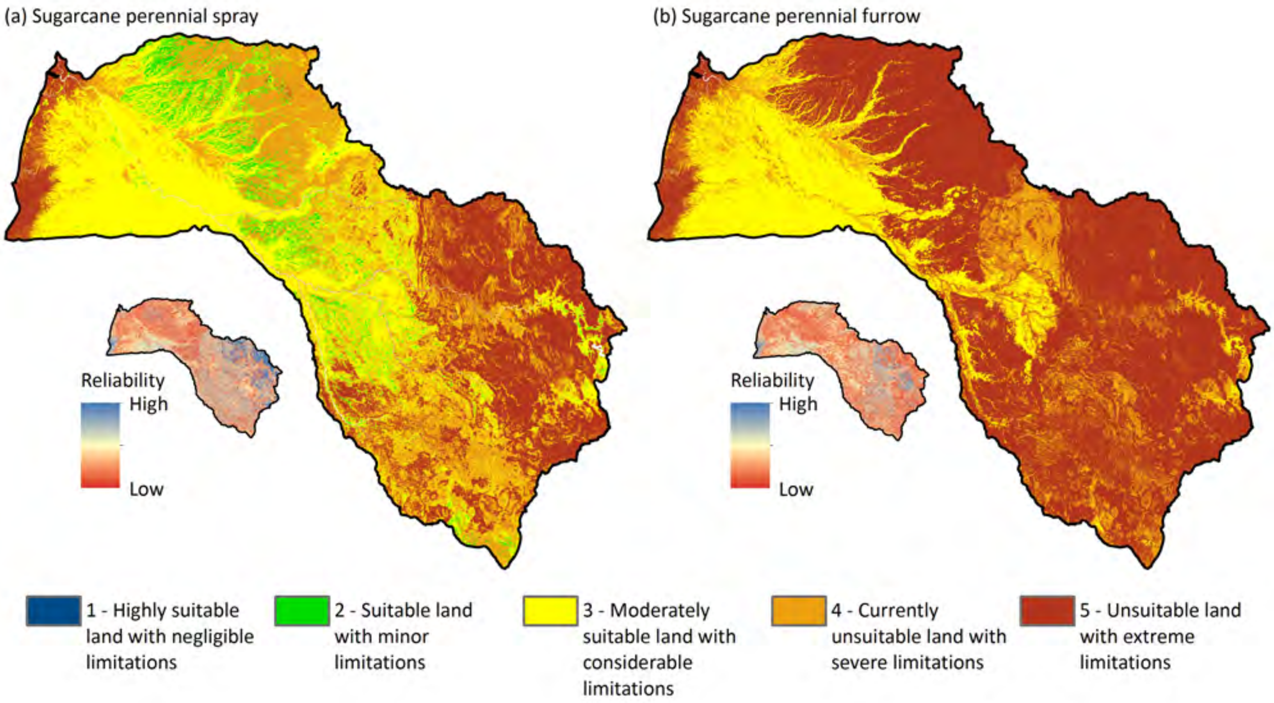

Figure 4-27 Modelled land suitability for sugarcane grown using (a) spray irrigation and (b) furrow irrigation
Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-28 Sugarcane
Photo: CSIRO

Table 4-19 Sugarcane (*Saccharum*)

PARAMETER	DESCRIPTION
Summary	Sugarcane is a tall tropical and sub-tropical perennial grass supplying 80% of the world's sugar production. Australia is the 3rd largest raw sugar producer, milling about 4 to 4.5 Mt raw sugar annually. Depending on the local conditions, sugar is usually harvested between July and November and allowed to regrow (ratoon) for a further 3 to 4 years. Sugarcane can be grown on the majority of well-structured arable soils, with a preference for free-draining soils. Acid sulfate soils can present management problems.
Growing season	Sugarcane is grown from 12 to 16 months before harvesting. A plant crop of 15 to 16 months is followed by four ratoon crops of 12 months. Harvesting occurs between June and December.
Land suitability assessment	While 43% of the catchment is Class 3 or Class 2 for spray irrigation of sugarcane (including about 400,000 ha of Class 2) this drops to 19% under furrow irrigation because of inadequate drainage limitations. About 10% is Class 3 for rainfed (dryland). The coastal strip is limited by potential acid sulfate soils, while the uplands are dominated by excessive slope, rockiness and low soil water storage due to shallow and/or lightly textured soils. The clay soils in the mid-catchment are most suitable for furrow irrigation but are also at risk of secondary salinisation.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (range)	6 to 15 ML/ha (May sowing, September harvest). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (range)	Irrigated: 80 to 160 t/ha (May planting, September harvest)
Salinity tolerance	Moderately sensitive – EC_e threshold for yield decline 1.7 dS/m
Downstream processing	Requires local processing soon after harvest.
By-products	Molasses, bagasse, ethanol. Ash and filter mud as a source of fertiliser
Production risks	Significant production losses occur if sugarcane is flooded for prolonged periods when less than 1 m tall. Productivity can be affected by rats, pigs, cane grubs and insects. Exotic pests and diseases present a significant threat to the sugarcane industry.
Rotations	5-year rotation (one plant and four ratoon crops). Can be sown in rotation with a legume crop, such as soybean.
Management considerations	Header, row crop planter, spray rig (pest control). Permits may be required for burning.
Complexity of management practices	Medium
Markets and emerging markets	Sugarcane is one of Australia's most important industries, worth $1.7 to $2.0 billion. Increasing demand from developing nations in South-East and southern Asia. More than 80% of all sugar produced in Australia is exported as bulk raw sugar, with key export markets including South Korea, Indonesia, Japan and Malaysia. Returns to producers are determined primarily by the world futures price for sugar but are also influenced by the level of the Australian dollar, regional sugar premiums, and the costs for marketing and transporting the product.
Prices	Currently approximately $400/t of sugar, which converts to a price of around $35/t of sugarcane
Opportunities and risks under a changing climate	Reduced water availability in a drier climate will reduce yields.
Further reading	Canegrowers (2017), DAFF (2012b)

4.5.9 INTENSIVE HORTICULTURE

Intensive horticulture is an important and widespread Australian industry, occurring in every state, particularly close to capital city markets. It is something of a ‘sleeping giant’ of Australian agriculture, employing approximately one-third of all people employed in agriculture, and having a farm gate value of approximately $10 billion (out of a total of about $28 billion for all Australian crops in 2015–16) (ABARES, 2018).

Production is highly seasonal and often involves the growth on a particular farm of a wide range of crops. The importance of freshness in many horticultural products means seasonality of supply is important in the market. The Mitchell catchment may have advantages in that it could supply southern markets ‘out of season’. This requires a heightened understanding of risks, markets, transport and supply chain issues.

The total value of Australian exports of fresh and processed fruit, nuts and vegetables was $1.23 billion in the 2010–11 financial year, compared with a total value of imports of these products of $1.81 billion (DAFF, 2012b).

The Assessment provides details on a subset of the horticultural crops possible in the catchment. Assuming unconstrained development and depending on the specific crop, about 3.5 million ha to 3.7 million ha of the catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for intensive horticultural crops under trickle irrigation, grown in the dry season (Figure 4-29a, b). Note that in many cases, intensive management activities, such as mounding soil or the use of black plastic mulch, can address mapped land suitability limitations. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

As with all other crops, water is more limiting than land in the Mitchell catchment. Potential yields for horticultural crops are not modelled as there are no simulation models that have been calibrated for the Mitchell catchment, or similar environments. Dryland production of horticultural crops is unlikely to be viable.

Horticulture typically requires specialised equipment and a large labour force. Therefore, a system for attracting, managing and retaining sufficient staff is also required. Harvesting is often by hand, but packing equipment is highly specialised. Irrigation is with micro equipment, but overhead spray is also feasible. Leaf fungal diseases need to be more carefully managed with spray irrigation. Micro spray equipment has the advantage of also being a nutrient delivery (fertigation) mechanism, as fertiliser can be delivered via the irrigation water.

Table 4-20 describes some key considerations relating to sweet corn production, as an exemplar of those relating to horticultural production more broadly.

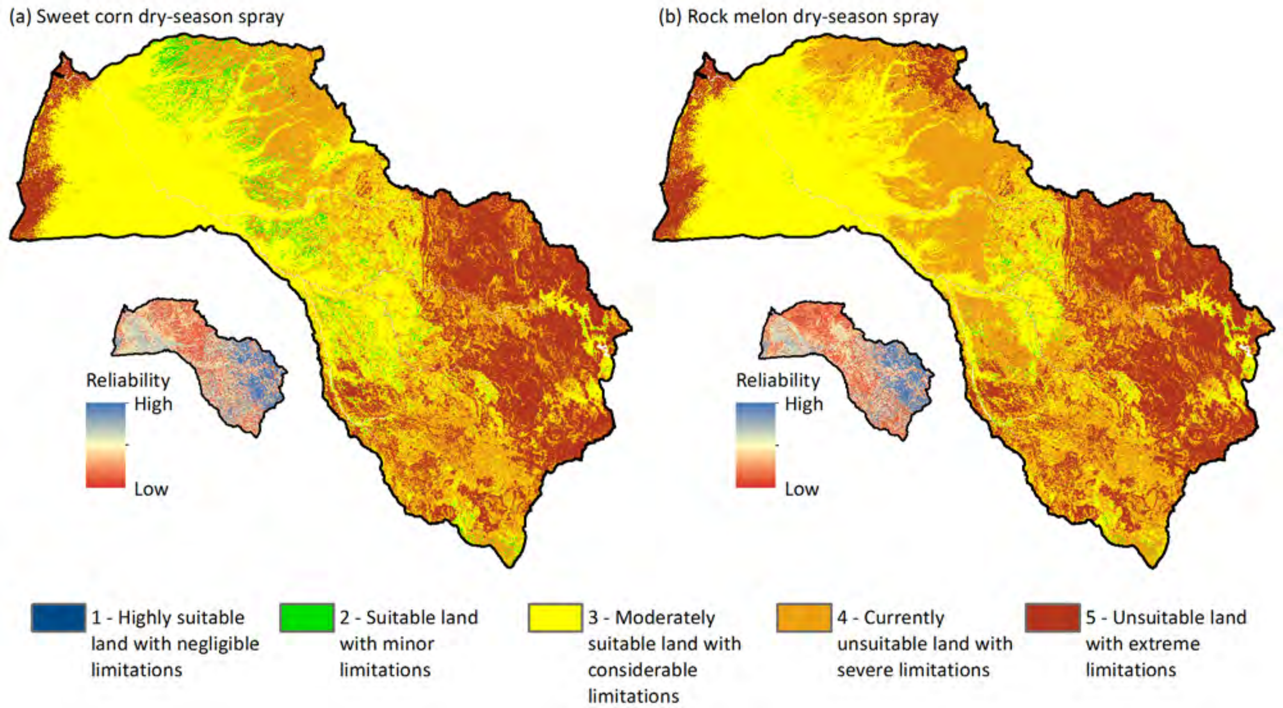

Figure 4-29 Modelled land suitability for (a) sweet corn and (b) cucurbits (e.g. rockmelon) both grown using spray irrigation in the dry season

Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-30 Sweet corn

Photo: CSIRO

Table 4-20 Sweet corn (*Zea mays* var. *saccharata*)

PARAMETER	DESCRIPTION
Summary	Sweet corn is a warm season, frost-sensitive crop with a preferred growing season temperature of 15 to 32 °C. Sweet corn can be produced for the fresh or processed market and is sold both locally and overseas. Sweet corn is currently grown under irrigation in the Burdekin.
Growing season	Sweet corn can be sown between March and August with harvesting from May to October. It matures in 75 to 105 days.
Land suitability assessment	About 45% of the catchment is Class 3 or Class 2 under spray irrigation of sweet corn in the dry season, including about 230,000 ha of Class 2 land. Most of the land in the lower to middle catchment is Class 3 or Class 2 except the coastal plains, where there is a risk of acid sulfate soils. In the upper parts of catchment inadequate soil depth, rockiness or excessive slope are the major limitations. In the wet season, inadequate drainage in the delta is a major limitation. In parts of the sandplains to the north-east of the delta the water holding capacity of the soil is too low.
Irrigation system requirements	Micro, spray
Applied irrigation water (median)	3.8 ML/ha, based on maize
Crop yield (median)	Irrigated: 8.5 t/ha (fresh weight) based on DPI Agrilink
Salinity tolerance	Moderately sensitive – EC_e threshold for yield decline 1.7 dS/m
Downstream processing	Requires local processing soon after harvest. Rapid transport and cooling of fresh market crops is important to maintain quality. 80% of sweet corn goes to the processing sector rather than the fresh food market.
By-products	Stubble can be grazed by livestock.
Production risks	Late sowings risk high temperature stress during flowering. Sweet corn is very prone to pest damage. Complete crop losses do occur.
Rotations	The plant grows quickly and is considered a valuable rotation crop.
Management considerations	Row crop planter, harvester, spray rig, fertiliser, insect pest control (chemical resistance). There is a high labour requirement for grading and packing.
Complexity of management practices	Medium
Markets and emerging markets	Most sweet corn is sold on the domestic market, which is dominated by the processing sector. Australia exports frozen or canned kernel, frozen cob, long-life vacuum sealed cobs and fresh cobs. The important markets are Japan, South-East Asia and Europe. Any growth in production will depend on access to export markets. Some increase in production for the domestic market is possible, though overproduction will rapidly occur.
Prices	Prices vary greatly depending on current supply and demand. Processing crops are generally grown under contract at a set price, depending on quality.
Opportunities and risks under a changing climate	Warmer climates allow multiple crops per year. Sweet corn is highly perishable in hot weather. Hot, dry, windy conditions at flowering time can stress plants and disrupt pollination and seed set. Sweet corn is more sensitive to heat stress than field maize.
Further reading	NSW Department of Primary Industries (2007), DAFF (2013b)

4.5.10 PLANTATION TREE CROPS

Of all the potential plantation tree species available to be grown in the Mitchell catchment, African mahogany and Indian sandalwood are the only two that would be considered economically feasible. Many other plantation species could be grown; however, returns are much lower than for these two crops. African mahogany is well-established in plantations near Katherine and Indian sandalwood is being grown in the Ord valley, around Katherine and in north Queensland. The first commercial crops of Indian sandalwood are being harvested and over that 16-year period, many agronomic challenges have been solved.

The cracking clay soils found in parts of the Mitchell catchment are not considered highly suited to silvicultural crops due to potential for root shear. Cracking clay soils shrink and swell with wetting and drying, potentially breaking roots as they move. It is possible to successfully grow perennial crops on cracking clay soils with well-managed irrigation practices. By keeping the soil wet enough, shrink–swell action can be minimised. A water limited environment increases the associated risk. Plantation species require greater soil depth than most other crop species.

Plantation timber species require over 15 years to grow, but once established can tolerate prolonged dry periods. Irrigation water is critical in the establishment and first 2 years of a plantation. In the case of Indian sandalwood, the provision of water is not just for the trees themselves but the leguminous host plant associated with Indian sandalwood, as it is a semi-parasite.

Assuming unconstrained development and depending on the specific tree species being planted, somewhere between about 2 million ha and 3.5 million ha of the catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for plantation trees under trickle or mini spray irrigation (Figure 4-31a, b). The actual area will depend significantly on the ability of the species to tolerate poorly drained soils and potential waterlogging. This is particularly the case on the extensive delta. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

Cyclones are a significant risk to long cycle tree crops and there is a reasonably high risk of cyclones in the Mitchell catchment.

Table 4-21 describes Indian sandalwood production.

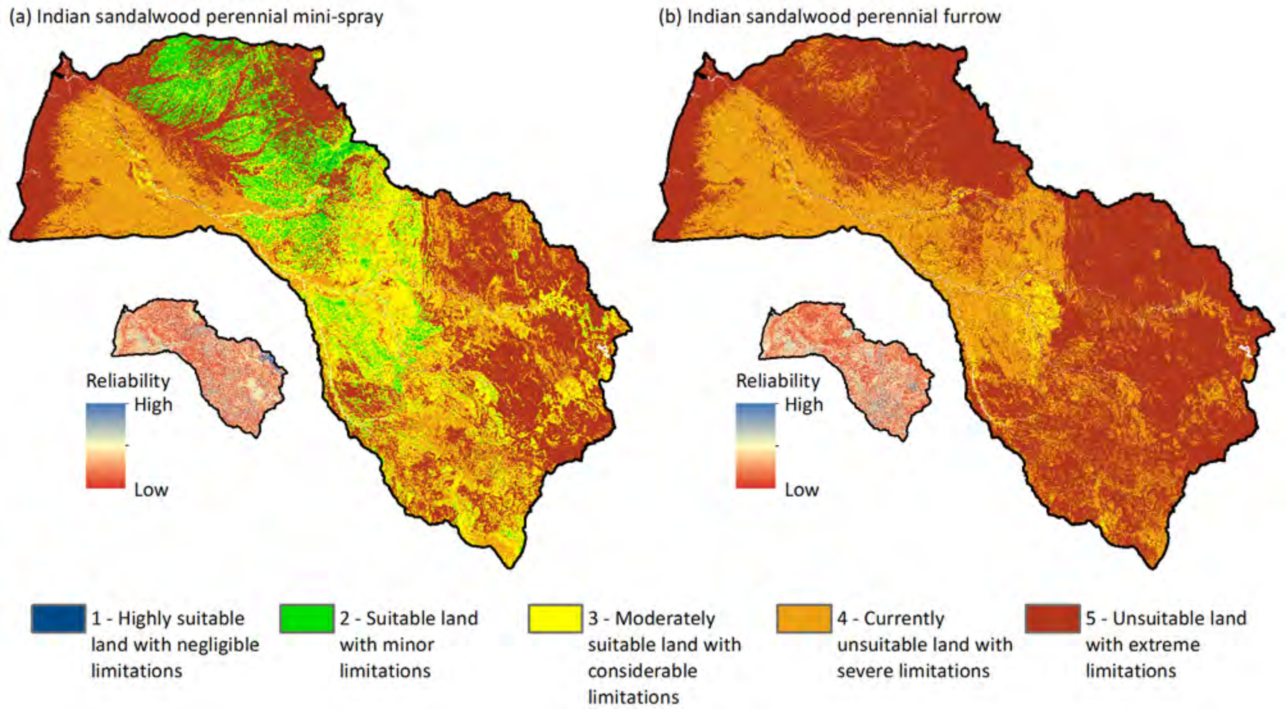

Figure 4-31 Modelled land suitability for Indian sandalwood grown using (a) mini spray or (b) furrow irrigation
Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-32 Indian sandalwood and host plant
Photo: CSIRO

Table 4-21 Indian sandalwood (*Santalum album*)

PARAMETER	DESCRIPTION
Summary	Sandalwood is a medium-sized, hemiparasitic tree grown for its aromatic wood and essential oils. The key product of value from sandalwood trees is the heartwood, which contains most of the oil and scented wood. Heartwood starts to develop when the tree is about 10 years old, with the proportion of heartwood (and value of the plantation) increasing with age after that time. Commercially viable sandalwood can take at least 15 years to reach harvestable maturity, but many plantations are not harvested for 20 to 35 years. Large areas of Indian sandalwood have been planted in the Ord River Irrigation Area, with some plantations reaching maturity in 2013. Production risks are mostly associated with the long period of time from planting to harvest, and uncertainty about the market for sandalwood in 20 years.
Land suitability assessment	About one-third of the catchment is Class 3 or Class 2 under trickle irrigation for Indian sandalwood. Much of the delta is rendered unsuitable due to inadequate drainage, which manifests particularly in the wet season. Inadequate drainage is also a limitation in many of the alluvial areas among the sandplains to the north-east of the delta. In much of the upper parts of the catchment inadequate soil depth, rockiness or excessive slope are the major limitations. Cyclones are also a risk to tree crops closer to the coast.
Irrigation system requirements	Surface, micro
Irrigation demand	6 ML/ha
Crop yield (median)	Heartwood 8 t/ha at 15 years, with oil 2 to 7% of heartwood
Salinity tolerance	Unknown
Downstream processing	Sandalwood can be processed in Australia or exported overseas for oil extraction.
By-products	Spent pulp after oil extraction is available for production of incense. Sandalwood nuts are edible, but there may also be potential markets in the cosmetics industry. The host plants may be harvested for timber or biofuels.
Production risks	Long length of time between planting and harvest. Termites can significantly reduce the yields of plantations. Synthetic and biosynthetic sandalwood oil is the greatest threat to the Australian sandalwood industry.
Rotations	Perennial tree crop not suited for rotation with other species. Sandalwood requires a host plant to supply water and nutrients.
Management considerations	Harvesting is usually done by contractors. May require several hosts during the lifespan of the tree. The first host is usually a herbaceous plant (e.g. *Alternanthera*) introduced to the container-grown sandalwood 1 month prior to planting. The second short-term host aims to produce rapid sandalwood growth and will die 2 to 4 years after establishment (e.g. *Sesbania formosa)*. A long-term host (e.g. *Cathormion umbellatum*) supports the sandalwood over its production life. These hosts are planted at the same time as the sandalwood. Host species also need to be suited to local soil type and climate. Two to three host trees are required per sandalwood tree. Using several species of host plants will minimise risks from pests and diseases. Weed control is important and must use methods that do not negatively impact the sandalwood or host plant.
Complexity of management practices	Medium
Markets and emerging markets	Globally, sandalwood is highly valued due to the presence of unique aromatic substances in the heartwood, and it is important to certain cultures and religions. The incense industry is the largest consumer of sandalwood material. High prices are paid for good-quality timber suitable for carving, but the proportion of such material is low. The next most valuable product is the oil, which is the main driver of international trade and is sought after for high-value end uses such as perfumery. The traditional markets of Taiwan, Hong Kong and China are the biggest consumers of sandalwood.

PARAMETER	DESCRIPTION
Prices	Prices have increased over the past decade in response to a steady decline in worldwide supply.
Opportunities and risks under a changing climate	Can take advantage of soil water at any time of year. Planting several species of sandalwood and host plants together makes the plantation more resilient to climate change. Sandalwood trees are not fire tolerant.
Further reading	Forest Products Commission Western Australia (2008), Clarke (2006), Brand et al. (2012)

4.5.11 TREE CROPS (FRUIT)

Some fruit and tree crops – such as mangoes, bananas and cashews – are well-suited to the climate of the Mitchell catchment and are grown within the catchment in the Mareeba–Dimbulah Water Supply Scheme. Other species such as avocado and lychee, while currently grown in the more benign climate of the Mareeba–Dimbulah Water Supply Scheme are not likely to be as well-adapted to the climate and soils further west in the catchment. Tree crops are generally not well-suited to cracking clays, which make up some of the suitable soils for irrigated agriculture in the Mitchell catchment.

Fruit production shares many of the marketing and risk features of intensive horticulture such as a short season of supply and highly volatile prices as a result of highly inelastic supply and demand. Managing these issues requires a heightened understanding of risks, markets, transport and supply chain issues. However, fruit and nut tree production has been growing rapidly in Australia and in 2015–16, gross value of production was $4.74 billion out of a total value of $11.3 billion for horticulture in Australia (Horticulture Innovation Australia, 2017).

The perennial nature of tree crops makes a reliable year-round supply of water essential. However, some species, such as mango and cashew, can survive well under mild water stress until flowering (generally August to October for most fruit trees). It is critical for optimum fruit and nut production that trees are not water stressed from flowering through to harvest. This is the period approximately from August up to November through to February, depending on the species. This is a period in the Mitchell catchment when very little rain falls, and farmers would need to have a system in place to access irrigation water during this time.

Depending on the specific fruit tree crops being planted and assuming unconstrained development, somewhere between 1 million ha and 2.5 million ha of the catchment are considered to be moderately suitable with considerable limitations (Class 3; Table 4-1) or better (Class 2) for tree crops under trickle irrigation (Figure 4-33a, b). For spray irrigation the area ranges between about 500,000 ha and 2.5 million ha. Flooding risk needs to be considered on the alluvial low-lying areas suited to all irrigation types.

Specialised equipment for fruit and nut tree production is required. The requirement for a timely and significant labour force necessitates a system for attracting, managing and retaining sufficient staff. Tree pruning and packing equipment is highly specialised for the fruit industry. Optimum irrigation is usually via micro spray. This equipment is also able to deliver fertiliser directly to the trees through fertigation.

Table 4-22 describes some key considerations relating to mango production in the Mitchell catchment, as an exemplar of those relating to tree crop production more broadly. Similar information for other fruit tree crops is described in the companion technical report on agricultural viability (Ash et al., 2018).

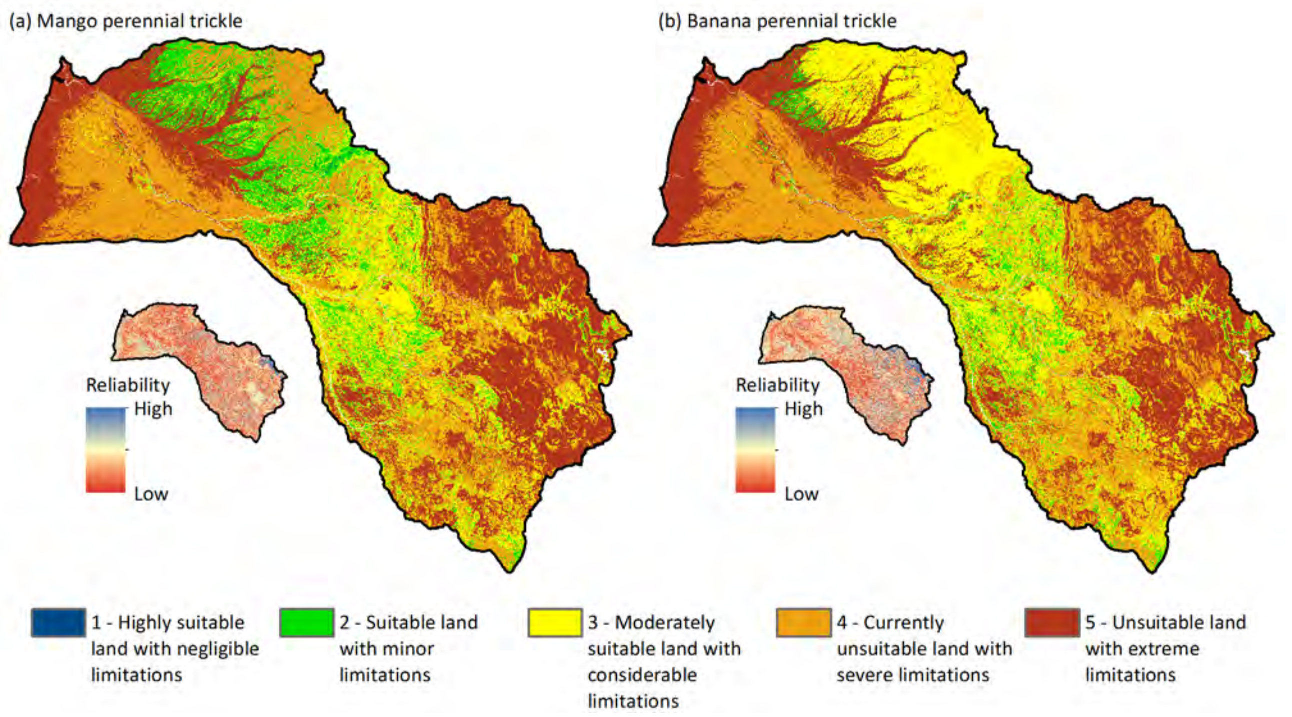

Figure 4-33 Modelled land suitability for (a) mango and (b) banana, both grown using trickle irrigation
Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water. The methods used to derive the reliability data in the inset map are outlined in Thomas et al. (2018b).

Figure 4-34 Mangoes
Photo: Shutterstock

Table 4-22 Mango *(Mangifera indica)*

PARAMETER	DESCRIPTION
Summary	Mangoes are one of the major horticultural crops grown in Australia and around 7000 ha are currently grown in Queensland. The main production areas are the Burdekin, Bundaberg and Mareeba regions.
Growing season	Mango harvests start in late October and extend to January – depending on variety.
Suitable soils	About one-third of the catchment is Class 3 or Class 2 under trickle irrigation for mango. Much of the delta is rendered unsuitable due to inadequate drainage, which manifests particularly in the wet season. Inadequate drainage is also a limitation in many of the alluvial areas among the sandplains to the north-east of the delta. In much of the upper parts of the catchment inadequate soil depth, rockiness or excessive slope are the major limitations. Cyclones are also a risk to tree crops closer to the coast.
Irrigation system requirements	Micro, need capacity to apply up to 0.3 ML/ha per week in peak demand
Applied irrigation water (median)	5.7 to 7.6 ML/ha
Crop yield (median)	Irrigated: 1000 trays/ha
Salinity tolerance	Sensitive
Downstream processing	Requires local processing soon after harvest. Unripe fruits are used in pickles, chutneys and salads. Ripe fruits can be eaten fresh or frozen, or can be dehydrated, canned or made into products such as jams and juices.
By-products	None
Production risks	Susceptible to cold and frost. Many varieties have irregular yields, with a heavy crop one year followed by several lighter crops.
Rotations	Perennial tree crop not suited for rotation. Could be planted for alley cropping.
Management considerations	Packing equipment, harvest aids. A wide range of climate zones in northern Australia provides opportunities to maintain a sustained period for supplying the domestic market. The two most common varieties grown in Queensland are Kensington Pride and Calypso, while other varieties are grown on a limited scale to extend seasonal availability or supply niche markets.
Complexity of management practices	Medium
Markets and emerging markets	The majority of fruit are sold on the domestic market with only 5–10% exported from Queensland (DAFF, 2013c).
Prices	Highly variable depending on timing.
Opportunities and risks under a changing climate	Increasing opportunity to supply processed market for canned mango, juice and flavoured products.
Further reading	Johnson and Parr (2000), DAFF (2013c)

4.6 The opportunity for more intensive aquaculture in northern Australia

4.6.1 INTRODUCTION

Based on the natural advantages that northern Australia possesses in terms of political stability, proximity to large global markets, and a climate suited to farming of valuable tropical species, and through the large areas identified as suitable for aquaculture in the three study areas (as shown below), there appears considerable opportunity for aquaculture development in northern Australia (see the companion technical report on aquaculture viability (Irvin et al., 2018)).

While challenges to the development and operation of aquaculture enterprises do present in terms of regulatory barriers, global cost competitiveness, and the remoteness of much of the available land area, the potential to exploit the natural advantages of northern Australia and develop modern and sustainable aquaculture industries appears a compelling opportunity.

The text below considers the most likely candidate species, an overview of production systems and the prospects for integrating aquaculture with agriculture. Information on biodiversity is provided in Chapter 7. Farm scale and scheme scale economics for an intensive and extensive prawn farm and for a barramundi farm are found in Chapter 6 and in the Development Examples Report (Petheram et al., 2018).

4.6.2 CANDIDATE SPECIES

There are a number of candidate species for aquaculture in northern Australia including black tiger prawns (*Penaeus monodon*), banana prawns (*Fenneropenaeus merguiensis*), barramundi (*Lates calcarifer*), red claw (*Cherax quadricarintus*), marron (*Cherax tenuimanus*), cobia (*Rachycentron canadum*), silver perch (*Bidyanus bidyanus*), Murray cod (*Maccullochella peelii peelii*), jade perch (*Scortum barcoo*) and oysters.

However, for a range of reasons, the most appropriate species for considering aquaculture potential in the Mitchell catchment are black tiger prawns (Figure 4-35), barramundi (Figure 4-36) and red claw. The first two species are suited to many marine and brackish water environments of northern Australia and 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 in northern Australia, whereas land-based culture of barramundi would likely be intensive. The red claw crayfish is another potential candidate, for fresh water, that is currently cultured by a much smaller industry than the previous two species.

Black tiger prawns are found naturally at low abundances across the waters of the Western Indo-Pacific region, with wild Australian populations making up the southernmost extent of the species. Within Australia, the species is most common in the tropical north, but does occur at lower latitudes.

Figure 4-35 Black tiger prawn, a candidate species for the Mitchell catchment
Photo: CSIRO

Barramundi are one of Australia's most recognisable and highly prized sporting and eating fish. Its iconic status coupled with excellent palatability has created significant recreational and commercial fishing industries in northern Australia as well as making it the most highly produced and valuable tropical fish species in Australian aquaculture. Barramundi inhabit the tropical north of Australia from the Exmouth Gulf in WA through to the Noosa River on Queensland's east coast. While the term 'barramundi' or 'barra' is used to describe the species in Australian waters, it is also commonly known as the 'Asian sea bass' or 'giant sea perch' throughout its natural areas of distribution in the Persian Gulf, the Western Indo-Pacific region and Southern China (Schipp et al., 2007).

Barramundi have many attributes that make them an excellent aquaculture candidate: fast growth (1 kg or more in 12 months); year-round fingerling availability; well-established production methods; and hardiness (i.e. they have a tolerance to low oxygen levels, high stocking densities and handling as well as a wide range of temperatures) (Schipp et al., 2007). Possibly the most attractive attribute is that barramundi are euryhaline, and so able to thrive and be cultured in fresh and marine water, although freshwater barramundi can have an earthy flavour that is not favoured by Australian consumers. Proper final preparation such as purging (holding in clean saltwater without feed) prior to final harvest can assist in removing these flavours.

Figure 4-36 Barramundi, a candidate species for the Mitchell catchment
Photo: CSIRO

There are over 100 species of freshwater crayfish in Australia. The main species of commercial interest in northern Australia is red claw. The name ‘red claw’ is derived from the distinctive red markings present on the claws of the male crayfish. Red claw is a warm water species, which inhabit still or slow-moving water bodies. The natural distribution of red claw ranges from the tropical catchments of Queensland and the NT to southern New Guinea.

Red claw have many traits that make them attractive for aquaculture production. A simple life cycle is beneficial, in that complex hatchery technology is not required (Jones et al., 1998). The crayfish can survive in high temperature and oxygen depleted water (<2 mg/L) and remain out of the water for extended periods. Low oxygen is a major stressor to most aquatic species. The ability of red claw to tolerate low oxygen levels is beneficial in terms of handling, grading and transport (Masser and Rouse, 1997). Red claw have a broad thermal tolerance, with optimal growth achievable between 23 and 31 °C.

4.6.3 GENERAL PRODUCTION SYSTEMS

Overview

Aquaculture production systems can be broadly classified into extensive, semi-intensive and intensive systems. Intensive systems require high inputs, with expected high outputs. They require high capital outlay; high running costs; specially formulated feed; specialised breeding, water quality and biosecurity processes; and high production per hectare (in the order of 5,000 to 20,000 kg/ha per crop). Recirculating aquaculture systems using indoor tanks are an example of intensive systems, but were not considered for the study area. Semi-intensive systems involve stocking seed from a hatchery, routine provision of a feed, and monitoring and management of water quality. Production is typically 1000 to 5000 kg/ha per crop. Extensive systems are characterised by low inputs and low outputs. They require less sophisticated management and often require no supplementary feed because the farmed species live on naturally produced feed in open air ponds. Extensive systems produce about half the volume of global aquaculture production. There are few examples of commercial extensive systems in Australia although there are many non-commercial examples, such as farm dams stocked with yabbies.

Water salinity and temperature are the key parameters that determine species selection and production potential for any given location. Most species can survive a broad range of temperatures. However, optimal production only occurs within a much narrower temperature range, and farming profitability is driven by the optimality of water temperature. Suboptimal water temperature (even within tolerable limits) will prolong the production season (slow growth) and increase the risk of disease.

Pond types

The primary culture unit for land-based farming is purpose-built ponds. Pond structures typically include an intake channel, production pond, discharge channel and a bioremediation pond (Figure 4-37). In most cases the ponds and channels are earthen based but may be partly or fully plastic-lined. The objective of the pond is to be a containment structure, an impermeable layer between the pond water and the local surface and groundwater.

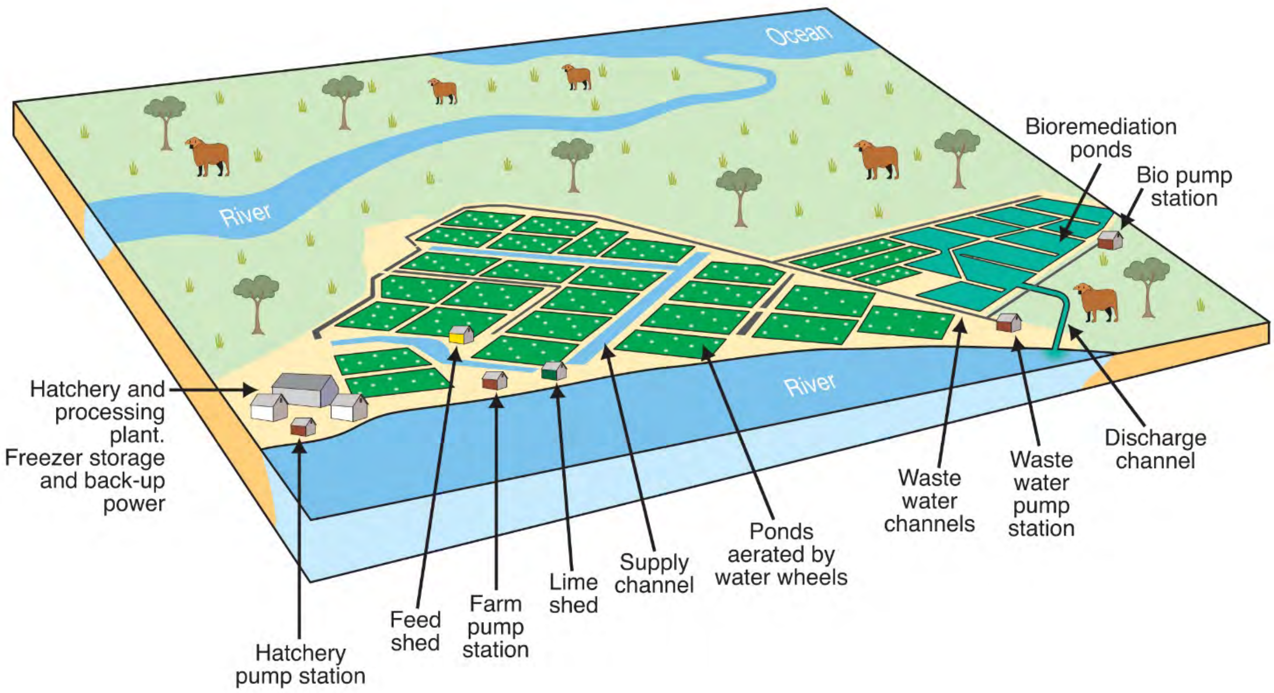

Figure 4-37 Schematic of marine aquaculture farm

Soils for earthen ponds should have low permeability and high structural stability. During production the environment in an established earthen pond is relatively stable, with the organic material from production being well mixed with the organic material that pre-existed in the soil. The production process results in the accumulation of organic materials on the pond base, which may require seasonal removal. The majority of production ponds in Australia are earthen.

Ponds should be lined if the soils are permeable and haulage of suitable soils is not an economical option. Synthetic liners have a higher capital cost but provide an impermeable layer between the pond and the local surface and groundwater. They are often used in high intensity operations, which require high levels of aeration conditions that would lead to significant erosion in earthen ponds.

Farm design and pond operation

Optimal sites for farms are flat and have sufficient elevation to enable ponds to be completely drained between seasons. The elevation of the land on which the ponds and channels are constructed has a large bearing on production efficiency. It is critical that all ponds and channels can be fully drained during the off (dry-out) season to enable machinery access to sterilise and undertake pond maintenance. Optimal land for ponds is flat and has an elevation of 5 to 10 m above the Australian Height Datum (AHD) due to the impact of floods and cyclone surges.

Farms use aerators (typically electric paddlewheels and aspirators) to help maintain optimal water quality in the pond. The aerators provide oxygen and create a current that concentrates waste material in the centre of the pond. A medium-sized 50-ha prawn farm in Australia uses around 4 GWh annually (Paterson and Miller, 2013). The majority of the power requirement is to run pond aeration. Back-up power, usually via a diesel generator, is required to run all the aerators on the farm during power failure. Large farms may require multiple generators.

4.6.4 PRODUCTION SYSTEMS FOR CANDIDATE SYSTEMS

Black tiger prawns

For black tiger prawns, a typical pond in the Australian industry would be rectangular in shape, about 1 ha in area and about 1.5 metre in depth, although there are considerable variations between and within farms. The ponds are either wholly earthen, lined on the banks with black plastic and earthen bottoms, or fully lined, although this is not common in the Australian industry. In Australia, pond grow-out of black tiger prawns typically operates at stocking densities considered as ‘semi-intensive’ or ‘intensive’ (‘intensive’ is used for the remainder of this report), which typically means that ponds are stocked with between 25 and 50 individuals per square metre. These pond systems are fitted with multiple aeration units, such as paddlewheels and aspirators that serve to both aerate and circulate the water, the former for purposes of consolidating the waste into a central sludge pile, which allows a greater area of the pond bottom to be optimal for the prawns while also making the sludge easier to remove at the end of the crop. As an example, for intensive farming, ponds may be fitted with about eight aeration units early in the crop, which might consist of six paddlewheels and two aspirators set up in an optimised configuration to achieve good water circulation, whereas the number required might double by the end of the crop when prawn biomass is greatest (Mann, 2012).

At the start of each prawn crop, prior to stocking with postlarvae, the ponds need to be prepared and filled with water. Between harvests, the pond bottoms are dried and unwanted sludge from the previous crops is removed, and if needed, additional substrate is added. Prior to filling the ponds lime is often added to buffer pH, particularly in areas where there are acid sulfate soils. The ponds are then filled with filtered seawater and left for about 1 week prior to postlarval stocking. Algal blooms in the water are encouraged through addition of organic fertiliser. These blooms are essential for both shading of the prawns and to discourage benthic algal growth, but also for the nutritional value they provide for the planktonic community within the ponds (QDPIF, 2006).

Postlarvae are produced at hatcheries and when transported great distances from the hatcheries to the ponds are typically packed into polystyrene boxes with highly oxygenated seawater, or stocked into specialist transporters fitted with aeration/oxygenation systems appropriate for holding postlarvae for many hours during transit (QDPIF, 2006).

In the first month after stocking, the postlarvae grow rapidly into small prawns, primarily relying on the natural productivity (zooplankton, copepods, and algae) supported by the algal bloom for their nutrition. Very small quantities of commercial feed are also added multiple times daily to assist with the weaning process and provide an energy source for the pond bloom. During this period no water exchange is required.

Approximately 1 month after the prawns are stocked, pellet feed becomes the primary nutrition source; this occurring when the daily feed requirement of the prawn population exceeds what is available from the natural productivity provided by the pond bloom. The major component of pelleted feeds are meals of terrestrial plant origin, and meals of captured marine fish and crustaceans (e.g. krill) origin, the latter typically the more expensive and valued of the basal components. Feed is a major cost of prawn production; around 1.5 kg of feed is required to produce 1 kg of prawns. Prawns typically reach optimal marketable size within 6 months of pond culture, with a common target prawn harvest size of 30 g. After harvest, prawns are typically processed immediately, with larger farms having their own production facilities that enable grading, cooking, packaging and freezing activities.

Effective prawn farm management involves maintaining water quality conditions within ranges optimal for prawn growth and survival, and this becomes progressively complex as prawn biomass and the quantity of feed added to the system increases. As the crop proceeds, both the prawn biomass increases, as does the biological oxygen demand required by the microbial population within the pond in breaking down organic materials. With these increasing demands, the requirement for water exchange and mechanical oxygen addition from paddlewheels increases. Towards the end of the production season the prawn biomass peaks and increasing numbers of aeration units are required in each pond to maintain optimal oxygen. Water exchange involves either the introduction of new water or recycling of existing water from the bioremediation pond back to the production pond. Fresh water, if available, can be added to manage high water salinity from evaporative losses. In most cases water salinity is not managed, except through seawater exchange, and will increase naturally with evaporation and decrease with rainfall and flooding. Strict regulation of the quality and volume of water that can be discharged means efficient use of water is standard industry practice.

Effluent water released to the environment from a prawn pond will often contain nutrients, algae and sediment particles at higher levels than occur naturally in ocean waters. To mitigate these impacts on the environment, most Australian prawn farms allocate up to 30% of their productive land for water treatment by pre-release containment in settlement systems. Such treatment reduces suspended solids and dissolved nutrients in the effluent before release to the environment (QDPIF, 2006). Many Australian farms also recirculate water, which minimises fluctuations in water quality and reduces the risk of introducing pathogens from the natural environment.

Barramundi

In commercial production systems, the conditioning and spawning of broodstock and the rearing of larval fish through to fingerlings takes place in land-based hatcheries. Barramundi are a highly fecund species, with females able to produce millions of eggs per spawning (Davis, 1984). However, subsequent mortality rates during the earliest larval and rearing phases can be very high. In the hatchery, at around 20 to 25 mm in length, the fingerlings are weaned off a live diet (rotifers and *Artemia*) to a commercial pellet. Due to the cost and infrastructure required many producers elect to purchase fingerlings from independent hatcheries, moving fish straight into their nursery cycle. Regular size grading is essential during the nursery stage due to aggressive and cannibalistic behaviour. Size grading helps to prevent mortalities and damage due to predation on smaller fish, and assists with consistent growth.

The main factors that determine productivity are the provision of optimal water temperature, dissolved oxygen, effective waste removal, expertise of farm staff and the overall health of the stock.

A pellet feed is produced by the two largest Australian aquafeed manufacturers (located in Brisbane and Hobart), providing a specific diet promoting efficient growth and feed conversion. The industry is heavily reliant on these mills to provide a regular supply of high-quality feed. Cost of feed transport would be a major cost to barramundi production in the study area. As a carnivorous species, high dietary protein levels, with fishmeal as a primary ingredient, is required for optimal growth. Barramundi typically require between 1.2 and 1.5 kg of pelleted feed for each kilogram of body weight produced.

In terms of stocking rates, typical pond biomass will be around 3 kg per 1000 L. Under optimal conditions barramundi can grow to over 1 kg in 12 months and to 3 kg within 2 years (Schipp et al., 2007). Warm water temperatures in northern Australia enable fish to be stocked in ponds year-round. Depending on the intended market, harvested product is processed whole or as fillets and delivered fresh (refrigerated, ice slurry) or frozen. Smaller niche markets for live barramundi are available for Asian restaurants in some capital cities.

Barramundi are susceptible to a variety of bacterial, fungal and parasitic organisms, and are at highest risk of disease when exposed to suboptimal water quality conditions (e.g. low oxygen, temperature extremes).

Red claw

The red claw life cycle is simple. In tropical regions, mature females can be egg bearing year-round. A 10-week incubation follows mating, after which the eggs hatch to produce small crayfish. After 3 months, the juveniles weigh around 15 g and around 100 g after 12 months. Red claw can live for up to 5 years and reach a maximum size of 600 g (Jones, 1990). Red claw breed freely in production ponds. A common industry practice is to manage mixed generations of red claw in the one pond. The crayfish are harvested at regular intervals, with re-stocking occurring from natural reproduction.

Water temperature and feed availability are the variables that most affect crayfish growth. Red claw are a robust species but are most susceptible to disease (including viruses, fungi, protozoa, bacteria) when conditions in the production pond are suboptimal (Jones, 1995).

Production ponds are earthen lined, rectangular in design and average 1 ha, and are sloping in depth from 1.2 m to 1.8 m. Sheeting is used on the pond edge to keep the red claw in the pond (migration tendency) and netting surrounds the pond to protect stock from predators (Jones et al., 2000).

At the start of each crop, prior to stocking with red claw, the ponds need to be prepared and filled with water. Between harvests, the pond bottoms are dried and unwanted sludge from the previous crops is removed, and if needed, additional substrate and shelters are added. Lime is often added prior to filling the ponds to buffer pH, particularly in areas where there are acid sulfate soils. The ponds are then filled with fresh water and left for about 2 weeks prior to stocking. Algal blooms in the water are encouraged through addition of organic fertiliser. These blooms are essential for both shading of the red claw and to discourage benthic algal growth, but also for the nutritional value they provide for the planktonic community within the ponds (Jones et al., 2000).

A prepared pond is stocked with around 250 females and 100 males that have reached sexual maturity. Natural mating results in the production of around 20,000 advanced juveniles. Red claw are omnivorous, foraging on natural productivity such as microbial biomass associated with decaying plant and animals. Early stage crayfish almost solely rely on natural pond productivity (phytoplankton and zooplankton) for nutrition. As the crayfish progress through the juvenile stages, the greater part of the diet changes from planktonic to organic particulates (detritus) found on the pond bottom. Very small quantities of a commercial feed are also added on a daily basis to assist with the weaning process and provide an energy source for the pond bloom. During this period no or minimal water exchange is required. The provision of adequate shelters (net bundles) is essential at this stage to improve survival (Jones, 2007). Approximately 4 months after stocking, the juveniles are harvested and graded by size and sex for stocking in production ponds.

Juveniles are stocked in production ponds from 5 to 10 per m^2. Shelters are important during the grow-out stage, with 250/ha recommended. During the grow-out phase pellet feed becomes an important nutrition source, along with the natural productivity provided by the pond. The major components of pelleted feeds are meals of terrestrial plant origin. The quality of pelleted red claw diets is often broadly ascribed to protein content, with most Australian farmers using diets consisting of 25 to 30% protein.

Effective farm management involves maintaining water quality conditions within ranges optimal for crayfish growth and survival, and this becomes progressively complex as crayfish biomass and the quantity of feed added to the system increase. As the crop proceeds, the crayfish biomass increases, as does the biological oxygen demand required by the microbial population within the pond in breaking down organic materials. With these increasing demands, the requirement for water exchange and mechanical oxygen addition from paddlewheels increases. Towards the end of the production season the crayfish biomass peaks and increasing numbers of aeration units may be required in each pond to maintain optimal oxygen levels in the pond. Water exchange involves either the introduction of new water or recycling of existing water from the bioremediation pond back to the production pond. Strict regulation on the quality and volume of water that can be discharged means efficient use of water is standard industry practice.

Red claw are harvested within 6 months of stocking to avoid reproduction in the production pond. At this stage the crayfish will range between 30 g to 80 g. Stock are graded by size and sex into groups for market, breeding or further grow-out (Jones, 2007). After harvest, red claw are transported to a processing shed where they are stocked in tanks until being packed live for market. There is high global demand for freshwater crayfish.

Current commercial feeds are low cost and provide a nutrition source for natural pond productivity as much as the crayfish. The small size of the industry means that feed is produced in a terrestrial animal (e.g. poultry) mill, rather than a dedicated aquaculture mill. This use of terrestrial animal mills has resulted in the production of feed with low water stability and limited ability to manipulate pellet size.

Red claw breed freely in production ponds. This is beneficial in that complex hatchery technology is not required. However, low fecundity, and the associated inability to source high numbers of quality seed, is also an impediment to intensive expansion of the industry. Fecundity of red claw compared to marine prawns is low, 1,000 to 200,000 eggs respectively. Unlike the prawn industry, where there is clear demarcation between the hatchery and grow-out operation, there is no dedicated hatchery operation to allow focused improvements in fecundity and seedstock production.

Predicted water use for candidate species production

A broad-scale assessment of the volumes of water used during the culture of the three candidate species in ponds under typical farming scenarios was provided as context for the overall water requirements of aquaculture. An average crop of prawns farmed in intensive pond systems (8 t/ha over 150 days) is estimated to require 127 ML of marine water, which equates to 15.9 ML of marine water for each tonne of harvested product. For pond culture of barramundi (30 t/ha over two years), 562 ML of marine water, or fresh water, is required per crop, equating to 18.7 ML of water for each tonne of harvested fish. For extensive red claw culture (3 t/ha over 300 days) 240 ML of fresh water is required per pond crop, equating to 16 ML of water for each harvested tonne of crayfish.

4.6.5 INTEGRATING AQUACULTURE WITH AGRICULTURE

While the practice of combining the production of fish and crops in a single system is commonly used by small-scale freshwater aquaculture enterprises in South-East Asia and developing countries, it is not widely practised in Australia. However, there are theoretically potential opportunities in northern Australia to optimise the integration between agriculture and aquaculture.

Fresh and marine pond-based operations provide up to 15 ML/ha/year of nutrient-rich waste water for potential diversion to irrigation. For obvious reasons, only waste water from freshwater aquaculture operations is suitable for irrigation of agricultural crops. The main nutrients of value in the discharge water are nitrogen and phosphorus.

In recent years a technology has been developed that utilises the discharge water from prawn farms for the production of high-value seaweed (MBD, 2017). The seaweed is efficient at stripping nitrogen, which enables the treated waste water to be recycled to the prawn ponds or discharged within allowable nutrient limits.

An integrated aquaculture–agriculture model for water use has been proposed for irrigated farming systems in Australia (Gooley et al., 2000). The concept involves stocking of fish in cages in water storage dams, which provide final irrigation to an agricultural crop. This is seen as an efficient use of water, as in this model the aquaculture component is a non-consumptive user of the water, which enhances the nutrient load of the water, possibly off-setting some of the farm fertiliser costs. Red claw is a good candidate because the crayfish readily consume raw agricultural plants and are suitable for production in irrigation storage water, on the provision that the pond or tanks are not completely emptied (Saoud et al., 2013).

There is wide scope for the use of raw agricultural plant products in the production of red claw. Red claw farmers commonly feed raw agricultural plant meals as a nutrition supplement to a pellet feed (e.g. maize). There is also opportunity for the direct use of raw and processed agricultural feed ingredients into prawn and barramundi pond systems. This currently involves the addition of plant products (e.g. molasses) into the pond to promote the development of algal blooms or addition as a carbon source in bio floc systems.

Aquaculture feeds for the majority of aquaculture species are a complete feed, specifically formulated for that species. The production of a water-stable feed, and the ability to manipulate pellet buoyancy, are key characteristics. In comparison to terrestrial stock feeds, aquaculture feeds are expensive with specialised equipment required for production. There are opportunities to use agricultural products (plant and animal) as ingredients in feeds for prawn and barramundi. However, this would require a specialised feed mill to be located in northern Australia to avoid the high cost of transport of raw ingredients to mills located in Brisbane and Hobart.

Unlike most aquaculture species, the commercial feed for red claw can be produced in a less specialised terrestrial animal mill. Therefore, there is an opportunity for the establishment of a multi-purpose mill (aquaculture and livestock) in northern Australia, with close proximity a major benefit in term of transport costs.

Bio floc is a relatively new technology that involves the use of raw or processed plant materials to maintain a diverse and productive bacterial population in pond aquaculture (Avnimelech, 2009). It can be used in prawn aquaculture and enables limited or zero water exchange, stable water conditions and the provision of a secondary nutrition source (bacteria and algae). In general terms, the technology involves close monitoring of water quality conditions and the addition of carbon to the pond to change the dynamics of the pond community from algal to bacterial. Constant aeration and supplemental carbon such as molasses from sugarcane is added throughout the production cycle to maintain a stable bio floc population. There is potential for the industry to utilise hundreds of tonnes of agricultural plant materials to manage bio floc systems in northern Australia.

Novacq™ is a dry feed ingredient developed by CSIRO based on bio floc technology. The ingredient is produced in isolation in conventional marine aquaculture ponds via the bio-conversion of low-value plant waste from agriculture. The bio-conversion process involves the addition of agricultural sources such as bagasse (from sugarcane) into a marine pond containing specific concentrations of a range of nutrients. There is excellent potential for Novacq™ to be produced in northern Australia.

4.6.6 WATER AND LAND SUITABILITY

A land suitability framework for the study area was developed for marine and freshwater ponds, either earthen or plastic-lined, using the set of five land suitability classes in Table 4-1. The suitability of specific areas for aquaculture development was assessed from the perspective of soil and land characteristics for all three species (considered generically as 'marine' and 'freshwater' species) and proximity to a marine water source for black tiger prawns and barramundi (Table 4-23). Water temperature and water salinity were modelled for specific pond filling scenarios taking into account management practice, evaporation and precipitation. These limitations are directly related to the health and production characteristics of the species, which have known tolerances. The land limitations included those relevant to geotechnical considerations such as the construction and stability of the pond walls and to the extent of effort required to develop the pond locations, caused by limitations such as slope. Distance to a marine water source for marine or euryhaline species is an important consideration for the capital and operating costs of an aquaculture enterprise. For further detail see the companion technical report on land suitability (Thomas et al., 2018b). It was not possible to include proximity to fresh water due to the large number of potential locations that water could be captured and stored within the catchment. Note also that the estimates for land suitability presented below represent the total areas of the catchment unconstrained by factors such as water availability, land tenure, environmental and other legislation and regulations, and a range of biophysical risks such as cyclones and flooding. These are addressed elsewhere by the Assessment. The land suitability maps are designed to be used predominantly at the regional scale. Planning at the enterprise scale would demand more localised assessment.

Table 4-23 Rationale for limitation assessment for aquaculture land and water suitability analysis

LIMITATION	BRIEF RATIONALE
Water temperature	Water temperature is a key factor for species selection for a given region. While most species have a broad thermal tolerance, optimal production occurs across a narrow range. Pond water temperature varies seasonally.
Water salinity	Water salinity is a key factor for species selection. For the majority of species, optimal production occurs across a relatively narrow range, usually either marine or fresh water. However, euryhaline species are efficiently produced under marine and freshwater conditions.
Distance to marine water source	Pond distance from a marine water source has a large bearing on the required capital investment and ongoing crop production efficiency.
Elevation	Land elevation has significant bearing on ability to drain production and bioremediation ponds, which affects ongoing production efficiency.
Slope	Land slope has a significant bearing on required capital investment to construct ponds and channels.
Soil clay content (%)	The objective of the pond containment structure is to provide an impermeable layer between the pond water and the local surface and groundwater. Soil clay content (%) is a good indicator of the potential to produce an impermeable soil layer.
Soil pH	Soil acidity or alkalinity may lead to certain toxicities.
Acid sulfate soils	Acid sulfate soils are more expensive to develop, manage and can be detrimental to animal health and reduce crop production efficiency.
Soil depth	Soil depth has significant bearing on required capital investment to construct ponds.
Permeability	A measurement of the ease that the pond water can travel through the pond base and wall.

LIMITATION	BRIEF RATIONALE
Rockiness	Rockiness has significant bearing on required capital investment to construct ponds.
Gilgai	Gilgai presence has a significant bearing on required capital investment to construct ponds.

Areas of shallow rocky soils, landscapes where slopes exceed 5% and those areas with high acid sulfate soil potential are generally precluded from aquaculture development. Earthen ponds are restricted to areas of deeper clay (>0.5 m depth) and heavier loam soils where soil compaction and stability properties are suitable for pond construction. Areas with moderate to rapid soil permeability, such as deep sands, are not suitable because loss of pond water and potential contamination of groundwater are major constraints. Marine species, including prawns, are constrained by distance from the coast or influence of marine tides, making large inland areas of the Mitchell catchment unsuitable. Suitability for marine species is therefore much more restricted than for freshwater species. The most extensive areas of suitable land were those for lined ponds for freshwater species.

Sea surface temperatures from oceanic waters offshore to the Mitchell catchment are ideal for the culture of a majority of tropical aquatic species from October to March. The comparatively shallow nearshore and estuarine waters in the Mitchell catchment are likely to be significantly higher in temperature than adjacent oceanic waters. If the warming trend of sea surface temperatures in northern Australia continues (see companion technical report on climate (Charles et al., 2016)) this may have the potential to prolong the grow-out season for some aquatic species.

For marine ponds, a pond filled on 1 October would exhibit salinity levels that are largely buffered by rainfall during the wet season. Elevated salinities during the dry season due to evaporation and low precipitation rates may be difficult to manage, as the addition of large amounts of fresh water to lower pond salinities may be impractical or too costly. For example, a standard marine pond (1 ha) receiving no precipitation and 10 mm evaporation per day would require daily addition of 100,000 L (0.1 ML) of fresh water to maintain optimal salinities. A 100-ha farm would require 10 ML of fresh water a day or 1.5 GL for a 150-day season. Evaporative effects and low precipitation periods would be considerably easier to manage by filling ponds at the lowest optimal salinity of the target species and regulating water exchanges at suitable intervals.

Pond water temperatures are optimised for most tropical aquaculture species between September and April. Minimum pond water temperatures during the mid-year dry season are shown to fall below the optimal growth threshold for tropical culture species. Distance from a marine water source is a major limiting factor, reducing suitability to the coastal parts of the catchment.

Freshwater ponds have no salt content and therefore water exchange has no effect on culture water salinity. However, there is a requirement to maintain pond volume. For example, a standard pond (1 ha) receiving no precipitation and 10 mm evaporation per day would require a daily addition of 100,000 L (0.1 ML) of fresh water to maintain pond volume. A 100-ha farm would require 10 ML of fresh water a day or 3 GL for a 300-day season.

Assuming unconstrained development, around 216,000 ha of coastal land was found to be suitable for marine earthen ponds, the majority of which is Class 3 (Figure 4-38). These areas are restricted to seasonally or permanently wet soils along and close to the coastline, and in sand or loam over sodic clay subsoils in the lowest reaches of the river and channels.

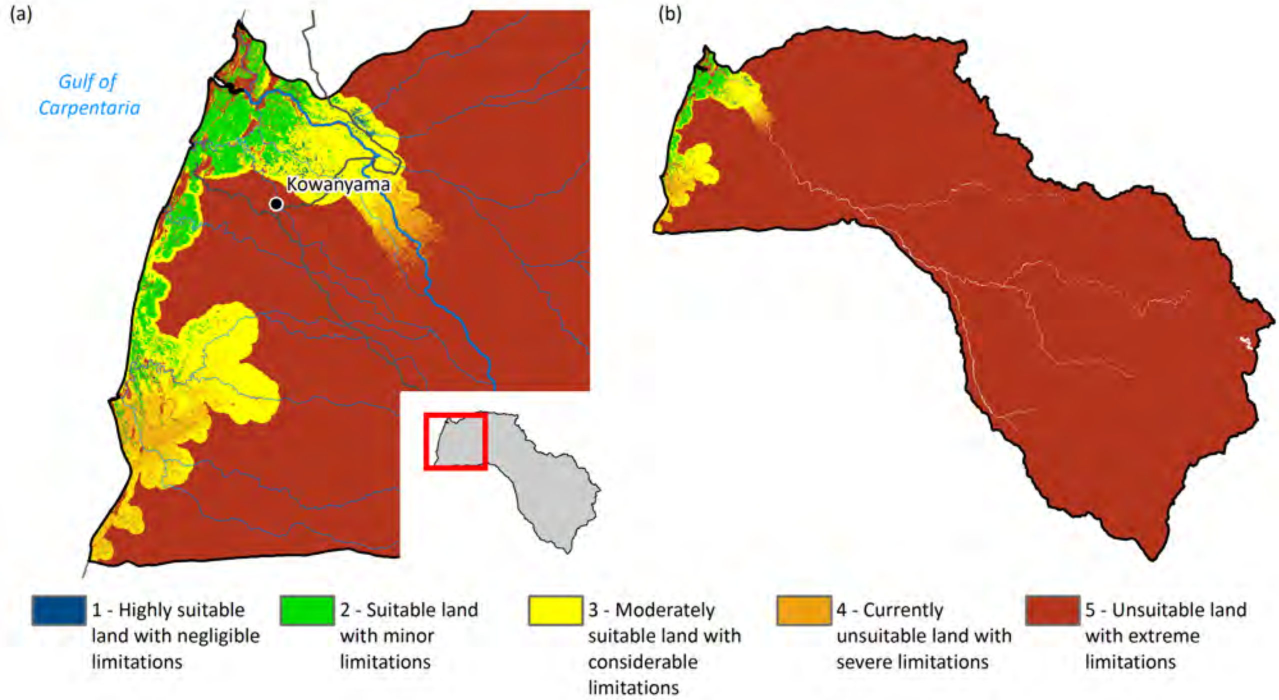

Figure 4-38 Land suitability in the Mitchell catchment for marine species aquaculture in earthen ponds; (a) the coastal extent and (b) within the catchment

Assuming unconstrained development, around 235,000 ha of coastal land was found to be suitable for marine lined ponds, the majority in Class 1 (Figure 4-39). These areas coincide strongest with seasonally or permanently wet soils and sand or loam over sodic clay subsoils.

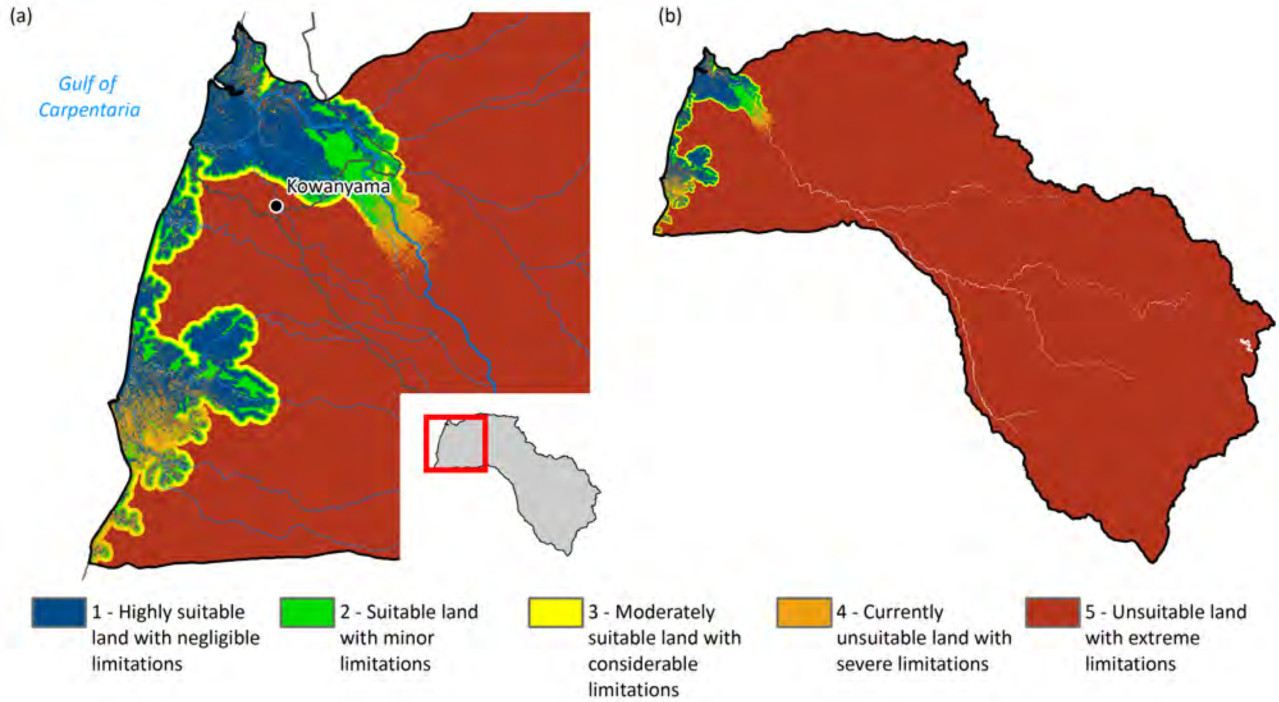

Figure 4-39 Land suitability in the Mitchell catchment for marine species aquaculture in lined ponds; (a) the coastal extent and (b) within the catchment

Assuming unconstrained development, around 1.9 million ha was found to be suitable for freshwater earthen ponds, the majority being in Class 3 (Figure 4-40). The area of suitable land is found on the northern coastal margin of the catchment where seasonally or permanently wet soils and brown, yellow and grey sandy soils dominate, as well as along the margins of the main river channels dominated by seasonally or permanently wet soils and sand or loam over sodic clay subsoils and cracking clay soils in the lowlands.

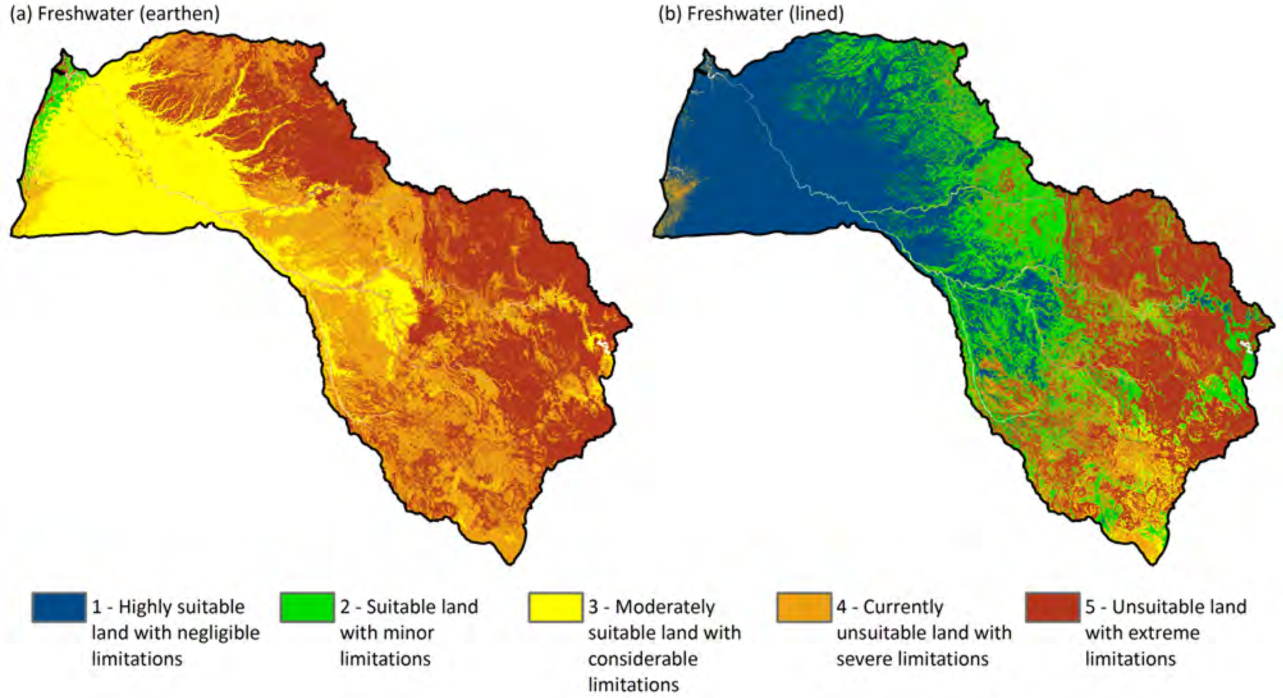

Figure 4-40 Land suitability in the Mitchell catchment for freshwater species aquaculture; (a) earthen ponds and (b) lined ponds

Assuming unconstrained development, around 4.6 million ha of land was found to be suitable for freshwater lined ponds, the majority in Class 1 (Figure 4-40). Almost all of the lowlands are suitable while areas of the eastern parts of the catchment are restricted in part by shallow and/or rocky soils.

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5 Opportunities for water resource development in the Mitchell catchment

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Chapter 5 examines the opportunities for water resource development in the Mitchell catchment, with a focus on the supply of water for irrigation. Evaluating the possibilities for water resource development and irrigation supply requires an understanding of the development-related infrastructure requirements, how much water it can supply and at what reliability, and the associated costs.

The key components and concepts of Chapter 5 are shown in Figure 5-1.

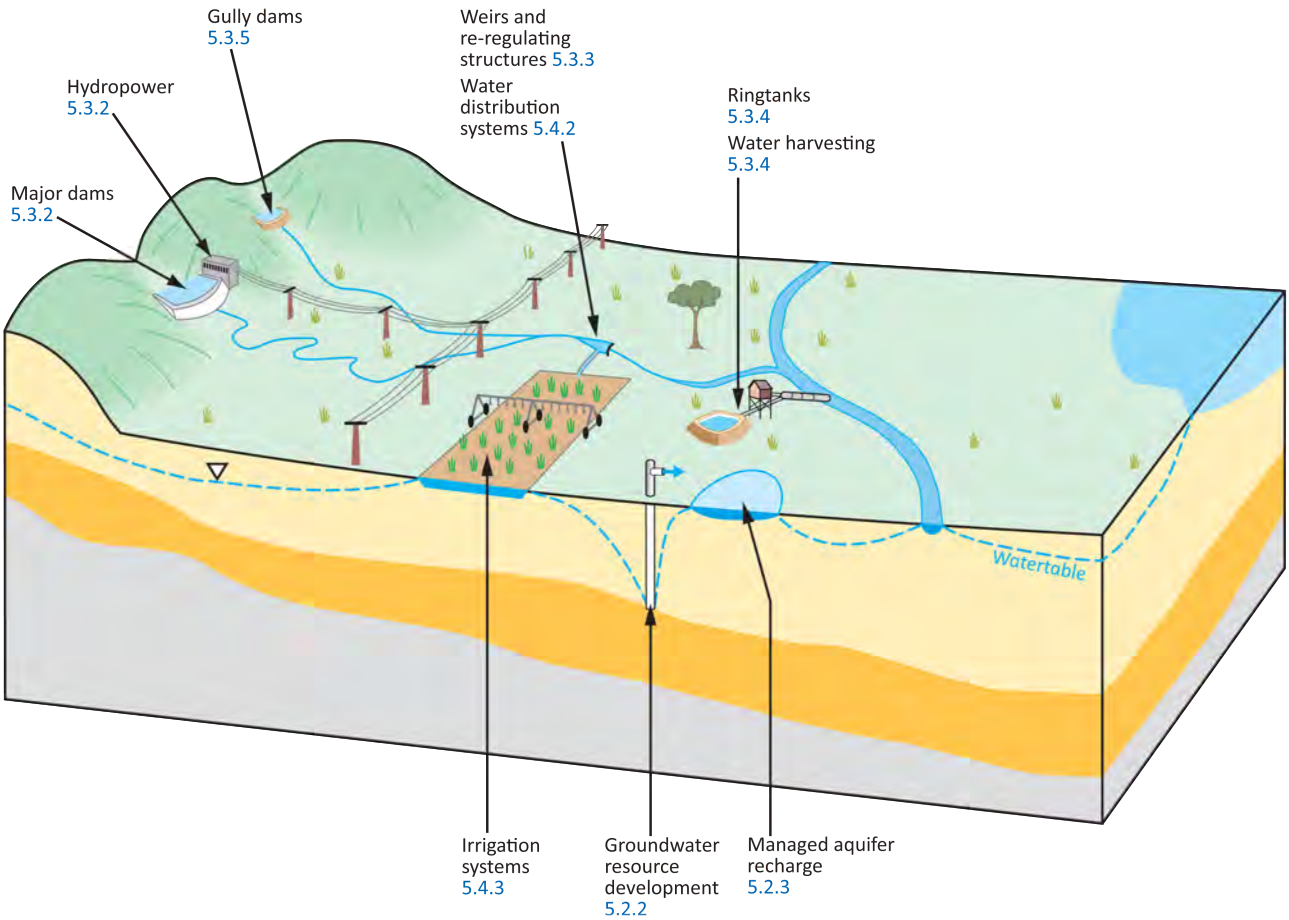

Figure 5-1 Schematic diagram of key engineering and agricultural components to be considered in the establishment of a water resource and greenfield irrigation development

5.1 Summary

This chapter provides information on a variety of potential options to supply water, primarily for irrigated agriculture. The methods used to generate these results involved a mixture of field surveys and desktop analysis. The potential water yields reported in this chapter are based largely on physically plausible volumes, and do not consider economic, social, environmental, legislative or regulatory factors, which will inevitably constrain many developments. In some instances, the water yields are combined with land suitability information from Chapter 4, so as to provide estimates of areas of land that could potentially be irrigated close to the water source or storage. These estimates are similarly based on physically plausible volumes and areas of land.

5.1.1 KEY FINDINGS

Water can be sourced and stored for irrigation in the Mitchell catchment in a variety of ways.

Major dams

Major instream dams could supply the largest quantities of reliable water of any of the storage options considered in the catchment. Four of the more promising major dams in the Mitchell catchment could supply about 2800 GL of water in 85% of years at the dam wall, or about 1540 GL to the crop after losses. This would provide sufficient water to irrigate about 140,000 ha of land throughout the year (e.g. a crop such as sugarcane), but this does not consider the current regulatory environment and the needs of other water users.

Eight potential dam sites were selected for pre-feasibility analysis on the basis that these were the more cost-effective sites in distinct geographic areas in proximity to soils suitable for irrigated agriculture. The sites with the lowest cost per ML supplied were the Pinnacles dam site on the Mitchell River, the Rookwood dam site on the Walsh River and the Palmer dam site on the Palmer River. These had equivalent annual unit costs of 45, 84 and 92 $/year per ML/year respectively. For any of the options to advance to construction, far more comprehensive studies would be required.

Groundwater extraction

Excluding the natural water bodies discussed later, groundwater extraction from the Bulimba Formation is the cheapest method of supplying water for irrigated agriculture in the Mitchell catchment (Table 5-1). However, the total groundwater resource in the Bulimba Formation is likely to be less than 5 GL/year, sufficient to irrigate a maximum of 350 ha throughout the year, with a maximum of 1–2 GL/year at each location. It is possible that up to an additional 5 GL/year of groundwater could potentially be extracted from the Gilbert River Formation within 50 km from the outcropping areas and up to another 5 GL/year could potentially be extracted from alluvial aquifers associated with the Gilbert River Fan Aggregation. At each location a maximum of about 1 GL could potentially be extracted, sufficient to support small-scale irrigation developments. Due to the steeply dipping nature of the Gilbert River Formation, groundwater extraction from this formation would need to be within 50 km from outcropping areas to be economically viable.

Water harvesting and farm-scale offstream storage

Water harvesting and large farm-scale offstream storages such as ringtanks are comparable in cost (i.e. equivalent annual unit cost) to major dams, but more expensive than groundwater and gully dams, largely due to the costs of pumping water. They can, however, enable larger areas of irrigated agriculture in the Mitchell catchment than groundwater and gully dams. It is possible to pump or divert about 2000 GL of water in 85% of years into large farm-scale offstream storages such as ringtanks sited adjacent to major rivers. After evaporation, seepage, conveyance and field application losses this is sufficient water (1100 GL) to irrigate about 200,000 ha of a single dry-season crop. Below the confluence of the Mitchell and Palmer rivers where broad–scale flooding occurs adjacent to the major river channels, well-constructed ringtanks can withstand slow-moving floodwaters. However, rotations that seek to maximise the use of land developed for irrigation by also cropping during the wet season would carry considerable risk, unless flood control measures are implemented. Furthermore, accessing land during the wet season, below the confluence of the Mitchell and Palmer rivers in particular, would be very challenging without considerable upgrades to infrastructure such as roads and bridges.

Large farm-scale gully dams

Large farm-scale gully dams are slightly more expensive than groundwater extraction, and are cheaper than other water supply options. However, topographically favourable locations for gully dams in the Mitchell catchment in the vicinity of soils suitable for the construction of impermeable embankments and irrigated agriculture are limited to specific parts of the catchment, predominantly the Alice River catchment. It is estimated large farm-scale gully dams could potentially supply up to 300 GL of water in 85% of years.

Managed aquifer recharge

A reconnaissance assessment suggests there is potential for managed aquifer recharge (MAR) to augment recharge to unconsolidated alluvial aquifers and sedimentary sandstone and limestone aquifers of the Mitchell catchment. Approximately 9100 km^2 of the catchment (13%) were identified as having potential for aquifers suitable for infiltration MAR techniques within 5 km of a major river, from which water could potentially be sourced for recharge. However, MAR will inevitably only be developed subsequent to the development of a groundwater resource, which is cheaper than a MAR scheme, and in many cases in northern Australia groundwater extraction may be necessary to create additional storage capacity within the aquifer. In areas of groundwater extraction 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. Three types of MAR scheme: recharge weirs, recharge release and infiltration basins, are examined to explore opportunities for MAR in the Mitchell catchment. The total equivalent annual costs for the construction and operation of a 1-GL MAR scheme range between $48 and $172/year per ML of stored water/year. Recharge release is the lowest cost ($48/year per ML/year) because it relies on existing (in this case, potential) dam and weir structures for release and the natural river channel for infiltration. An infiltration basin scheme is the next lowest cost at $82/ year per ML/year, however, these costs do not include pumping infrastructure to pump water from the river or a temporary detention storage. The most expensive is the recharge weir ($172/ year per ML/year), however, it does not require any additional infrastructure. For each configuration, groundwater extraction bores have also been costed as there are few bores targeting the alluvium. 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.

Other potential sources of water

The remaining sources of water and storage options, namely weirs and natural water bodies, were estimated to be capable of reliably supplying considerably smaller volumes than major instream dams (i.e. 10 times less). Nevertheless, as shown in Table 5-1, each option may have a role to play in maximising the cost effectiveness of water supply in different parts of the Mitchell catchment. Although unlikely to support small-scale development in most cases, sourcing water from natural water bodies is cheap and may be effective in staging a development, where ideas are tested and lessons are learnt on a small scale (e.g. 1 to 20 ha) before large capital investment occurs. The main limitation to the use of natural water bodies that persist throughout the dry season is that they are key ecological refugia.

Summary of investigative, capital, and operation and maintenance costs of different water supply options and potential scale of unconstrained development

Table 5-1 provides a summary of indicative investigative, capital and operation and maintenance costs of different water supply options and estimates of the potential scale of unconstrained development. The development of any of these options will impact on existing uses, including ecological systems, to varying degrees, and will depend on the level of development. This is examined in Section 7.2.

All of the water source options reported in Table 5-1 are considerably cheaper than the cost of desalinisation. The initial cost of constructing four large desalinisation plants (capacity of 90 to 150 GL/year) in Australia between 2010 and 2012 ranged from $15,000/ML to $25,000/ML (AWA, 2018), indexed to 2017. This does not include the cost ongoing operation (e.g. energy) and maintenance or the cost of conveying the water to the demand.

Table 5-1 Summary of capital costs, yields and costs per ML supply including operation and maintenance (O&M)
Costs and yields are indicative and will vary locally. Values are rounded. Capital costs are the cost of construction of the water storage/source infrastructure. They do not include the cost of constructing associated infrastructure for conveying water or irrigation development. Water supply options are not independent of one another and the maximum yields and areas of irrigation cannot be added together. Equivalent annual cost assumes a 7% discount rate over the service life of the infrastructure. Total yields and areas are based on physical plausibility unconstrained by economic, social, environmental, legislative or regulatory factors, which will inevitably constrain many developments.

WATER SOURCE/STORAGE	GROUND-WATER†	MANAGED AQUIFER RECHARGE‡	MAJOR DAM	WEIR§	LARGE FARM-SCALE RINGTANK	LARGE FARM-SCALE GULLY DAM	NATURAL WATER BODY
Cost and service life of individual representative unit							
Capital cost ($ million)	0.5	1.7	650–750	10–40	2.2	1.5	0.02
Operation and maintenance (O&M) ($ million/y)*	0.005	0.05	2.8	0.2–0.8	0.1	0.03–0.05	~0
Assumed service life (y)	50	50	100	40	40	30	15

WATER SOURCE/STORAGE	GROUND-WATER†	MANAGED AQUIFER RECHARGE‡	MAJOR DAM	WEIR§	LARGE FARM-SCALE RINGTANK	LARGE FARM-SCALE GULLY DAM	NATURAL WATER BODY
Potential yield of individual representative unit at water source							
Yield at source†† (GL)	1	1	550–1250	2–15	2.8	3	0.125–0.5
Unit cost ($/ML)§§	500	1,700	600–1250	2,700	785	500	40–160
Equivalent annual unit cost ($ million/y) per ML/y†††	40	172	45–90	250	~100	55	5–20
Potential yield of individual representative unit at paddock							
Assumed conveyance efficiency to paddock (%)‡‡	95	95	65	80	90	90	90
Yield at paddock (GL)	0.95	0.95	360–810	1.6–12	2.5	2.7	0.11–0.45
Unit cost ($/ML)§§	525	1,790	930–1915	3,375	870	555	45–180
Equivalent annual unit cost ($ million/y) per ML/y†††	42	181	70–140	333	114	59	6–23
Total potential yield and area							
Total potential yield (GL/y) at source ≥85% reliability‡‡‡	15	NA	2,800	<400	1,420	<200	<100
Potential area that could be irrigated at ≥85% reliability (ha)§§§	1000	NA	135,000	<20,000	200,000	<10,000	<5000

†Value assumes extraction from the Bulimba Formation and that drilling is successful on first attempt.
‡Recharge weir structure.
§Sheet piling weir.
*O&M cost is the annual cost of operating and maintaining infrastructure, including cost of pumping water into ringtank. For groundwater assumes artesian conditions and no cost for pumping from depth.
††Yield at dam wall (taking into consideration net evaporation from surface water storages prior to release) or at groundwater bore. Value assumes large farm-scale ringtanks do not store water past August.
‡‡Conveyance efficiency between dam wall/groundwater bore and edge of paddock (does not include field application losses).
§§Capital cost divided by the yield.
†††Equivalent annual cost of storage/bore per ML of yield of water. Includes capital cost and O&M costs. Assumes 7% discount rate over service life of infrastructure. For major dams includes cost of re-regulating structure and cost of pumping from weir pool into trunk channel.
‡‡‡Likely maximum cumulative yield at the dam wall/groundwater bore. Potential yield of major dams based on yield of dams at Dimond Gorge and on the Margaret River. In the case of large farm-scale ringtanks, 2000 GL of water could be extracted from the Mitchell catchment in 85% of years but only 1420 GL would be released after evaporative and seepage losses. Up to 5 GL/year could potentially be extracted from the Bulimba Formation, with no one development extracting more than 12 GL/year. Up to a total of 15 GL/year could potentially be extracted from the Bulimba Formation, Gilbert River Formation (within 50 km of outcropping areas) and alluvial aquifers associated with the Mitchell River.
§§§Likely maximum area that could be irrigated (after conveyance and field application losses) in at least 85% of years. Value assumes a crop under full canopy cover is grown all year round at an applied irrigation water of 11.5 ML/ha. Value assumes ringtanks are only used to irrigate a single dry-season crop (5.4 ML/ha) with crop planted at end of wet season.
NA = data not available

5.1.2 INTRODUCTION

Irrigation during the dry season and other periods when soil water is insufficient for crop growth requires sourcing water from a suitable aquifer or from a water storage. However, decisions regarding groundwater extraction, river regulation and water storage are complex and the consequences of decisions can be inter-generational, where even relatively small inappropriate releases of water may preclude the development of other more appropriate (and possibly larger) developments in the future. Consequently, governments and communities benefit by having a wide range of reliable information available prior to making decisions, including the manner of ways water can be sourced and stored, as this can have long-lasting benefits and facilitate an open and transparent debate.

This chapter provides information on groundwater and subsurface storage opportunities (Section 5.2) and surface water storage (Section 5.3) opportunities in the Mitchell catchment. Information is presented in a manner to enable the comparison of the variety of options. Section 5.4 discusses the conveyance of water from the storage and its application to the crop. Transmission and field application efficiencies and associated costs and considerations are examined.

All costs presented in this chapter are indexed to 2017.

Concepts

The following concepts are used in sections 5.2 and 5.3.

- Each of the water source and storage sections are structured around a reconnaissance assessment and a pre-feasibility assessment, where:
  - Reconnaissance assessments involved a review of the existing literature and a high-level desktop assessment using methods and datasets that could be consistently applied across the entire study area. The purpose of the reconnaissance assessment is to provide a general indication of the likely scale of opportunity and geographic location of each option.
  - Pre-feasibility assessments involved a more detailed desktop assessment of sites/geographic locations that were considered more promising. This involved a broader and more detailed analysis including the development of bespoke numerical models, site-specific cost estimates and site visits.
- Yield is a term used to report the performance of a water source or storage. It is the amount of water that can be supplied for consumptive use at a given reliability. For a dam of a given capacity (i.e. reservoir volume), an increase in water yield results in a decrease in reliability. For groundwater, an increase in water yield results in an increase in the ‘zone of influence’ and can result in a decrease in reliability, particularly in local- and intermediate-scale groundwater systems.
- Equivalent annual cost is the annual cost of owning, operating and maintaining an asset over its entire life. Equivalent annual cost allows a comparison of the cost effectiveness of various assets that have unequal service lives/lifespans.

Other economic concepts reported in this chapter, such as discount rates, are outlined in Chapter 6.

5.2 Groundwater and subsurface water storage opportunities

5.2.1 INTRODUCTION

Groundwater, where the water bearing formation is at an economical depth (<300 m) and is of sufficient yield to support irrigation (>10 L/second), is often one of the cheapest sources of water available, particularly where the potentiometric surface is artesian or near artesian thereby reducing pumping costs. Even the cheapest form of managed aquifer recharge (MAR), infiltration-based techniques, are usually considerably more expensive than developing a groundwater resource. Further to this, in the wetter parts of northern Australia many unconfined aquifers, which are best suited to infiltration-based MAR, have no 'free' storage capacity at the end of the wet season and consequently it is not possible to further recharge the aquifers. For these reasons MAR will inevitably only be developed subsequent to development of the groundwater resource, which is cheaper, and groundwater extraction may create additional storage capacity within the aquifer. However, if developed, MAR can enhance the quantity of water available for extraction and help mitigate impacts to the environment.

It should be noted that where water has a higher value than irrigation (e.g. mining, energy operations, town water supply), other more expensive but versatile forms of MAR, such as aquifer storage and recovery, can be economically viable and should be considered.

The Assessment undertook a catchment-wide reconnaissance assessment and at selected locations a pre-feasibility assessment of:

- groundwater resource development opportunities (Section 5.2.2)
- MAR opportunities (Section 5.2.3).

Unless stated otherwise, the material presented in sections 5.2.2 and 5.2.3 has been summarised from the companion technical reports on hydrogeological assessment (Taylor et al., 2018) and on assessment of MAR opportunities (Vanderzalm et al., 2018), respectively.

5.2.2 GROUNDWATER RESOURCE DEVELOPMENT OPPORTUNITIES

Introduction

Planning future groundwater resource developments and authorising groundwater allocations requires value judgements of what is an acceptable impact to receptors such as environmental assets or existing users. These decisions can be complex and typically require considerable input from a wide range of stakeholders, particularly government regulators and communities.

Scientific information to help inform these decisions include identifying aquifers that may be potentially suitable for future groundwater resource development, characterising their depth and spatial extent, conceptualising the nature of their flow systems, estimating aquifer water balances and providing initial estimates of potential extractable volumes and associated drawdown in groundwater level over time and distance. Unless stated otherwise, the material presented in this section has been summarised from the companion technical report on hydrogeological assessment (Taylor et al., 2018).

Reconnaissance assessment of groundwater resource development opportunities in the Mitchell catchment

The hydrogeological units of the Mitchell catchment host a variety of local- to regional-scale groundwater systems, the latter being better suited for future groundwater resource development. Regional-scale aquifers underlie large parts of the Mitchell catchment (Section 2.5.1) and contain mostly low salinity water (<1000 µs/cm) and can yield water at a sufficient rate to support irrigation development (>10 L/s). Given their larger spatial extent, they also underlie and coincide with larger areas of soil suitable for irrigated agriculture (Section 4.3). The regional-scale aquifers contain larger volumes of groundwater in storage (gigalitres to teralitres) than local-scale aquifers, and therefore are less impacted by short-term (yearly) climate variations in recharge rates that may arise due to inter-annual variability in rainfall. Furthermore, their larger spatial extent provides greater opportunities for groundwater resource development away from groundwater-dependent ecosystems (GDEs) at the land surface such as springs, spring-fed vegetation and surface water, which can be ecologically and culturally significant. In contrast, local-scale aquifers in the Mitchell catchment such as fractured rock and alluvial aquifers, host local-scale groundwater systems that are highly variable in composition, salinity and yield. They also have a smaller spatial extent and less storage compared to the regional-scale aquifers, limiting groundwater resource development to localised opportunities such as stock and domestic use, or as a conjunctive water resource.

The Assessment identified five hydrogeological units that may have potential for future groundwater resource development in the Mitchell catchment:

1. Tertiary basalts
2. Etheridge and Hodgkinson provinces
3. Quaternary alluvium
4. Gilbert River Formation
5. Bulimba Formation.

Reconnaissance-level estimates of the potential scale of groundwater resource development for each of these hydrogeological units are summarised in Table 5-2 and are based on current available hydrogeological data.

Table 5-2 Reconnaissance estimates of the potential scale of groundwater resource development opportunities in the Mitchell catchment (see Figure 5-2 for the location of each hydrogeological unit)

HYDROGEOLOGICAL UNIT	INDICATIVE MAXIMUM SCALE OF RESOURCE (GL/y)	LEVEL OF KNOWLEDGE	COMMENT
Tertiary basalts	<0.5	None	Local-scale fractured rock aquifers with variable bore yields and water quality. Primarily stock and domestic, occasionally only likely to offer potential for small-scale (<0.5 GL/y) localised developments or as a conjunctive water resource. Very little currently known about the resource.
Etheridge and Hodgkinson provinces	<0.5	Medium	Local-scale fractured rock aquifers with variable bore yields and water quality. Primarily stock and domestic, occasionally only likely to offer potential for small-scale (<0.5 GL/y) localised developments or as a conjunctive water resource. Limited opportunities due to a lack of connectivity across large areas.
Quaternary alluvium	<5†	Low	Local-scale alluvial aquifers with variable bore yields and water quality. Primarily stock and domestic, occasionally only likely to offer potential for small-scale (<1 GL/year) localised developments or as a conjunctive water resource. Limited opportunities due to the high potential for impacting dry-season flow in major rivers.
Gilbert River Formation	<5†	Low	Regional-scale aquifer with high bore yields and good quality water. The most promising areas for development are likely to be near the aquifer outcrop (i.e. approximately within 50 km west of the outcrop); however, further drilling is required to better understand spatial changes in the depth to the top of the aquifer. Aquifer is prohibitively deep to warrant drilling for irrigation water supplies >50 km west of the aquifer outcrop.
Bulimba Formation	<5†	Medium to high	Most promising regional-scale aquifer. Artesian across large area with high bore yields and good water quality. Better suited to supporting a few small (~1 GL/y) dispersed developments. Opportunities may be limited in areas close to the coast (i.e. <40 km from the coast) where there is potential for seawater intrusion, as well as areas close to the aquifer outcrop which may results in aquifer depletion.

†No single development is likely to be greater than 2 GL.

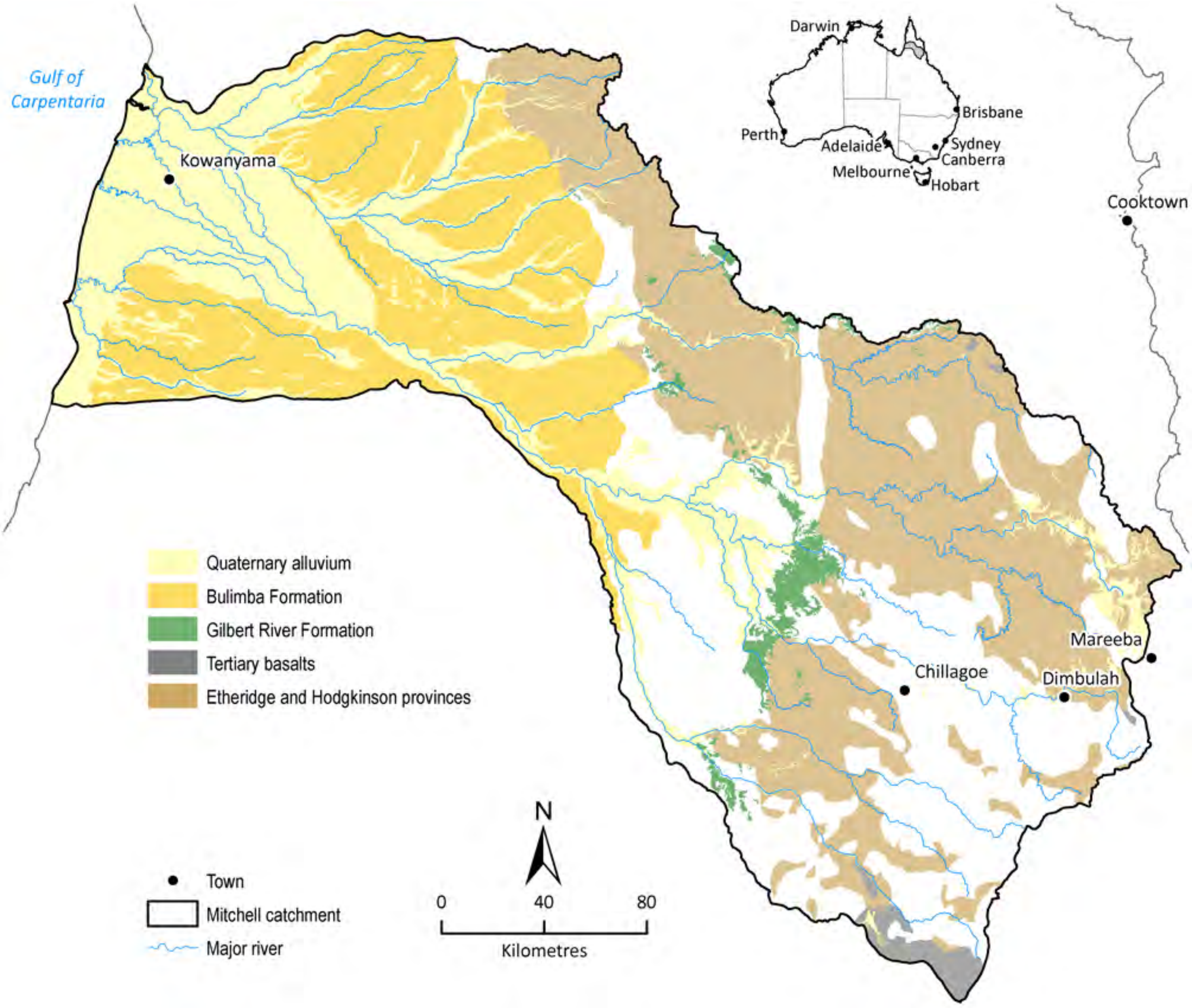

Figure 5-2 Hydrogeological units with potential for future groundwater resource development
Presents only the spatial extent of the outcropping and subcropping component of hydrogeological units. The exception is the Bulimba Formation where the entire spatial extent is known from detailed desktop investigations.

Pre-feasibility assessment of groundwater resource development in the Bulimba Formation

Based on the reconnaissance-level assessment, the Bulimba aquifer in the central to western part of the Mitchell catchment was identified as the most promising regional-scale aquifer for future groundwater resource development. Consequently, the Bulimba aquifer was the focus of a pre-feasibility assessment involving targeted field, desktop and modelling investigations (Figure 5-3).

(a) (b)

Figure 5-3 Field investigations of the Bulimba aquifer (a) purging an existing artesian stock bore and (b) collecting groundwater samples
Photo: CSIRO

This section presents information relevant to the cost of developing the groundwater resource in the Bulimba aquifer, including the depth to water-bearing formation (relevant to the cost of drilling) and the elevation of the potentiometric surface (relevant to the cost of pumping). Information on the spatial extent of drawdown of groundwater levels is also presented, which is relevant to informing decisions regarding groundwater allocations.

The Assessment's refined hydrogeological conceptual model confirmed the aquifer occurs as a series of relatively thin (5 to 25 m thick) palaeochannels that extend from the aquifer outcrop in the centre of the catchment and dip in the subsurface extending west to the coastline (for a detailed description of the aquifer see Section 2.5.1). The entire aquifer from approximately 40 to 60 km west from the aquifer outcrop is currently artesian; therefore, pump infrastructure and operating costs would be minimal for extracting groundwater (Figure 5-4). However, it should be noted that groundwater extraction may result in a reduction in the elevation of the potentiometric surface, which would result in an increase in the cost of pumping.

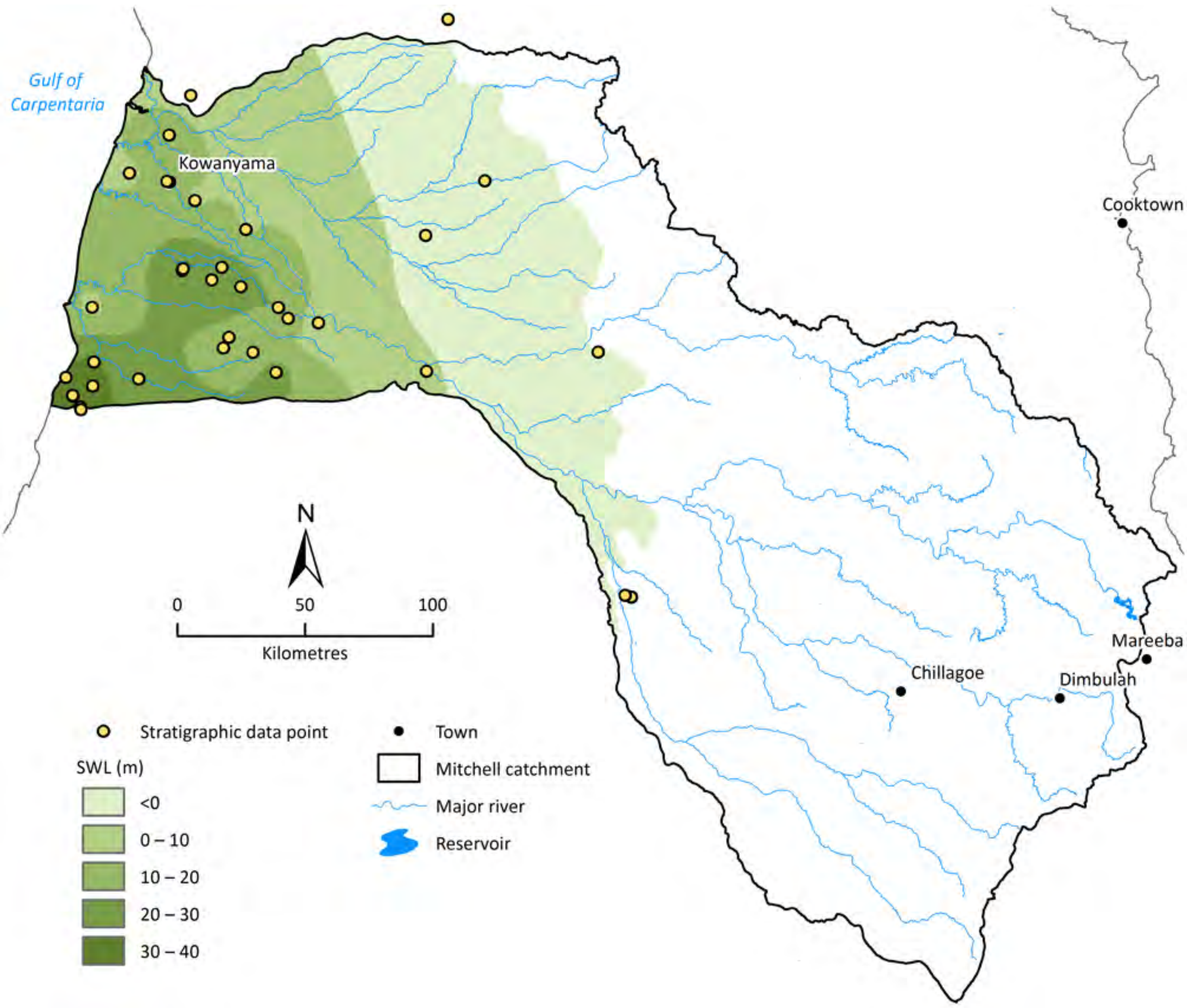

Figure 5-4 Interpolated hydraulic head for the Bulimba aquifer
This map provides an indication of areas where the aquifer is artesian or sub-artesian.

Hydraulic head (groundwater level) data points were used to interpolate the areas of artesian versus sub-artesian conditions in the Bulimba aquifer. Confidence in the interpolated hydraulic heads is highest in those areas with a higher density of data points. Indicative bore yields from existing stock bores in the Bulimba aquifer were found to be high, ranging up to 50 L/second, indicating bore yields are suitable for irrigation development. Groundwater is fresh, with low salinity (>1000 µS/cm) and ionic composition, making the water suitable for a variety of uses. However, the groundwater does have a consistently low pH (5.7 to 6.5); therefore, bore construction and materials need to be carefully considered to avoid corrosion of bore infrastructure. Based on existing drilling, the Bulimba aquifer can be intersected at economical depths at most locations, with depth below ground level (BGL) ranging from approximately 20 m near the outcrop areas, to 150 m in places approximately 100 km west of the outcrop and up to 100 km from the coast (Figure 5-5). Figure 5-6 shows a bore in the Bulimba Formation under artesian conditions.

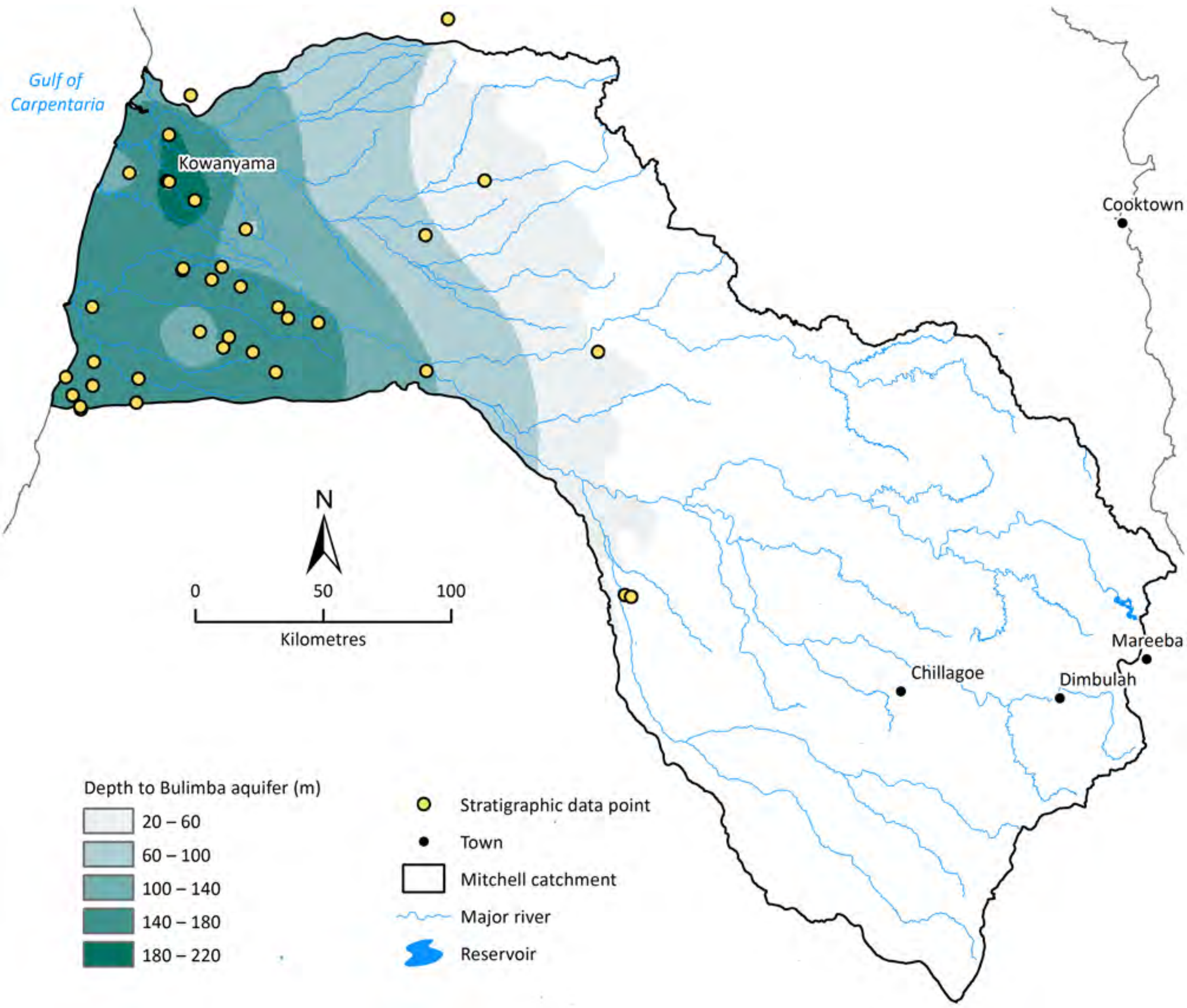

Figure 5-5 Spatial map of interpolated depth to the top of the Bulimba aquifer
Stratigraphic data points and aquifer outcrop areas (Figure 2-22) were used to interpolate the depth to the top of the Bulimba aquifer. Confidence in depth to the Bulimba aquifer is highest in those areas with a higher density of stratigraphic data points.

A refined conceptual model of the aquifer (Taylor et al., 2018) was used to test a range of extraction rates at four potential pumping sites to provide initial estimates of potential groundwater extraction volumes. Importantly, the modelled groundwater extraction rates at potential pumping sites does not provide an assessment or expert opinion of whether the impacts of groundwater level drawdown to receptors such as environmental assets or existing users are acceptable. However, the information provided here is considered useful for informing discussion on the potential scale of groundwater development of the Bulimba Formation and indicative investment required to develop the resource.

Five extraction rates were modelled and the potential impacts of the extraction rates are reported at three potential pumping sites. Current groundwater extraction at Kowanyama was simultaneously considered. Results of groundwater extraction modelling indicate that an initial range of 1 to 5 GL/year could potentially be extracted from different parts of the aquifer, though extraction volumes are location dependent. At each location, extraction from the aquifer will lead to spatial variations in modelled drawdown of groundwater level and changes to the natural flow regime. For example, in the middle of the aquifer approximately 80 km from the coast and 120 km from the aquifer outcrop, up to 5 GL/year of groundwater extraction may be possible (Figure 5-7). At distances less than 40 km from the coast, however, groundwater extraction volumes greater than 5 GL/year may not be possible due to the potential for seawater intrusion (Figure 5-8). Likewise, at distances less than 20 km from the aquifer outcrop, extraction volumes greater than 2.5 GL/year (Figure 5-9) have the potential to deplete the groundwater resource. Given the spatial variability in aquifer thickness, the groundwater resource would likely host extraction regimes best suited to mosaic-style irrigated agriculture of several dispersed small-scale (i.e. 1 to 2 GL/year) developments as opposed to one large development of equivalent size.

Groundwater development costs

Future groundwater development of the Bulimba aquifer may require investigations of the resource at two different scales, regional and local. At the regional scale the regulator may be interested in further characterisation of aquifer properties to better understand the resource potential, as well as current and future constraints to development. Key considerations are likely to include:

- characterising the aquifer extent and thickness within approximately 100 km west of the aquifer outcrop
- quantifying spatial variability in recharge
- mapping the position of the freshwater–saltwater interface, which may occur offshore
- characterising the mechanisms and rates of upward leakage from the Bulimba aquifer.

Estimates of costs associated with these regional-scale investigations are summarised in Table 5-3. At the local scale, individual proponents would typically need to undertake sufficient localised investigations in order to provide confidence around aquifer properties and bore performance. This information would usually also form part of an on-site hydrogeological assessment required by the regulator in order to grant an authorisation to extract groundwater. Key considerations for an individual proponent are likely to include:

- determining the location to drill a production bore
- testing the production bore
- determining the location and number of monitoring bores required
- conducting a hydrogeological assessment as part of applying for an authorisation to extract groundwater.

Estimates of costs associated with these local-scale investigations are summarised in Table 5-4.

Table 5-3 Summary of estimated costs to further characterise the Bulimba aquifer at the regional scale

INVESTIGATION TYPE	METHOD	ESTIMATED COST ($)
Characterising aquifer extent and thickness	Drilling	200,000†‡§
Quantifying spatial variability of recharge	Drilling, sampling and analysis	300,000†‡§*
Mapping freshwater–saltwater interface	Airborne electromagnetic survey	170,000††
Characterising upward leakage	Drilling, coring, sampling and analysis	210,000§‡‡

†Value assumes five 150 mm PVC monitoring bores drilled and constructed at an average depth of 75 m at a cost of $500/m.
‡Value assumes a mobilisation/demobilisation rate of $10/km from Cairns (approximately 1000-km round trip).
§Drilling and coring do not include time for project management or an on-site hydrogeologist.
*Value assumes sampling for groundwater chemistry and a range of environmental tracers at a cost of $3000 per bore.
††Costs are based on previous surveys conducted by CSIRO including mobilisation of $15,000 and a cost of $300 per line km for a survey of 500 line kms.
‡‡Value assumes five cored holes at an average depth of 100 m at a cost of $200/m and six core samples per hole analysed at a cost of $400 each.

Table 5-4 Summary of estimated costs for a small-scale (1 GL/year) mosaic-style irrigation development using groundwater from the Bulimba aquifer

DRILLING, CONSTRUCTION, INSTALLATION AND TESTING OF BORES	ESTIMATED COST ($)
Production bore	150,000†
Monitoring bores	230,000‡
Aquifer testing	40,000§
Mobilisation/demobilisation	10,000*
Hydrogeological assessment	50,000††

†Value assumes one production bore drilled and constructed using FRP at an average depth of 150 m at a cost of $1000/m.
‡Value assumes two 150 mm FRP monitoring bores drilled and constructed at an average depth of 150 m at a cost of $750/m.
§ Value assumes a 72-hour aquifer test (48 hours pumping, 24 hours recovery) at a cost of $500 per hour and $4000 mobilisation/demobilisation.
*Value assumes a mobilisation/demobilisation rate of $10/km from Cairns (approximately 1000-km round trip).
†† Value assumes a small-scale development away from existing users and GDEs.

Figure 5-6 Groundwater bore in the Bulimba Formation under artesian conditions
Photo: CSIRO

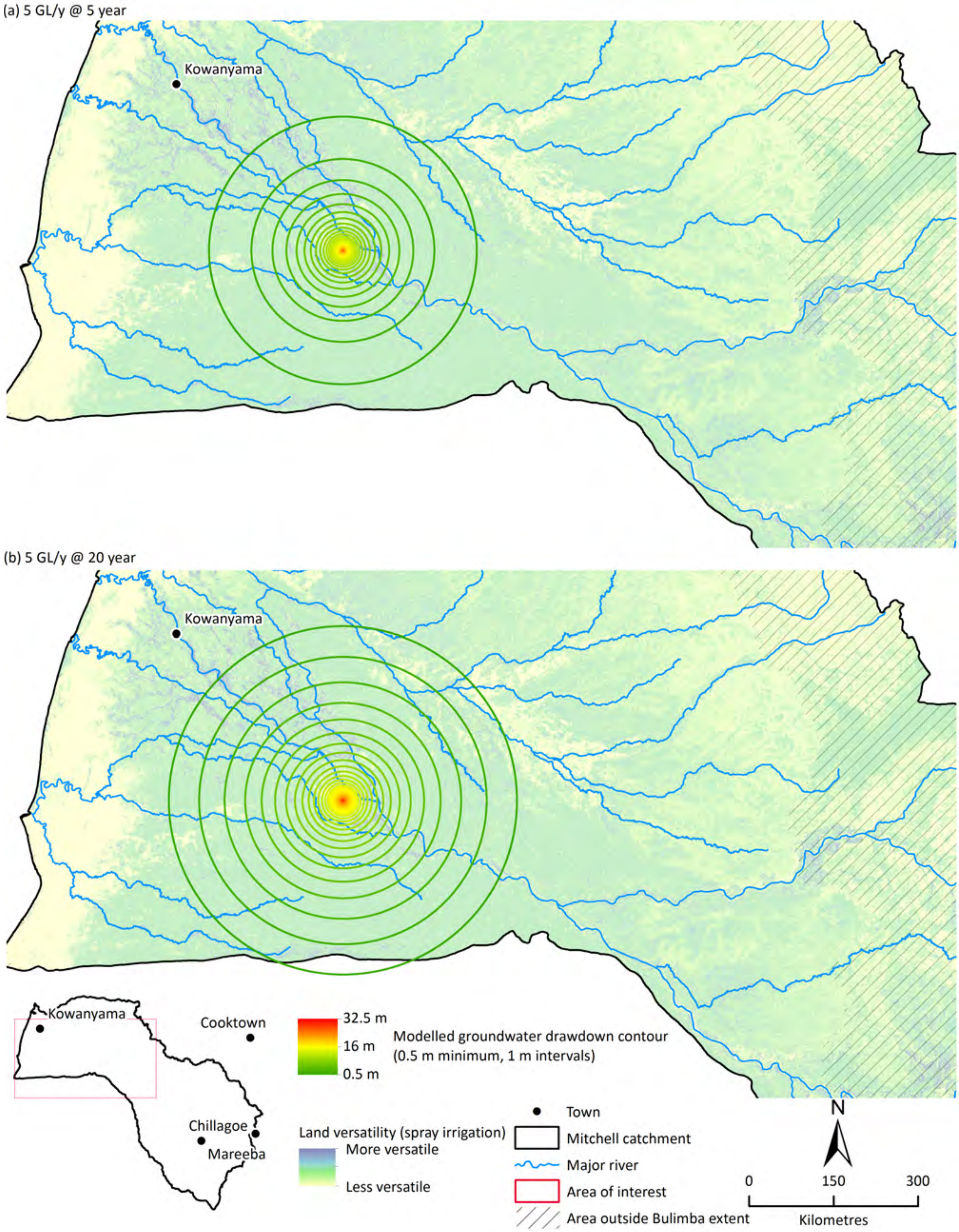

Figure 5-7 Example of spatial variations in modelled drawdown in the centre of the aquifer
(a) After 5 years and (b) after 20 years as a result of testing a 5 GL/year groundwater extraction rate from the Bulimba aquifer.

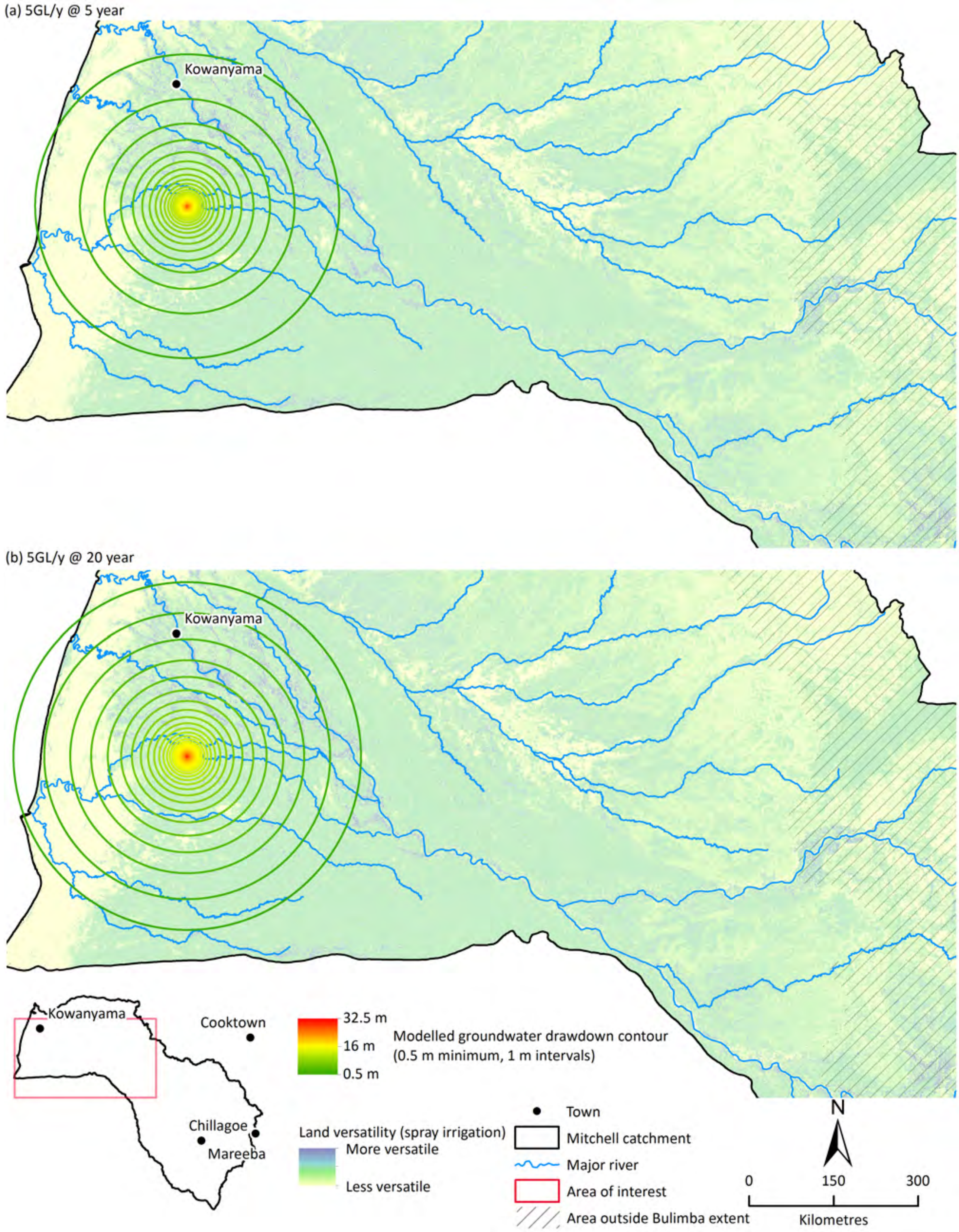

Figure 5-8 Example of spatial variations in modelled drawdown approximately 40 km from the coast
(a) After 5 years and (b) after 20 years as a result of testing a 5 GL/year groundwater extraction rate from the Bulimba aquifer.

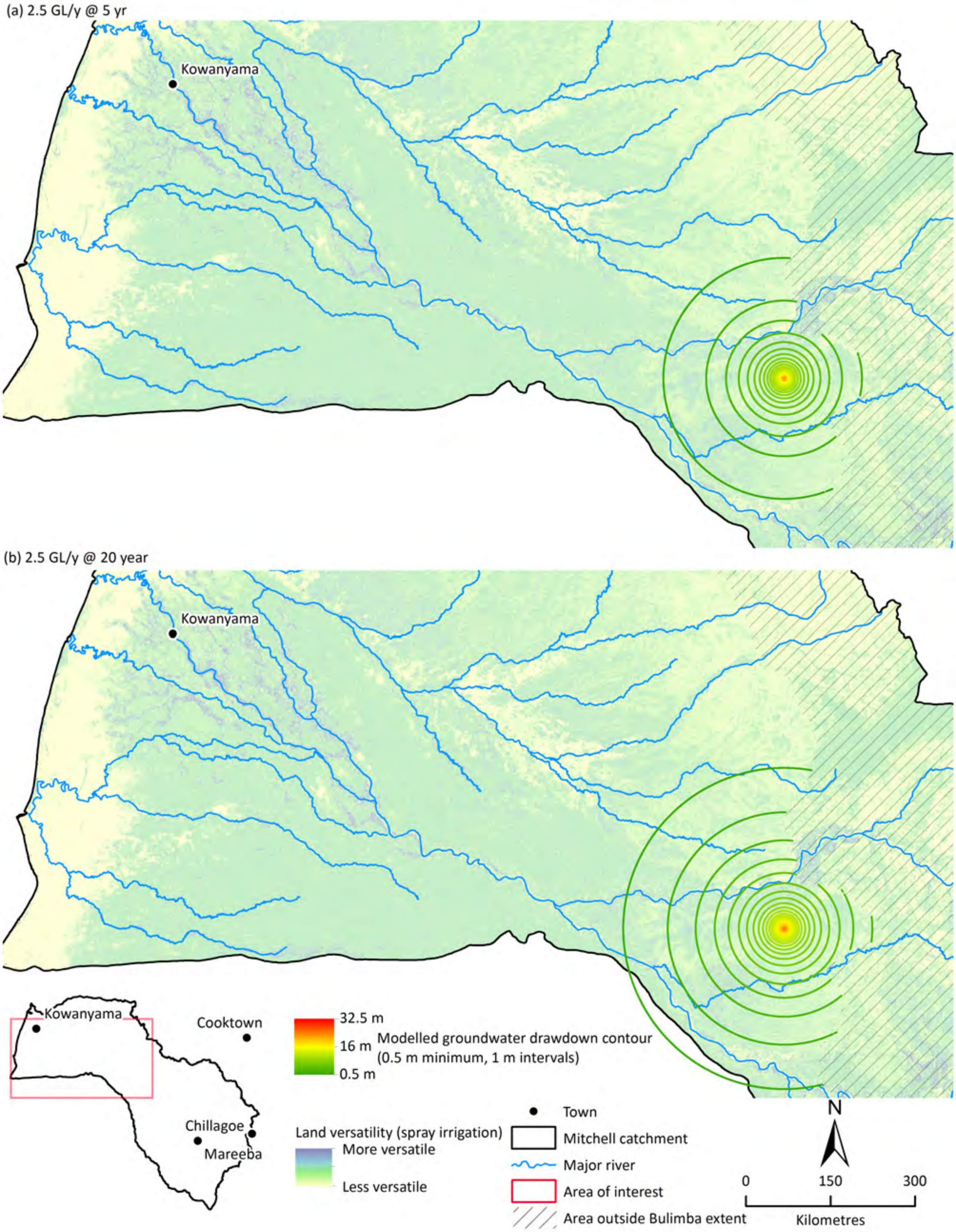

Figure 5-9 Example of spatial variations in modelled drawdown near the aquifer outcrop

(a) After 5 years and (b) after 20 years as a result of testing a 2.5 GL/year groundwater extraction rate from the Bulimba aquifer.

5.2.3 MANAGED AQUIFER RECHARGE

Introduction

MAR is the intentional recharge of water to aquifers for subsequent recovery or environmental benefit (NRMMC-EPHC-NHMRC, 2009). Importantly for northern Australia, which has a high intra-annual variability in rainfall (Petheram et al., 2008), MAR can contribute to planned conjunctive use, whereby excess surface water can be stored in an aquifer in the wet season, for subsequent reuse in the dry season (Evans et al., 2013; Lennon et al., 2014). Individual MAR schemes are typically small- to intermediate-scale storages, with annual extractable volumes of up to 5 GL/year currently operating predominantly within the urban and industrial, but also agricultural sectors, of Australia. This scale of operation can sustain rural urban centres, contribute to diversified supply options in large urban centres, provide localised water management options and is suited to mosaic-type irrigation developments.

Reconnaissance assessment of MAR considered the basic requirements for a MAR scheme: the presence of a suitable aquifer for storage, the availability of an excess water source for recharge and a demand for water. Presence of suitable aquifers is determined from previous regional-scale hydrogeological and surface geological mapping (see companion technical report on hydrogeological assessment (Taylor et al., 2018)). While current demand is not explicit, future demand is assumed to exist through economic development drivers. Source water availability is considered in terms of presence/absence rather than volumes with respect to any existing water management plans.

Pre-feasibility assessment was based on MAR scheme entry-level assessment in the *Australian guidelines for water recycling: managed aquifer recharge* (NRMMC-EPCH-NHMRC, 2009 (referred to as the 'MAR guidelines')). The MAR guidelines provide a framework to assess feasibility of MAR and incorporate four stages of assessment and scheme development. Stage one is entry-level assessment (pre-feasibility), stage two involves investigations and risk assessment, stage three is MAR scheme construction and commissioning, and stage four is operation of the scheme.

There are numerous types of MAR (Figure 5-10) and the selection of MAR type is influenced by the characteristics of the aquifer, the thickness and depth of low-permeability layers, land availability and proximity to the recharge source. Infiltration techniques can be used to recharge unconfined aquifers, with water infiltrating through permeable sediments beneath a dam, river or basin. If infiltration is restricted by superficial clay, the recharge method may involve a pond or sump that penetrates the low-permeability layer. Bores are used to divert water into deep or confined aquifers. Infiltration techniques are typically lower cost than bore injection (Dillon et al., 2009; Ross and Hasnain, 2018) and are generally favoured in the Assessment; the challenge in northern Australia is to identify suitable unconfined aquifers with capacity to store additional water when water is available for recharge. In the Mitchell catchment, suitable unconfined aquifers are typically thought to rapidly recharge to full capacity during the wet season.

This lack of additional storage capacity during and after the wet season and the higher cost of development relative to groundwater extraction are reasons why MAR is only likely to be undertaken subsequent to the development of the groundwater resource.

Unless stated otherwise, the material presented in this section has been summarised from the companion technical report on managed aquifer recharge opportunities (Vanderzalm et al., 2018).

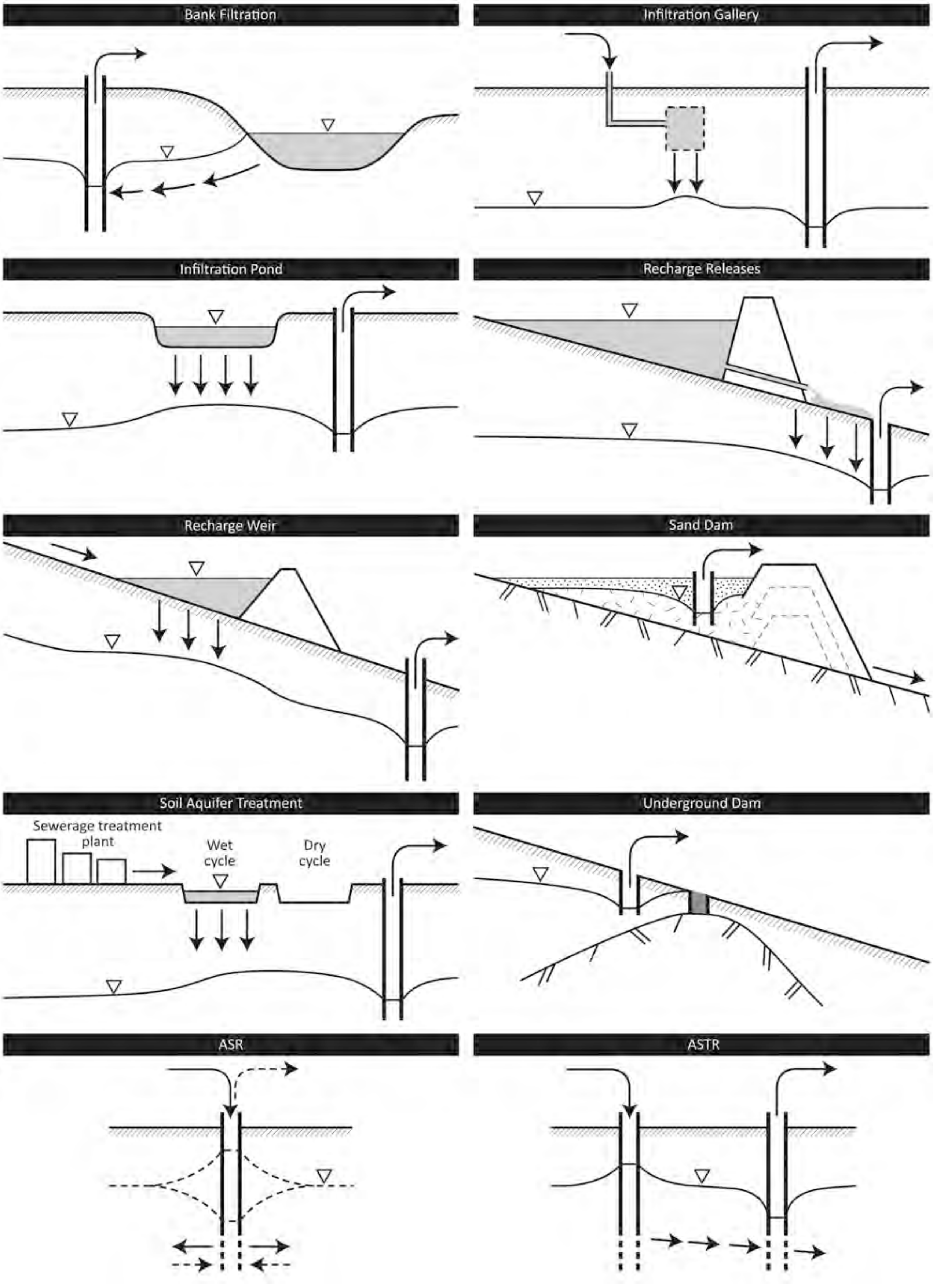

Figure 5-10 Types of managed aquifer recharge (MAR)

ASR = aquifer storage and recovery; ASTR = aquifer storage, transfer and recovery

Source: adapted from NRMMC-EPHC-NHMRC (2009).

Reconnaissance assessment of MAR in the Mitchell catchment

The most promising aquifer types for MAR in the Mitchell catchment are within the unconsolidated alluvial sediments and the sedimentary sandstones and limestones of the Carpentaria and Karumba basins (Section 2.5). Highly heterogeneous fractured rock aquifers within the Hodgkinson Formation are not considered as reliable targets for MAR. Therefore, the assessment of opportunity for MAR in the Mitchell catchment was limited to the potential for storage within the Quaternary alluvium, Tertiary alluvium, Wyaaba Beds, Bulimba Formation and Gilbert River Formation (Figure 2-21). Infiltration techniques are generally favoured for producing cost-effective water supplies, hence the focus on recharge techniques and limitations for unconfined aquifers.

MAR opportunity maps were developed from the best available data at the catchment scale (see companion technical report on assessment of managed aquifer recharge opportunities (Vanderzalm et al., 2018)) and the results are shown in Figure 5-11 and Figure 5-12. Because hydrogeological data are limited in the Mitchell catchment, the reconnaissance assessment was based on promising aquifer types, modelled depth of regolith greater than 10 m as a surrogate for thickness of alluvial aquifers, terrain slope less than 10% and permeability greater than 50 mm/day (moderate- and high- permeability soils).

The reconnaissance assessment identifies approximately 16,400 km^2 (23%) of the Mitchell catchment that are more likely to have aquifers with potential for MAR using infiltration techniques. Approximately 7000 km^2 (~10%) of the catchment are within the most favourable zone with low slope (<5%) and high-permeability soils, while another 8600 km^2 (12% of the catchment) are within a zone of low slope and moderate-permeability soils (Figure 5-11).

Major rivers and dam sites were assessed as potential water sources for recharge using MAR. Proximity to water source will impact on the economic feasibility of a MAR scheme and for the purposes of this reconnaissance assessment it was considered that distances greater than 5 km from a water source would be unlikely to be economically feasible. The geographic distribution of MAR opportunity within 5 km of major river reaches within the selected aquifer types is shown in Figure 5-12. Approximately 9100 km^2 (13%) of the Mitchell catchment may have aquifers with potential for MAR within 5 km of a major river, from which water could be sourced for recharge. Of this, approximately 3900 km^2 (~5%) of the catchment lie within the most favourable zone with lower slope and high-permeability soils, and 4900 km^2 (~7%) are within a zone of lower slope and moderate-permeability soils (Figure 5-12).

The connection between groundwater and surface water is a key consideration when selecting a site for MAR feasibility assessment. For this reason those areas adjacent to ephemeral river reaches (i.e. river reaches that do not flow all year round) are preferred locations for MAR because the additional recharge applied via infiltration is less likely to be discharged directly into the river. Streamflow in the upper reaches of the Mitchell, Lynd, Palmer and Walsh rivers is generally perennial. In the mid-catchment, flow is close to perennial in the Palmer and Mitchell rivers whereas the Walsh and Lynd rivers are ephemeral (see companion technical report on river model simulation (Hughes et al., 2018); annual flow days greater than 90% and water persistence in 90% or more of dry-season satellite imagery (Figure 5-11) are indicative of perennial flow).

Proximity to potential large dam sites is illustrated in Figure 5-12 to highlight the potential for conjunctive use of dams and aquifers. Intentional release of water from surface storage to provide groundwater recharge is an example of MAR (recharge release, Figure 5-10). In addition, surface detention is considered potentially beneficial prior to MAR in the Mitchell catchment to provide treatment through settling of suspended solids (turbidity) in the recharge source. Particulates in the recharge source may lead to clogging of the infiltration surface and reduce the infiltration rate. Pre-treatment before recharge can be used to manage clogging and reduce the need for ongoing maintenance, such as de-silting.

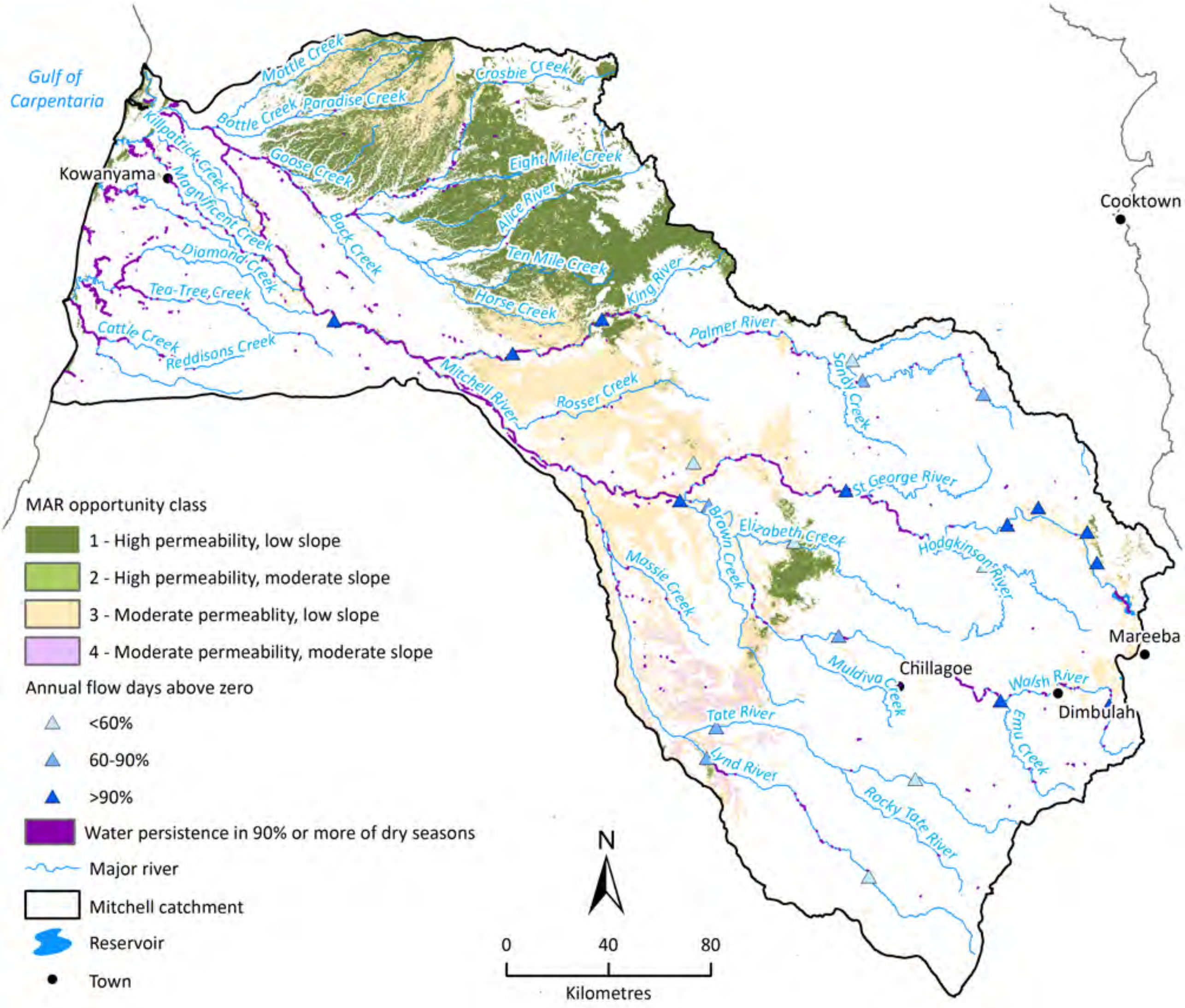

Figure 5-11 MAR opportunities for the Mitchell catchment irrespective of distance from a water source for recharge
Analysis based on the depth of regolith (Wilford et al., 2015), permeability (Thomas et al., 2018) and terrain (Gallant et al., 2011) slope datasets, and limited to the following aquifer formations: Quaternary alluvium, Tertiary alluvium, Wyaaba Beds, Bulimba Formation and Gilbert River Formation (Figure 2-21). Water persistence in dry seasons and annual days of flow calculated from stream gauge data are shown for context; presence of water in 90% or more of dry-season imagery is considered indicative of perennial flow.

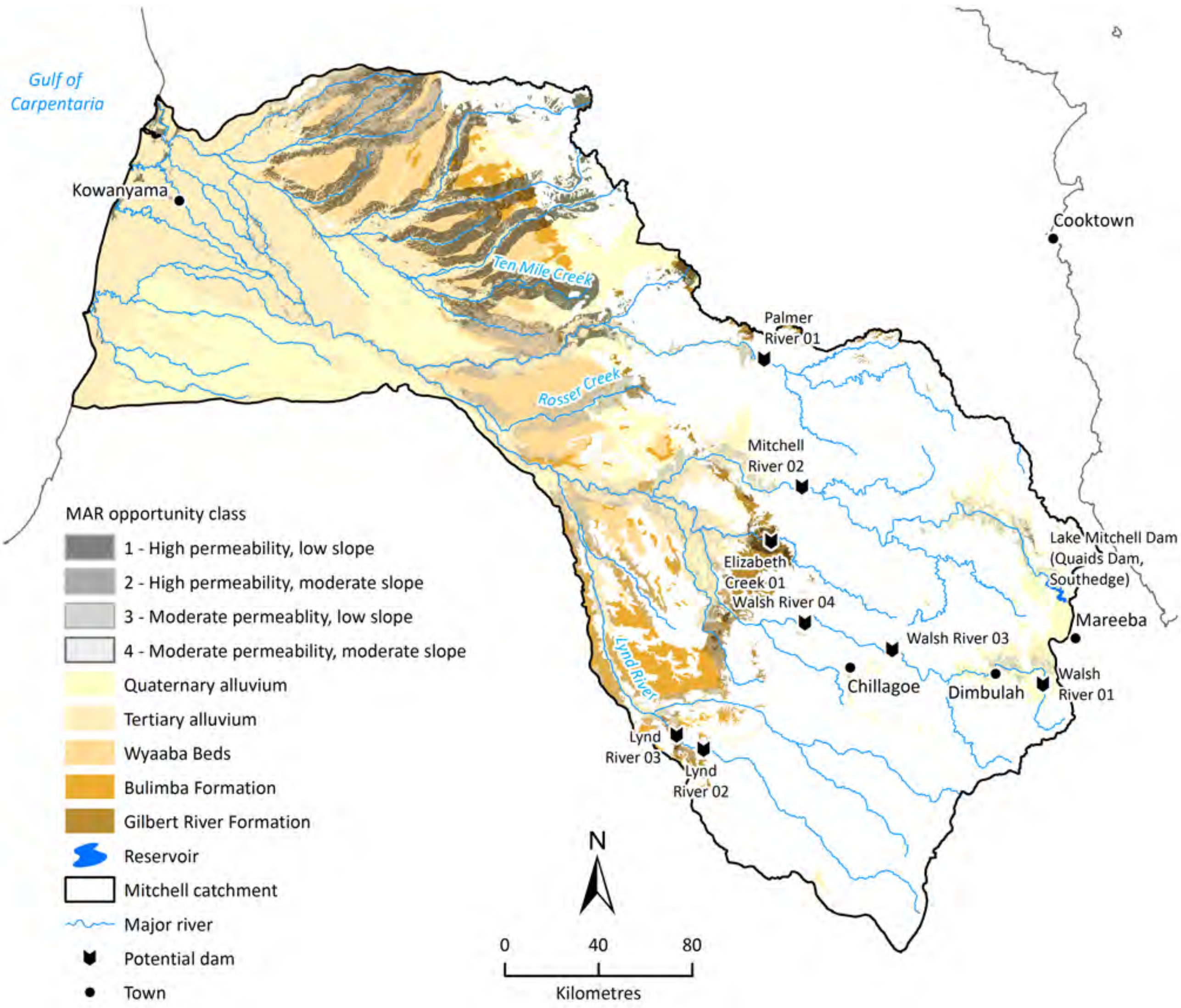

Figure 5-12 MAR opportunities with existing (within 5 km of major rivers) and potential additional water sources in the Mitchell catchment

Analysis based on the depth of regolith (Wilford et al., 2015), permeability (Thomas et al., 2018) and terrain (Gallant et al., 2011) slope datasets, and limited to within 5 km of a major river in the following aquifer formations: Quaternary alluvium, Tertiary alluvium, Wyaaba Beds, Bulimba Formation and Gilbert River Formation (Figure 2-21). Potential large dams in the Mitchell catchment are shown for context.

Three types of infiltration-based MAR scheme are described in areas of the Mitchell catchment to explore the potential opportunities for MAR. Each is intended to augment recharge in the alluvium, the lowest-cost opportunity for MAR based on the reconnaissance assessment. Selection of hypothetical scheme types was based on the potential for suitable unconfined aquifers within 5 km of major river reaches (Figure 5-12) and the proximity to ephemeral river reaches and potential large dam sites. However, there are insufficient hydrogeological data in the Mitchell catchment to identify specific locations for MAR. Three example locations (Figure 5-12) are used in the following discussion to demonstrate the potential application of each of these configurations of MAR (Figure 5-10):

- recharge weir in an ephemeral reach of river. Example location: Rosser Creek
- recharge release from a dam in an ephemeral reach of river that is downstream from a potential large dam site. Example location: Lynd River

- offstream infiltration basin in thick alluvial aquifer in close proximity to an ephemeral reach of river. Example location: Ten Mile Creek.

Each type of MAR scheme is described as comprising up to seven individual components, as proposed in the MAR guidelines (NRMMC-EPHC-NHMRC, 2009):

1. ‘capture zone’ is the catchment zone of the source of water
2. ‘pre-treatment’ if required (e.g. filtration)
3. ‘recharge’ or the type of MAR infrastructure used (e.g. infiltration basin)
4. ‘subsurface storage’ or the aquifer the water is stored in
5. ‘recovery’, such as bores to recover stored water for use
6. ‘post-treatment’ if required, any water quality treatment needed prior to use
7. the intended ‘end use’ (e.g. irrigation).

Each component represents a step where water quantity or quality impacts can be assessed and managed as required. It is not necessary that each of the seven components is present in each example of MAR in the Mitchell catchment.

Pre-feasibility assessment of three potential MAR schemes in the Mitchell catchment

Recharge weir

The ephemeral Rosser Creek is located mid-catchment between the perennial Palmer and Mitchell rivers. It lies within an area of moderate permeability and low slope, and the modelled depth of regolith (as a surrogate for thickness of the unconsolidated sediments) in the vicinity of Rosser Creek is typically greater than 20 m. There are no bores in the alluvium in this area. The closest groundwater levels are for bores within the Bulimba Formation. Here, groundwater is deeper than 4 m below ground level, the minimum depth to water recommended to avoid issues associated with any rise in water level resulting from recharge. While there is potential for MAR in the alluvium, it is essential to confirm there is sufficient storage capacity at the end of the wet season. Groundwater resource development, and extraction during the previous dry season, is expected to increase the capacity for storage during the wet season. Land with potential for spray-irrigated agriculture can be found along Rosser Creek (i.e. area of MAR opportunity), predominantly toward the confluence with the Mitchell River (Section 4.3).

The potential opportunity for MAR using a recharge weir (Figure 5-12) is explored along a 40-km reach of Rosser Creek, where water pooling behind a weir could infiltrate to an underlying unconfined aquifer, with potential capacity to store water at the end of the wet season. Groundwater extraction bores are required to recover the stored water, unless there are suitable existing bores in the area. The components of a recharge weir MAR system suited to an ephemeral river reach are presented in Figure 5-13 and summarised in Table 5-5. Within this area of MAR opportunity, the width of the river channel varies considerably, from around 10 m to greater than 50 m. Towards the centre of the area of opportunity, the width of the river is approximately 20 m and the width of the Quaternary alluvium is estimated at 900 m.

A detailed site investigation would be required to identify suitable locations to install one or more recharge weirs. Assuming a recharge weir along a 5-km stretch of river, where the alluvium is

900 m wide and has a porosity of 10%, if the water level rises 2 m this would equate to approximately 900 ML of additional stored water in the alluvium per recharge weir. Therefore, a 40-km river reach may provide opportunity for multiple recharge weirs to be installed and operated in an incremental development. A recharge weir was installed in the Ashburton River in the Pilbara region of WA to augment recharge to an alluvial aquifer used for irrigation supply (1.2 GL/year). A detailed analysis of the recharge weir at Minderoo on the Ashburton River is documented in the companion technical report on managed aquifer recharge (Vanderzalm et al., 2018). The weir structure, with low-flow v-notch to aid in preserving the dynamics of the flow hydrograph and rock armour for scour protection, is shown in Figure 5-14.

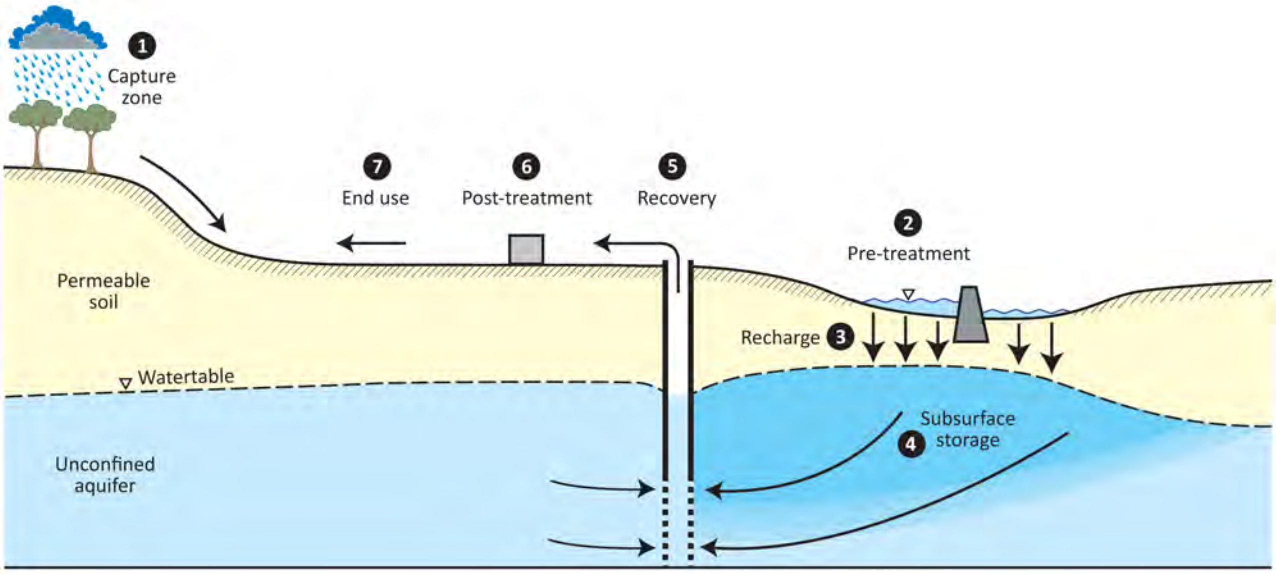

Figure 5-13 Schematic diagram of the hypothetical Rosser Creek recharge weir MAR scheme
Infrastructure requirements are recharge weir (3) and extraction bores for recovery (5). Details of the seven components are provided in Table 5-5.

Table 5-5 Components of the hypothetical Rosser Creek recharge weir MAR scheme

COMPONENT		COMPONENTS OF RECHARGE WEIR MAR SCHEME
1.	**Capture zone**	Rosser Creek streambed
2.	**Pre-treatment**	Detention in weir pool provides particulate settling but contributes to clogging of infiltration surface, no additional pre-treatment required
3.	**Recharge**	Recharge weir and streambed infiltration, channel width up to 50 m (15–50 m). Weir would span the width of the river and height up to 3 m above streambed
4.	**Subsurface storage**	Quaternary alluvial aquifer, width >500 m
5.	**Recovery**	Groundwater extraction bores (assume depth ~20 m)
6.	**Post-treatment**	Not required for irrigation use
7.	**End use**	Multiple, expect salinity <750 µS/cm given recharge source is fresh surface water and groundwater is fresh (<750 µS/cm)

Figure 5-14 Recharge weir on Ashburton River
Photo: CSIRO

Recharge release

The ephemeral reaches of the Lynd River are located toward the southern boundary mid-catchment and are downstream from two potential dam sites on the Lynd River (Figure 5-12). Land adjacent to ephemeral reaches of the Lynd River appears to have moderate permeability and low slope near the confluence with the Mitchell River. The modelled depth of regolith is between 11 and 20 m. Narrow strips of alluvium adjacent to the Lynd River have a moderate to high versatility for spray-irrigated agriculture (Section 4.3).

There appears to be potential for MAR using recharge release along reaches of the Lynd River upstream of its confluence with the Mitchell River. Recharge release relies on existing (in this case, potential) dam and weir structures for release and the natural river channel for infiltration. Groundwater extraction bores are required to recover the stored water, unless there are suitable existing bores in the area. SunWater operates recharge release schemes from Callide (136.7 GL) and Kroombit (14.6 GL) dams to augment groundwater for agricultural use in the Callide Valley, Queensland. Callide Dam was also constructed to provide water to the first Callide Power Station. The components of a recharge release MAR system that could be situated downstream from a surface storage location are presented in Figure 5-15 and are summarised in Table 5-6.

There are no bores in the alluvium in this area. The nearest bores completed in the Bulimba Formation suggest a yield less than 2 L/second, electrical conductivity less than 750 µS/cm and a water level up to 10 m below ground level. Based on the uncertainty regarding groundwater level in the alluvium, it is essential to confirm there is sufficient storage capacity in the alluvial aquifer to store water at the end of the wet season. Groundwater resource development, and extraction during the previous dry season, is expected to increase the capacity for storage during the wet season.

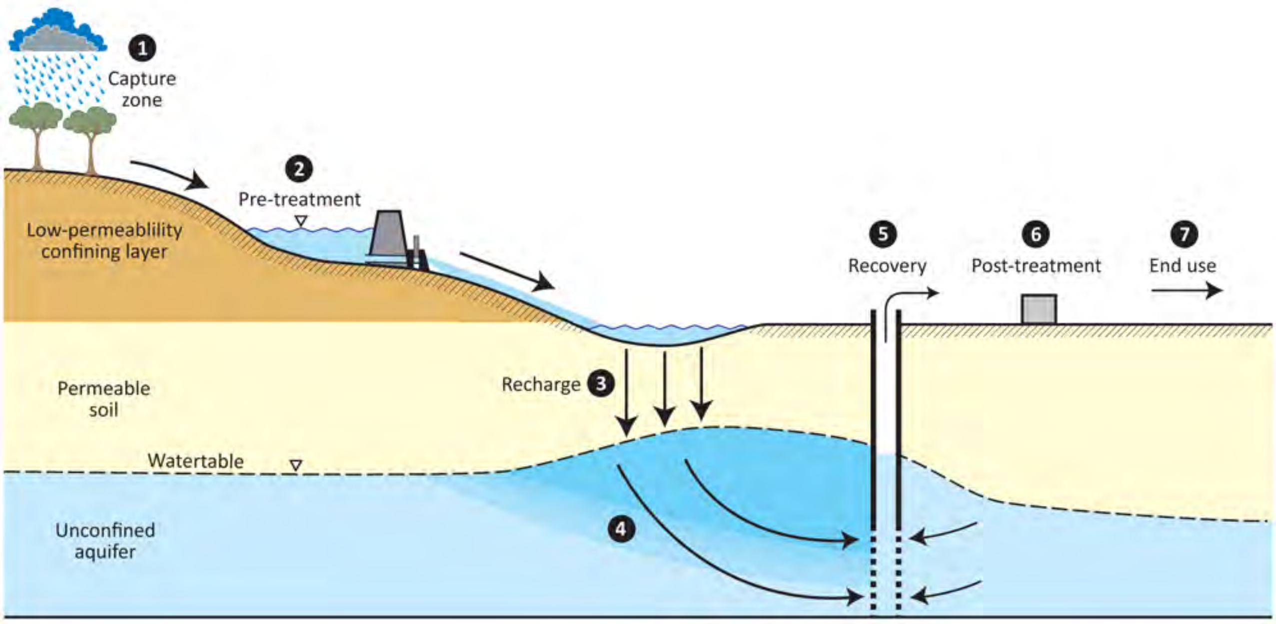

Figure 5-15 Schematic diagram of the hypothetical Lynd River recharge release MAR scheme
Infrastructure requirements are extraction bores for recovery (5). Details of the seven components are provided in Table 5-6. A dam and weir is assumed to exist for consideration of a recharge release MAR scheme.

Table 5-6 Components of the hypothetical Lynd River recharge release MAR scheme

COMPONENT		COMPONENTS OF RECHARGE RELEASE MAR SCHEME
1.	**Capture zone**	Potential dam on Lynd River
2.	**Pre-treatment**	Detention in weir pool provides particulate settling, no additional pre-treatment required
3.	**Recharge**	Dam release to Lynd River, streambed infiltration
4.	**Subsurface storage**	Alluvial aquifer
5.	**Recovery**	Groundwater extraction bores (assume depth ~10 m)
6.	**Post-treatment**	Not required for irrigation use
7.	**End use**	Multiple, expect salinity <750 µS/cm given recharge source is fresh surface water and groundwater is fresh (<750 µS/cm)

Infiltration basin

The ephemeral Ten Mile Creek is located toward the northern boundary mid-catchment (Figure 5-11). The modelled depth of regolith is over 30 m immediately upstream of Ten Mile Creek and is coincident with high-permeability soil and low slope. The nearest bores do not have any construction details and therefore cannot be associated with a specific aquifer formation; no yield data are available, but electrical conductivity is less than 750 µS/cm and water level is up to

20 m below ground level. To confirm the potential of the aquifer for MAR, it is essential to confirm there is sufficient storage capacity at the end of the wet season. Land of moderate to high versatility for spray-irrigated agriculture is located immediately upstream of Ten Mile Creek (i.e. area of MAR opportunity).

Potential opportunity for MAR using an infiltration basin was identified nearby Ten Mile Creek. Surface water transferred to an offstream infiltration basin is allowed to infiltrate to an underlying unconfined aquifer, with potential capacity to store water at the end of the wet season. Groundwater extraction bores are required to recover the stored water, unless there are suitable existing bores in the area. The components of an infiltration basin MAR system that could be situated nearby Ten Mile Creek are presented in Figure 5-16 and described in Table 5-7.

Infiltration channels and basins in the Burdekin Delta, Queensland (Figure 5-17), recharge up to 45 GL/year to support irrigated agriculture and mitigate coastal seawater intrusion. Water for recharge is reliably supplied by the Burdekin Falls Dam (also known as Lake Dalrymple). This is Australia's oldest MAR scheme, and has been in operation since 1965.

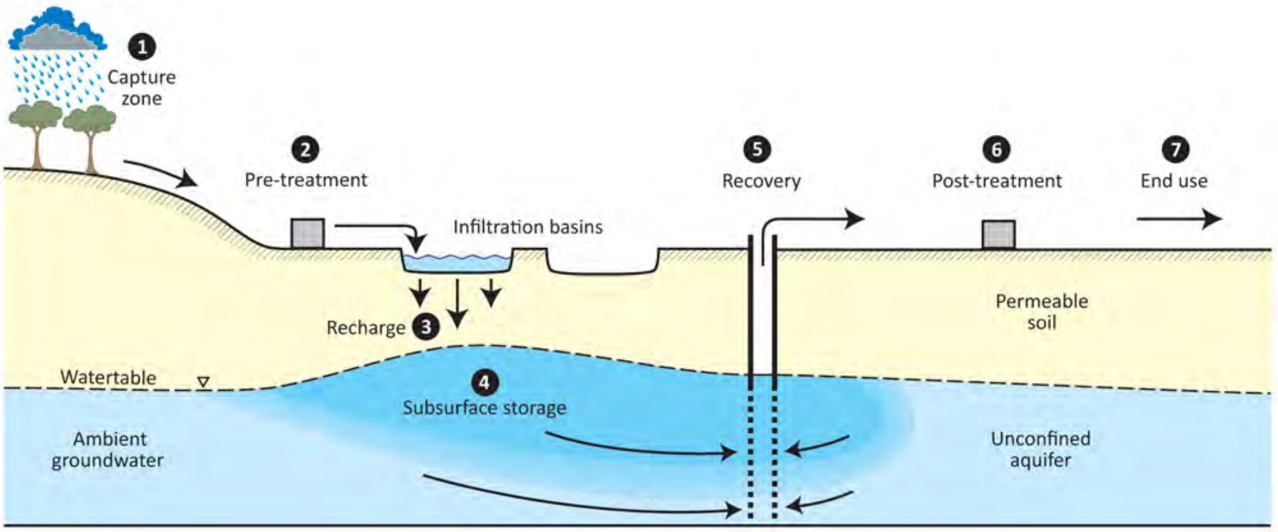

Figure 5-16 Schematic diagram of the hypothetical Ten Mile Creek infiltration basin MAR scheme
Infrastructure requirements are infiltration basins (e.g. turkey nests) (3) and extraction bores for recovery (5). Details of the seven components are provided in Table 5-7.

Table 5-7 Components of the hypothetical Ten Mile Creek infiltration basin MAR scheme

COMPONENT	COMPONENTS OF INFILTRATION BASIN MAR SCHEME
1. Capture zone	Ten Mile Creek streambed
2. Pre-treatment	Not required, but maintenance of the infiltration surface (e.g. basin scraping) is assumed to be necessary on an annual basis. Pre-feasibility assessment can be used to determine the viability of pre-treatment versus ongoing maintenance
3. Recharge	Transfer to offstream infiltration basin/s
4. Subsurface storage	Alluvial aquifer
5. Recovery	Groundwater extraction bores (assume depth ~20 m)
6. Post-treatment	Not required for irrigation use
7. End use	Multiple, expect salinity <750 µS/cm given recharge source is fresh surface water and groundwater is fresh (<750 µS/cm)

Figure 5-17 Managed aquifer recharge infiltration basins in Lower Burdekin Irrigation Area, Queensland
Photo: CSIRO

Investigations required to assess feasibility of a MAR scheme

Several investigations are required to obtain sufficient data to assess the feasibility of a specific MAR scheme. These investigations and the associated risk-based feasibility assessment represent stage two of project assessment and development in the MAR guidelines (NRMMC-EPHC-NHMRC, 2009). For recharge weir, recharge release or infiltration basin type MAR schemes intending to store water via infiltration in an alluvial aquifer, it is necessary to:

- Assess the quality of the source water with respect to the potential for clogging, in particular the potential for suspended solids to lead to clogging of the recharge surface and a reduction in infiltration rate. If a clogging risk is confirmed, pre-treatment of the source water or maintenance to mitigate clogging will be required. Recharge release involves surface detention prior to recharge, which is likely to reduce the suspended solids load of the recharge source water and thus mitigate the risk of clogging. Common maintenance for infiltration basins involves scraping and removing the clogging layer at regular intervals. Recharge weirs may need de-silting at regular intervals.
- Assess the suitability of the groundwater quality for the intended use, which will influence the amount of mixing between the recharge source and the ambient groundwater that can be tolerated. Salinity is the key parameter to consider with respect to limitations on mixing. Based on available data, the groundwater in the Mitchell catchment is reasonably fresh and therefore mixing between the recharge water and groundwater is unlikely to limit use of the recovered water.
- Undertake a hydrogeological and geochemical investigation to confirm there is sufficient storage capacity within the aquifer, confirm a suitable infiltration rate is viable, estimate the hydraulic impacts to connected ecosystems or nearby groundwater users and predict water quality or permeability changes that may occur due to reactive minerals. It is critical to identify the

presence of low-permeability layers that may inhibit infiltration. If present at shallow depths they may be removed to facilitate infiltration or bores may be required to penetrate low-permeability layers.

- Undertake a hydrological assessment to quantify the volume of source water available for recharge from ephemeral river reaches.
- Develop the project in accordance with stage three (construction and commission) and stage four (operation) of the MAR guidelines (NRMMC-EPHC-NHMRC, 2009). Central to this is including a field trial to confirm all risk management strategies before progressing to an operational scheme.

MAR economic considerations

A recharge weir, recharge release from a dam site (potential) and an infiltration basin are examples of methods to supplement recharge to an alluvial aquifer. Capital and operating cost estimates (Table 5-8) are presented in relation to the seven components of a MAR scheme, to illustrate how each of these components contributes to the overall cost of a scheme. Capital costs for a 1-GL MAR scheme were estimated at $1,700,000 using a recharge weir, $290,000 for recharge release assuming that a large dam is situated upstream to provide a source of water and $690,000 using an infiltration basin. Annual operating and maintenance costs ranged from $27,000 to $49,000.

Table 5-9 compares the total capital and operating costs and an equivalent annual unit cost for each of the three schemes. The total equivalent annual costs for the construction and operation of a 1-GL MAR scheme range between $48 and $172/year per ML of stored water/year (Table 5-9). Recharge release is the lowest cost per ML of water ($48/year per ML/year) as it relies on existing (in this case, potential) dam and weir structures for release and the natural river channel for infiltration. An infiltration basin scheme is the next lowest cost at $82/ year per ML/year, followed by the recharge weir ($172/ year per ML/year). For each of these examples, groundwater extraction bores have also been costed as there are few bores currently targeting the alluvium.

However, there are no data on the properties of the alluvium or the depth to groundwater in the areas that show potential for MAR. It is important to infer the degree of hydraulic connection between surface water and groundwater, to understand the potential for groundwater recharge or discharge in the alluvial system. Greater understanding of the hydrogeology is required to determine which MAR scheme is compatible with the conditions at a given site. Further investigations required for a feasibility assessment would allow the cost estimates to be revised based on the most viable MAR configuration, with a targeted end use allowing benefits to be quantified.

For the purposes of the economic assessment, the following assumptions were applied:

- A 50-year infrastructure service life was adopted.
- A discount rate of 7% was used.
- Construction of all infrastructure is completed within the first year, with operations therefore assumed to commence in the second year, following construction.

- There is no volumetric water loss in the aquifer, as mixing between the source water and groundwater is not expected to limit the use of the recovered water.
- A nominal scheme size of 1 GL/year was assessed.
- Operating and maintenance costs were assumed to be 2% of capital costs, unless specified.
- No provision was made for infrastructure to transfer water to the MAR site.
- No provision was made for infrastructure to transfer water to the end use; typical costs to deliver groundwater from an extraction bore to an irrigation system could be around $140,000 per bore.
- For infiltration basins, an infiltration rate of 0.5 m/day was used to calculate infiltration area, and a depth of 2 m was used to calculate the volume of material to be removed during construction.
- One recharge weir of width up to 50 m can provide 1 GL/year additional recharge if there is hydraulic disconnection between the surface water and groundwater (based on an assessment of recharge provided by an operating recharge weir in the Ashburton River (Vanderzalm et al., 2018)).
- Two bores are drilled for hydrogeological assessment and then subsequently used as monitoring bores.
- Capital costs for MAR component 3, 'recharge', include the recharge structure and site establishment costs such as site-access tracks, workforce accommodation, mobilisation and demobilisation of plant and land clearing.
- Capital costs for MAR component 5, 'recovery', include recovery bore costs where required (as outlined in the components for each scheme assessed).
- Capital costs for MAR component 7, 'end use', include investigations required to assess scheme viability and manage potential risks, cultural heritage management, approvals, monitoring bores and development of a risk management plan. Operating costs for component 7 include ongoing monitoring for risk management of the scheme. As noted above, the end use costs do not include the cost of reticulation to users.

Base costs are summarised in Table 5-10.

Table 5-8 Capital and operating costs for individual components of three 1 GL/year infiltration types of MAR schemes in the Mitchell catchment

MAR SCHEME COMPONENT	COST	RECHARGE WEIR (e.g. ROSSER CREEK)	RECHARGE RELEASE (e.g. LYND RIVER)	INFILTRATION BASIN (e.g. TEN MILE CREEK)
1. Catchment	Capital ($)	0	0	0
	Operating ($/y)	0	0	0
2. Pre-treatment	Capital ($)	0	0	0
	Operating ($/y)	0	0	0
3. Recharge†	Capital ($)	1,300,000	0	290,000
	Operating ($/y)	20,000	0	3,200
4. Storage	Capital ($)	0	0	0
	Operating ($/y)	0	0	0
5. Recovery‡	Capital ($)	200,000	100,000	200,000
	Operating ($/y)	4,000	2,000	4,000
6. Post-treatment	Capital ($)	0	0	0
	Operating ($/y)	0	0	0
7. End use§	Capital ($)	195,000	185,000	200,000
	Operating ($/y)	25,000	25,000	25,000
Total	**Capital ($)**	**1,700,000**	**290,000**	**690,000**
	Operating ($/y)	**49,000**	**27,000**	**32,000**

†Capital costs = weir or infiltration basin and site establishment; operating costs = weir de-silt or basin scraping.
‡Capital costs = bores; operating costs = pumping.
§Capital costs = investigations required for the establishment of the scheme, cultural heritage management, approvals, risk management plan; monitoring bore costs included in hydrogeological investigation; operating costs = ongoing monitoring for risk management.

Table 5-9 Indicative capital and operating costs for three infiltration types of MAR schemes in the Mitchell catchment

MAR TYPE	EXAMPLE LOCATION	VOLUME (GL)	CAPITAL COST ($)	COST ($/ML)	OPERATING COST ($/y)	LEVELISED CAPITAL COST ($/ML)	LEVELISED OPERATING COST ($/ML)	LEVELISED COST† ($/ML)
Recharge weir	Rosser Creek	1	1,700,000	1700	49,000	123	49	172‡
Recharge release	Lynd River	1	290,000	290	27,000	21	27	48‡§
Infiltration basin	Ten Mile Creek	1	690,000	690	32,000	50	32	82‡

†May also be referred to a equivalent annual unit cost, assuming a 7% real discount rate and a MAR scheme life of 50 years.
‡Cost includes recovery bore costs. This cost will be reduced if groundwater resource development occurs prior to implementation of the MAR scheme as recovery bores may not be required.
§Large dam is assumed to exist for consideration of a recharge release MAR scheme.

Table 5-10 Summary of base costs used in MAR scheme cost estimates for the Mitchell catchment

ITEM	BASE COST IN 2017 ($)	COMMENT
Infiltration basin construction ($/m³)	4	Estimate
Injection or recovery bore construction cost ($/m)	1,000	Estimate based on real costs (drilling costs in catchments)
Monitoring bore construction cost ($/m)	500	Estimate based on real costs (Vanderzalm et al., 2015)
Recharge weir for 1 GL/y ($)	1,000,000	Design estimate
Field-site establishment fixed cost ($)	100,000	Field-site establishment includes site-access tracks, workforce accommodation, mobilisation and demobilisation of plant and land clearing. Total field-site establishment cost = fixed cost + variable cost (for developed or remote sites, see below)
Field-site establishment variable cost – remote sites ($)	20% of recharge structure capital	Bore construction cost estimate includes contingency for remoteness
Monitoring for risk management plan based on two monitoring bores – not drinking water end use ($/y)	20,000	Ongoing groundwater monitoring, as outlined in the risk management plan
Water quality assessment ($/water source) – not drinking water end use	5,000	Water quality assessment recommended for feasibility assessment
Hydrogeological assessment including groundwater modelling	110,000–300,000	Hydrogeological assessment recommended for feasibility assessment. Two bores drilled at variable depths, which subsequently become monitoring bores (monitoring bore construction cost used)
Geochemical assessment	25,000	Geochemical assessment recommended for feasibility assessment
Development of a risk management plan	25,000	Establishment of an operational risk management plan
Cultural heritage management	15,000	Estimate based on real costs
Approvals	25,000	Estimate based on real costs

5.3 Surface water storage opportunities

5.3.1 INTRODUCTION

In a highly seasonal climate, such as that of the Mitchell catchment, and in the absence of suitable groundwater, water storages are essential to enable irrigation during the dry season and other periods when soil water is insufficient for crop growth.

The Assessment undertook a pre-feasibility assessment of four types of surface water storage options. These were:

- major dams that supply water to multiple properties (Section 5.3.2)
- re-regulating structures such as weirs (Section 5.3.3)
- large farm-scale or on-farm dams, which supply water to a single property (Section 5.3.4 and Section 5.3.5)
- natural water bodies (Section 5.3.6).

Although natural water bodies do not require construction, their capacity may be enhanced with strategically constructed embankments.

Both major dams and large farm-scale dams can be further classified as instream or offstream water storages. In this Assessment instream water storages are defined as structures that intercept a drainage line (creek or river) and are not supplemented with water from another drainage line. Offstream water storages are defined as structures that (i) do not intercept a drainage line, or (ii) intercept a drainage line and are supplemented with water extracted from another larger drainage line. Ringtanks and turkey nest tanks are examples of offstream storages with a continuous embankment, and the former is the focus in the Assessment due to their higher storage to excavation ratios. Major dams, large farm-scale dams, offstream storages, re-regulating structures and natural water bodies are also briefly discussed below.

The performance of a dam is often assessed in terms of water yield or demand. This is the amount of water that can be supplied for consumptive use at a given reliability. For a given dam, an increase in water yield results in a decrease in reliability.

Importantly, the Assessment does not seek to provide instruction on the design and construction of farm-scale water storages. Numerous books and online tools provide detailed information on nearly all facets farm-scale water storage (e.g. QWRC, 1984; Lewis, 2002; IAA 2007; FAO, 2010). Siting, design and construction of weirs, large farm-scale ringtanks and gully dams are heavily regulated in Australia and should always be undertaken in conjunction with a suitably qualified professional and tailored to the nuances that occur at every site. Major dams are complicated structures and usually involve a consortium of organisations and individuals.

Unless otherwise stated, the material in Section 5.3 originates from the companion technical report on surface water storage (Petheram et al., 2017).

5.3.2 MAJOR DAMS

Introduction

Major dams are usually constructed from earth, rock and/or concrete materials, typically as a barrier wall across a river so as to store water in the reservoir created. They need to be able to safely discharge the largest flood flows likely to enter the reservoir and the structure has to be designed so that the dam meets its purpose, generally for at least 100 years. Some dams, such as Kofini Dam in Greece and Anfengtang Dam in China, have been in continuous operation for over 2000 years, with Schnitter (1994) consequently coining dams as ‘the useful pyramids’.

An attraction of major dams over farm-scale dams is that if the reservoir is large enough relative to the demands on the dam (i.e. water supplied for consumptive use and ‘lost’ through evaporation and seepage), when the reservoir is full water can last 2 or more years. This has the advantage of mitigating against years with low inflows to the reservoir. For this reason major dams are sometimes referred to as ‘carry-over storages’.

Major instream versus offstream dams

Offstream water storages were among the first man-made water storages (Nace, 1972; Scarborough and Gallopin, 1991) because people initially lacked the capacity to build structures that could block rivers and withstand large flood events. One of the advantages of offstream storages is that, if properly designed, they can cause less disruption of the natural flow regime than large instream dams. Less disruption occurs if water is extracted from the river using pumps, or if there is a diversion structure it has raiseable gates, which in northern Australia need to be able to operate in remote environments, to allow water and aquatic species to pass when not in use.

The primary advantage of large instream dams is that they provide a very efficient way of intercepting the flow in a river, effectively trapping all flow until the full supply level is reached. For this reason, however, they also provide a very effective barrier to the movement of fish and other species within a river system, alter downstream flow patterns and can inundate large areas of land.

Types of major dams

Two types of major dams are particularly suited to northern Australia: embankment dams and concrete gravity dams. Embankment dams (EB) are usually the most economical, provided suitable construction materials can be found locally, and are best suited to smaller catchment areas where the spillway capacity requirement is small. Concrete gravity dams with a central overflow spillway are generally more suitable where a large capacity spillway is needed to discharge flood inflows, as is the case for most large catchments in northern Australia.

Traditionally, concrete gravity dams were constructed by placing conventional concrete in formed 'lifts'. Since 1984 in Australia, however, roller compacted concrete (RCC) has been used, where low cement concrete is placed in continuous thin layers from bank to bank and compacted with vibrating rollers. This approach allows large dams to be constructed in a far shorter time frame than required for conventional concrete construction, often with large savings in cost (Doherty, 1999). RCC is best used for high dams where a larger scale plant can provide significant economies of scale. This is now the favoured type of construction in Australia whenever foundation rock is available within reasonable depth, and where a larger capacity spillway is required. In those parts of the Mitchell catchment with topography and hydrology most suited to large instream dams, RCC was deemed to be the most appropriate type of dam.

Reconnaissance assessment of potential major dams in the Mitchell catchment

A promising dam site requires inflows of sufficient volume and frequency, topography that provides a physiographic constriction of the river channel, and critically, favourable foundation geology. The reconnaissance assessment of potential major dams in the Mitchell catchment was undertaken using two approaches applied in parallel:

- a review of the literature – two potential dams in the Mitchell catchment were identified from published and unpublished literature: the Pinnacles dam site on the Mitchell River and Nullinga dam site (Figure 5-18) on the Walsh River (GHD, 2008; SunWater, 2008). The former had simply been referred to in a 4-page unpublished document with no prior investigation, while the latter has had some relatively detailed hydrological assessments and preliminary level geotechnical and costing studies
- a spatial analysis – to ensure no potential dam site had been overlooked the Assessment used a bespoke computer model, the DamSite model (Petheram et al., 2017), to assess over 50 million

potential dam sites in the Mitchell catchment for their potential as major offstream or instream dams.

Figure 5-18 Nullinga potential dam site on the Walsh River AMTD 270.0 km
Photo: CSIRO

Broad-scale geological considerations

Favourable foundation conditions include a relatively shallow layer of unconsolidated materials such as alluvium (e.g. Figure 5-19), and rock that is relatively strong, resistant to erosion, non-permeable or capable of being grouted. Geological features that make dam construction challenging include the presence of faults, weak geological units, landslides and deeply weathered zones.

The best potential major dam sites in the Mitchell catchment are found where rivers have eroded through meta-sedimentary or volcanic rocks in the Mossman Orogen. Some of the potential dam sites in the area are where rivers have cut through ridges of strong sedimentary or metamorphic rock (such as arenite or chert) of the Hodgkinson Formation. Other potential dam sites occur where rivers have eroded through the younger volcanic rocks (ignimbrites and lavas) of Carboniferous to Permian age. The ignimbrites in this area are strong rocks formed by the welding of pyroclastic flows (hot mixtures of ash, and gas that flow rapidly from a volcano during an eruption). They have formed thick deposits covering large areas, which have been preserved because they have been deposited in subsidence areas (volcanic cauldrons). As ignimbrite is resistant to weathering and erosion, river valleys tend to be relatively narrow with relatively little alluvium.

Figure 5-19 Bedrock in the Walsh River
Favourable foundation conditions for major dams include a relatively shallow layer of unconsolidated materials such as alluvium. Photo: CSIRO

Major offstream storages for water and irrigation supply

Figure 5-20 displays the most promising sites for major storages across the Mitchell catchment in terms of topography, assessed in terms of approximate cost of construction per storage volume (ML). Favourable locations with a small catchment area and adjacent to a large river may be suitable as large offstream storages.

In Figure 5-20 only those locations with a ratio of cost to storage less than $4000/ML are shown. This provides a simple way of displaying those locations in the Mitchell catchment with the most favourable topography for a large reservoir relative to the size (i.e. cost) of the dam wall necessary to create the reservoir. This figure is particularly useful for identifying more promising sites for offstream storage (i.e. where some or all of the water is pumped into the reservoir from an adjacent drainage line). The threshold value of $4000/ML is nominal and was used to minimise the amount of data displayed. This analysis does not consider evaporation or hydrology.

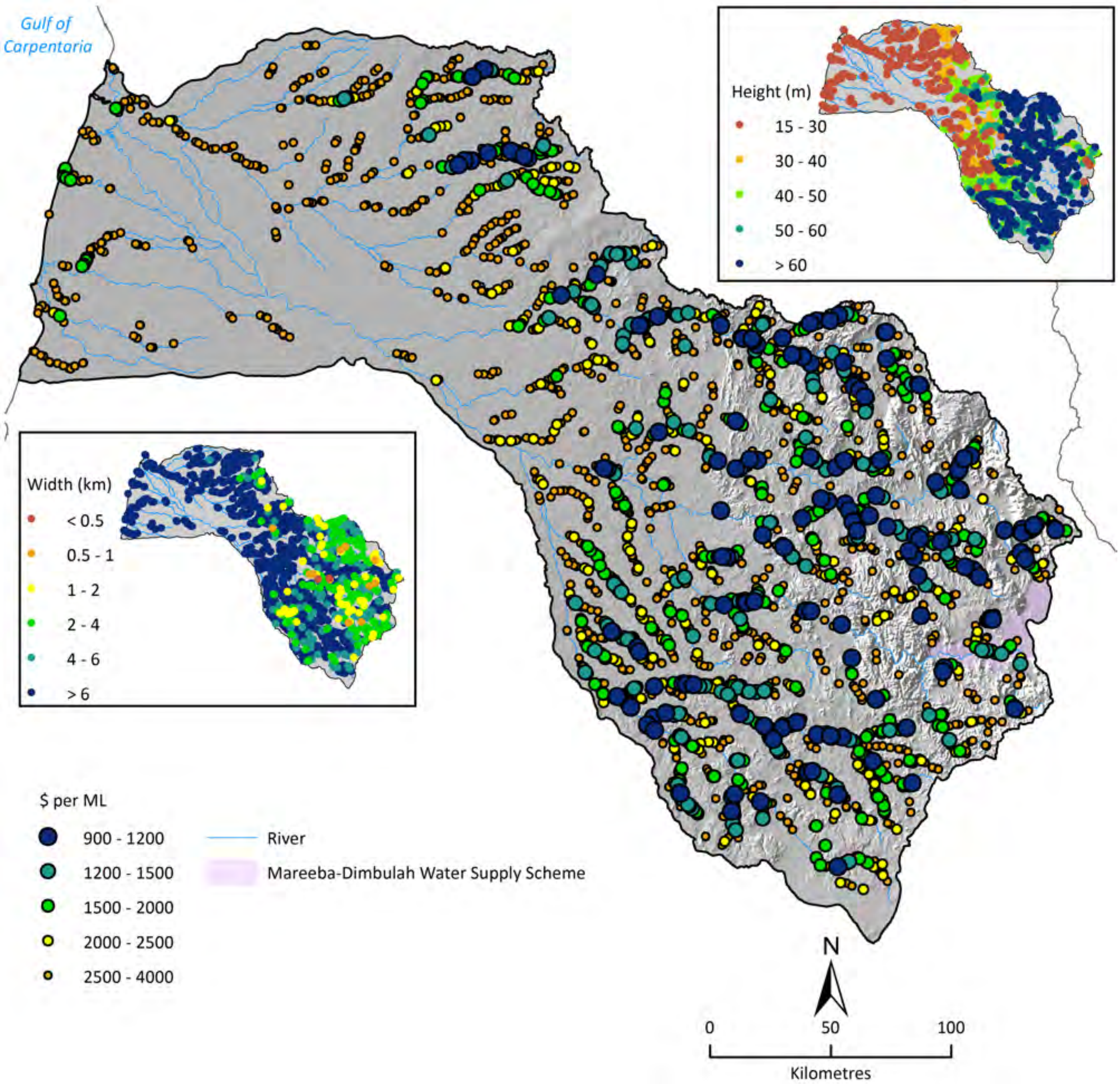

Figure 5-20 Potential storage sites in the Mitchell catchment based on minimum cost per ML storage capacity
This figure can be used to identifying locations where topography is suitable for large offstream storages. At each location the minimum cost per ML storage capacity is displayed. The smaller the minimum cost per ML storage capacity the more suitable the site for a large offstream storage. Analysis does not take into consideration geological considerations, hydrology or proximity to water. Only sites with a minimum cost to storage volume ratio of less than $4000/ML are shown. $1000/ML is equivalent to 1 GL per million dollars. Costs are based on unit rates and quantity of material and site establishment for a RCC dam. Data are underlain by a shaded relief map. Inset displays height of full supply level (FSL) at the minimum cost per ML storage capacity. For more details see companion technical report on surface water storage (Petheram et al., 2017).

Figure 5-20 shows that the parts of the Mitchell catchment with the most favourable topography for storing water are on the upper Walsh River immediately downstream of the Mareeba–Dimbulah Water Supply Scheme (MDWSS). Other topographically favourable locations are on the upper Palmer and upper Mitchell rivers.

Major instream storages for water and irrigation supply

The potential for large instream dams to cost-effectively supply water is summarised in Figure 5-21 in terms of minimum cost of construction per unit yield (GL).

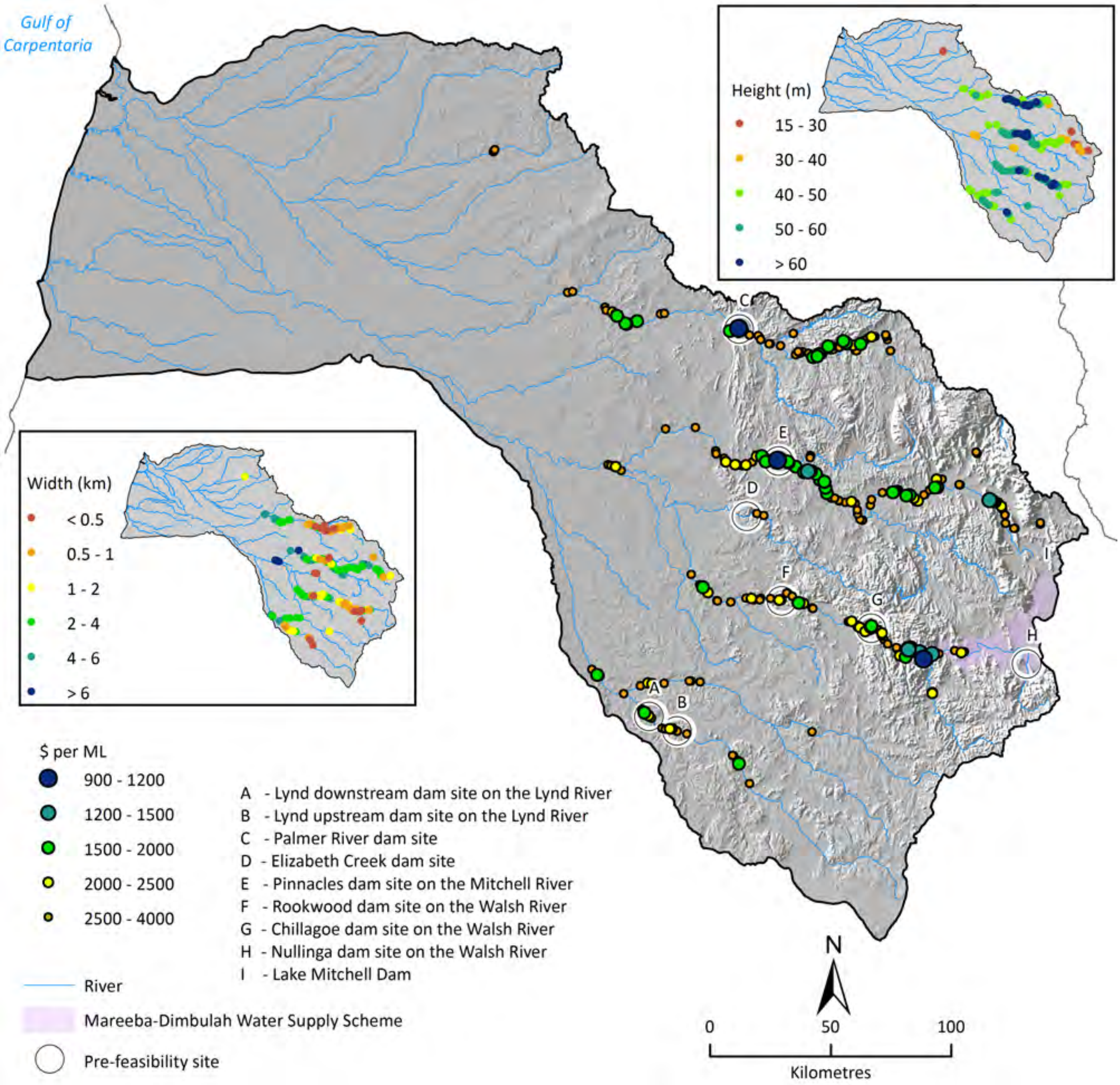

Figure 5-21 Potential dam sites in the Mitchell catchment based on minimum cost per ML yield at the dam wall
This figure indicates those sites more suitable for major dams in terms of cost per ML yield at the dam wall in 85% of years. At each location the minimum cost per ML storage capacity is displayed. The smaller the cost per ML yield ($/ML) the more favourable the site for a large instream dam. Only sites with a minimum cost to yield ratio less than $4000/ML are shown. Costs are based on unit rates and quantity of material required for a RCC dam with a flood design of 1 in 10,000. Cost includes site establishment, fish ladders and land resumption for that area of land impounded by a flood event of annual exceedance probability 1%. Data are underlain by a shaded relief map. Left inset displays height of full supply level (FSL) at the minimum cost per ML yield and right inset displays width of FSL at the minimum cost per ML yield. See companion technical report on surface water storage (Petheram et al., 2017) for more information.

Figure 5-21 indicates that the most cost-effective potential dam sites are on the Palmer River (Figure 5-22), the Mitchell River at the Pinnacles and on the Walsh River immediately downstream of the MDWSS. The latter site, however, would inundate large areas of the MDWSS adjacent to the Walsh River.

Based on this analysis, eight potential dam sites were selected for pre-feasibility analysis on the basis that these were the more cost effective sites in distinct geographic areas in proximity to soils suitable for irrigated agriculture. In reality, the most favourable potential dam site will depend upon the location and magnitude of the demand and what impacts of development are considered acceptable by the community. The locations of the pre-feasibility potential dam sites are denoted in Figure 5-21 by black circles, key parameters and performance metrics are summarised in Table 5-11 and an overall summary comment is recorded in Table 5-12. More detailed analysis of the eight pre-feasibility sites is provided in the companion technical report on surface water storage (Petheram et al., 2017).

Figure 5-22 Potential Palmer River dam site on the Palmer River AMTD 121.2 km

Hydro-electric power generation potential in the Mitchell catchment

The potential for major instream dams to generate hydro-electric power is presented in Figure 5-23, following a reconnaissance assessment of more than 50 million potential dam sites in the Mitchell catchment (Petheram et al., 2017). This figure provides indicative estimates of hydro-electric power generation potential, but does not consider the existence of supporting infrastructure.

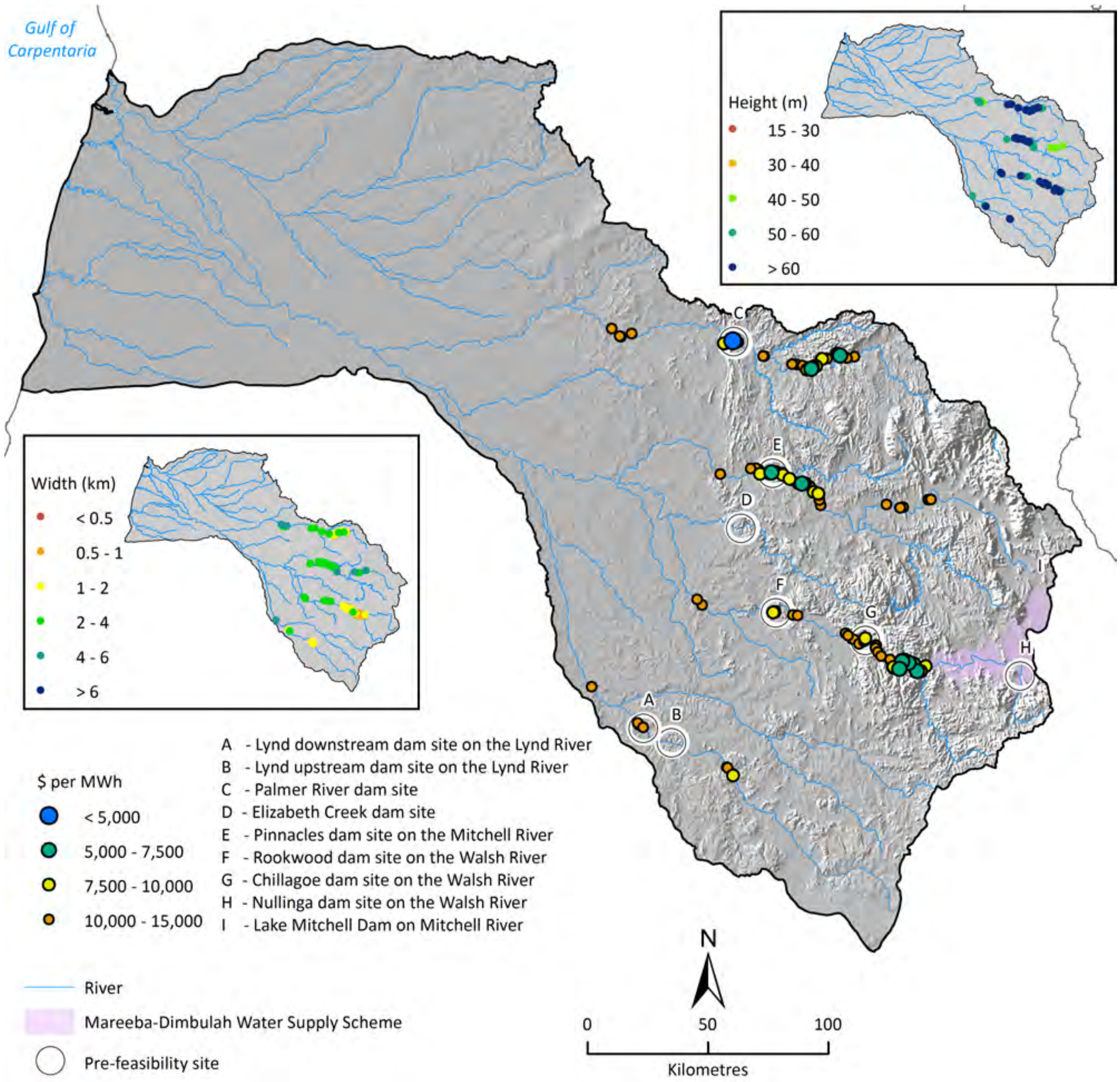

Figure 5-23 Mitchell catchment hydro-electric power generation opportunity map

Costs are based on unit rates and quantity of material required for a RCC dam with a flood design of 1 in 10,000. Cost includes site establishment, fish ladders and land resumption for that area of land impounded by a flood event of annual exceedance probability 1%. Data are underlain by a shaded relief map. For more details see companion technical report on surface water storage (Petheram et al., 2017).

Pre-feasibility-level assessment of potential major dams in the Mitchell catchment

Eight potential dam sites in the Mitchell catchment were examined as part of this pre-feasibility-level assessment. These are summarised in Table 5-11 and Table 5-12. Two of these sites were previously identified, the Nullinga dam site on the Walsh River and the Pinnacles dam site on the Mitchell River, although the only reference to the latter was a location name and brief description. The Pinnacles dam site on the Mitchell River and the Rookwood dam site on the Walsh River are further detailed below.

Table 5-11 Potential dam sites in the Mitchell catchment examined as part of the pre-feasibility assessment
All numbers have been rounded.

NAME	DAM TYPE†	SPILLWAY HEIGHT ABOVE BED (m)‡	CAPACITY AT FSL (GL)	CATCHMENT AREA (km²)	ANNUAL WATER YIELD (GL)§	CAPITAL COST* ($ million)	UNIT COST†† ($/ML)	EQUIVALENT ANNUAL UNIT COST‡‡ ($/y PER ML/y)
Lynd downstream dam site on the Lynd River	RCC	45	810	4554	507	731□	1442	107
Lynd upstream dam site on the Lynd River	RCC	36	644	3983	412	750□	1820	142
Palmer River dam site	RCC	56	1444	3801	553	690□	1248	92
Elizabeth Creek dam site	RCC	36	149	580	55	189◘	3436	256
Pinnacles dam site on the Mitchell River	RCC	58	2316	7728	1248	755◘	605	45
Rookwood dam site on the Walsh River	RCC	61	1288	4855	575	655◘	1139	84
Chillagoe dam site on the Walsh River	RCC	50	600	3423	388	601◘	1549	115
Nullinga dam site on the Walsh River	RCC	31	145	327	65	349 □	5269	398

†Roller compacted concrete dam (RCC).
‡The height of the dam abutments and saddle dams will be higher than the spillway height.
§Water yield is based on 85% annual time based reliability using a perennial demand pattern for the baseline river model under Scenario A. This is yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These yield values do not take into account downstream existing entitlement holders or environmental considerations.
◘ indicates manually derived preliminary cost estimate, which is likely to be –10% to +30% of 'true cost'. □ indicates modelled preliminary cost estimate, which is likely to be –25% to +50% of 'true' cost. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher.
††This is the unit cost of annual water supply and is calculated as the capital cost of the dam divided by the water yield at 85% annual time reliability.
‡‡Value assumes a 7% real discount rate and a dam service life of 100 years. Includes operation and maintenance (O&M) costs, assuming O&M costs are 0.4% of the total capital cost.

Table 5-12 Summary comments for potential dams in the Mitchell catchment

NAME	SUMMARY COMMENT
Lynd downstream dam site on the Lynd River	This site is remote and is situated in a relatively wide valley and has poor quality rock on the abutments. Compared to potential sites on the Palmer, Mitchell and Walsh rivers the site has a high cost to yield ratio. The nearest large continuous areas of land suitable for irrigated agriculture occur below the junction of the Mitchell and Lynd rivers. For these reasons the site was not short-listed.
Lynd upstream dam site on the Lynd River	This site is situated in a relatively wide valley and has a high cost to yield ratio relative to the potential sites on the Palmer, Mitchell and Walsh rivers. It has a similar cost to yield ratio as the Lynd downstream site and is also similar in terms of having poor quality rock on the abutments and being remote. The site is slightly further from large contiguous areas of land suitable for irrigated agriculture than the downstream site. For these reasons the site was not short-listed.
Palmer River dam site	This site has a one of the lowest cost to yield ratios of the potential dam sites in the Mitchell catchment. However, the site is relatively remote and the nearest large contiguous areas of land suitable for irrigated agriculture are located a considerable distance downstream on more flood-prone areas below of the junction of the Palmer and Mitchell rivers. For these reasons the site was not short-listed.
Elizabeth Creek dam site	The Elizabeth Creek dam site has the smallest catchment area and the lowest yield of the potential dam sites examined in the Mitchell catchment. However, the site is situated in a narrow sandstone gorge and is relatively close to land suitable for irrigated agriculture.
Pinnacles dam site on the Mitchell River	This site has the largest catchment area and highest yield of all sites examined in the Mitchell catchment. A storage at this site could support a large irrigation development downstream of Wrotham Park. At the level of development assessed, a very long saddle dam is required on the right bank. Nevertheless, the site has the lowest cost to yield ratio in the Mitchell catchment as a result of its high

NAME	SUMMARY COMMENT
	yield. Further assessment including geotechnical investigation of the saddle dam area would be required to determine the optimal level of development. Although a fish transfer facility has been proposed, the dam's potential impact on migratory fish species including the freshwater sawfish and barramundi would need to be further considered.
Rookwood dam site on the Walsh River	This site is situated at the upstream end of a straight gorge section and is the most downstream site on the Walsh River suitable for a large dam. The site is easily accessed from the Bourke Development Road and is about 30 km from Chillagoe. It is about 60 km upstream of large contiguous areas of land suitable for irrigated agriculture near Wrotham Park. Commanding a larger catchment area than the upstream Chillagoe dam site, the Rookwood dam site has the second lowest cost to yield ratio. Extensive saddle dams are required, at the level of development assessed.
Chillagoe dam site on the Walsh River	This site is approximately 30 km from Chillagoe and is one of the less remote sites in the Mitchell catchment although it is somewhat wider than the alternative Rookwood site downstream. The site commands a relatively large catchment and has a favourable cost to yield ratio. The nearest large contiguous land area suitable for irrigated agriculture is downstream of the Rookwood dam site.
Nullinga dam site on the Walsh River	The Nullinga dam site on the upper Walsh River was first examined as an alternative to the Tinaroo Falls Dam as the major storage development in the MDWSS. The latter site was ultimately adopted because of the higher rainfall experienced in its catchment area and its better location and elevation to service the proposed irrigation area. Since the Nullinga site was first considered, considerable irrigation development has occurred within the inundation area. A dam at the Nullinga site on the Walsh River could provide for an expansion of irrigated production of lands riparian to the Walsh River downstream as far as the Leafgold weir area and with a delivery pipeline to the West Barron Main Channel could supply areas currently supplied from Tinaroo Falls Dam. This would free up supply from the dam that then could be used to supplement supply to Cairns and to the Barron Gorge hydro-electric power station. Although the site has a high cost to yield ratio, its proximity to the existing MDWSS and its potential to ensure the long-term security of Cairns water supply have led to interest in its possible development. A preliminary business case is currently being prepared by Building Queensland, with funding provided by the Australian Government.
Lake Mitchell on the Mitchell River	The dam is an existing privately owned development on the headwaters of the Mitchell River. Originally intended to support commercial and residential development with associated recreation, the dam has never been used. There are small areas of soil downstream that could be used for irrigation development. If the Lake Mitchell Dam owners agreed to supply water at a price comparable to that charged by SunWater, it is technically feasible that water could be pumped from Lake Mitchell to parts of the MDWSS near Mareeba. The existing water plan provides for a general reserve volume of 20 GL/y in the Mitchell River section upstream of the Rifle Creek junction, which includes the dam.

The investigation of a potential large dam site generally involves an iterative process of increasingly detailed studies over a period of years, occasionally over as few as 2 or 3 years but often over 10 or more years. It is not unusual for the cost of the geotechnical investigations for a potential dam site alone to exceed several million dollars. For any of the options listed in this chapter to advance to construction, far more comprehensive studies would be needed, including geotechnical investigations, field measurements of sediment yield, archaeological surveys and ground-based vegetation and fauna surveys. Studies at that detail are beyond the scope of this reconnaissance resource Assessment. The companion technical report on surface water storage (Petheram et al., 2017) outlines the key stages in investigation of design, costing and construction of large dams. More comprehensive descriptions are provided by Fell et al. (2005).

Pre-feasibility-level hydro-electric power assessment

Four of the eight potential dam sites examined for pre-feasibility analysis in the Mitchell catchment (Table 5-11 and Table 5-12) were also examined for a pre-feasibility-level hydro-electric power assessment (Figure 5-23). These were the Pinnacles dam site on the Mitchell River, Elizabeth Creek dam site, Rookwood dam site on the Walsh River and Chillagoe dam site on the

Walsh River. Although the potential for hydro-electric power generation was not specifically considered in the original selection of the eight pre-feasibility sites, as illustrated in the hydro-electric power opportunity map presented in Figure 5-23, these sites are nonetheless some of better sites for hydro-electric power generation in the Mitchell catchment.

Results of the pre-feasibility-level hydro-electric power assessment are presented for two release patterns:

- energy generation from irrigation releases
- energy generation with the dam operating as a hydro-electric power storage dam only.

Energy generation under the two release patterns is presented in Table 5-13 for two design discharge values. The design discharge values are based on the:

- 10th percentile exceedance of daily inflows (P10)
- 30th percentile exceedance of daily inflows (P30).

Capital expenditure (CAPEX) and operational expenditure (OPEX) for each design discharge include the cost of the penstock, power plant and turbine generators, substation and (66 kV) transmission lines to interconnect to the nearest connection point on the existing National Electricity Market (NEM). The NEM is the interconnected power system across SA, NSW, Victoria and Queensland. However, the costs do not include those associated with acquiring easements, native vegetation offsets, grid connection charges or contingencies. The Pinnacles and Elizabeth Creek potential dam sites are located approximately 60 km from the Mulligan Highway, which has a three-phase distribution line adjacent to it. Hydro-electric power infrastructure at both sites could connect to the grid via this distribution line, however, a new substation that allows for the 'cut-over' to the NEM would need to be built. The potential power plants at Rookwood and Chillagoe dam sites could potentially connect to the local distribution network in the town of Chillagoe.

Further detail on the pre-feasibility-level hydro-electric power assessment is provided in the companion technical report on hydropower (Entura, 2017).

Table 5-13 Summary of pre-feasibility-level hydro-electric power assessment for four sites in the Mitchell catchment

CAPEX is the capital expenditure including the cost of the penstock, power plant and turbine generators, substation and (66 kV) transmission lines, but not the RCC dam. OPEX is the operational expenditure of the hydro-electric power infrastructure. For more information, refer to companion technical report on hydropower (Entura, 2017).

POTENTIAL DAM SITE	PARAMETER	UNIT	P10 DESIGN DISCHARGE	P30 DESIGN DISCHARGE
Elizabeth Creek	Rated discharge	m^3/s	6.45	0.77
	Installed capacity	MW	1.70	0.21
	Power generated per year under hydro-electric power release pattern	MWh	9,867	1,589
	Power generated per year under irrigation release pattern	MWh	2,802	1,731
	CAPEX	$ million	31	14
	OPEX	$/y	563,451	66,968
	Cost per MW	$ million/MW	18.2	66.7

POTENTIAL DAM SITE	PARAMETER	UNIT	P10 DESIGN DISCHARGE	P30 DESIGN DISCHARGE
Pinnacles	Rated discharge	m^3/s	107.10	16.33
	Installed capacity	MW	44.48	6.93
	Power generated per year under hydro-electric power release pattern	MWh	257,926	52,010
	Power generated per year under irrigation release pattern	MWh	104,902	56,837
	CAPEX	$ million	143	30
	OPEX	$/y	3,957,812	562,819
	Cost per MW	$ million/MW	3.2	4.3
Rookwood	Rated discharge	m^3/s	53.53	6.20
	Installed capacity	MW	23.35	2.92
	Power generated per year under hydro-electric power release pattern	MWh	147,847	21,785
	Power generated per year under irrigation release pattern	MWh	48,336	23,894
	CAPEX	$ million	84	15
	OPEX	$/y	2,330,086	274,702
	Cost per MW	$ million/MW	3.6	5.1
Chillagoe	Rated discharge	m^3/s	42.49	4.84
	Installed capacity	MW	13.58	1.65
	Power generated per year under hydro-electric power release pattern	MWh	56,768	12,246
	Power generated per year under irrigation release pattern	MWh	27,768	14,141
	CAPEX	$million	63	12
	OPEX	$/y	1,730,927	199,933
	Cost per MW	$ million/MW	4.6	7.3

Indicative hydro-electric power generation annual revenues were calculated based on a lower bound ($60/MWh) and an upper bound ($90/MWh) of prices paid to generators in Queensland under the Australian Energy Market arrangements in 2017 (Table 5-14). Of the four potential dam sites investigated in the Mitchell catchment the Pinnacles on the Mitchell River had the largest generating potential, where approximately 257,900 MWh could be generated if the dam operated exclusively for hydro-electric power generation (Table 5-13). Revenue streams under hydro-electric power release pattern and assuming the upper bound price of $90/MWh would be $23.2 million/year (Table 5-14). With a total capital cost of dam ($755 million) and hydro-electric power infrastructure ($143 million) of $898 million, the total capital costs would be 38.7 times the annual revenue. This indicates that revenues under this set of conditions would not be fully commercial unless there was a substantial increase in the price paid to generators.

Under the irrigation release pattern and assuming the upper bound price of $90/MWh approximately 56,800 MWh could be generated under a P30 design discharge. If the cost of the dam was wholly attributed to irrigation, the cost of hydro-electric power infrastructure ($30 million) to revenue ($5.1 million) ratio is 5.9.

Table 5-14 Indicative hydro-electric power generation revenues for four potential sites in the Mitchell catchment
Assumes a P10 and P30 design discharge. Revenues have nominally been estimated for power prices at $60/MWh and at $90/MWh. These prices reflect the prices paid to Queensland generators under the Australian Energy Market in 2017.

POTENTIAL DAM SITE (DESIGN DISCHARGE)	ANNUAL REVENUE AT $60/MWh ($ million/y)		ANNUAL REVENUE AT $90/MWh ($ million/y)		CAPTIAL COST OF HYDRO-ELECTRIC POWER STATION† ($ million)	CAPITAL COST OF DAM ($ million)
	Hydro-electric power release pattern	Irrigation release pattern	Hydro-electric power release pattern	Irrigation release pattern		
Elizabeth (P10)	0.6	0.2	0.9	0.3	31	189
Elizabeth (P30)	0.1	0.1	0.1	0.2	14	189
Pinnacles (P10)	15.5	6.3	23.2	9.4	143	755
Pinnacles (P30)	3,1	3,4	4.7	5.1	30	755
Rookwood (P10)	8.9	2.9	13.3	4.4	84	655
Rookwood (P30)	1.3	1.4	2.0	2.2	15	655
Chillagoe (P10)	3.4	1.7	5.1	2.5	63	601
Chillagoe (P30)	0.7	0.8	1.1	1.3	12	601

†Cost includes the cost of the power station at the dam and connection to the grid.

Other considerations

Ecological considerations of the dam wall and reservoir

The water impounded by a dam inundates an area of land, drowning not only instream habitat but surrounding flora and fauna communities. Most potential dam sites in the Mitchell catchment would inundate some regional ecosystems considered to be 'of concern' (Figure 3-13). Complex changes in habitat resulting from inundation could create new habitat to benefit some of these species, while other species would be impacted by loss of habitat.

For instream ecology, the dam wall acts as a barrier to movements of plants, animals and nutrients, potentially disrupting connectivity of populations and ecological processes. There are many studies linking water flow with nearly all the elements of instream ecology in freshwater systems (e.g. Robins et al., 2005).

A dam also creates a large, deep lake, a habitat that is in stark contrast to the usually shallow and often flowing habitats it replaces. This lake-like environment favours some species over others and will function completely differently to natural rivers and streams. The lake-like environment of an impoundment is often used by sports anglers to augment natural fish populations by artificial stocking. Whether fish stocking is a benefit of dam construction is a matter of debate and point-of-view. Stocked fisheries provide a welcome source of recreation and food for fishers, and no doubt an economic benefit to local businesses, but they have also created a variety of ecological challenges. Numerous reports of disruption of river ecosystems (e.g. Drinkwater and Frank, 1994; Gillanders and Kingsford, 2002) highlight the need for careful study and regulatory management.

Impounded waters may be subject to unauthorised stocking of native fish and releases of exotic flora and fauna.

Terrestrial and freshwater biodiversity of the Mitchell catchment is rich and many species and ecological communities are listed for conservation at a federal and state level (Section 3.2). Species of conservation importance that could be impacted by potential dams include migratory birds, migratory fish and stable spawners, and vulnerable water monitors.

About 57 fish species have been recorded in the Mitchell catchment (Section 3.2). All potential dam sites examined as part of the pre-feasibility assessment will impede the movement of barramundi (Figure 3-5), except perhaps Nullinga. It is possible that potential dams in the mid-reaches of the Palmer, Mitchell, Walsh and Lynd rivers will impede the movement of sawfish (Figure 3-5).

Further investigation of any of these potential dam sites would typically involve a thorough field investigation of vegetation and fauna communities.

Potential changes to instream, riparian and near-shore marine species arising from changes in flow are discussed in Section 7.2.

Sedimentation

Rivers carry fine and coarse sediment eroded from hill slopes, gullies, banks and sediment stored within the channel. The delivery of this sediment into a reservoir can potentially be a problem because it can progressively reduce the volume available for active water storage. The deposition of coarser grained sediments in backwater (upstream) areas of reservoirs can also cause back-flooding beyond the flood limit originally determined for the reservoir.

Although infilling of the storage capacity of smaller dams has occurred in Australia (Chanson, 1998), these dams had small storage capacities, and infilling of a reservoir is generally only a potential problem where the volume of the reservoir is small relative to the catchment area – sediment yield is strongly correlated to catchment area (Wasson, 1994; Tomkins, 2013). Sediment yield to catchment area relationships developed for northern Australia (Tomkins, 2013) were found to predict lower sediment yield values than global relationships. This is not unexpected given the antiquity of the Australian landscape (i.e. it is flat and slowly eroding under 'natural' conditions).

Potential dams in the Mitchell catchment, which were examined as part of the Assessment, were estimated to have about 1% sediment infilling after 30 years and about 3% sediment infilling after 100 years.

Cultural heritage considerations

Indigenous people traditionally situated their campsites and subsistence activities along major watercourses and drainage lines. Consequently, potential dams are more likely to impact on areas of high cultural significance than most other infrastructure developments (e.g. irrigation schemes, roads).

It is highly likely that the Mitchell catchment will contain a large number of Indigenous cultural sites, including archaeological pre-colonial sites, some of which are likely to be of national scientific significance. The cultural heritage value of these landforms and their immediate surrounds is therefore assumed to be moderate to very high. Figure 3-31 illustrates the registered Indigenous cultural heritage sites in the Mitchell catchment, however, the actual number of sites is likely to be substantially larger. There is insufficient information relating to the cultural heritage values of the potential dam sites examined as part of the pre-feasibility assessment to allow full understanding or quantification of the likely impacts of water storages on Indigenous cultural heritage.

The cost of cultural heritage investigations associated with dam sites is high relative to other development activities.

Cumulative yield of multiple dams in the Mitchell catchment

The combined or cumulative yield of multiple dams in the Mitchell catchment is shown in Figure 5-24. Here it is shown that the total divertible yield, before losses, from four and six of the more promising potential dam sites was about 2800 GL and 3000 GL, respectively in 85% of years at the dam wall. It was found that after the fourth dam there were marginal returns with the addition of each subsequent dam.

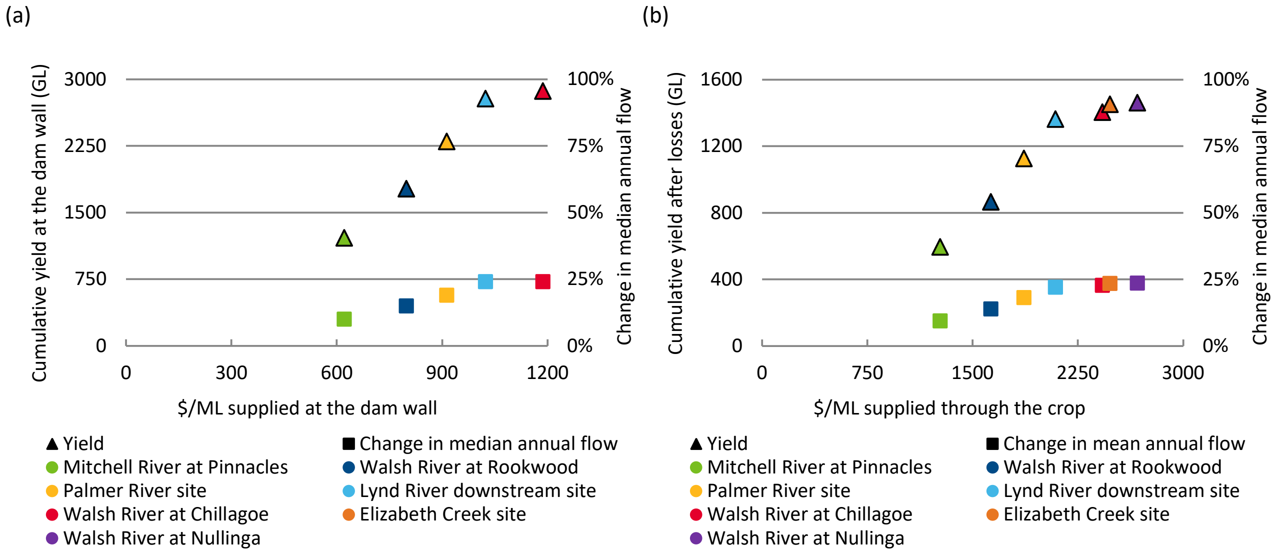

Figure 5-24 Cost of water in $/ML versus cumulative divertible yield at 85% annual time reliability and change in flow at the end of system in the Mitchell catchment

(a) Yield at the dam wall versus cost of water at the dam wall under the historical climate and future development and (b) yield after river, channel (10%), on-farm (10%) and field application (15%) losses (i.e. equivalent to the amount of water available to go through the plant) versus cost of water after losses under the historical climate and future development. Plot (b) is indicative of the amount of water that may be available to go through the plant. Triangles indicate combined water yield at 85% annual time reliability of one or more dams, with the colour of the dot indicating the most recently included dam in the cumulative yield calculation. Squares indicate change in median (a) and mean (b) annual streamflow at the end of system from the baseline (i.e. under the historical climate and current development).

Two selected potential dam sites in the Mitchell catchment

This section provides more detail on two of the eight potential dam sites examined as part of the pre-feasibility analysis. These sites were selected because they are two of the more high-yielding and cost-effective potential dam sites in the Mitchell catchment, in close proximity to the large continuous areas of land suitable for irrigated agriculture and are sited on different rivers.

Detailed descriptions of the eight sites selected for pre-feasibility assessment are provided in the companion technical report on surface water storage (Petheram et al., 2017).

The Pinnacles dam site on the Mitchell River

The site is on the Mitchell River some 80 km north-north-west of the township of Chillagoe, commands a large catchment area (7728 km^2) and has the highest yield of the eight pre-feasibility sites examined in the Mitchell catchment. The potential dam is located in a relatively wide gorge (about 230 m bed width) with outcrop on the valley floor and on both abutments and in the river bed. The left abutment is a very steep rocky slope at the end of a prominent steep sided northwest/south-east-trending ridge of chert known as the Pinnacles Range (Figure 5-25). Chert is exposed in a steep cliff on the north-eastern side of the ridge.

Given the need to provide a large spillway capacity and to minimise the risk of flood damage during construction, a RCC structure with a 240-m wide central uncontrolled spillway with crest level up to 60 m above bed level is proposed. A hydraulic jump type stilling basin would be provided to protect the river bed against erosion during spillway overflows. Outlet works and a fish transfer facility are proposed to be located on the left abutment of the dam. The full supply level (FSL) with the highest yield to cost ratio was at 240 mEGM96 (mEGM96 is the datum of the Shuttle Radar Terrain Mission digital elevation model), approximately 58 m above the river bed. At this level a RCC retaining wall would be required at the top of the right abutment to retain the zoned earth and rockfill saddle dam, which would be up to 1.85 km in length and have a height of up to 42 m. At the Pinnacles dam site a RCC dam with a FSL 240 mEGM96 would cost approximately $755 million and yield about 1248 GL in 85% of years (Figure 5-26).

A storage at this site could potentially support a large irrigation development downstream of Wrotham Park. There are no known urban or mining demands that could be met by a dam at this site.

A dam constructed at this site could affect the migration or movement of fishes, most of them stable flow spawners such as barred grunter. Other freshwater fish found near this site could be indirectly affected by a dam as it would limit the amount of available prey such as other fish, crustaceans and molluscs.

Of the eight pre-feasibility sites examined in the Mitchell catchment this site has the highest number of species of national significance (41 species) – most of them migratory birds (27 species), including the critically endangered great knot (*Calidris tenuirostris*) and curlew sandpiper (*Calidris ferruginea*). Six frog species have been recorded near this site, two of which are critically endangered. Approximately 25% of the potential inundated area at the selected full supply level is covered by a regional ecosystem 'of concern' (3641 ha) (Figure 5-27).

A dam at the Pinnacles site at the nominated FSL would substantially alter the area inundated downstream. This would particularly occur during small flood events where there was a 56% reduction in peak inundated area (Figure 5-28), but also during large flood events (Figure 5-28b), where there was a 32% reduction in peak inundated area.

Substantial land in the area is subject to current and/or future native title claims. There are no currently recorded cultural heritage sites in the inundation area, but there are recorded sites in the vicinity and in the wider catchment. There is a high likelihood of unrecorded sites in the inundation area.

Further assessment, including geotechnical investigation of the saddle dam area, would be required to determine the optimal level of development. Although a fish transfer facility has been proposed, the dam's potential impact on migratory fish species, including the freshwater sawfish and barramundi, would need to be further considered.

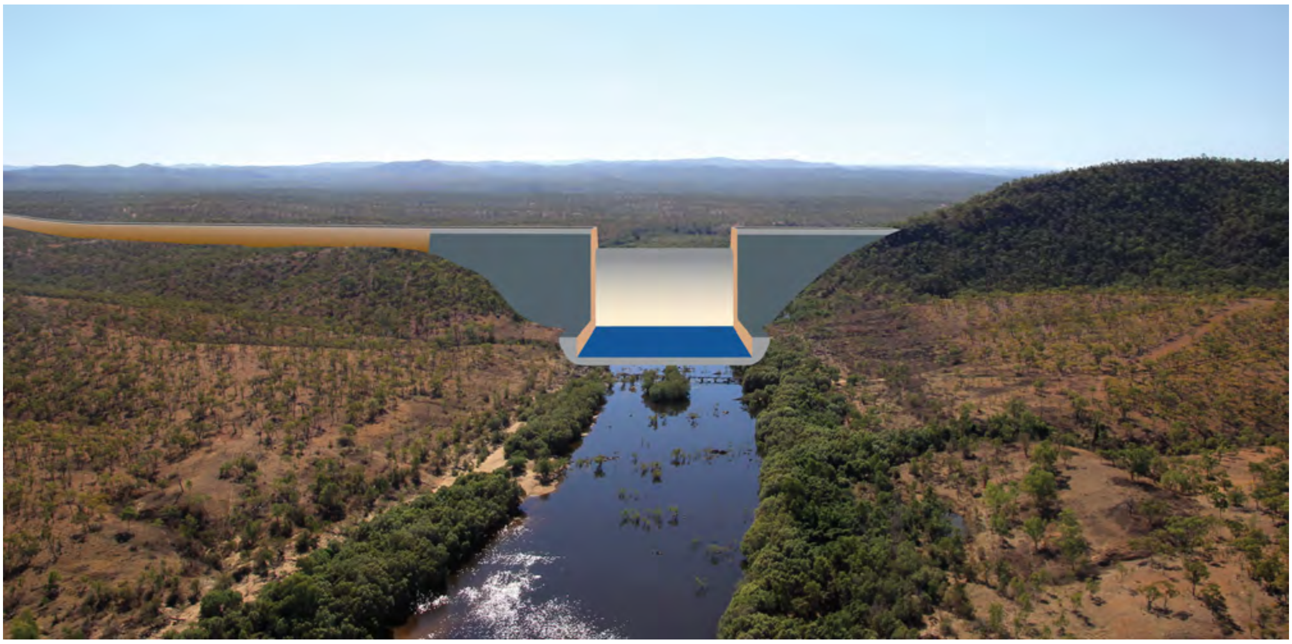

Figure 5-25 The potential Pinnacles dam site on the Mitchell River looking upstream
Photo: CSIRO

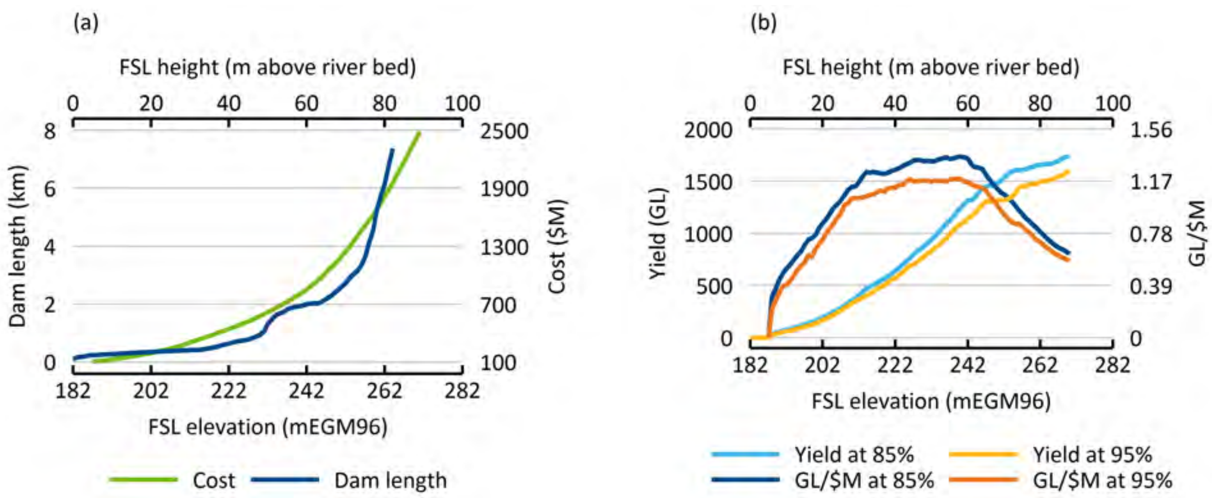

Figure 5-26 The Pinnacles dam site on the Mitchell River: cost, yield at the dam wall and evaporation
(a) Dam length and dam cost versus full supply level (FSL) and (b) dam yield at 85% and 95% annual time reliability and yield (GL) per million dollars at 85% and 95% annual time reliability.

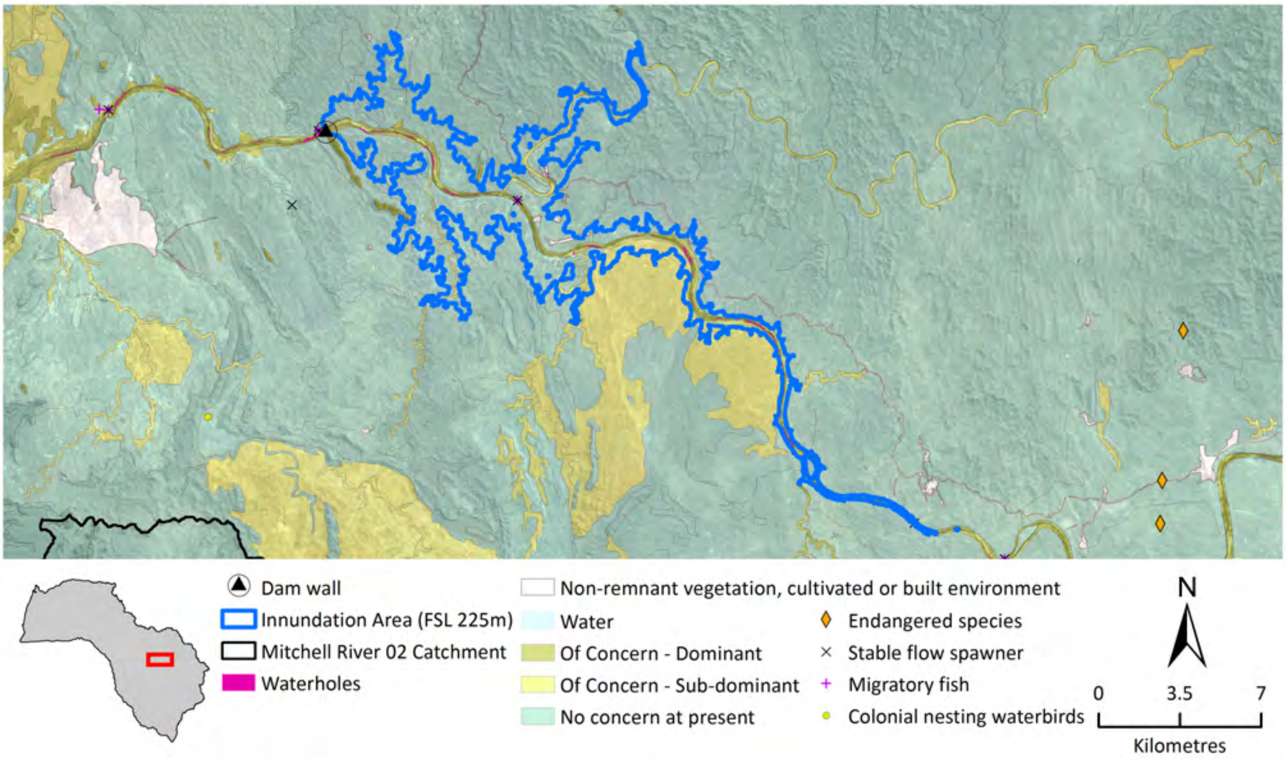

Figure 5-27 Regional ecosystem mapping and reservoir extent of the potential Pinnacles dam site

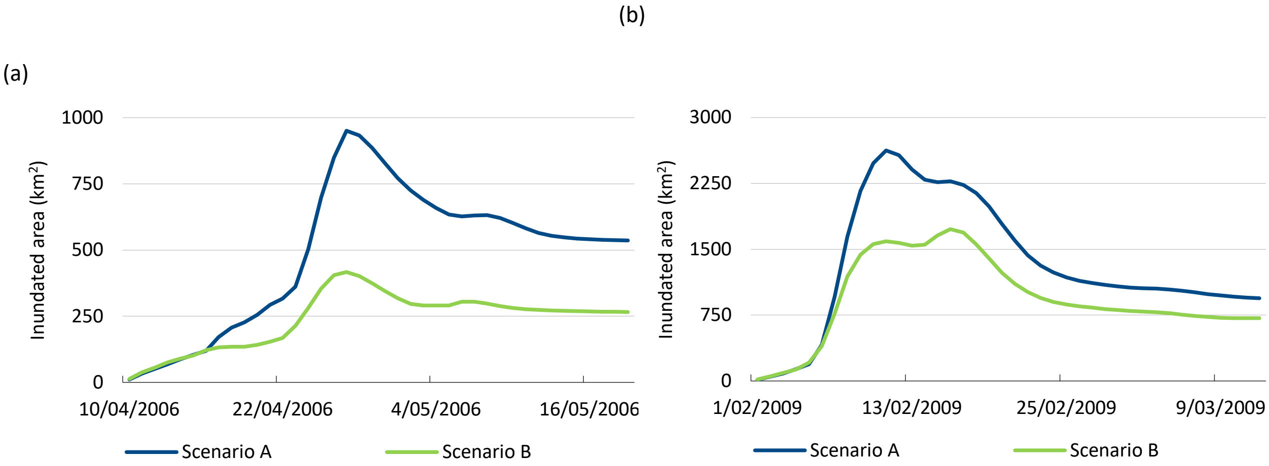

Figure 5-28 Comparisons of modelled inundated area with and without construction of the Pinnacles dam under historical climate

(a) For an event in 2006 (equivalent to an event of AEP 50% (1 in 2 years) at gauging station 919011). (b) For an event in 2009 (equivalent to an event of AEP 4% (1 in 26 years) at gauging station 919011). Gauging station locations are shown in Figure 2-31. Scenario B assumes the Pinnacles dam reservoir is at half capacity at commencement of flood. See companion technical report on flood mapping and modelling (Karim et al., 2018).

Rookwood dam site on the Walsh River

The potential Rookwood dam site commands a catchment area of 4990 km^2 and is near the upstream end of a straight relatively narrow gorge within the Walsh River some 28 km north-west of the town of Chillagoe. In the gorge section, fresh rock is exposed in the river bed and over much of both banks (Figure 5-30).

A RCC gravity dam with crest level up to 66 m above bed level is proposed with a 300-m wide uncontrolled central overflow spillway. A hydraulic jump type stilling basin would be provided to protect the river bed against erosion during spillway overflows. At the optimal FSL (of

295 mEGM96) saddle dams are required on both the right and on the left bank of the reservoir to contain reservoir rises during flood inflows. The gorge is easily accessed from the Bourke Development Road.

A manual cost estimate undertaken as part of the Assessment for a RCC dam at the Rookwood dam site on the Walsh River at FSL 295 mEGM96 found the dam would cost approximately $655 million and yield 575 GL in 85% of years (Figure 5-31).

The potential dam site is about 60 km upstream of large contiguous areas of land suitable for irrigated agriculture near Wrotham Park. Commanding a larger catchment area than the upstream Chillagoe dam site, the Rookwood dam site has the second lowest cost to yield ratio in the Mitchell catchment.

A dam at this site may impact on the migration, movement and colonisation of a number of fish species. Other freshwater fish found near this site could be indirectly affected by a barrier that limits the amount of prey such as other fish, crustaceans and molluscs. A potential reservoir at this site may impact the habitat of a number of species. There are records of 12 migratory bird species, two of which are listed as endangered. There are also records of four mammals (one critically endangered, one endangered and one vulnerable), three frog species (two endangered and one vulnerable) and four plant species (all listed as vulnerable). The potential reservoir would inundate some regional ecosystems 'of concern' (Figure 5-32).

Substantial land in the area is subject to current and/or future native title claims. There are no currently recorded cultural heritage sites in the inundation area, but there are recorded sites in the vicinity and in the wider catchment. There is a high likelihood of unrecorded sites in the inundation area.

Figure 5-29 The town of Chillagoe is near the potential Rookwood dam site
Photo: Nathan Dyer

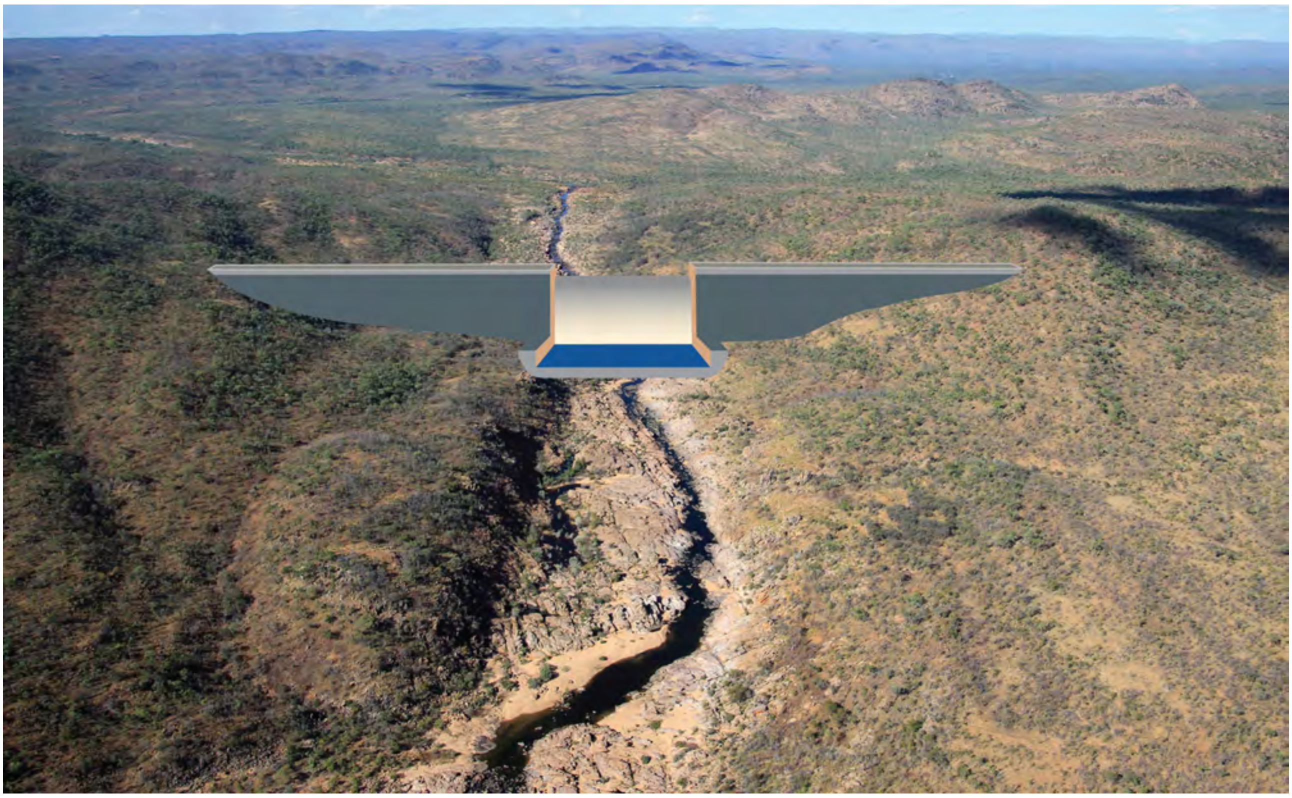

Figure 5-30 Potential Rookwood dam site on the Walsh River looking upstream
Photo: CSIRO

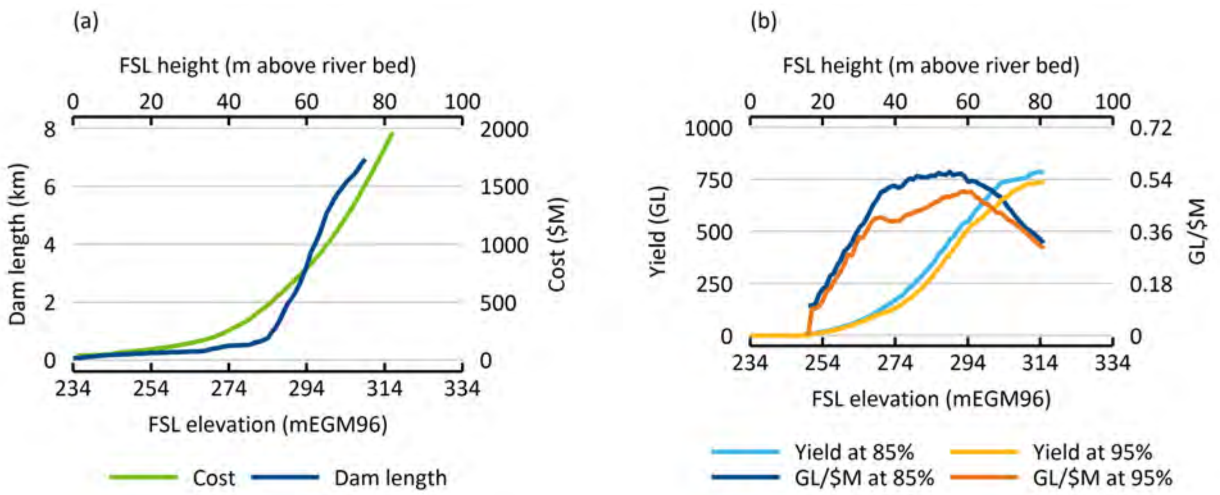

Figure 5-31 Rookwood dam site on the Walsh River site: cost, yield at the dam wall and evaporation
(a) Dam length and dam cost versus full supply level (FSL) and (b) dam yield at 85% and 95% annual time reliability and yield per million dollars at 85% and 95% annual time reliability.

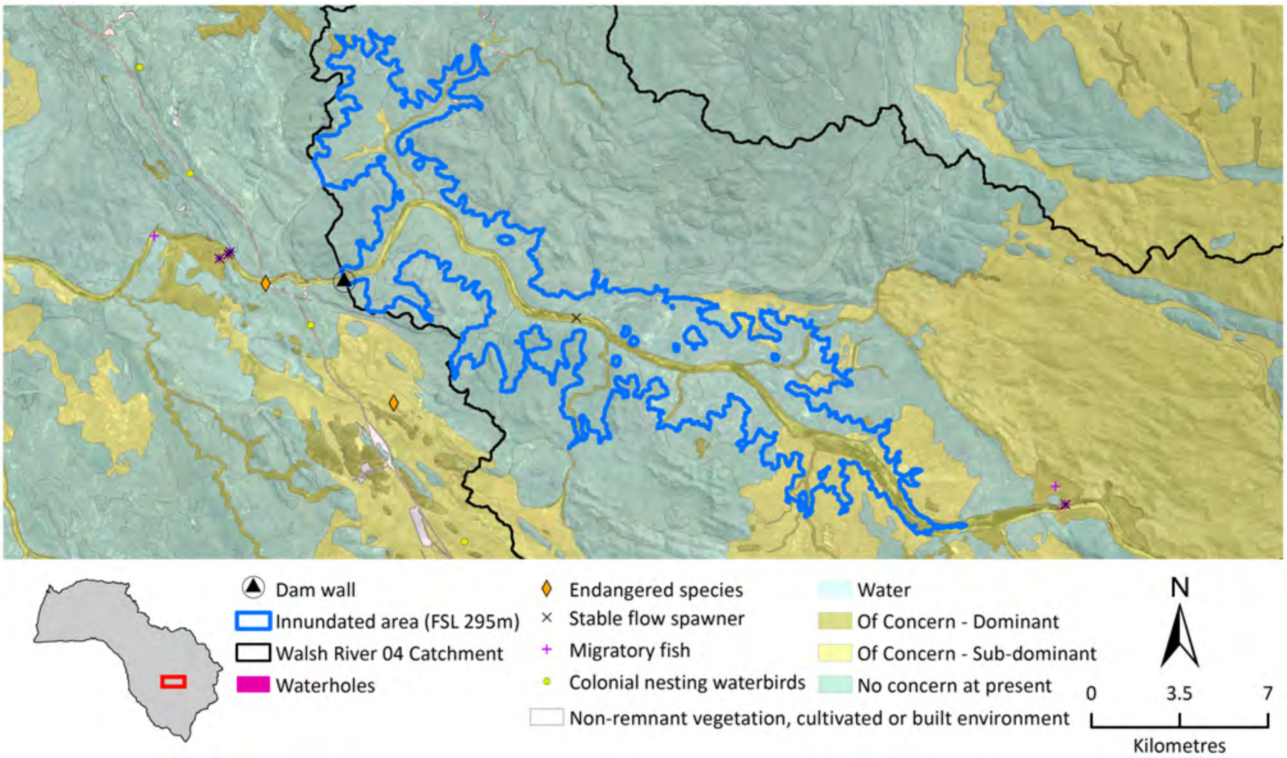

Figure 5-32 Regional ecosystem mapping and reservoir extent of the potential Rookwood dam site on the Walsh River

5.3.3 WEIRS AND RE-REGULATING STRUCTURES

Re-regulating structures, such as weirs, are typically located downstream of large dams. They allow for more efficient releases from the storages and for some additional yield from the weir storage itself, thereby reducing the transmission losses normally involved in supplemented river systems.

As a rule of thumb, however, weirs are constructed to half to two-thirds of the river bank height. This height allows the weirs to achieve maximum capacity, while ensuring the change in downstream hydraulic conditions does not result in excessive erosion of the toe of the structure. It also ensures that large flow events can still be passed without causing excessive flooding upstream.

Broadly speaking, there are two types of weir structure: concrete gravity type weirs and sheet piling weirs. These are discussed below. For each type of weir, rock-filled mattresses are often used on the stream banks, extending downstream of the weir to protect erodible areas from flood erosion. A brief discussion on sand dams is also provided.

Weirs, sand dams and diversion structures obstruct the movement of fish in a similar way to dams during the dry season.

Concrete gravity type weirs

Where rock bars are exposed at bed level across the stream, concrete gravity type weirs have been built on the rock at numerous locations across Queensland. This type of construction is less vulnerable to flood erosion damage both during construction and in service.

Assuming favourable foundation conditions, the cost of a 6m-high and 400 m-wide concrete gravity weir is estimated to be approximately $23 million. This includes a fish lock ($1 million), bank protection ($850,000) and outlet works ($500,000), investigation and design ($650,000), on-site overheads ($2 million) and risk adjustment ($5.6 million). It does not include acquisition and approval costs. Leafgold weir is an example of a concrete gravity type weir in the MDWSS on the Walsh River (Figure 5-33).

Figure 5-33 Leafgold Weir on the Walsh River, Queensland
Photo: CSIRO

Sheet piling weirs

Where rock foundations are not available, stepped steel sheet piling weirs have been successfully used in many locations across Queensland. These weirs consist of parallel rows of steel sheet piling, generally about 6 m apart with a step of about 1.5 to 1.8 m high between each row. Reinforced concrete slabs placed between each row of piling absorb much of the energy as flood flows cascade over each step. The upstream row of piling is the longest, driven to a sufficient depth to cut off the flow of water through the most permeable material (Figure 5-34). Indicative costs are provided in Table 5-15.

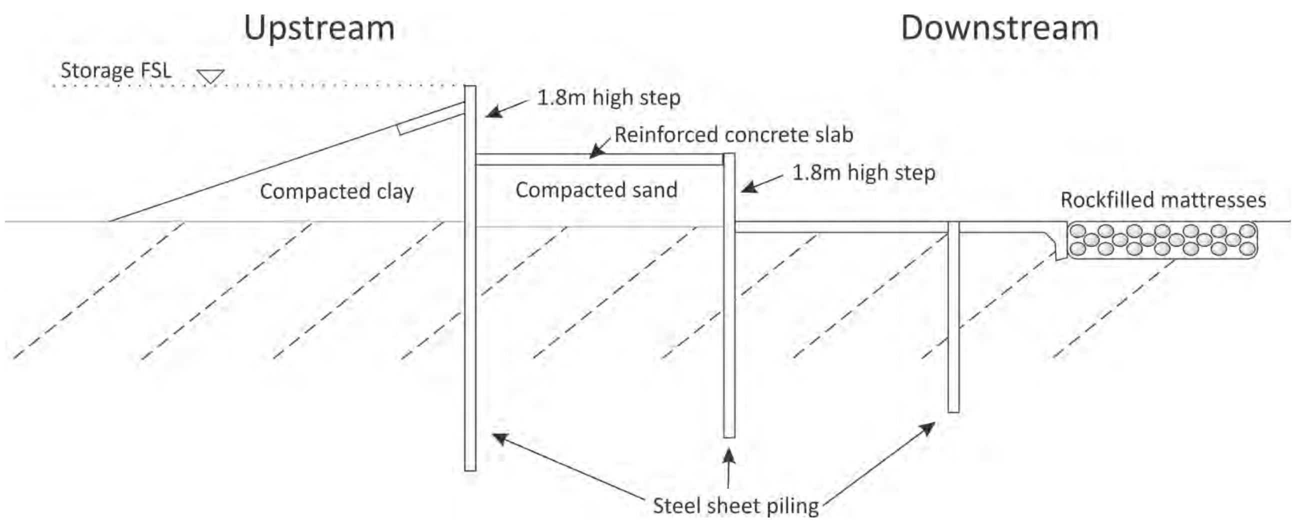

Figure 5-34 Schematic cross-section diagram of sheet piling weir
Source: Petheram et al. (2013)

Table 5-15 Estimated construction cost of 3-m high sheet piling weir

WEIR CREST LENGTH (m)	ESTIMATED CAPITAL COST ($ million)
100	25
150	32
200	38

Sand dams

As many of the large rivers in northern Australia are very wide (e.g. >300 m), weirs are likely to be impractical and expensive at many locations. An alternative structure is sand dams, which are low embankments built of sand on the river bed. They are constructed at the start of each dry season during periods of low or no flow when heavy earth moving machinery can access the bed of the river. They are constructed to form a pool of depth sufficient to enable pumping (i.e. typically greater than 4 m depth), and are widely used in the Burdekin River near Ayr in Queensland, where the river is too wide to construct a weir.

Typically, sand dams take three to four large excavators about 2 to 3 weeks to construct and no further maintenance is required until they need to be reconstructed again after the wet season. Bulldozers can construct a sand dam quicker than a team of excavators, but have greater access difficulties. Because sand dams only need to form a pool of sufficient size and depth from which to pump water, they usually only partially span a river and are typically constructed immediately downstream of large, naturally formed waterholes.

The cost of 12 weeks of hire for a 20-tonne excavator and float (i.e. transportation) is approximately $80,000. Although sand dams are cheap to construct relative to a concrete or sheet piling weir, they require annual rebuilding and have much larger seepage losses beneath and through the dam wall. No studies are known to have quantified losses from sand dams.

5.3.4 LARGE FARM-SCALE RINGTANKS

Large farm-scale ringtanks are usually fully enclosed circular earthfill embankment structures constructed close to major watercourses/rivers so as to minimise the cost of pumping infrastructure by ensuring long 'water harvesting' windows. For this reason they are often subject to reasonably frequent inundation, usually by slow-moving flood waters. In some exceptions embankments may not be circular; rather, they may be used to enhance the storage potential of natural features in the landscape such as horseshoe lagoons or cut-off meanders adjacent to a river (see Section 5.3.6).

An advantage of ringtanks over gully dams is that the catchment area of the former is usually limited to the land that it impounds, so costs associated with spillways, failure impact assessments and constructing embankments to withstand flood surges are considerably less than large farm-scale gully dams. Another advantage of ringtanks is that unless a diversion structure is utilised in a watercourse to help 'harvest' water from a river, a ringtank and its pumping station do not impede the movement of aquatic species or transport of sediment in the river. Ringtanks also have to be sited adjacent to major watercourses to ensure there are sufficient days available for pumping. While this limits where they can be sited, it also means that because they can be sited adjacent to major watercourses (on which gully dams would be damaged during flooding – large farm-scale gully dams are typically sited in catchments less than 30 km^2) they often have a higher reliability of being filled each year than gully dams. However, operational costs of ringtanks are usually higher than gully dams because water must be pumped into the structure each year from an adjacent watercourse, typically using diesel powered pumps (solar and wind energy do not generate sufficient power to operate high volume axial flow or 'china' pumps). Even where diversion structures are utilised to minimise pumping costs, the annual cost of excavating sediment and debris accumulated in the diversion channel can be in the order of tens of thousands of dollars.

For more information on ringtanks in the Mitchell catchment refer to the companion technical reports on surface water storage (Petheram et al., 2017), large farm-scale dams (Benjamin, 2018) and river model simulation (Hughes et al., 2018).

In this section, the following assessments of ringtanks in the Mitchell catchment are reported:

- suitability of the landscape for large farm-scale ringtanks
- reliability with which water can be extracted from different reaches
- indicative evaporative and seepage losses from large farm-scale ringtanks
- indicative capital, operating and maintenance costs of large farm-scale ringtanks.

Suitability of land for ringtanks in the Mitchell catchment

Figure 5-36 displays the broad-scale suitability of large farm-scale ringtanks in the Mitchell catchment. Large contiguous areas of land downstream of the Palmer and Mitchell rivers (>1 million ha) are classed as being suitable for ringtanks. This part of the Mitchell catchment is particularly susceptible to flooding (Figure 2-41), however, in many places floodwaters are likely to be slow moving and simply maintaining good grass coverage on the outside embankment slope and/or reducing the slope of the lower part of the outer batter may provide adequate protection. At locations where flow velocities are higher, riprap protection to above the peak flood elevation may be required. Sites should be assessed for expected depth of inundation and flow velocity during the investigation and design stage to determine if protection of the outer batters of the embankment and pump station is required.

Narrow sections of land adjacent to the lower Palmer and lower Lynd rivers are also classed as being suitable for ringtanks. There is also a relatively large area of heavier soils above the confluence of the Mitchell and Walsh rivers that is likely to be suitable. With the exception of small areas of land along the upper Mitchell and Walsh rivers, the upper parts of the Mitchell catchment are unsuitable for large farm-scale ringtanks because the soils are generally too shallow and/or the land too steep.

Figure 5-35 Rectangular ringtank in the Flinders catchment, Queensland
Photo: CSIRO

Reliability of water extraction

The reliability at which an allocation or volume of water can be extracted from a river depends upon a range of factors including:

- quantity of discharge and the natural inter- and intra-variability within a river system (Section 2.5)
- capacity of the pumps or diversion structure (expressed here as the number of days taken to pump an allocation)
- quantity of water being extracted by other users and their location
- conditions associated with a licence to extract water, such as:
  – a minimum threshold at which pumping can commence (pump start threshold)

– an end-of-system flow requirement, the minimum flow that must pass the lowest gauge in the system before pumping can commence.

Licence conditions can be imposed on a potential water user to ensure downstream entitlement holders are not impacted by new water extractions and to minimise environmental change that may arise from perturbations to streamflow. In some cases a pump start threshold is a physical threshold below which it is difficult to pump water from a natural pumping pool.

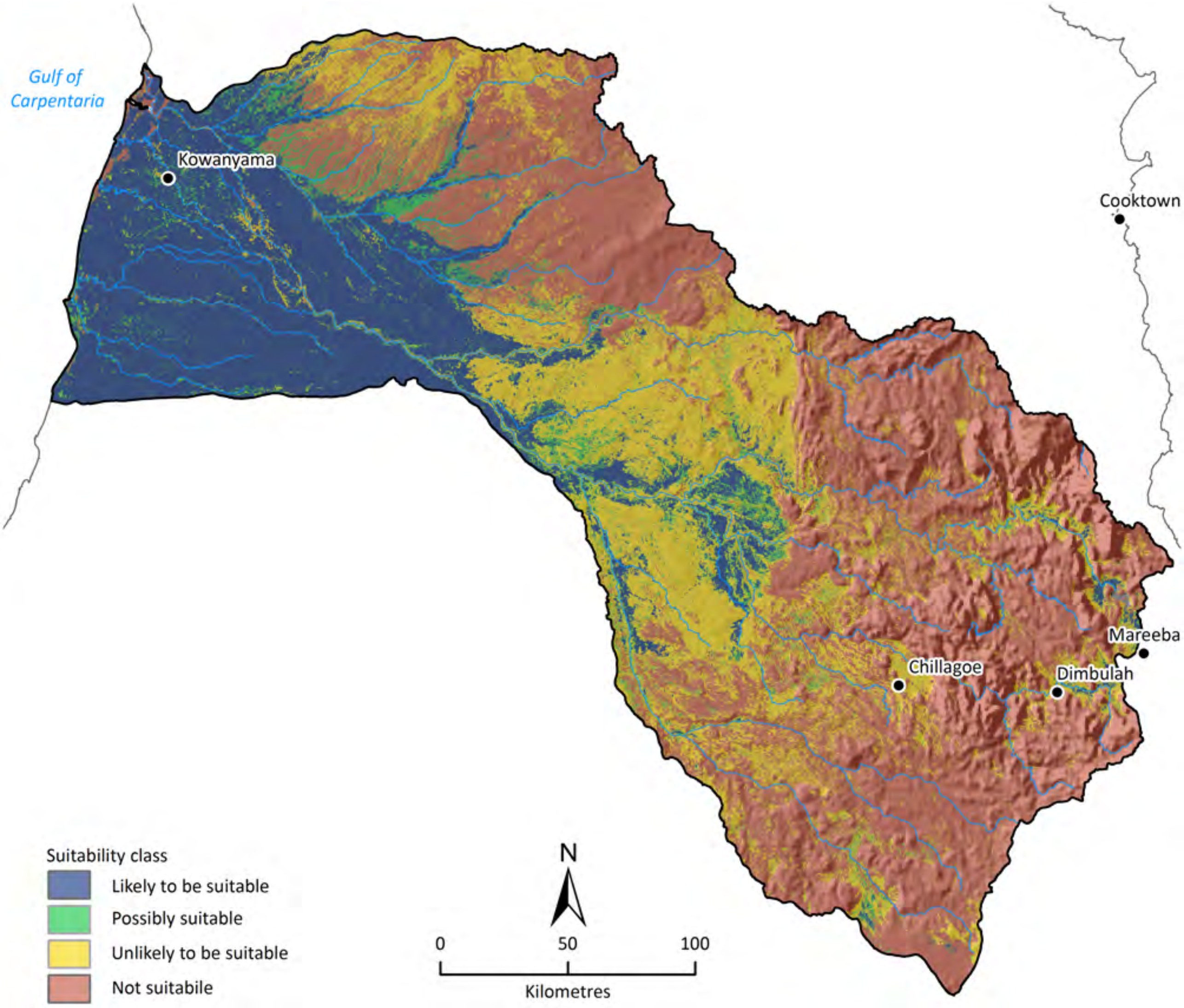

Figure 5-36 Suitability of large farm-scale ringtanks in the Mitchell catchment
Soil and subsurface data were only available to a depth of 1.5 m, hence this Assessment does not consider the suitability of subsurface material below this depth. This figure does not consider the availability of water. Data are overlaid on a shaded relief map. The results presented in this figure are only indicative of where suitable locations for siting a ringtank may occur and site-specific investigations by a suitably qualified professional should always be undertaken prior to their construction.

Figure 5-38 can be used to explore the reliability at which increasing volumes of water can be extracted ('harvested') in seven river reaches (letters a through g indicate the most downstream location of each reach) under varying pump start thresholds, pump capacities and an of end-of-system flow requirement at the lowermost streamflow gauge (9190090). The impact of an end-of-system flow requirement on extraction reliability is examined because it is the least complex environmental flow provision to regulate and police in a remote catchment like the Mitchell catchment. Within each river reach water could be harvested by one or more hypothetical water harvesters and the water nominally stored in ringtanks adjacent to the river reach. The locations of the hypothetical water harvesters illustrated in Figure 5-38 and their relative proportion of the total system allocation (left vertical axis) are assigned based on joint consideration of crop versatility, broad-scale flooding, ringtank suitability and river discharge (see companion technical report on river model simulation (Hughes et al., 2018)). The allocation assigned to each reach is shown on the right vertical axis.

At the smallest pump start threshold examined, 200 ML/day (nominally representative of a physical pumping limit), approximately 1500 GL of water can be extracted in the Mitchell catchment in 85 to 95% of years depending upon the location (Figure 5-38). As the total system allocation increases, the reliability at which each water harvester can extract their proportion of the system allocation decreases. For example, at a total system allocation of 3000 GL water harvesters can extract their proportion of the 3000 GL/year in 75 to 85% of years, except the lowest reach (g), which has the highest reach allocation (approximately one-third of the system allocation) and is impacted by upstream extractions. Consequently, the lowest reach has a reliability of extraction of only 70% (Figure 5-38).

At low system allocations (i.e. 1500 GL/year) and a pump start threshold of 200 ML/day, the reliability of extraction decreases slightly with decreasing pump capacity (i.e. increasing days to pump allocation). At high system allocations (i.e. 4000 GL/year) the reliability of extraction decreases more steeply with a decrease in pump capacity.

A Diesel powered axial flow pump is pictured in Figure 5-37.

Figure 5-37 Diesel powered axial-flow flood-harvesting pump in Flinders catchment, Queensland
Photo: CSIRO

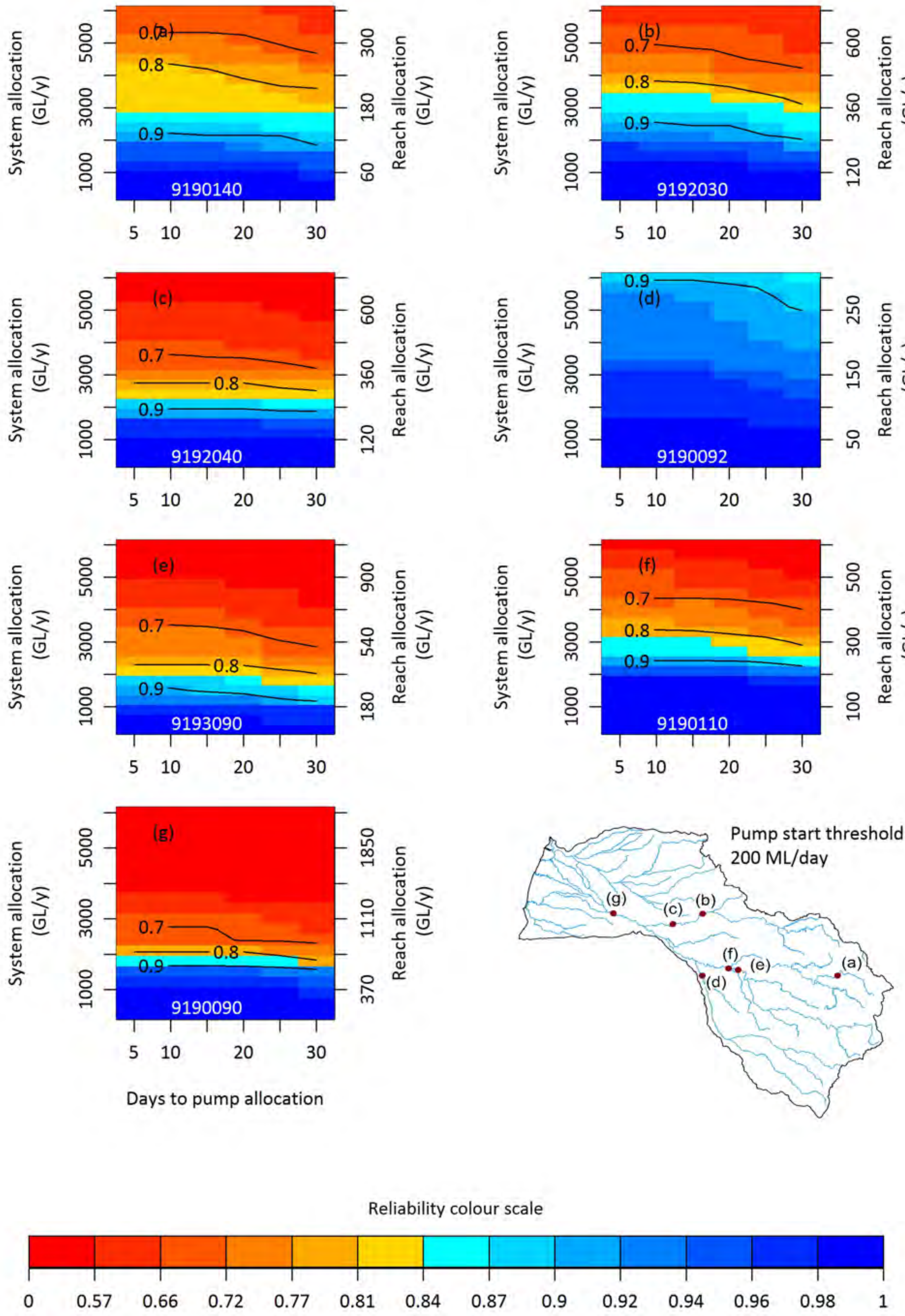

Figure 5-38 Reliability of extracting water up to the annual system/reach entitlement volume for seven water harvesting users for a pump start threshold of 200 ML/day

On the inset map the letters (a) through (g) indicate the most downstream location of each reach.

As the pump start threshold increases (Figure 5-39), the reliability of extracting a given system/reach allocation generally decreases. This is because the time over which pumping is permitted decreases. The reduction in reliability is particularly noticeable at low pump capacities. The exception occurs at the lowest extraction point (g), which is below the confluence of the Palmer, Mitchell, Walsh and Lynd rivers. At this location (g) streamflow in the Mitchell River exceeds 1000 ML/day on many occasions where the streamflow in the upstream contributing tributaries is less than 1000 ML/day and hence pumping is not permitted.

Under conditions where 1000 GL of water has to pass the lowest streamflow gauge in the system (9190090) before pumping can commence in a given wet season (i.e. the end-of-system requirement is 1000 GL), and for a pump start threshold of 200 ML/day, the reliability at which a system allocation of 1500 GL/year can be extracted decreases from 85 to 95% (Figure 5-38) to between 75 and 85% (Figure 5-40).

Figure 5-41 and Figure 5-42 show the 50% and 80% annual exceedance streamflow relative to Scenario A, respectively, for a 200 ML/day pump start threshold and under a range of end-of-system (i.e. lowermost gauge) flow requirements. At location (e) in the Mitchell catchment it can be seen that for a system allocation of 1500 GL/year and a zero lowermost gauge flow requirement and with a pump rate of 10 days, the median annual flow (i.e. 50% annual exceedance flow) in the river immediately downstream of this location is slightly less than 70% of the median annual flow under Scenario A (i.e. without development) (Figure 5-41). However, at the same location and same system allocation of 1500 GL/year the 80% annual exceedance flow is about 40% of the 80% annual flow under Scenario A (Figure 5-42). Implementing a lowermost gauge flow requirement appears to have little effect on the median annual flow below the point of extraction under Scenario B. However, as the lowermost gauge flow requirement increases above about 1000 GL/year the impact of extractions on the 80% annual exceedance streamflow value decreases sharply.

These results illustrate how water harvesting/extractions have greater impact on those years of low streamflow, unless lowermost gauge flow requirements are imposed, in which case there is a trade-off with the reliability with which water can be extracted.

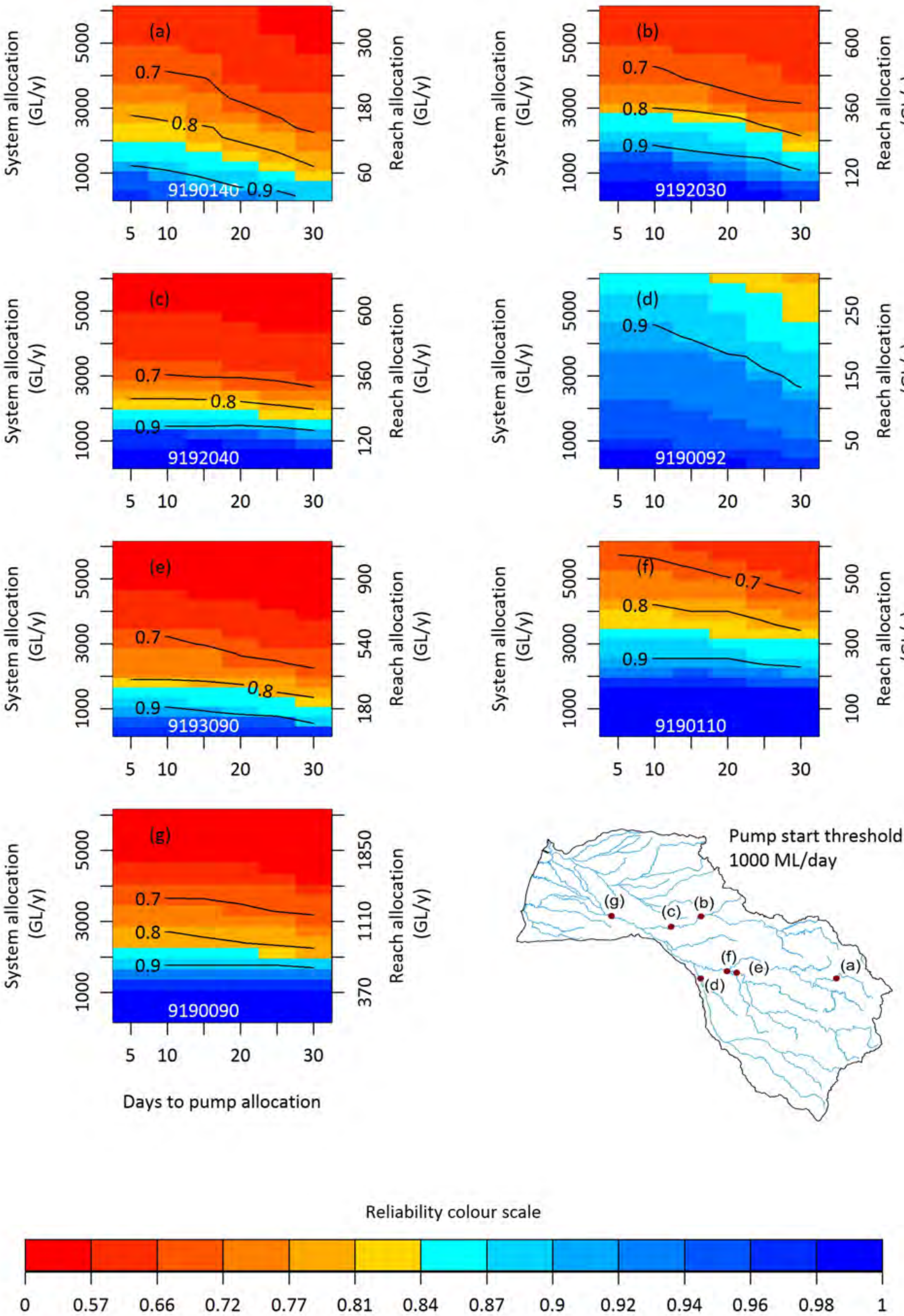

Figure 5-39 Reliability of extracting water up to the annual system/reach entitlement volume for seven water harvesting users for a pump start threshold of 1000 ML/day

On the inset map the letters (a) through (g) indicate the most downstream location of each reach.

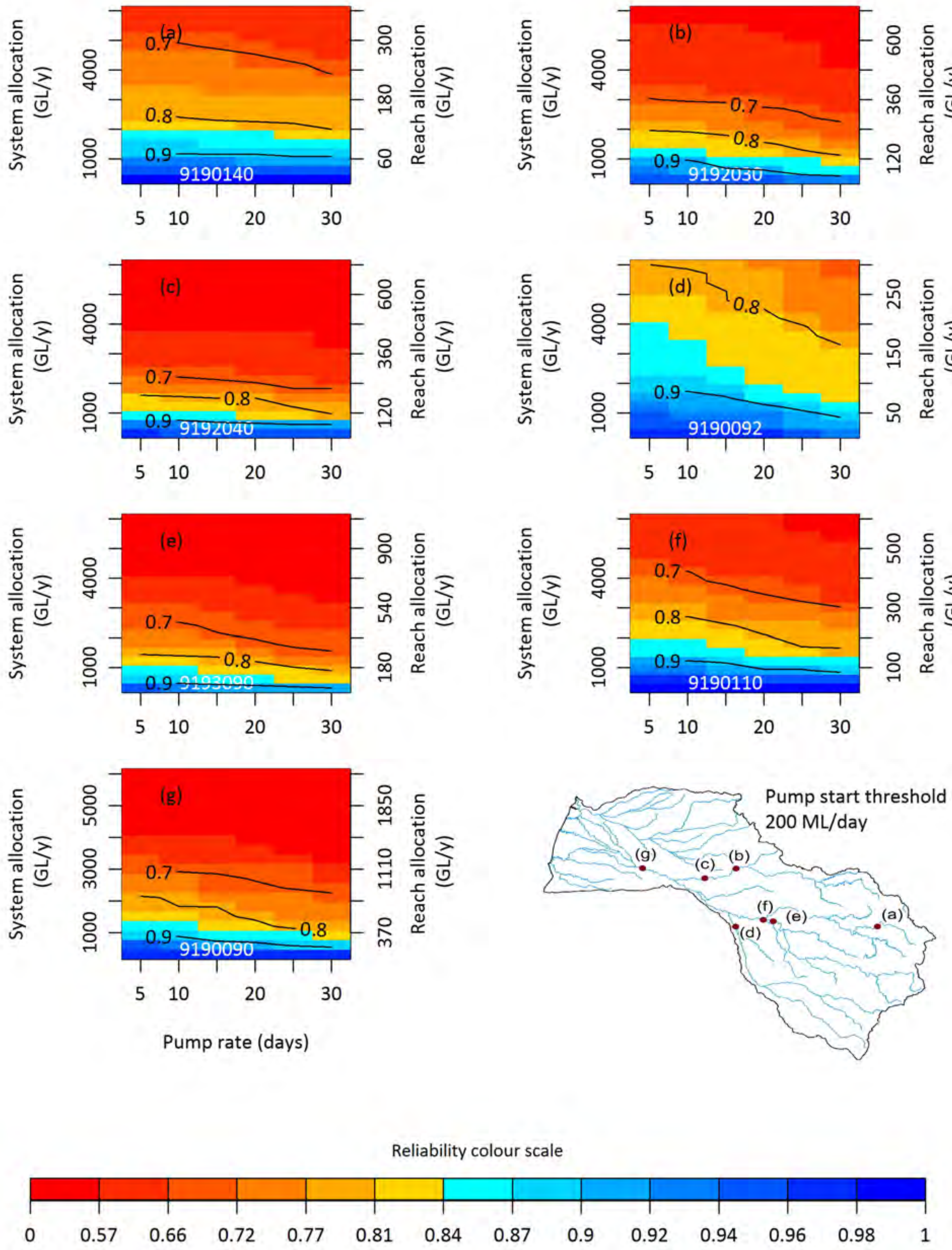

Figure 5-40 Reliability of extracting water up to the annual system/reach entitlement volume for seven water harvesting users for a pump start threshold of 200 ML/day and an end-of-system flow requirement of 1000 GL/year
On the inset map the letters (a) through (g) indicate the most downstream location of each reach.

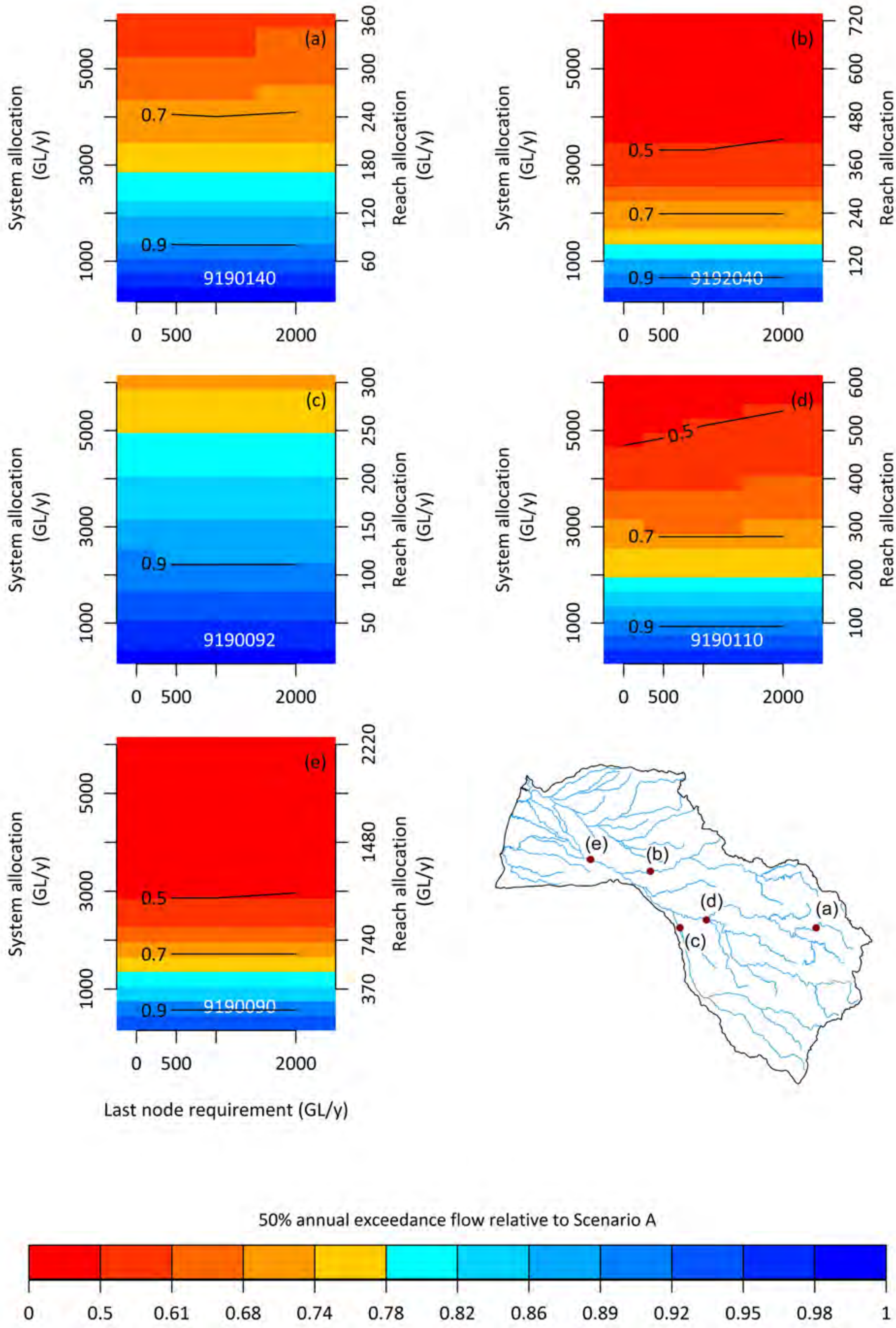

Figure 5-41 50% annual exceedance (median) streamflow relative to Scenario A in the Mitchell catchment for a pump start threshold of 200 ML/day and a pump capacity of 10 days

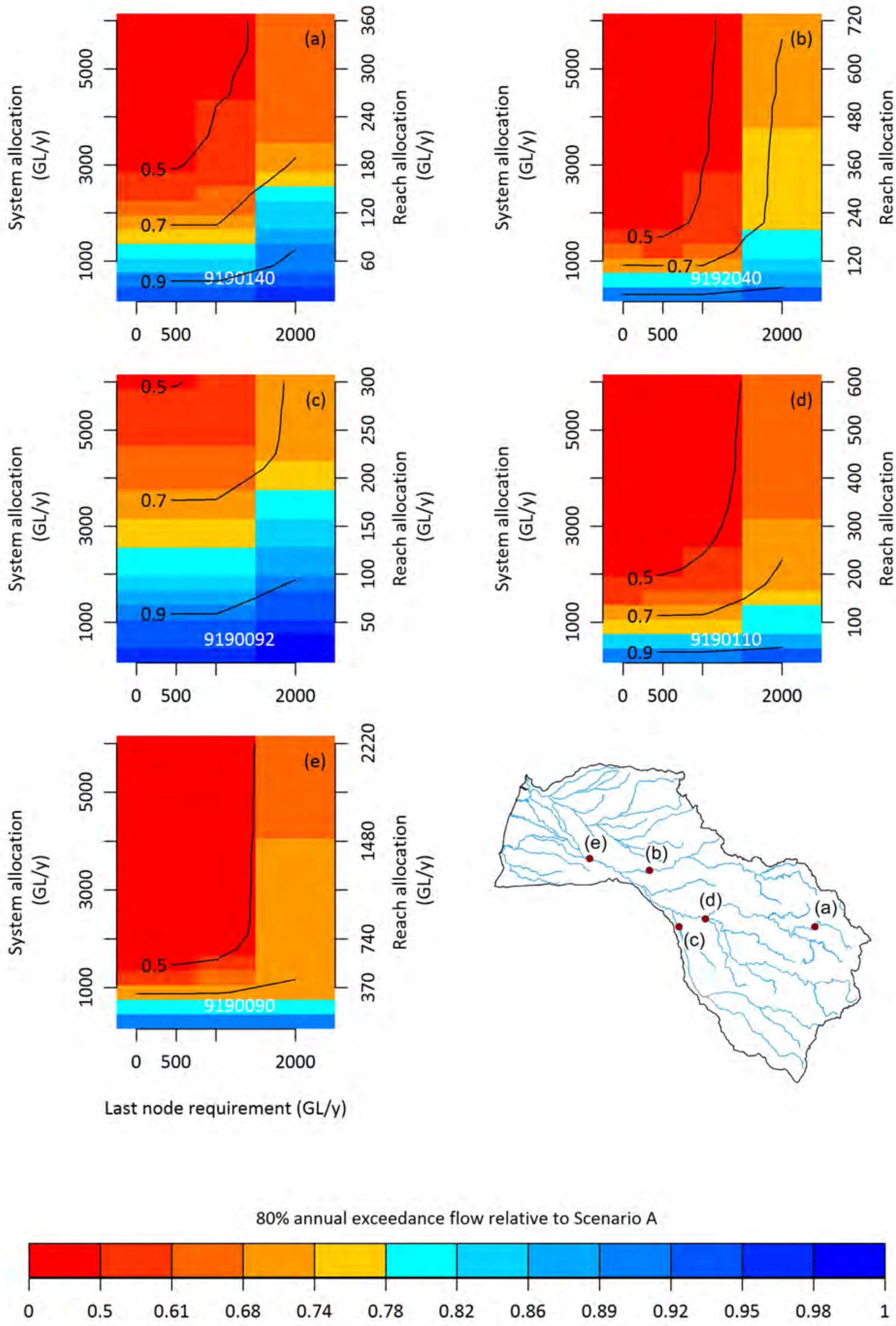

Figure 5-42 80% annual exceedance streamflow relative to Scenario A in the Mitchell catchments for a pump start threshold of 200 ML/day and a pump capacity of 10 days

Evaporation and seepage losses

Losses from a farm-scale dam occur through evaporation and seepage. When calculating evaporative losses from a storage it is important to calculate net evaporation (i.e. evaporation minus rainfall) rather than just evaporation. Strategies to minimise evaporation include liquid and solid barriers, but these are typically expensive per unit of inundated area (e.g. \$10 to \$30 per m^2). In non-laboratory settings liquid barriers such as oils are susceptible to being dispersed by wind and have not been shown to reduce evaporation from a water body (Barnes, 2008). Solid barriers can be effective in reducing evaporation but are expensive, approximately two to four times the cost of constructing the ringtank. Evaporation losses from a ringtank can also be reduced slightly by sub-dividing the storage into multiple cells and extracting water from each cell in turn so as to minimise the total surface water area. However, constructing a ringtank with multiple cells requires more earthworks and incurs higher construction costs than outlined in this section.

A study of 138 farm dams ranging in capacity from 75 to 14,000 ML from southern NSW to central Queensland by the Cotton Catchment Communities CRC (2011) found mean seepage and evaporation rates of 2.3 and 4.2 mm/day, respectively. Of the 138 dams examined, 88% had seepage values of less than 4 mm/day and 64% had seepage values less than 2 mm/day. These results largely concur with IAA (2007), which states that reservoirs constructed on suitable soils will have seepage losses equal to or less than 1 to 2 mm/day and seepage losses will be greater than 5 mm/day if sited on less suitable (i.e. permeable) soils.

Ringtanks with greater average water depth lose a lower percentage of their total storage capacity to evaporation and seepage losses, however, they have a smaller storage capacity to excavation ratio. In Table 5-16 effective volume refers to the actual volume of water that could be used for consumptive purposes after losses due to evaporation and seepage. For example, if water is stored in a ringtank with average water depth of 3.5 m until December and the average seepage loss is 2 mm/day, nearly half the stored volume (i.e. 44%) would be lost to evaporation and seepage. The example provided in Table 5-16 is for a 4000 ML storage, however, the effective volume expressed as a percentage of the ringtank capacity is applicable to any storage (e.g. ringtanks or gully dams) of any capacity for average water depths of 3.5, 6 and 8.5 m.

Table 5-16 Effective volume after net evaporation and seepage for ringtanks of three average water depths and under three seepage rates at Chillagoe

Effective volume refers to the actual volume of water that could be used for consumptive purposes as a result of losses due to net evaporation and seepage, assuming a storage capacity is 4000 ML. For storages of 4000 ML capacity and average water depths of 3.5, 6 and 8.5 m, reservoir surface areas are 110, 65 and 45 ha respectively. S:E ratio is the storage capacity to excavation ratio. For more details see companion technical report on surface water storage (Petheram et al., 2017).

AVERAGE WATER DEPTH† (m)	S:E RATIO	SEEPAGE LOSS (mm/day)	EFFECTIVE VOLUME (ML)	EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY (%)	EFFECTIVE VOLUME (ML)	EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY (%)	EFFECTIVE VOLUME (ML)	EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY (%)
			4 months (April to July)		6 months (April to September)		9 months (April to December)	
3.5	14:1	1	3422	86	3051	76	2553	64
	14:1	2	3288	82	2851	71	2252	56
	14:1	5	2888	72	2250	56	1350	34
6	7.5:1	1	3663	92	3446	86	3156	79
	7.5:1	2	3585	90	3330	83	2981	75
	7.5:1	5	3351	84	2979	74	2454	61
8.5	5:1	1	3762	94	3609	90	3404	85
	5:1	2	3707	93	3527	88	3280	82
	5:1	5	3542	89	3280	82	2909	73

†Average water depth above ground surface.

Capital, operation and maintenance costs of ringtanks

Construction costs of a ringtank may vary considerably depending on its size and the way the storage is built. For example, circular storages have a higher storage volume to excavation cost ratio than rectangular or square storages. As discussed in the section on large farm-scale gully dams (Section 5.3.5) it is also considerably more expensive to double the height of an embankment wall than double its length due to the low angle of the walls of the embankment (often at a ratio of 3 horizontal to 1 vertical).

Table 5-17 provides a high-level breakdown of the capital and operation and maintenance (O&M) costs of a large farm-scale ringtank, including the cost of the water storage, pumping infrastructure and up to 100 m of pipes, and operation and maintenance of the scheme. In this example it is assumed that the ringtank is within 100 m of the river and pumping infrastructure. It should be noted that the cost of pumping infrastructure and conveying water from the river to the storage is particularly site-specific.

In flood-prone areas where flood waters move at moderate to high velocities, riprap protection may be required, and this may increase the construction costs presented in Table 5-17 and Table 5-18 by 10 to 20% depending upon volume of rock required and proximity to a quarry with suitable rock.

For more detailed breakdown of ringtank costs see the companion technical report on large farm-scale dams (Benjamin, 2018).

Table 5-17 Indicative costs for a 4000-ML ringtank

Assumes a 4.25-m wall height, 0.75-m freeboard, 3:1 ratio on upstream slope, 3:1 ratio on downstream slope and crest width of 3.1 m, approximately 60% of material can be excavated from within storage, and cost of earthfill and compacted clay is $5/m³ and $6.50/m³, respectively. Earthwork costs include vegetation clearing, mobilisation/demobilisation of machinery and contractor accommodation. For more detail on costs see companion technical report on large farm-scale dams (Benjamin, 2018).

SITE DESCRIPTION/ CONFIGURATION	EARTHWORKS ($)	GOVERNMENT PERMITS AND FEES ($)	INVESTIGATION AND DESIGN FEES ($)	PUMP STATION ($)	TOTAL CAPITAL COST ($)	O&M OF RINGTANK ($/y)	O&M OF PUMP STATION ($/y)	TOTAL O&M ($/y)
4000-ML ringtank	1,602,500	35,500	76,000	500,000	2,214,000	17,000	84,000	101,000

The capital costs can be expressed over the service life of the infrastructure (assuming a 7% discount rate, see Chapter 6) and combined with O&M costs to give an equivalent annual cost for construction and operation. This enables infrastructure with differing capital and O&M costs and service lives to be compared. The total equivalent annual costs for the construction and operation of a 1000-ML ringtank with 4.25-m high embankments and 55 ML/day pumping infrastructure is about $117,100 (Table 5-18). For a 4000-ML ringtank with 4.25-m high embankments and 160 ML/day pumping infrastructure, the total equivalent annual cost is about $284,500. For a 4000-ML ringtank with 6.75-m high embankments and 160 ML/day pumping infrastructure, the total equivalent annual cost is about $402,000.

Table 5-18 Annualised cost for the construction and operation of three ringtank configurations

Assumes freeboard of 0.75 m, pumping infrastructure can fill ringtank in 25 days and assumes a 7% discount rate. Costs based on those provided for 4000 ML provided in companion technical report on large farm-scale dams (Benjamin, 2018).

CAPACITY AND EMBANKMENT HEIGHT	ITEM	CAPITAL COST ($)	LIFESPAN (y)	EQUIVALENT ANNUAL CAPITAL COST ($)	ANNUAL O&M COST ($)
1000 ML and 4.25 m	Ringtank	858,000	40	64,000	8,600
	Pumping infrastructure†	200,000	15	22,000	4,000
	Pumping cost (diesel)	NA	NA	NA	18,500‡
4000 ML and 4.25 m	Ringtank	1,714,000	40	128,500	17,000
	Pumping infrastructure†	500,000	15	55,000	10,000
	Pumping cost (diesel)	NA	NA	NA	74,000‡
4000 ML and 6.75 m	Ringtank	3,095,000	40	232,000	31,000
	Pumping infrastructure†	500,000	15	55,000	10,000
	Pumping cost (diesel)	NA	NA	NA	74,000‡

NA = data not available.
†Costs include rising-main, large-diameter concrete or multiple strings of high density polypipe, control valves and fittings, concrete thrust-blocks and head-walls, dissipater, civil works and installation.
‡Value assumes water is piped between river pumping infrastructure and ringtank.

Although ringtanks with an average water depth of 3.5 m (embankment height of 4.25 m) lose a higher percentage of their capacity to evaporative and seepage losses than ringtanks of equivalent capacity with average water depth of 6 m (embankment height of 6.75 m) (Table 5-16), their annualised unit costs are lower (Table 5-19) due to the considerably lower cost of constructing embankments with lower walls (Table 5-18).

In Table 5-19 the equivalent annual cost of the water supplied from the ringtank takes into consideration net evaporation and seepage from the storage, which increase with the length of time water is stored (i.e. crops with longer growing seasons will require water to be stored longer). In these tables, the results are presented for the equivalent annual cost of water yield from a ringtank of different seepage rates and lengths of time for storing water.

Table 5-19 Equivalent annual cost per ML for two different capacity ringtanks under three seepage rates
Assumes a 0.75-m freeboard, 3:1 ratio on upstream slope, 3:1 ratio on downstream slope. Crest widths are 3.1 m and 3.6 m for embankments with heights of 4.25 m and 6.75 m, respectively, and assumes earthfill and compacted clay costs of $5/m^3$ and $6.50/m^3$, respectively. Earthwork costs include vegetation clearing, mobilisation/demobilisation of machinery and contractor accommodation. 1000-ML ringtank reservoir has surface area of 27 ha and storage volume to excavation ratio of about 7:1. 4000-ML ringtank and 4.25-m embankment height reservoir has a surface area of 110 ha and a storage volume to excavation ratio of about 14:1. 4000-ML ringtank with 6.75-m embankment height reservoir has a surface area of 64 ha and a storage volume to excavation ratio of about 7.5:1.

CAPACITY AND EMBANKMENT HEIGHT	ANNUAL-ISED COST* ($)	SEEPAGE LOSS (mm/day)	UNIT COST ($/ML)	EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)	UNIT COST ($/ML)	EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)	UNIT COST ($/ML)	EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)
			4 months (April to July)		6 months (April to September)		9 months (April to December)	
1000 ML and 4.25 m	117,100	1	1237	137	1389	154	1661	184
	117,100	2	1288	143	187	165	1884	208
	117,100	5	1467	162	1885	209	3155	349
4000 ML and 4.25 m	284,500	1	647	83	726	93	2553	111
	284,500	2	673	87	777	100	2252	126
	284,500	5	767	99	984	126	1350	211
4000 ML and 6.75 m	402,000	1	982	110	1043	117	1139	127
	402,000	2	1003	112	1080	121	1206	135
	402,000	5	1073	120	1207	135	1465	164

Taking into consideration the cost of constructing ringtanks and net evaporation and seepage losses, the optimal embankment height will vary depending upon the capacity of the storage. Based on the cost assumptions used in this section and assuming 2 mm/day of seepage and a requirement that water is stored until August (i.e. 6 months), Table 5-20 provides an indication of how the optimum embankment height and annualised cost at the optimum embankment height vary with increasing ringtank capacity.

Table 5-20 Annualised unit cost at optimum embankment height for ringtanks of varying capacity
Assumes 2 mm/day of seepage and a requirement that water is stored until August (i.e. 6 months).

CAPACITY (ML)	OPTIMUM EMBANKMENT HEIGHT (m)	ANNUALISED UNIT COST AT OPTIMUM EMBANKMENT HEIGHT ($/ML)
1,000	3.7	161
2,000	3.75	119
4,000	3.9	99
6,000	4.05	90

CAPACITY (ML)	OPTIMUM EMBANKMENT HEIGHT (m)	ANNUALISED UNIT COST AT OPTIMUM EMBANKMENT HEIGHT ($/ML)
8,000	4.15	85
10,000	4.25	81
15,000	4.45	75

5.3.5 LARGE FARM-SCALE GULLY DAMS

Large farm-scale gully dams are generally constructed of earth or earth and rockfill embankments with compacted clay cores and usually to a maximum height of about 20 m. Dams with a crest height of over 10 or 12 m typically require some form of downstream batter drainage incorporated in embankments. Large farm-scale gully dams typically have a maximum catchment area of about 30 km^2 due to the challenges in passing peak floods from large catchments (large farm-scale gully dams are generally designed to pass an event with an annual exceedance probability of 1%), unless a site has an exceptionally good spillway option.

Like ringtanks, large farm-scale gully dams are a compromise between best-practice engineering and affordability. Designers need to follow accepted engineering principles relating to important aspects of materials classification, compaction of the clay core and selection of appropriate embankment cross-section. However, costs are often minimised where possible; for example, by employing earth bywashes and grass protection for erosion control rather than more expensive concrete spillways and rock protection as found on major dams. This can compromise the integrity of the structure during extreme events and its longevity as well as increase the ongoing maintenance costs, but can considerably reduce the upfront capital costs.

In this section the following assessments are reported:

- suitability of the landscape for large farm-scale gully dams
- indicative capital, operating and maintenance costs of large farm-scale gully dams.

Net evaporation and seepage losses also occur from large farm-scale gully dams. The analysis presented in Section 5.3.4 is also applicable to gully dams.

Importantly, the Assessment does not seek to provide instruction on the design and construction of farm-scale water storages. Numerous books and online tools provide detailed information on nearly all facets of farm-scale water storage (e.g. QWRC ,1984; Lewis, 2002; IAA, 2007). Siting, design and construction of farm-scale dams should always be undertaken in conjunction with a suitably qualified professional and tailored to the nuances that occur at every site.

Suitability of land for large farm-scale gully dams

Figure 5-43 provides an indication of where it may be more economical to construct large farm-scale gully dams in the Mitchell catchment and the likely density of options. This analysis takes into consideration those sites likely to have more favourable topography and soil for the construction of the embankment and to minimise seepage from the reservoir base. In reality, dams can be constructed on eroded or skeletal soils provided there is access to a clay borrow pit nearby for the cut-off trench and core zone. However, these sites are likely to be less economically viable.

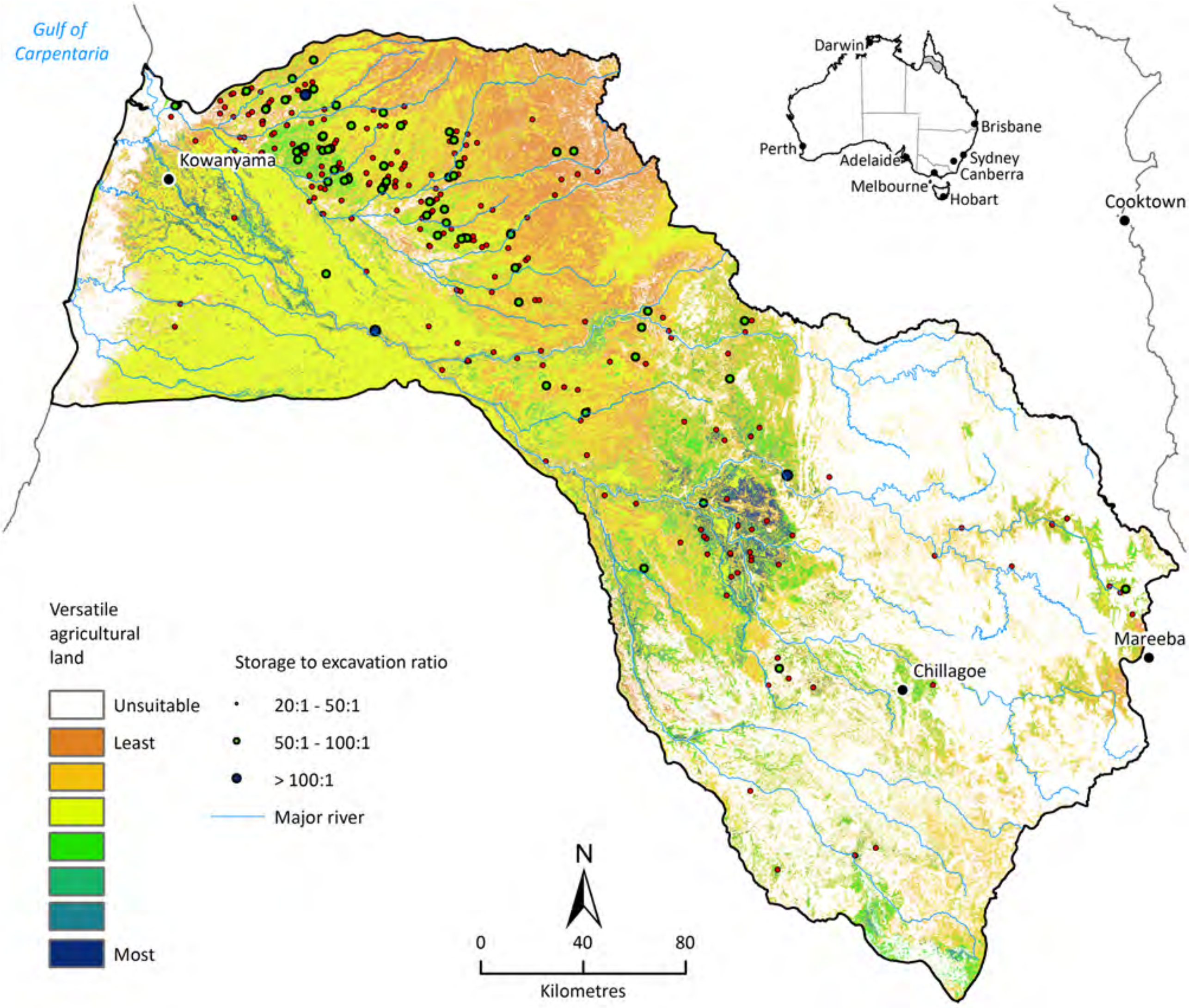

Figure 5-43 Most economically suitable locations for large farm-scale gully dams in the Mitchell catchment
Gully dam data overlaid on agricultural versatility data (see Section 4.3). Agricultural versatility data indicate those parts of the catchment that are more or less versatile for irrigated agriculture. For the gully dam analysis soil and subsurface data were only available to a depth of 1.5 m, hence this Assessment does not consider the suitability of subsurface material below this depth. Sites with catchment areas greater than 30 km^2 or yield to excavation ratio less than 10 are not displayed. The results presented in this figure are modelled and consequently only indicative of the general locations where siting a gully dam may be most economically suitable. This analysis may be subject to errors in the underlying digital elevation model, such as affects due to the vegetation removal process. An important factor not considered in this analysis was the availability of a natural spillway. Site-specific investigations by a suitably qualified professional should always be undertaken prior to their construction.

Capital, operation and maintenance costs of large farm-scale gully dams

The cost of a large farm-scale gully dam will vary depending upon a range of factors including the suitability of the topography of the site, the size of the catchment area, quantity of runoff, proximity of site to good quality clay, availability of durable rock in the upper bank for a spillway and the size of the embankment. The height of the embankment, in particular, has a strong influence on cost. An earth dam to a height of 8 m is about 3.3 times more expensive to construct than a 4-m high dam, and a dam to a height of 16 m will require 3.6 times more material than the 8-m high version, but cost may be 5 times greater, due to design and construction complexity.

Actual costs for four large farm-scale gully dams in northern Queensland are presented in Table 5-21.

Table 5-21 Actual costs for four gully dams in north Queensland
Costs are indexed to 2017.

DAM NAME	LOCATION	CAPACITY (ML)	YIELD (ML/y)	COST ($)	UNIT COST ($/ML)	COMMENT
Sharp Rock Dam	Lakelands	3300	1070	322,800	302	Chimney filter and drainage under-blanket. Two stage concrete sill spillway. No fishway. Pump station not included
Dump Gully Dam	Lakelands	1450	420	786,000	1871	Deep and wet cut-off. Chimney filter and downstream under drainage. No fishway. Pump station was $91,000
Spring Dam #2	Lakelands	2540	1377	895,600	650	Chimney filter and drainage under-blanket. Two stage rock excavation. Spillway with fishway. Fishway was $36,500. Pump station not included
Ronny's Dam	Georgetown	9975	1700	447,900	263	Very favourable site. Low embankment and 450-ha ponded area. Natural spillway. No pump station, gravity supply via through pipe

Performance and cost of three hypothetical farm-scale gully dams in northern Australia

A summary of the key parameters for three hypothetical 4-GL capacity farm-scale gully dam configurations is provided in Table 5-22 and a high-level breakdown of the major components of the capital costs for each of the three configurations are provided in Table 5-23. Detailed costs for the three sites are provided in the companion technical report on large farm-scale dams (Benjamin, 2018).

Table 5-22 Cost of three hypothetical large farm-scale gully dams of capacity 4 GL
Costs include government permits and fees, investigation and design and fish passage. For complete list of costs and assumptions, see companion technical report on large farm-scale dams (Benjamin, 2018).

SITE DESCRIPTION/ CONFIGURATION	CATCHMENT AREA (km^2)	EMBANK-MENT HEIGHT (m)	EMBANK-MENT LENGTH (m)	S:E RATIO	AVERAGE DEPTH (m)	RESERVOIR SURFACE AREA (ha)	TOTAL CAPITAL COST ($)	O&M COST ($)
Favourable site with large catchment, suitable topography and simple spillway (e.g. natural saddle)	30	9.5	1100	29:1	5.0	80	1,280,000	55,000
Unfavourable site with small catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)	15	14	750	21:1	6.3	63	1,474,000	35,000
Unfavourable site with moderate catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)	20	14	750	21:1	6.3	63	1,554,000	40,000

Table 5-23 High-level break down of capital costs for three hypothetical large farm-scale gully dams of capacity 4 GL
Earthworks includes vegetation clearing, mobilisations/demobilisation of equipment and contractor accommodation. Investigation and design fees include design and investigation of fish passage device and failure impact assessment (i.e. investigation of possible existence of population at risk downstream of site).

SITE DESCRIPTION/CONFIGURATION	EARTHWORKS ($)	GOVERNMENT PERMITS AND FEES ($)	INVESTIGATION AND DESIGN FEES ($)	TOTAL CAPITAL COST ($)
Favourable site with large catchment, suitable topography and simple spillway (e.g. natural saddle)	1,157,500	36,000	86,500	1,280,000
Unfavourable site with small catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)	1,340,000	40,000	94,000	1,474,000
Unfavourable site with moderate catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)	1,420,000	40,000	94,000	1,554,000

In Queensland if a large farm-scale gully dam is constructed on a watercourse, as defined by the state's legislation, then it is likely that conditions applicable to the water licence would include bed-level outlet works capable of passing a prescribed flow. This may range from relatively small volumes required to meet downstream riparian rights (stock and domestic water supplies), to relatively large volumes to meet existing entitlements of downstream irrigators. Small throughflows of less than about 0.5 ML per day could best be achieved by means of an overbank syphon at a relatively minimal cost. Releases of more than about 25 ML per day would, however, require considerable investment. Cost varies greatly, with a likely range of $50,000 to $100,000 (Benjamin, 2018).

Table 5-24 presents calculations of the effective volume for three configurations of 4-GL capacity gully dams (varying average water depth/embankment height) for combinations of three seepage losses and water storage over three time periods.

Table 5-24 Effective volumes and cost per ML for a 4-GL storage with different average depths and seepage loss rates at Chillagoe in the Mitchell catchment

AVERAGE DEPTH AND RESERVOIR SURFACE AREA	CON-STRUCTION COST ($)	COST ($/ML)	SEEPAGE LOSS (mm/day)	EFFECTIVE VOLUME (ML)	COST ($/ML)	EFFECTIVE VOLUME (ML)	COST ($/ML)	EFFECTIVE VOLUME (ML)	COST ($/ML)
				4 months (April to July)		6 months (April to September)		9 months (April to December)	
3 m and 133 ha	1,000,000	250	1	3295	303	2843	352	2236	447
	1,000,000	250	2	3132	319	2599	385	1869	535
	1,000,000	250	5	2644	378	1867	536	769	1300
6 m and 66 ha	1,500,000	375	1	3648	411	3421	438	3118	481
	1,500,000	375	2	3566	421	3299	455	2935	511
	1,500,000	375	5	3322	452	2933	511	2385	629
9 m and 44 ha	2,000,000	500	1	3765	531	3614	553	3412	586
	2,000,000	500	2	3711	539	3533	566	3290	608
	2,000,000	500	5	3548	564	3289	608	2923	684

Based on the information presented in Table 5-22 an equivalent annual unit cost including annual operation and maintenance cost for a 4-GL gully dam with an average depth of about 6 m is about $174,000 (Table 5-25). Based on the information in Table 5-22 two other hypothetical 4-GL gully dam configurations in
Table 5-26 are provided to illustrate the trade-off between cost and evaporative and seepage losses. These examples are illustrative and each situation will be specific to the location.

Table 5-25 Cost of construction and operation of three hypothetical 4-GL gully dams
Assumes operation and maintenance (O&M) cost of 3% of capital cost and a 7% discount rate. Figures have been rounded.

AVERAGE DEPTH AND RESERVOIR SURFACE AREA	ITEM	CAPITAL COST ($)	EQUIVALENT ANNUAL CAPITAL COST ($)	ANNUAL O&M COST ($)	EQUIVALENT ANNUAL COST ($)
3 m and 1133 ha	Low embankment, wide gully dam	1,000,000	86,000	30,000	116,000
6 m and 66 ha	Moderate embankment gully dam	1,500,000	129,000	45,000	174,000
9 m and 44 ha	High embankment, narrow gully dam	2,000,000	172,000	60,000	232,000

Table 5-26 Equivalent annualised cost and effective volume for three hypothetical 4-GL gully dams
Dams detailed in Table 5-25. Assumes a 7% discount rate.

AVERAGE DEPTH AND RESERVOIR SURFACE AREA	EQUIVALENT ANNUAL COST ($)	SEEPAGE LOSS (mm/day)	EFFECTIVE VOLUME (ML)	EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)	EFFECTIVE VOLUME (ML)	EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)	EFFECTIVE VOLUME (ML)	EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)
			4 months (March to June)		6 months (March to August)		9 months (April to December)	
3 m and 133 ha	116,000	1	3295	35	2843	41	2236	52
	116,000	2	3132	37	2599	45	1869	62
	116,000	5	2644	44	1867	62	769	151
6 m and 66 ha	174,000	1	3648	48	3421	51	3118	56
	174,000	2	3566	49	3299	53	2935	59
	174,000	5	3322	52	2933	59	2385	73
9 m and 44 ha	232,000	1	3765	62	3614	64	3412	68
	232,000	2	3711	63	3533	66	3290	71
	232,000	5	3548	65	3289	71	2923	79

Where the topography is suitable for large farm-scale gully dams and a natural spillway is present, large farm-scale gully dams are typically cheaper to construct than ringtanks.

Figure 5-44 Large farm-scale gully dam in the Mitchell catchment
Photo: CSIRO

5.3.6 NATURAL WATER BODIES

Wetland systems and waterholes that persist throughout the dry season are natural water bodies characteristic of large parts of the northerly draining catchments of northern Australia. Many station homesteads in northern Australia use natural waterholes for stock and domestic purposes. However, the quantities of water required for stock and domestic supply are orders of magnitude less than that required for irrigated cropping and it is partly for this reason that naturally occurring persistent water bodies in northern Australia are not used to source water for irrigation.

For example, a moderately sized 5-ha rectangular water body of average depth of 3.5 m may contain about 175 ML of water. Based on the data presented in Table 5-16 and assuming minimal leakage (i.e. 1 mm/day) approximately 86, 76 and 64% of these volumes would be available if a crop were to be irrigated until July, September and December, respectively. Assuming a crop or fodder with a 6-month growing season requires 5 ML/ha of water before losses, and assuming an overall efficiency of 80% (i.e. the waterhole is adjacent to land suitable for irrigation, 95% conveyance efficiency and 85% field application efficiency), a 175-ML waterhole could potentially be used to irrigate about 21 ha of land for half a year if all the water was able to be used for this purpose. A large natural water body of 20 ha and average depth of 3.5 m could potentially be used to irrigate about 85 ha of land if all the water was able to be used for this purpose.

Although the areas of land that could be watered using natural water bodies are likely to be small, the costs associated with storing water are minimal. Consequently, where these waterholes occur in sufficient size and adjacent to land suitable for irrigated agriculture, they can be a very cost-effective source of water. It would appear that where natural water bodies of sufficient size and suitable land for irrigation coincide, natural water bodies may be effective in staging a development (Section 6.3), where lessons are learnt and mistakes are made on a small-scale area before large capital investment occurs.

In a few instances it may be possible to enhance the storage potential of natural features in the landscape such as horseshoe lagoons or cut-off meanders adjacent to a river.

The main limitations to the use of wetlands and persistent waterholes for the consumptive use of water is that they have considerable ecological significance (e.g. Kingsford, 2000; Waltham et al., 2013), and in many cases there is a limited quantity of water contained within the water bodies. In particular, water bodies that persist throughout the dry season are considered key ecological refugia (Waltham et al., 2013).

It should also be noted that where a water body is situated in a sandy river, the waterhole is likely to be connected to water within the bedsands of the river. Hence, during and following pumping water within the bedsands of a river, the bedsands may partly replenish the waterhole and vice versa. While water within the bedsands of the river may partly replenish a depleted waterhole, in these circumstances it also means that pumping from a waterhole will have a wider environmental impact than just the waterhole from which water is being pumped.

Figure 2-47 indicates the location of (1 km) river reaches containing waterholes that persist more than 90% of the time in the Landsat TM data archive in the Mitchell catchment. For the purposes of this Assessment they are referred to as 'persistent' waterholes. This figure shows that the main river reaches containing permanent water are the Mitchell and Palmer rivers.

5.4 Water distribution systems – conveyance of water from storage to crop

5.4.1 INTRODUCTION

In all irrigation systems, water needs to be conveyed from the water source through artificial and/or natural water distribution systems, before ultimately being used on-field for irrigation. This section discusses water losses during conveyance and application of water to the crop and the associated costs.

5.4.2 CONVEYANCE AND APPLICATION EFFICIENCIES

Some water diverted for irrigation is lost during conveyance to the field before it can be used by a crop. These losses need to be taken into account when planning irrigation systems and developing likely irrigated areas. The amount of water lost during conveyance depends on the:

- river conveyance efficiency, from the water storage to the re-regulating structure or point of extraction
- channel distribution efficiency, from the river offtake to the farm gate
- on-farm distribution efficiency, in storing (using balancing storages) and conveying water from the farm gate to the field

- field application efficiency, which is the efficiency to which water can be delivered from the edge of the field and applied to the crop.

The overall or system efficiency is the product of these four components.

Little research on irrigation systems has been undertaken in the Mitchell catchment. The time frame of the Assessment did not permit on-ground research into irrigation systems. Consequently, a brief discussion on the four components listed above is provided based on relevant literature from elsewhere in Australia and overseas. Table 5-27 summarises the broad range of efficiencies associated with each of these components.

The total conveyance and application efficiency of the delivery of water from the water storage to the crop (i.e. the overall or system efficiency) is dependent upon the product of the four components listed in Table 5-27. For example, if an irrigation development has a river conveyance efficiency of 80%, a channel distribution efficiency of 90%, an on-farm distribution efficiency of 90% and a field application efficiency of 85%, the overall efficiency is 55% (i.e. 80% * 90% * 90% * 85%). This means only 55% of all water released from the dam can be used by the crop.

Table 5-27 Summary of conveyance and application efficiencies

COMPONENT	TYPICAL EFFICIENCY (%)
River conveyance efficiency	50–90†
Channel distribution efficiency	50–95
On-farm distribution efficiency	80–95
Field application efficiency	60–90

†River conveyance efficiency varies with a range of factors (including distance) and may be lower than the range quoted here. Under such circumstances, it is unlikely that irrigation would proceed. It is also possible for efficiency to be 100% in gaining rivers. Achieving higher efficiencies requires a re-regulating structure (see Section 5.3.3).

River conveyance efficiency

The conveyance efficiency of rivers is difficult to measure and even more difficult to predict. Although there are many methods for estimating groundwater discharge to surface water, there are few suitable methods for estimating the loss of surface water to groundwater. In the absence of existing studies for northern Australia, conveyance efficiencies as nominated in water resource plans and resource operation plans for four irrigation water supply schemes in Queensland were examined collectively. The results are summarised in Table 5-28.

The conveyance efficiencies listed in Table 5-28 are from the water storage to the farm gate and are nominated efficiencies based on experience delivering water in these supply schemes. These data can be used to estimate conveyance efficiency of similar rivers elsewhere.

Table 5-28 Water distribution and operational efficiency as nominated in water resource plans for four irrigation water supply schemes in Queensland

WATER SUPPLY SCHEME IN QUEENSLAND	TOTAL ALLOCATION VOLUME (ML)	RIVER AND CHANNEL CONVEYANCE EFFICIENCY† (%)	COMMENT
Burdekin Haughton	928,579	78	The primary storage is the Burdekin Falls Dam (1860 GL), approximately 100 km upstream of Clare weir, the major extraction point. The Bowen River, a major unregulated tributary of the Burdekin River, joins the Burdekin River downstream of Burdekin Falls Dam. This may assist in reducing transmission losses between the dam and Clare weir.
Lower Mary	34,462	93.8‡	The Lower Mary irrigation area is supplied from two storages, a barrage on the Mary River and a barrage on Tinana Creek. Water is drawn directly from the barrage storages to irrigate land riparian to the streams. Water distribution is predominantly via pipelines.
Proserpine River	87,040	72	The scheme has a single source of supply, Peter Faust Dam (491 GL). At various distances downstream of the dam, water is extracted from the river bedsands and is distributed to urban communities, several irrigation water supply boards and individual irrigators.
Upper Burnett	26,870	68	The Upper Burnett is a long run of river scheme with one major storage (Wuruma Dam (165 GL)) and four weir storages. The total river length supplied by the scheme is 165 km.

†Ignores differences in efficiency between high and medium priority users and variations across the scheme zone areas.
‡Channel conveyance efficiency only.

Channel distribution efficiency

Across Australia, the average water conveyance efficiency from the river to the farm gate has been estimated to be 71% (Marsden Jacob Associates, 2003). For heavier textured soils and well-designed irrigation distribution systems, conveyance efficiencies are likely to be higher.

In the absence of larger scheme-scale irrigation systems in the Mitchell catchment, it is useful to look at the conveyance efficiency of existing irrigation developments to estimate the conveyance efficiency of irrigation developments in the study area. Australian conveyance efficiencies are generally higher than those found in similarly sized overseas irrigation schemes (Cotton Catchment Communities CRC, 2011; Bos and Nugteren, 1990); therefore, Australian data should be preferentially used.

The most extensive review of conveyance efficiency in Australia was undertaken by the Australian National Commission on Irrigation and Drainage, which tabulated system efficiencies across irrigation developments in Australia (ANCID, 2001). Conveyance losses were reported as the difference between the volume of water supplied to irrigation customers and the water delivered to the irrigation system. For example, if 10,000 ML of water was diverted to an irrigation district and 8,000 ML was delivered to irrigators, then the conveyance efficiency was 80% and the conveyance losses were 20%.

Figure 5-45 shows reported conveyance losses across irrigation areas of Australia between 1999 and 2000, along with the supply method used for conveying irrigation water and associated irrigation deliveries. There is a wide spread of conveyance losses both between years and across the various irrigation schemes. Factors identified by Marsden Jacob Associates (2003) that affect the variation include delivery infrastructure, soil types, distance that water is conveyed, type of agriculture, operating practices, infrastructure age, maintenance standards, operating systems, in-line storage, type of metering used and third-party impacts such as recreational, amenity and environmental demands. Differences across irrigation seasons are due to variations in water availability, operational methods, climate and customer demands.

Based on these industry data, Marsden Jacob Associates (2003) concluded that, on average, 29% of water diverted into irrigation schemes is lost in conveyance to the farm gate. However, some of this 'perceived' conveyance loss may be due to meter underestimation (about 5% of water delivered to provider (Marsden Jacob Associates, 2003)). Other losses were from leakage, seepage, evaporation, outfalls, unrecorded usage and system filling.

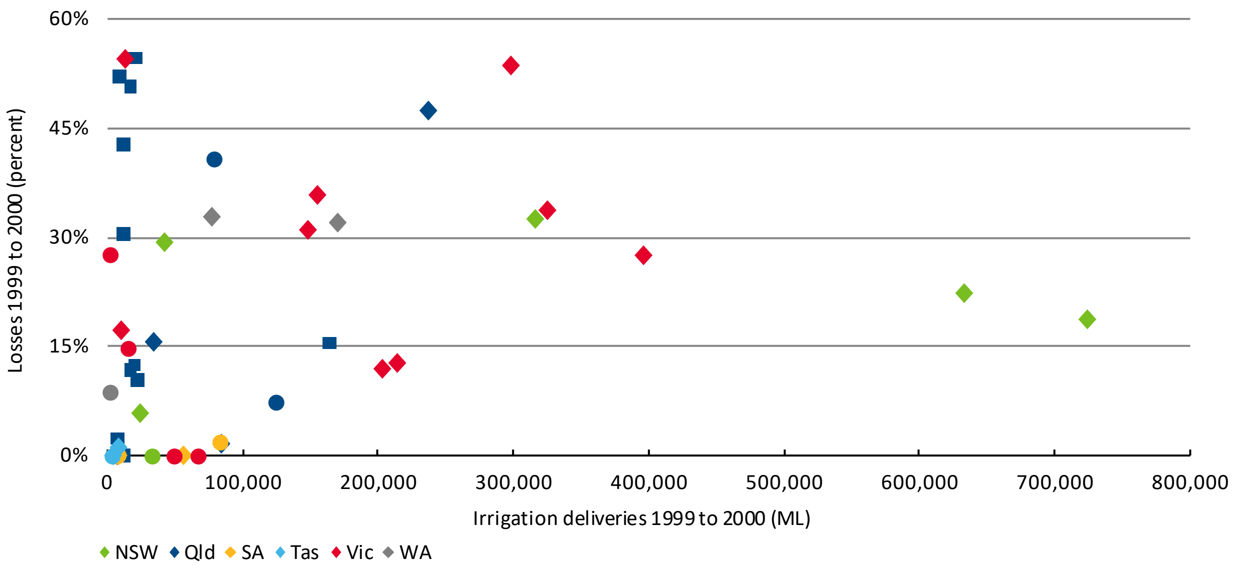

Figure 5-45 Reported conveyance losses from irrigation systems across Australia
The shape of the marker indicates the supply method for the irrigation scheme: square (▪) indicates natural carrier, circle (•) indicates pipe, and diamond (♦) indicates channel. The colour of the marker indicates the location of the irrigation system (by state), as shown in the legend.
Source: ANCID (2001).

On-farm distribution efficiency

On-farm losses are losses that occur between the farm gate and delivery to the field. These losses usually take the form of evaporation and seepage from on-farm storages and delivery systems. Even in irrigation developments where water is delivered to the farm gate via a channel, many farms have small on-farm storages (i.e. less than 250 ML for a 500-ha farm). These on-farm storages enable the farmer to have a reliable supply of irrigation water with a higher flow rate, and also enable recycling of tailwater. Several studies have been undertaken in Australia on on-farm distribution losses. Meyer (2005) estimated an on-farm distribution efficiency of 78% in the Murray and Murrumbidgee regions, while Pratt Water (2004) estimated on-farm efficiency to be 94% and 88% in the Coleambally Irrigation and Murrumbidgee Irrigation areas, respectively. For nine farms in these two irrigation areas, however, Akbar et al. (2000) measured channel seepage to be less than 5%.

Field application efficiency

Once water is delivered to the field, it needs to be applied to the crop using an irrigation system. The application efficiency of irrigation systems typically varies between 60 and 90%, with more expensive systems usually resulting in higher efficiency.

There are three types of irrigation systems that can potentially be applied in the Mitchell catchment: surface irrigation, spray irrigation and micro irrigation (Figure 5-46). Irrigation systems applied in the Mitchell catchment need to be tailored to the soil, climate and crops that may be grown in the catchment and matched to the availability of water for irrigation. This is taken into consideration in the land suitability assessment figures presented in Section 4.3. System design will also need to consider investment risk in irrigation systems as well as likely returns, degree of automation, labour availability, and operation and maintenance costs (e.g. the cost of energy).

Irrigation systems have a trade-off between efficiency and cost. Table 5-29 summarises the different types of irrigation systems, including their application efficiency, indicative cost and their limitations. Across Australia the ratio of areas irrigated using surface, spray and micro irrigation is 83:10:7, respectively. Irrigation systems that allow water to be applied with greater control, such as micro irrigation, cost more (Table 5-29) and as a result are typically used for irrigating higher value crops such as horticulture and vegetables. For example, although only 7% of Australia's irrigated area uses micro irrigation; it generates about 40% of the total value of produce produced by irrigation (Meyer, 2005). Further details on the three types of irrigation systems follow Table 5-29.

(a) (b) (c)

Figure 5-46 Efficiency of different types of irrigation systems
(a) In furrow irrigation, application efficiencies range from 60 to 85%. (b) In spray irrigation systems, application efficiencies range from 75 to 90%. (c) For pressurised micro irrigation systems on polymer-covered beds, application efficiencies range from 80 to 90%.

Table 5-29 Application efficiencies for surface, spray and micro irrigation systems
Application efficiency is the efficiency with which water can be delivered from the edge of the field to the crop.

IRRIGATION SYSTEM	TYPE	APPLICATION EFFICIENCY (%)	CAPITAL COST ($/ha)†	LIMITATIONS
Surface	Basin	60–85	3400	Suitable for most crops; topography and surface levelling costs may be limiting factor
	Border	60–85	3400	Suitable for most crops; topography and surface levelling costs may be limiting factor
	Furrow	60–85	3400	Suitable for most crops; topography and surface levelling costs may be limiting factor
Spray	Centre pivot	75–90	2500–5500	Not suitable for tree crops; high energy requirements for operation
	Lateral move	75–90	2500–5000	Not suitable for tree crops; high energy requirements for operation
Micro	Drip	80–90	6000–9000	High energy requirement for operation; high level of skills needed for successful operation

Adapted from Hoffman et al. (2007), Raine and Bakker (1996) and Wood et al. (2007).
†Source: DEEDI (2011a, 2011b, 2011c).

Surface irrigation systems

Surface irrigation encompasses basin, border strip and furrow irrigation, as well as variations on these themes such as bankless channel systems. In surface irrigation, water is applied directly to the soil surface with check structures (banks or furrows) used to direct water across a field. Control of applied water is dictated by the soil properties, soil uniformity and the design characteristics of the surface system. Generally, fields are prepared by laser levelling to increase the uniformity of applied water and allow ease of management of water and adequate surface drainage from the field. The uniformity and efficiency of surface systems are highly dependent on the system design and soil properties, timing of the irrigation water and the skill of the individual irrigator in operating the system. Mismanagement can severely degrade system performance and lead to systems that operate at poor efficiencies.

Surface irrigation has the benefit that it can generally be adapted to almost any crop and it usually has a lower capital cost compared with alternative systems. Surface irrigation systems perform better when soils are of uniform texture as infiltration characteristics of the soil play an important part in the efficiency of these systems. Therefore, surface irrigation systems should be designed into uniform soil management units and layouts (run lengths, basin sizes) tailored to match soil characteristics and water supply volumes.

High application efficiencies are possible with surface irrigation systems, provided soil characteristic limitations, system layout, water flow volumes and high levels of management are applied. On ideal soil types and with systems capable of high flow rates, efficiencies can be higher than 85%. On poorly designed and managed systems on soil types with high variability, efficiencies can be below 60%.

Generally, the major cost in setting up a surface irrigation system is land grading and levelling, with costs directly associated with the volume of soil that must be moved. Typical earth moving volumes are in the order of 800 m^3/ha but can exceed 2500 m^3/ha. Volumes greater than 1500 m^3/ha are generally considered excessive due to costs (Hoffman et al., 2007).

Surface irrigation systems are the dominant form of irrigation systems used throughout the world. Their potential suitability in the Mitchell catchment would be due to their generally lower setup costs and adaptability to a wide range of irrigated cropping activities. They are particularly suited to the heavier textured soils, which are found upstream of the confluence of the Mitchell and Walsh rivers and downstream of the apex of the Mitchell mega-fan, and in areas that have small natural topographical changes in elevation, which reduce setup or establishment costs of these systems. With surface irrigation, little or no energy is required to distribute water throughout the field and this 'gravity-fed' approach reduces energy requirements of these systems (Table 5-30).

Surface irrigation systems generally have lower applied irrigation water efficiency than spray or micro systems when compared across an industry and offer less control of applied water; however, well-designed and well-managed systems can approach efficiencies found with alternative irrigation systems in ideal conditions.

Spray irrigation systems

In the context of the Mitchell catchment, spray irrigation refers specifically to lateral move and centre pivot irrigation systems. Centre pivot systems consist of a single sprinkler, laterally supported by a series of towers. The towers are self-propelled and rotate around a central pivot point, forming an irrigation circle. Time taken for the pivot to complete a full circle can range from as little as half a day to multiple days depending on crop water demands and application rate of the system. Generally, lateral spans are less than 500 m.

Lateral or linear move systems are similar to centre pivot systems in construction, but rather than move around a pivot point the entire line moves down the field in a direction perpendicular to the lateral. Water is supplied by a lateral channel running the length of the field. Lateral lengths are generally in the range of 800 to 1000 m. They offer the advantage over surface irrigation systems in that they can be utilised on rolling topography and generally require less land forming.

Both centre pivot and lateral move irrigation systems have been extensively used for irrigating a range of annual broadacre crops and are capable of irrigating most field crops. They are generally not suitable for tree crops or vine crops or for saline irrigation water applications in arid environments, which can create foliage damage. Centre pivot and lateral move systems usually have higher capital costs, but are capable of very high efficiencies of water application. Generally, application efficiencies for these systems range from 75 to 90% (Table 5-29). They are used extensively for broadacre irrigated cropping situations in high evaporative environments in northern NSW and south-west Queensland. These irrigation developments have high irrigation crop water demand requirements, which are similar to those found in the Mitchell catchment. A key factor in the suitable use of spray systems is sourcing the energy needed to operate these systems, which are usually powered by electricity or diesel depending on costs and infrastructure available. Where available, electricity is considerably cheaper than diesel for powering spray systems (Table 5-30).

In moving to pressurised systems such as spray or micro irrigation systems, the water can be more easily controlled, and potential benefits of the system through fertigation (application of crop nutrients through the irrigation system (i.e. liquid fertiliser)) are also available to the irrigator.

Micro irrigation systems

For high-value crops, such as horticultural crops, where yield and quality parameters dictate profitability, micro irrigation systems should be considered suitable across the range of soil types and climate conditions found in the Mitchell catchment.

Micro irrigation systems use thin-walled polyethylene pipe to apply water to the root zone of plants via small emitters spaced along the drip tube. These systems are capable of precisely applying water to the plant root zone, thereby maintaining a high level of irrigation control and applied irrigation water efficiency. Historically, micro irrigation systems have been extensively used in tree, vine and row crops, with limited applications in complete cover crops such as grains and pastures due to the expense of these systems. Micro irrigation is suitable for most soil types and can be practised on steep slopes. Micro irrigation systems are generally of two varieties: above ground and below ground (where the drip tape is buried beneath the soil surface). Below-ground micro systems offer advantages in reducing evaporative losses and improving trafficability. However, below-ground systems are more expensive and require higher levels of expertise to manage.

Properly designed and operated micro irrigation systems are capable of very high application efficiencies, with field efficiencies of 80 to 90% (Table 5-29). In some situations, micro irrigation systems offer water and labour savings and improved crop quality (i.e. more marketable fruit through better water control). Management of micro irrigation systems, however, is critical. To achieve these benefits requires a much greater level of expertise than other traditional systems such as surface irrigation systems, which generally have higher margins of error associated with irrigation decisions. Micro irrigation systems also have high energy requirements, with most systems operating at pressure ranges from 135 to 400 kPa with diesel or electric pumps most often used (Table 5-30).

5.4.3 IRRIGATION SYSTEM COSTS

The capital costs for surface irrigation reported in Table 5-29 include earthworks for a supply channel, head ditch, field land forming and drainage (including tailwater return), as well as pumps and structures. Mason and Larard (2011) reported capital costs for surface (furrow) irrigation in the Flinders catchment, north-west Queensland to be $1482/ha. This is considerably less than the $3400/ha reported for surface irrigation in Table 5-29; however, the calculation of Mason and Larard (2011) omitted expensive items such as laser levelling (which costs between $300 and $650/ha (DEEDI, 2011a)) and tailwater return ($580/ha (DEEDI, 2011a)). These items significantly increase the capital cost of surface irrigation.

The capital costs associated with the purchase of a centre pivot or lateral move in Table 5-29 include the purchase of the machine and installation costs, such as earthworks. In addition to the cost of the machine, Table 5-29 includes the cost other items such as pipe work, pumping equipment and the power plant (either diesel or electric). The unit cost ($/ha) of both centre pivots and lateral moves is generally less for machines servicing a larger area. The most significant influence on machine price is the pipe diameter of spans (DEEDI, 2011b). As for surface irrigation, other site-specific capital costs could include power lines (and connection), supply channels, laser levelling, land clearing and road construction. Laser levelling and land forming are often limited to cut to drain as opposed to cut to grade. These additional items can add up to 50% of the system cost (DEEDI, 2011b). Mason and Larard (2011), in a report conducted for the Flinders catchment, estimated capital costs of pivot irrigation at approximately $4470/ha (which is in the range provided in Table 5-29), with $3800/ha for the centre pivot systems, and earthworks averaging around $670/ha.

Ongoing operational costs for all systems include pumping costs and general maintenance. Operation and maintenance of irrigation equipment is often costed at about 2% of the capital cost. These irrigation systems have various trade-offs between capital, operating and labour requirements. An important consideration in selecting an irrigation system is energy requirements, and this may become a more important consideration in the future if energy prices rise. Table 5-30 shows the variation in pumping costs for diesel and electricity for different irrigation systems. In addition, there are trade-offs between these costs and efficiency factors. Surface irrigation systems, for example, tend to have lower capital and annual operating costs, but are less efficient with higher water losses (Table 5-30).

Table 5-30 Energy demands and costs by irrigation type

PARAMETER	UNITS	FLOOD HARVESTING	SURFACE IRRIGATION	TAILWATER RETURN	CENTRE PIVOTS	LATERAL MOVES	SUBSURFACE DRIP
Flow rate	ML/day	120	120	50	8.6	24.2	16.6
Total dynamic head	m	7	6	5.5	50	35	50
Pumping plant efficiency	%	50	50	50	66	66	75
Power required	kWh/ML	38.9	33.3	30.6	210.4	147.3	185.2
Specific fuel consumption	L/kWh	0.25	0.25	0.25	0.25	0.25	0.25
Equivalent diesel requirement	L/ML	9.7	8.3	7.6	52.6	36.8	46.3
Pumping cost, electricity	$/ML	7.0	6.0	5.5	37.9	26.5	33.4
Pumping cost, diesel	$/ML	10.9	9.3	8.5	58.9	41.2	51.9

Adapted from Culpitt (2011), with costs based on assumption of $1.12/L for diesel ($1.50/L less $0.38/L rebate) and $0.18/kWh for electricity.

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Part IV Economics of development and accompanying risks

Chapters 6 and 7 describe economic opportunities, constraints and risks for water development in the Mitchell catchment. This information covers:

- economic opportunities and constraints (Chapter 6)
- a range of risks to development (Chapter 7).

6 Overview of economic opportunities and constraints

Authors: Chris Stokes and Diane Jarvis

Chapter 6 examines which types of opportunities for irrigated agriculture development in the Mitchell catchment are most likely to be commercially viable. The chapter considers the costs of building new infrastructure (both within the scheme and beyond), the financial viability of different types of schemes (considered from an investor's perspective), and the regional economic impacts (the direct and flow-on effects for businesses across the catchment) (Figure 6-1).

The intention is not to provide a full economic analysis, but to focus on costs and benefits that are the subject of normal market transactions. Non-market impacts and risks are dealt with in chapters 3 and 7, but given the often subjective and publicly contested nature of valuing such impacts, these are not converted to dollar amounts here. Commercial factors are likely to be one of the most important criteria in deciding between potential development opportunities. Those options that can be clearly identified as being commercially non-viable at the pre-feasibility stage could likely be deprioritised. More detailed project-specific agronomic, ecological, social, cultural and regulatory assessments could then be focused on those opportunities identified as showing the most commercial promise.

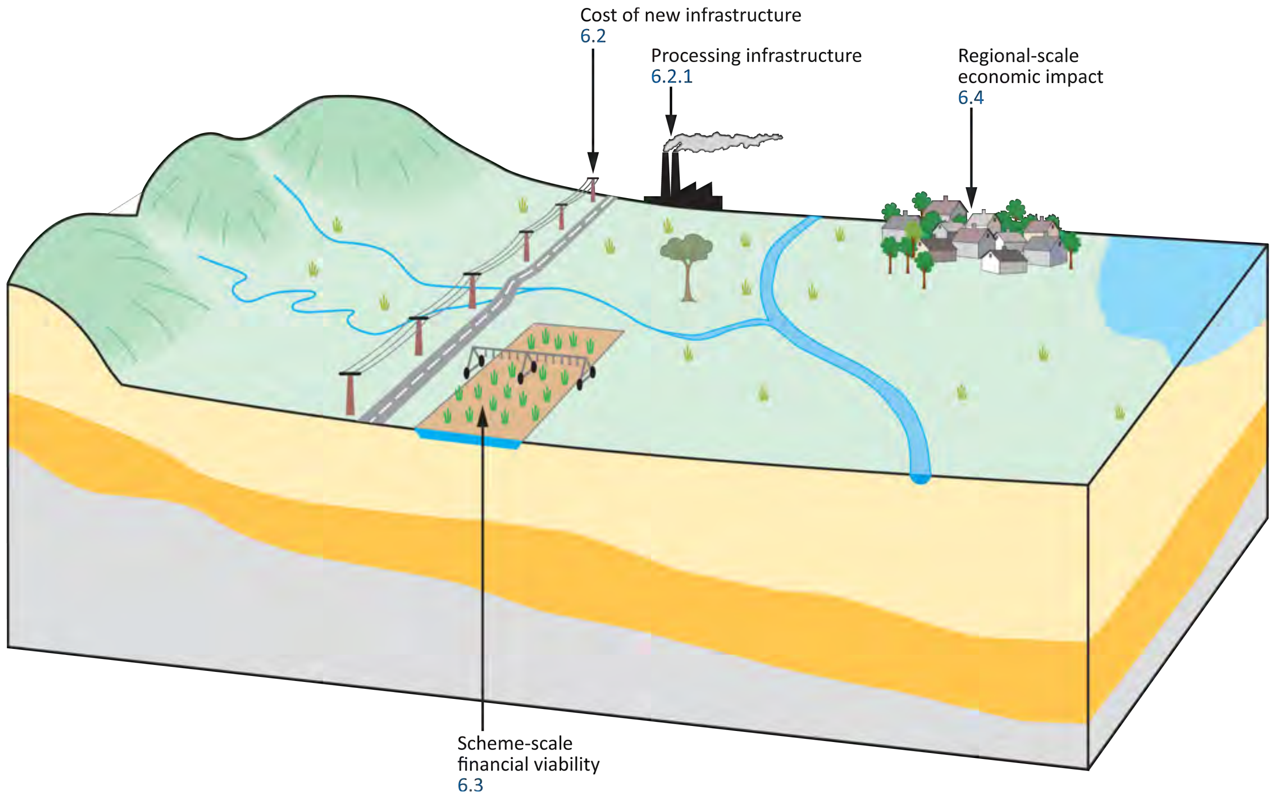

Figure 6-1 Schematic diagram of key components affecting the commercial viability of a potential greenfield irrigation development opportunity

6.1 Summary

6.1.1 KEY FINDINGS

Scheme-scale financial viability

Viable new irrigation development in the Mitchell catchment would require challenging combinations of low-cost infrastructure, high-productivity farms, management of a wide range of risks, and/or off-farm value adding. The capital cost of development is the dominant factor affecting scheme viability. It is unlikely that farm gate revenue from irrigated broadacre agriculture alone would be sufficient to fully cover the development costs of irrigation schemes with capital costs above $15,000/ha (plus farm setup costs of about $7000/ha). Adding a processor to a scheme (i.e. vertical integration) could provide increases in revenues (from processed versus unprocessed goods) that are proportionally larger than the additional capital cost of the processing facility. This, or other off-farm value adding options, can assist in improving the commercial viability of a scheme, but can also add risk. Viable processors, particularly in remote locations, rely on secure supplies of raw farm commodities at scale, which requires upfront commitments from farmers supported by assured access to the required water and land.

Farm performance can be affected by a range of risks, including water reliability, climate variability, price fluctuations, and learning to adapt farming practices to new locations. Setbacks that occur early on after a scheme is established have the largest effect on scheme viability. There is a strong incentive to start any new irrigation development with well-proven crops and technologies, and to be thoroughly prepared for the anticipatable agronomic risks of establishing new farmland. Staging development can reduce some of the early learning risks. Risks that cannot be avoided need to be managed, mitigated where possible, and accounted for in determining the realistic returns that may be expected from a scheme, and the capital buffers that would be required.

Regional economic impacts

Justifying the costs of public investment in new water infrastructure and/or supporting community infrastructure in the Mitchell catchment could well depend on indirect benefits beyond the irrigation scheme. It was found that during the initial construction phase of a new irrigation development in the Mitchell catchment, there could be an additional $1.22 of indirect regional benefits, over and above the direct benefits of each dollar spent on construction within the local region. During the ongoing production phase of a new irrigation development, there could be an additional $0.96 to $1.10 of indirect regional benefits for each dollar of direct benefits from increased agricultural activity (gross revenue), depending on the type of agricultural industry. Indirect regional benefits would be reduced if there was leakage of some of the extra expenditure generated by a new development outside the catchment. Each $25 million increase in agricultural activity could create about 190 to 250 jobs, depending on the agricultural industry.

6.1.2 INTRODUCTION

Large infrastructure projects, such as new irrigation developments in the Mitchell catchment, are complex and costly investments. The difficulty in accurately estimating costs and the chance of incurring unanticipated expenses during construction, or not meeting revenue projections when completed, means that there are risks to the viability of developments if they are not thoroughly planned and assessed. For example, in a global review of dam-based megaprojects, Ansar et al. (2014) found forecast costs were systematically biased downwards, with three-quarters of projects running over budget and the mean of actual costs almost double the initial estimates. In recent decades there has been growing emphasis in Australia on greater accountability and transparency in how water resources are managed and priced (e.g. the reforms under the National Water Commission (2004 to 2015). Part of this shift has involved greater scrutiny of the commerciality of potential new dams.

Ultimately, economic factors are likely to be one of the most important criteria in deciding between potential development opportunities in the Mitchell catchment. Ash et al. (2014), in an assessment of 13 agricultural developments in northern Australia, found that while the natural environments are challenging for agriculture, the most important factors determining the viability of developments were management, planning and finances. Even at a pre-feasibility stage, those options that can be clearly identified as being financially non-viable could likely be deprioritised, instead focusing expensive, more detailed, project-specific agronomic, ecological, social, cultural and regulatory assessments on more promising opportunities. This chapter aims to assist in planning and evaluating investments in large-scale irrigated development by highlighting the types of projects that are more likely to be commercially viable, and quantifying the costs, benefits and risks involved. The intention is to provide a generic information resource that is broadly applicable to a range of irrigated agriculture development opportunities, rather than examining any specific options in detail. Results are presented in a way that allows readers to estimate whether particular projects they are interested in are likely to be commercially viable using costs, risks and farm productivity specific to those particular opportunities.

Chapter 4 assessed the viability of new irrigated agriculture and aquaculture opportunities in the Mitchell catchment at the enterprise level. Section 6.2 provides indicative costs for a variety of hard, post-processing and community infrastructure that may be required for large water and irrigation developments, beyond the costs presented in Chapter 5. Section 6.3 builds on this with a financial evaluation of new developments at the scheme (water infrastructure and associated new farms) scale from an investor’s perspective using a discounted cashflow framework. Section 6.4 then quantifies the regional economic impacts of irrigated development using regional input–output (I–O) analysis. Other non-market impacts were addressed in Chapter 3, and additional risks are discussed in Chapter 7.

6.2 New infrastructure costs

A range of infrastructure would be required to support development of a new irrigation scheme in the Mitchell catchment, both within the scheme itself and beyond. Infrastructure can be considered ‘hard’ or ‘soft’, which within the context of a large irrigation development can be broadly defined as follows:

- Hard infrastructure refers to the physical assets necessary for the functioning of a development and can include water storage, roads, irrigation supply channels and energy, but also processing infrastructure such as sugar mills, cotton gins, abattoirs and feedlots.
- Soft infrastructure refers to the specialised services required to maintain the economic, health, cultural and social standards of a population. They are indirect costs of a development and are usually less obvious than hard infrastructure costs. They can include expenses that continue after the construction of a development has been completed. Soft infrastructure can include:
  - physical assets, such as community infrastructure (e.g. schools, hospitals, housing)
  - non-physical assets, such as institutions, supporting rules and regulations, compensation packages, law enforcement and emergency services.

New processing infrastructure and community infrastructure are particularly pertinent to large, remote, greenfield developments, and these costs to other providers of infrastructure can be substantial even after a new irrigation scheme is developed. For example, a review of the Ord-East Kimberley Development Plan (for expansion of the Ord irrigation system by about 15,000 ha) found that there were additional costs of $114 million to the Western Australian Government, and $195 million to the Australian Government beyond the planned $220 million state investment in infrastructure to directly support the expansion (Western Australian Auditor General, 2016).

Given the systematic tendency of proponents of large infrastructure projects to substantially under estimate development costs (Wachs, 1990; Odeck and Skjeseth, 1995; Flyvbjerg et al., 2002; Ansar et al., 2014; Western Australian Auditor General, 2016), the purpose of this section is to provide a reference of component infrastructure cost estimates that are as unbiased as possible. The intention here is not to diminish the potential benefits of development and population growth in a region, but to highlight potentially overlooked costs that are required to realise those benefits.

6.2.1 COSTS OF HARD INFRASTRUCTURE

Establishing new irrigated agriculture in the Mitchell catchment would involve the initial costs of developing water and land resources, and additional farm setup costs for equipment and facilities on each new farm. It may also involve costs associated with constructing processing facilities, extending electricity networks and upgrading road transport.

Costs of water storage and conveyance are provided in Sections 5.3 and 5.4, respectively. Indicative costs for processing facilities are provided in Table 6-1 and indicative costs for roads and electricity infrastructure are provided in Table 6-2. Indicative costs for transporting goods to key markets are also listed (Table 6-3). All tables are summarised from information provided in the companion technical report on socio-economics (Stokes et al., 2017).

Table 6-1 Indicative costs of agricultural processing facilities

ITEM	CAPITAL COST	OPERATING COST	COMMENT
Meat works	$33 million	$315/head	Operational capacity 100,000 head/y
Cotton gin	$30 million	$1 million/y plus $22 to $30/bale	Operational capacity of 2000 bales/day Operating costs depend on scale of gin and source of energy
Sugar mill	$396 million	$33 million/y	Operational capacity of 1000 t cane/h, 6-month crushing season Basic mill producing sugar only (no electricity or ethanol)

Table 6-2 Indicative costs of road and electricity infrastructure

ITEM	CAPITAL COST	COMMENT
Roads		
Seal dirt road	$0.25 to $2 million/km	Upgrade and widen dirt road to sealed road
New floodway	about $20 million	Costs of bridges and floodways vary widely
Electricity		New generation capacity may also be required
Transmission lines	$0.4 to $1.1 million/km	High-voltage lines deliver bulk flow of electricity from generators over long distances
Distribution lines	$0.2 million/km	Lower-voltage lines distribute power from substations over shorter distances to end users
Substation	$10 to $50 million	Transformers and switchgear connect transmission and distribution networks

Table 6-3 Indicative road transport costs between Kowanyama and key markets and ports

DESTINATION	TRANSPORT COST ($/t)
Sydney	459
Darwin	288
Brisbane	341
Adelaide	431
Melbourne	530
Perth	646
Weipa Port	134
Cairns Port	120
Karumba Port	58

6.2.2 COSTS OF SOFT INFRASTRUCTURE

The availability of community services and facilities would play an important role in attracting or deterring people from living in a new development in the Mitchell catchment. If local populations increase as a result of new irrigated developments, then there would be increased demand for public services in the Mitchell catchment, and provision of those services would need to be anticipated and planned. Indicative costs for constructing a range of different facilities that may be required to support population growth are listed in Table 6-4. Each 1000 people in Australia require 4.0 hospital beds served by 28 full-time equivalent hospital staff and $4.0 million/year funding to maintain current mean national levels of hospital service (AIHW, 2017). Health care services in remote locations generally focus on primary and some secondary care, while the broadest range of more specialised tertiary services are concentrated in referral hospitals that are mainly located in large cities, but serve large surrounding areas. Primary schools tend to be smaller and more widespread, while larger secondary schools are more centralised.

Demand for community services is growing, both from population increases in Australia and rising community expectations. New infrastructure that is built to service that demand would occur irrespective of any development in the Mitchell catchment. However, if new irrigation projects shift some people to live in the Mitchell catchment, this could then shift the locations of where some services are delivered and associated infrastructure is built. The costs of delivering services and building infrastructure is generally higher in more remote locations like the Mitchell catchment. The net cost of any new infrastructure that is built to support development in the Mitchell catchment is the difference in cost of shifting some infrastructure to this more remote location (not the full cost of facilities (Table 6-4) that would otherwise have been built elsewhere).

Table 6-4 Indicative costs of community facilities

Costs are quoted for Darwin as a reference capital city for northern Australia. Costs in remote parts of northern Australia are estimated to be about 30 to 60% higher than those quoted for Darwin. School costs were estimated separately from a range of sources across northern Australia. See companion technical report on socio-economics (Stokes et al., 2017) for details.

ITEM	CAPITAL COST	COMMENT
Hospital	$0.2 to $0.5 million/bed	Higher end costs include major operating theatre and larger area of hospital per bed
School	$25,000 to $33,000 per student	Secondary schools tend to be larger and more centralised than primary schools
House (each)	$485,000 to $850,000	Single or double storey house
Unit (each)	$260,000 to $390,000	Unit, fewer than 10 stories, 90 to 120 m^2
Offices	$2,200 to $2,800/$m^2$	1 to 3 stories

6.3 Scheme-scale financial viability

Designing a new irrigation project in the Mitchell catchment would require balancing a number of factors to find combinations that might collectively constitute a viable investment. Four key determinants of irrigation scheme financial performance examined here are:

1. capital cost of development (Section 6.3.2)
2. farm performance (Section 6.3.2)
3. risks (and associated required level of investment return) (Section 6.3.3)
4. value adding beyond the farm gate (Section 6.3.4).

Other assumptions were limited as much as possible, restricting these to factors with greater certainty and/or lower sensitivity, so that the principles derived would be as generalisable as possible.

A key finding of the irrigation scheme financial analyses is that no single factor is likely to provide a silver bullet to meet the substantial challenge of designing a commercially viable new irrigation scheme. Bridging the financial gap to viability would likely require contributions from each of the above factors, with careful selection to piece together a workable combination. The broad principles for balancing each of these factors is summarised below. However, to understand the discussions of how these factors influence irrigation scheme financial performance in the Mitchell catchment, some background information is needed, and this is provided next.

6.3.1 DISCOUNTED CASHFLOW FRAMEWORK, TERMS AND ASSUMPTIONS

Scheme financial evaluations used a discounted cashflow framework to evaluate the commercial viability of irrigation developments. The framework, detailed in the companion technical report on socio-economics (Stokes et al., 2017), was intended to provide a purely financial evaluation of the conditions that would be required to produce an acceptable return from an investor's perspective. It is not a full economic evaluation of the costs and benefits to other industries, nor does it consider 'unpriced' impacts that are not the subject of normal market transactions, or the equity of how costs and benefits are distributed. For the discussion that follows, a scheme was taken to be all the costs and benefits from the development of the land and water resources to the produce leaving the farm gate.

Initially, a generic 'top-down' approach was taken, working backwards from the costs of developing a new irrigation scheme to determine the farm gross margins that would be required to make the investment commercially viable. This approach complements the 'bottom-up' approach to calculating indicative farm gross margins for different farming options in the Chapter 4.

A discounted cashflow analysis considers the lifetime of costs and benefits following capital investment in a new project. Costs and benefits that occur at different times are expressed in constant real dollars, with a discount rate applied to streams of costs and benefits. This section explains the terminology and standard assumptions used.

The discount rate is the percentage by which future cost and benefits are discounted each year (compounded) to convert them to their equivalent present value (PV). A discount rate of 7% is typically used when evaluating public investments.

For an entire project, the net present value (NPV) can be calculated by subtracting the PV of the stream of all costs from the PV of the stream of all benefits. The benefit–cost ratio (BCR) of a project is the PV of all the benefits of a project divided by the PV of all the costs involved in achieving those benefits. To be commercially viable (at the nominated discount rate), a project would require an NPV that is greater than zero (in which case the BCR would be greater than one).

The internal rate of return (IRR) is the discount rate at which the NPV is zero (and the BCR is one). The project's target IRR needs to be above the appropriate discount rate for a project to be considered commercially viable based on the risk profile of the development and alternate investment opportunities available to developers.

A project evaluation period of 30 years was used for scheme-scale assessments in this chapter. This project life was selected to reflect the life of the principal infrastructure assets in the scheme.

To simplify the tracking of assets (particularly where staged development is later considered) assets were approximated into three categories of life spans: 15, 40 and 100 years. It was assumed assets would be replaced at the end of their life, and costs were accounted for in full in the actual year of their replacement. At the end of the 30-year evaluation period, a residual value was calculated to account for assets that had not reached the end of their working life. Residual values were calculated as the proportional asset life remaining multiplied by the original asset price.

Capital costs of infrastructure were assumed to be the costs at completion (accounted for in full in the year of delivery), such that the assets commenced operations the following year. The capital costs of developing the water and land resources for irrigated farming (evaluated for costs of $10,000/ha to $40,000/ha) were considered separately to the additional setup costs for buildings, vehicles and equipment required to establish each new farm (assumed to total $7424/ha).

The main costs for operating a large dam and associated water distribution infrastructure are fixed costs for administering and maintaining the infrastructure, expressed here as percentage of the original capital cost, and variable costs associated with pumping water into distribution channels.

At the farm scale, fixed overhead costs are incurred each year whether or not a crop is planted in a particular year. For a generic broadacre crop, these costs were assumed to be $600/ha plus 1% of the original capital value of farm assets. Fixed costs were dominated by the fixed component of labour costs, assuming four full-time equivalent staff per 500 ha farm. Overheads included a lease fee to account for the use of the land prior to irrigation. Other components of overheads include maintenance, insurance, professional services and registrations.

A farm annual gross margin is the difference between the gross income from crop sales and variable costs of growing a crop each year. Net farm revenue is calculated by subtracting fixed overhead costs from the gross margin. Variable costs vary in proportion to the area of land planted, the amount of crop harvested and/or the amount of water and other inputs applied. Farm gross margins can vary substantially within and between locations, as indicated in Section 4.5. Gross margins presented here are the values before subtracting the variable costs of supplying water to farms, with these costs instead accounted for in the capital costs of developing water and land resources (and equivalent unit costs of supplying water presented separately below).

6.3.2 BREAK-EVEN ANALYSES OF DEVELOPMENT OPTIONS FOR GENERIC SCHEMES

The capital costs of developing water and land resources in the Mitchell catchment vary widely, such that even when technically feasible options are found, many of these are unlikely to be profitable at the returns and over time periods expected by many investors. The results presented below suggest that development costs above $15,000/ha (plus $7424/ha farm setup costs) would be difficult to cover from farm gate revenues alone. Gross margins (excluding water supply costs) would need to be above $3000/ha, before accounting for the negative effects of risks. There is little that potential investors can do in this regard other than focusing on the cheapest development options. However, consideration also needs to be given to ongoing maintenance and operating costs, which are typically higher for lower-cost, lower life span infrastructure (particularly where assets are engineered to a lower standard).

The costs of developing water and land resources for a new irrigation development can vary substantially depending on a wide range of case-specific factors dealt with in other parts of this Assessment. These factors include the type and nature of the water source, the type of water storage, geology, topography, soil characteristics, the water distribution system, the type of irrigation system, the type of crop to be grown, land preparation requirements, and the level to which infrastructure is engineered. Initial analyses focused on the capital costs of development, given their importance in determining the financial performance of a scheme, and the high variability in these costs between potential development opportunities. The above financial framework was applied generically, working backwards from broad assumptions about developments with different capital costs to determine the farm gross margins that would be required for the scheme as a whole to break even (scheme NPV = zero, scheme BCR = 1). The baseline assessments considered the simplest case, where costs and farm performance stayed the same over time, first for a scheme built around a large inchannel dam, and then for an indicative on-farm water source.

Generic scheme based on a large, off-farm dam

Assumptions

The first assessment considered the case where a single developer would invest in a scheme in the Mitchell catchment that included all costs and benefits from initial construction of a large dam (>25 GL/year) off-farm and land preparation up to the revenue received for produce at the farm gate. A range of development costs and target rates of return were considered. A relative breakdown of dam development costs was used to apportion infrastructure assets for dams with different costs of development (Table 6-5). This breakdown was based on costings for two indicative dams in the companion technical report on socio-economics (Stokes et al., 2017). 'Core' infrastructure consisted of those off-farm assets, such as the dam wall, weir, main supply channel, scheme access road and costs of approvals. 'Area-dependent' infrastructure consisted of those assets that scaled with each extra unit of additional irrigated land, such as land development costs, farm roads and channels for distributing water to each farm. In addition to the costs of developing land and water resources, irrigators would have setup costs for purchasing buildings, vehicles and equipment for each new farm (assumed here to total an extra $7424/ha, Table 6-5).

Table 6-5 Assumed capital and operating costs for a new irrigation scheme with a new large dam
Annual operating and management (O&M) costs are expressed as a percentage of the capital costs of assets.

SCHEME COMPONENT	ITEM	LIFE SPAN (y)	UNIT COST ($)	UNIT	O&M COST (% capital cost)
Water supplier capital and operating costs (water and land development)					
Capital costs (split as per percentages below)			$10,000 to $40,000	ha	
'Core' infrastructure %	100-year infrastructure	100	57%		0.4%
	40-year infrastructure	40	9%		1.6%
'Area-dependent' infrastructure %	100-year infrastructure	100	0%		
	40-year infrastructure	40	34%		1.0%
Operating costs (+ asset O&M costs)	Pumping from weir		$30	ML	
Irrigator capital and operating costs (farm buildings and equipment)					
Farm setup capital costs (setup costs total $7,424/ha)	Buildings and structures	40	$2,190	ha	1.0%
	Irrigation system	15	$3,960	ha	1.0%
	Vehicles and equipment	15	$1,274	ha	1.0%
Farm overheads (annual) (+ O&M costs: 1% of capital costs)	Labour, services etc.		$600	ha	

Water losses affect volumes of water passing various points from the dam to the crop (see Section 5.4). The analyses required the volume of water reaching the farm gate (used as the pricing point in the next section) and volume of water being pumped from re-regulation structures into supply channels. Analyses assumed that 10 ML/ha/year of irrigation water was used by crops (before accounting for application losses) with an application efficiency of 85%, on-farm distribution efficiency of 90% and channel distribution efficiency of 90%. On this basis, applied irrigation water at the farm gate would be 13.1 ML/ha/year (= 10 ÷ (85% × 90%) ML/ha/year, after accounting for distribution losses) and water pumped by the water supplier would be 14.5 ML/ha/year (= 13.1 ÷ 90% ML/ha/year). Water supplies were assumed to be 100% reliable and all other factors affecting farm performance were ignored for the initial baseline set of analyses. Sources of risk affecting farm performance are covered separately in Section 6.3.3 and provide a set of risk adjustment multipliers for these baseline results.

The assumed applied irrigation water has a relatively small direct effect on these analyses, by contributing to scheme operating costs. The main way in which applied irrigation water influences results below is indirectly, through the effect on development costs per hectare. A given water supply will be able to irrigate a smaller area for farming options that use more water, so scheme development costs per hectare would be higher and would need to be paid for from a smaller area of farmland.

Break-even farm gross margins

Cost and benefit streams, totalled across the scheme, were tracked in separate components for the water supplier and irrigator operations. For the water supplier, these streams were (i) the capital costs (including replacement costs and residual values) of developing the water and land resources, and (ii) the costs of maintaining and operating those assets. For the farm, these streams were (i) the capital costs of the farm buildings and equipment; (ii) the fixed overhead costs, applied to the full area of developed farmland; and (iii) the total farm gross margin (across all farms in the scheme), applied to the mean proportion of land in production. Table 6-6 shows farm annual gross margins that would be required for a scheme to break even (scheme NPV = zero) for a range of different capital costs of development and target investment returns (IRR). The costs of supplying water to the farm gate are accounted for in the capital costs of development (rather than being subtracted as a variable cost in the farm gross margins presented).

Table 6-6 Break-even farm gross margins required for schemes with different dam development costs to meet target investment returns (IRR)

Assumes 100% farm performance in all years and an additional $7424/ha farm setup cost for buildings and equipment (Table 6-5). Gross margins exclude costs of water supply. Risk adjustment multipliers are provided in Section 6.3.3.

TARGET IRR	BREAK-EVEN FARM GROSS MARGIN ($/ha/y)					
	Capital costs for developing water and land ($/ha)					
	$10,000	$15,000	$20,000	$25,000	$30,000	$40,000
0%	1,751	1,869	1,987	2,106	2,224	2,461
1%	1,871	2,028	2,185	2,343	2,500	2,814
2%	1,996	2,193	2,390	2,587	2,784	3,179
3%	2,125	2,363	2,601	2,840	3,078	3,554
5%	2,396	2,719	3,043	3,366	3,690	4,337
7%	2,680	3,093	3,506	3,918	4,331	5,156
10%	3,130	3,682	4,233	4,785	5,336	6,439
12%	3,442	4,088	4,735	5,382	6,028	7,322
14%	3,760	4,504	5,247	5,991	6,734	8,221

As expected, higher farm gross margins are required to cover higher capital costs and higher investment returns. These generic tables can be used together with information on costs and returns for particular cases. For example, Chapter 4 showed that indicative farm gross margins for single broadacre crops were unlikely to exceed $3000/ha (depending on crop, location and soils), and scheme development costs for the most promising potential dam sites in this Assessment were estimated at about $20,000/ha to $30,000/ha (assuming crop applied irrigation water of 10 ML/ha, 45% water losses from dam to crop, and $11,000/ha scheme development costs after building the dam wall, before allowing for contingencies or farm setup costs) (Stokes et al., 2017). On this basis, farm gate revenues alone would fall short of reaching a 7% return on capital invested (Table 6-6).

Break-even pricing of dam water

If the water supplier and farmers were separate investors, then a price would need to be set for the delivery of water from the dam operator to the irrigators. This arrangement is broadly analogous to some large SunWater-operated irrigation schemes in Queensland, such as the Burdekin Haughton Water Supply Scheme and the Mareeba–Dimbulah Water Supply Scheme. From the water supplier's perspective, two options for pricing water were considered. The first

was on a fully commercial basis for the same combinations of development costs and target IRRs as used above (Table 6-7). The second, as a lower bound, was the water pricing that would be required to cover just the ongoing maintenance and operating costs (excluding the initial capital costs of constructing the dam and developing the land) (
Table 6-8).

Table 6-7 Break-even water pricing required for schemes with different dam development costs to meet target investment returns (IRR) for the water supplier (developer of dam, water distribution infrastructure and land)
Water priced at farm gate to cover both capital and operating costs of water supplier, assuming applied irrigation water of 13.1 ML/ha/year at farm gate, 14.5 ML/ha/year at weir, scheme pumping costs of $30/ML at weir, and 100% farm performance.

TARGET IRR	WATER PRICE THAT WATER SUPPLIER WOULD NEED TO CHARGE TO BE PROFITABLE ($/ML AT FARM GATE)					
	Capital costs for water supplier to develop water and land ($/ha)					
	$10,000	$15,000	$20,000	$25,000	$30,000	$40,000
0%	51	61	70	79	88	106
1%	57	69	81	93	105	130
2%	63	79	94	109	124	154
3%	70	88	106	124	143	179
5%	83	108	132	157	182	231
7%	96	128	160	191	223	286
10%	118	160	202	244	286	371
12%	132	182	231	281	330	429
14%	147	204	261	318	375	488

Table 6-8 Minimum price water supplier would have to charge for water for schemes with different costs of development to cover annual O&M costs
Fully covers annual water supplier operating costs each year, so discount rate assumptions have no effect. Water was priced at farm gate assuming applied irrigation water of 13.1 ML/ha/year at farm gate, 14.5 ML/ha/year at weir, scheme pumping costs of $30/ML at weir, and 100% farm performance.

WATER PRICE TO COVER ONLY WATER SUPPLIER OPERATING COSTS ($/ML AT FARM GATE)					
Capital costs for water supplier to develop water and land ($/ha)					
$10,000	$15,000	$20,000	$25,000	$30,000	$40,000
39	42	45	47	50	56

Water pricing was then considered from the irrigator's perspective and the capacity of irrigators to pay. Table 6-9 shows water prices for a farm to break even (farm NPV = zero) for a range of different farm gross margins and applied irrigation water combinations.

Under a favourable scheme for a broadacre crop with a gross margin of $3000/ha and an irrigator seeking an IRR of 7%, irrigators would be able to pay $121/ML for a crop using 10 ML/ha/year (of irrigation water before application losses, Table 6-9). Water payments from irrigators at these water prices would more than cover the ongoing operating costs of a water supplier

(<$100/ML across a wide range of development costs,
Table 6-8), but would fall short of covering the full costs of supplying water at a commercial rate of return (e.g. $160/ML for a 7% IRR on supplier capital development costs of $20,000/ha, Table 6-7).

Table 6-9 Break-even water pricing for what an irrigator could afford to pay depending on the annual gross margin of the farm, crop applied irrigation water (before application losses), and the irrigator's target internal rate of return (IRR)

Assumes water volumes metered at the farm gate were 1.31 times the crop applied irrigation water after accounting for losses (based on 90% on-farm distribution efficiency and 85% application efficiency).

TARGET IRR (%)	GROSS MARGIN ($/ha)	IRRIGATOR CAPACITY TO PAY FOR WATER AND STILL BE PROFITABLE ($/ML AT FARM GATE)				
		Crop applied irrigation water [and farm gate applied irrigation water] (ML/ha)				
		4 [5.2]	6 [7.8]	8 [10.5]	10 [13.1]	12 [15.7]
3%	**$1500**	55	37	27	22	18
	$2000	151	100	75	60	50
	$2500	246	164	123	98	82
	$3000	342	228	171	137	114
7%	**$1500**	15	10	8	6	5
	$2000	111	74	56	44	37
	$2500	207	138	103	83	69
	$3000	302	202	51	121	101
10%	**$1500**	na†	na	na	na	na
	$2000	78	52	39	31	26
	$2500	174	116	87	70	58
	$3000	269	180	135	108	90

†na = not applicable, situations where farm is not profitable even if there was no charge for water

Generic modular development using an on-farm water source

The second baseline case considered an irrigation development in the Mitchell catchment that substituted the large dam (above) with an on-farm source of water. The indicative on-farm water source was based on greenfield development using bores and pivots. A detailed breakdown of costs for this option is provided in the companion technical report on socio-economics (Stokes et al., 2017). Aside from being on-farm, this option contrasted with the dam water option in using an alternative water source (ground versus surface water) and using shorter life span infrastructure (potentially cheaper upfront capital costs but higher ongoing costs). It is also very modular, which would be more amenable to staging (Section 6.3.3), alternative models of investment (less reliant on a single large investor/developer) and developments across a wide range of scales (from part of a farm to large schemes).

Assumptions

Assumptions for the costs of developing and operating on-farm water sources were the same as for the off-farm dam example above, except that the dam water source was replaced with costs of developing and operating a series of bores (Table 6-10). Analyses initially assumed the developed water source would fully meet crop demand (with 100% reliability). Pumping costs would be part of the variable costs that would have to be included in the farm gross margin for a particular cropping option before comparing to the break-even gross margins calculated here (whereas for the dam option above, pumping costs for delivering water to the farm gate were a scheme cost, recovered through the price charged to farms for supplying water).

Table 6-10 Assumed capital and operating (O&M) costs for a new development using an on-farm water source
Modular on-farm development involves only separate 'Area-dependent' infrastructure for each farm, and there is no shared 'Core' infrastructure (as there was for the large dam).

SCHEME COMPONENT	ITEM	LIFE SPAN (y)	UNIT COST ($)	UNIT	O&M COST (% capital cost)
Costs of developing on-farm water resource and preparing land					
Capital costs (split as per percentages below)			$5,000 to $40,000	ha	
'Area-dependent' infrastructure % (no 'Core' infrastructure)	40-year infrastructure	100	49%		1.0%
	15-year infrastructure	40	51%		1.0%
Irrigator capital and operating costs (farm buildings and equipment)					
Farm setup capital costs	Buildings and structures	40	$2,190	ha	1.0%
	Irrigation system (spray)	15	$3,960	ha	1.0%
	Vehicles and equipment	15	$1,160	ha	1.0%
Farm overheads (annual) (+ O&M costs: 1% of capital costs)	Labour, services etc.		$600	ha	

Break-even farm gross margins

Table 6-11 shows the farm gross margins that would be required for the scheme to break even (NPV = zero). Note that while shorter life span infrastructure may reduce development costs of on-farm infrastructure, this leads to more frequent asset replacement so higher farm gross margins were required for the scheme to break even relative to the same development cost per area for a large dam (Table 6-6). Thus, although some on-farm options for water development may be cheaper than building a new large dam, higher ongoing costs associated with shorter life span infrastructure offset some of that advantage. Small offstream storages, an alternative on-farm water source, can also be less reliable water sources than large instream dams and are less able to carry water through the dry season, which limits farming options.

Table 6-11 Break-even farm gross margins required for schemes with different costs of developing on-farm water sources to meet target investment returns (IRR)
Assumes an additional $7424/ha farm setup costs for buildings and equipment (Table 6-11) and that the developed water source is able to fully meet crop requirements to deliver 100% farm performance in all years. Risk adjustment multipliers are provided in Section 6.3.3.

TARGET IRR	BREAK-EVEN FARM GROSS MARGIN ($/ha/y)						
	Capital costs for developing water and land ($/ha)						
	$5,000	**$10,000**	**$15,000**	**$20,000**	**$25,000**	**$30,000**	**$40,000**
0%	1,359	1,640	1,921	2,202	2,483	2,764	3,326
1%	1,432	1,743	2,054	2,365	2,676	2,987	3,609
2%	1,508	1,851	2,193	2,536	2,878	3,221	3,906

TARGET IRR	BREAK-EVEN FARM GROSS MARGIN ($/ha/y)						
3%	1,588	1,964	2,339	2,715	3,090	3,466	4,217
5%	1,758	2,204	2,650	3,095	3,541	3,986	4,878
7%	1,940	2,461	2,982	3,503	4,023	4,544	5,585
10%	2,233	2,874	3,515	4,156	4,798	5,439	6,721
12%	2,438	3,164	3,890	4,616	5,342	6,068	7,519
14%	2,651	3,464	4,277	5,090	5,904	6,717	8,343

6.3.3 RISKS ASSOCIATED WITH VARIABILITY IN FARM PERFORMANCE

This section assessed the impacts of two types of risks on scheme financial performance: those that reduce farm performance through the early establishment and learning years, and those occurring periodically and continuously. Setbacks that occur early on after a scheme is established were found to have the largest effect on scheme viability, particularly at higher discount rates. There is a strong incentive to start any new irrigation development with well-established crops and technologies, and to be thoroughly prepared for the anticipatable agronomic risks of establishing new farmland. Analyses showed that delaying full development for longer periods than the learning time had only a slight negative effect on IRRs, whereas proceeding to full development before learning was complete had a much larger impact. This implies that it would be prudent to err on the side of delaying full development (particularly given that in practice, it would only be possible to know when full performance was achieved in retrospect, not in advance). An added benefit of staging would be limiting losses where small-scale testing proves initial assumptions of benefits to be over-optimistic and that full-scale development could never be profitable, even after trying to overcome unanticipated challenges.

For an investment to be viable, farm gross margins need to be sustained at high levels over long periods. Thus, variability in farm performance poses risks that need to be considered and managed. Gross margins can vary between years either because of short-term initial underperformance or because of periodic shocks. Initial underperformance is likely to be associated with learning as farming practices are adapted to local conditions, overcoming initial challenges to reach their long-term potential. There would be further unavoidable periodic risks associated with water reliability, climate variability, flooding, outbreaks of pests and diseases, periodic technical/equipment failures, and fluctuations in commodity prices and market access. Periodic risks, such as reliability of water supply, are less easy to avoid. Risks that cannot be avoided need to be managed, mitigated where possible, and accounted for in determining the realistic returns that can be expected from a scheme. This would include having adequate capital buffers to survive through challenging periods. Another perceived risk for investors is that of uncertainty around future policy changes and delays in regulatory approvals. Reducing this, or any other sources of risk, would contribute to making marginal investment opportunities more attractive.

Results for analyses of both periodic and learning risks are shown below. Findings are also presented for how staging might be able to mitigate the costs of learning, and additional risks that staging could introduce. Throughout this section, farm performance in a given year is quantified as the proportion of the long-term mean gross margin a farm attains, where 100% performance is when this level is reached and zero % equates to a performance where revenues only balance variable costs (gross margin = $zero).

Risks from periodic underperformance

Analyses considered periodic risks generically, without assuming any of the particular causes listed above. Periodic risks were characterised in terms of three components to test their effects on scheme financial performance:

- reliability: the proportion of ‘good’ years where the ‘full’ 100% farm performance was achieved, with the remainder of years being ‘failures’ where some negative impact was experienced
- severity: the farm performance in a ‘failed’ year where some type of setback occurs
- timing: for ‘early’ timing a 10-year cycle was used where, for example, with 80% reliability failures would occur in the first 2 years of the scheme and the first 2 years of each 10-years in a cycle after that. For ‘late’ timing, the ‘failures’ came at the end of each 10-year cycle. Where timing was not used, each year was represented as having the long-term mean farm performance of ‘good’ and ‘failed’ years (frequency weighted).

Table 6-12 summarises the effects of a range of different reliabilities and severities for periodic risks (without considering timing of impacts) on scheme viability. Periodic risks had a consistent proportional effect on break-even gross margins, irrespective of development options or costs, so results were simplified as a set of risk adjustment multipliers (which could be applied to the baseline tables of break-even gross margins presented before). These same multipliers apply to the break-even water prices that irrigators can afford to pay.

Table 6-12 Risk adjustment multipliers for break-even gross margins, accounting for the effects of reliability and severity (level of farm performance in ‘failed’ years) of periodic risks

Results are not affected by discount rates. ‘Good’ years = 100% farm performance; ‘Failed’ = <100% performance. ‘Failed year performance’ is the mean farm gross margin in years where some type of setback is experienced relative to the mean gross margin when the farm is running at ‘full’ performance.

FAILED YEAR PERFORMANCE	BREAK-EVEN GROSS MARGIN RISK ADJUSTMENT MULTIPLIER (VS BASE 100% RELIABILITY TABLES)									
	Reliability (Proportion of 'good' years)									
	1.00	0.90	0.85	0.80	0.70	0.60	0.50	0.40	0.30	0.20
85%	1.00	1.02	1.02	1.03	1.05	1.06	1.08	1.10	1.12	1.14
75%	1.00	1.03	1.04	1.05	1.08	1.11	1.14	1.18	1.21	1.25
50%	1.00	1.05	1.08	1.11	1.18	1.25	1.33	1.43	1.54	1.67
25%	1.00	1.08	1.13	1.18	1.29	1.43	1.60	1.82	2.11	2.50
0%	1.00	1.11	1.18	1.25	1.43	1.67	2.00	2.50	3.33	5.00

As would be expected, the greater the frequency and severity of ‘failed’ years, the greater the impact on scheme viability and the greater the increase in farm gross margins that would be required to offset these impacts. As an example, the reliability of water supply is one of the more important sources of unavoidable variability in productivity of irrigated farms. If the planted area of land was reduced in years without a full supply (‘failed’ years) so that the cropped area was always fully irrigated, then the water reliability is the same as the periodic risk reliability

(Table 6-12) and the proportion of water available in a 'failed' year is equivalent to the mean farm performance. For example, if a water supply was 85% reliable and provided on average 75% of its full supply in 'failed' years, the risk adjustment multiplier that would have to be applied to baseline break-even gross margins (Table 6-6 and Table 6-11) would be 1.04 (Table 6-12). This means a 4% higher gross margin would be required to break even than if water could be supplied at 100% reliability. For crops where the quality of produce is more important than the quantity, such as annual horticulture crops, the approach of reducing planted land area in proportion to available water in 'failed' years seems reasonable. However, for perennial horticulture or tree crops it may be difficult to reduce (or increase) areas on an annual basis and farmers of these crops will therefore tend to opt for systems with a high degree of reliability of water supply (e.g. 95%). For many broadacre crops, it may be possible to deficit irrigate a larger area to slightly mitigate the impact of years with lower water allocations. As shown in Section 4.5, the agronomic optimum does not necessarily equal the economic optimum. Measures such as deficit irrigation could partially mitigate impacts on farm performance in years with reduced water availability, as could carryover effects from inputs (such as fertiliser) in a failed year that reduce input costs the following year.

Table 6-13 summarises how timing of periodic impacts affects scheme viability, providing break-even risk adjustment multipliers for a range of reliabilities for an impact that had 50% severity with late timing, early timing, and no (long-term frequency weighted mean performance) timing.

These results show that any negative disturbances that reduce farm performance will have a larger effect if they occur early on after the scheme is established, and that this effect is greater at higher discount rates (or higher target IRRs). For example, at a 7% discount rate and 70% reliability with 'late' timing (where setbacks occur in the in the last three of every 10 years) the gross margin multiplier is 1.13, meaning the annual farm gross margin would need to be 13% higher than if farm performance were 100% reliable. In contrast, for the same settings with 'early' timing, the gross margin multiplier is 1.23, so impacts of early setbacks are more severe and the farm gross margin would have to be 23% higher than if farm performance were 100% reliable.

Table 6-13 Risk adjustment multipliers for break-even gross margins, accounting for the effects of reliability and timing of periodic risks

Assumes 50% farm performance during 'failed' years, where 50% farm performance means 50% of the gross margin at 'full' potential production.

TARGET IRR	TIMING OF FAILED YEARS	BREAK-EVEN GROSS MARGIN RISK ADJUSTMENT MULTIPLIER (VS BASE 100% RELIABILITY TABLES)								
		Reliability (proportion of 'good' years)								
		1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20
3%	Late	1.00	1.05	1.10	1.16	1.22	1.30	1.39	1.50	1.63
	Mean – no timing	1.00	1.05	1.11	1.18	1.25	1.33	1.43	1.54	1.67
	Early	1.00	1.06	1.13	1.20	1.28	1.37	1.47	1.58	1.70
7%	Late	1.00	1.04	1.08	1.13	1.19	1.26	1.35	1.46	1.59
	Mean – no timing	1.00	1.05	1.11	1.18	1.25	1.33	1.43	1.54	1.67
	Early	1.00	1.07	1.15	1.23	1.32	1.41	1.51	1.62	1.74
10%	Late	1.00	1.03	1.07	1.12	1.17	1.24	1.32	1.42	1.56

TARGET IRR	TIMING OF FAILED YEARS	BREAK-EVEN GROSS MARGIN RISK ADJUSTMENT MULTIPLIER (VS BASE 100% RELIABILITY TABLES)								
	Mean – no timing	1.00	1.05	1.11	1.18	1.25	1.33	1.43	1.54	1.67
	Early	1.00	1.08	1.16	1.25	1.35	1.45	1.55	1.66	1.77

Risks from initial 'learning' period

Another form of risk arises from the initial challenges in establishing and adapting agriculture in a new part of the Mitchell catchment, and includes setbacks from delays, such as gaining regulatory approvals. Some of these risks are avoidable if investors and farmers learn from past experiences of development in northern Australia (e.g. Ash et al., 2014), avoid previous mistakes, and select farming options that are already well proven in analogous locations. However, even if developers are well-prepared, there are likely to be initial challenges in adapting to the unique circumstances of a new location. Newly developed farmland can take some time to reach its productive potential as soil nutrient pools are established, soil limitations are ameliorated, suckers and weeds are controlled, and pest management systems are established.

'Learning' (used here to broadly represent all aspects of overcoming initial sources of farm underperformance) was assessed in terms of two simplified generic characteristics:

- initial level of performance: represented as described before, as the proportion of the long-term, mean gross margin that the farm achieves in its first year
- time to learn: the number of years taken to reach the long-term, mean farm performance. Performance was represented as increasing linearly over the learning period from the starting level to the long-term mean performance level (100%).

The effect of learning on scheme financial viability was considered for a range of initial levels of farm performance and learning times. As before, learning had consistent proportional effects on break-even gross margins, so results were simplified as a set of risk adjustment multipliers (Table 6-14). As would be expected, the impacts on scheme viability are greater the lower the starting level of farm performance and the longer it takes to reach the long-term performance level. Since these impacts, by their nature, are weighted to the early years of a new development, they have more impact at higher discount rates (and investors' target IRRs). To minimise risks of learning impacts, there is a strong incentive to start any new irrigation development with well-established crops and technologies, and to be thoroughly prepared for the anticipatable agronomic risks of establishing new farmland. Higher-risk options (e.g. novel crops, equipment or practices that are not currently in profitable commercial use in analogous environments) could be tested and refined on a small scale until locally proven.

Table 6-14 Risk adjustment multipliers for break-even gross margins, accounting for the effects of learning risks
Learning risks were expressed as the level of initial farm underperformance and time taken to reach full performance levels. Initial farm performance is the initial gross margin as a percentage of the gross margin at 'full' performance.

TARGET IRR	INITIAL FARM PERFORMANCE	BREAK-EVEN GROSS MARGIN RISK ADJUSTMENT MULTIPLIER (VS BASE 100% RELIABILITY TABLES)					
		Learning time (years to 100% performance)					
		2	**4**	**6**	**8**	**10**	**15**
3%	**85%**	1.01	1.02	1.03	1.03	1.04	1.05
	75%	1.02	1.03	1.04	1.05	1.07	1.10

TARGET IRR	INITIAL FARM PERFORMANCE	BREAK-EVEN GROSS MARGIN RISK ADJUSTMENT MULTIPLIER (VS BASE 100% RELIABILITY TABLES)					
	50%	1.04	1.06	1.09	1.12	1.14	1.21
	25%	1.06	1.10	1.14	1.19	1.23	1.35
	0%	1.08	1.14	1.20	1.26	1.33	1.53
7%	**85%**	1.02	1.03	1.04	1.05	1.05	1.07
	75%	1.03	1.05	1.06	1.08	1.09	1.13
	50%	1.06	1.10	1.13	1.17	1.21	1.29
	25%	1.09	1.15	1.22	1.28	1.35	1.51
	0%	1.12	1.21	1.31	1.41	1.52	1.83
10%	**85%**	1.02	1.03	1.05	1.06	1.07	1.09
	75%	1.04	1.06	1.08	1.10	1.11	1.15
	50%	1.08	1.12	1.17	1.21	1.26	1.35
	25%	1.12	1.20	1.28	1.36	1.44	1.65
	0%	1.16	1.28	1.41	1.55	1.69	2.10

Risks and benefits of staged development

One possible strategy for dealing with learning risks could be to stage development, so that the bulk of the overall capital investment is delayed until farming systems have been tested and locally adapted to new parts of the Mitchell catchment on a smaller scale. Illustrative examples are provided below to demonstrate general principles about the risks and benefits of staging.

Table 6-15 shows the effects on scheme financial returns for seven severities of learning risk: initial farm performance was set at levels from 100 to –20% and performance was increased by 10% each year so that corresponding learning times to full performance were zero to 12 years (as per the first two columns of Table 6-15).

Staging considered four options in which initially only 5% of the total land area was developed and the remaining area was developed after delays of zero, 4, 8 and 12 years (where the zero-year delay corresponds to no staging). Staging was considered for both the dam and on-farm water source development options used in the baseline assessments (Section 6.3.2) retaining the standard assumptions (Table 6-5 and Table 6-10). However, some extra details had to be specified in order to run the analyses. These were set towards the more favourable end of what might be possible, but with an emphasis on making relative comparisons between staging options. Both the dam and the on-farm water source developments used a farm gross margin of $2500/ha (representative of the upper range for broadacre crops, see Section 4.5) and an annual water reliability of 85%, with 77% of the full water supply available on average in the other 15% of years. The total costs at project completion were assumed to be unaffected by how the project was staged (i.e. no wasted test infrastructure from stage 1, or cost inefficiencies from developing parts of the assets at different times).

For the dam development option, staging involved building the weir first and delaying building the main dam. It was assumed that the weir and other 'core' off-farm infrastructure (e.g. access road, channels and approvals) required to get the test stage of development operational would cost 7% of the total project costs for 'core' infrastructure (Table 6-5). 'Area-dependent' infrastructure was scaled linearly with the area developed, so 5% of those costs (Table 6-5) were incurred in the test stage. Costs for developing water and land resources were assumed to be $20,000/ha.

The on-farm water source was assumed to be entirely modular, so that each unit of farmland could be developed entirely independently of the next, scaling total project costs to the proportion of land developed (5% in the test stage). Costs for developing water and land resources were assumed to be $10,000/ha.

A comparison of IRRs between staging options (Table 6-15) shows that the financial penalties for not staging increase as learning risks become more severe (in terms of lower starting performance and longer learning times). The impacts of learning risks could best be offset by matching the delay in proceeding to full-scale development to the learning time (i.e. completing development only once the test stage had reached full financial performance). Delaying full development for longer periods than the learning time had only a slight negative effect on IRRs, whereas proceeding to full development before learning was complete had a much larger impact. This implies that it would be prudent to err on the side of delaying full development (particularly given that in practice, it would only be possible to know when full performance was achieved in retrospect, not in advance).

Staging is complex and there is a wide range of other risks and benefits that would need to be considered beyond these simple, illustrative examples. An added benefit of staging would be limiting losses where small-scale testing proves initial assumptions of costs and benefits to be over-optimistic and that full-scale development could never be profitable, even after trying to overcome unanticipated challenges. In such cases, losses could be reduced by opting not to proceed with further development. Indeed, financiers of a development might stage release of loans for this reason as a risk control measure. However, staging can transfer risks from one party to another and might not be uniformly beneficial to all parties involved in a development. For example, staged finance might delay development stages beyond what is optimal for learning times, even when development options are well proven and developers would prefer to proceed more quickly. Similarly, if staging is implemented to control risks of farm performance, while farming practices are adapted to local conditions, this could transfer risks to investors in supporting infrastructure further down the supply chain. This is particularly the case for crops such as sugarcane and cotton, where local processing is integral to the industry and requires production at large scale to be viable. Delays in development beyond optimal learning times could also be imposed for other reasons, such as logistic constraints on the rate at which land could be developed, seed material could be propagated (for clonal crops) or skilled labour could be recruited. The IRRs in Table 6-15 indicate that short-term delays (<2 years) would likely have only a minimal impact on scheme financial performance.

Table 6-15 Effect of different staging options on scheme performance for a range of learning risks

Scheme performance was measured as the internal rate of return (IRR) for each combination of staging and learning. The staging delay with the highest IRR for each level of learning risk (row) is highlighted in darker blue, and delays with IRRs within 0.2% of the best IRR are highlighted in lighter blue. Staging involved initially developing 5% of the farmland for testing, then allowing for learning periods of different durations before proceeding to full development.

STARTING PERFORMANCE	LEARNING TIME (y)	IRR FOR STAGING OPTION (%)			
		Dam/weir staging options (no. years delay to full development)			
		0 (no staging)	4	8	12
100%	0	2.1	2.0	1.9	1.9
80%	2	2.0	2.0	1.9	1.9
60%	4	1.6	1.9	1.9	1.8
40%	6	1.2	1.7	1.9	1.8
20%	8	0.6	1.2	1.8	1.7
0%	10	-0.1	0.6	1.5	1.7
–20%	12	-0.8	0.0	1.0	1.5
		On-farm bore staging options (no. years delay to full development)			
		0 (no staging)	4	8	12
100%	0	6.7	6.5	6.3	6.3
80%	2	6.3	6.4	6.3	6.2
60%	4	5.5	6.3	6.2	6.1
40%	6	4.5	5.6	6.1	6.0
20%	8	3.3	4.6	5.9	5.8
0%	10	2.1	3.5	5.1	5.6
–20%	12	0.9	2.2	4.1	5.3

Some of the assumptions in the illustrative examples were oversimplified. For example, staging may well incur extra costs if purchasing assets and services for development at different times is less efficient than doing so over one concentrated period, or if some of the infrastructure from the test stage does not fit with the requirements of the completed scheme. In addition, learning was considered to occur entirely at the small test scale and to then be completely scalable to full development. In reality, as highlighted by Ash et al. (2014), some of the most substantial challenges in past agricultural developments in northern Australia have come in the scaling-up phase. There is no guarantee that success at the level of an individual farm will necessarily scale easily to establishing a large new industry in a certain location. This is particularly the case if success at the farm level is based on taking advantage of case-specific opportunities that are not easily duplicated at scale. Challenges in scaling up production could include the need for local processing facilities, access to sufficient capital, establishing and expanding markets and supply chains, training and recruiting skilled labour, availability of local support services, and building new transport and utilities infrastructure to address bottlenecks. There would be a component of learning associated with addressing these scaling challenges. An intermediate staging step, after the initial small-scale testing, might help with this learning. Such intermediate stages are better suited to developments using modular on-farm water sources than those that are based on a single, large dam.

6.3.4 POTENTIAL BENEFITS FROM INDUSTRY SYNERGIES AND INTEGRATION

Off-farm value adding and synergies could contribute to the viability of a potential new scheme in the Mitchell catchment. The illustrative example explored here was adding a sugar mill to an irrigated sugarcane scheme, which demonstrated that the benefit from the higher value of the processed cane exceeds the additional costs of building and running a mill. This also suggested that an additional by-product, cogeneration of electricity, would likely be required if any such scheme were to be viable.

Sugar was used as an illustrative example because of the relatively high value adding from local processing to illustrate the upper-end potential of synergies beyond the farm gate. A wide range of other synergies could also be considered to improve scheme revenues or share costs, as listed at the end of this section. It should be noted, however, that the more complex a scheme becomes and the more strongly interdependent its components, the greater the risk that underperformance of one component could undermine the viability of the entire scheme.

Results are presented for two options for integrating a sugar mill into a scheme:

- a mill operating on a standard 6-month harvest/crushing season, producing sugar only
- a mill operating on a 6-month season with electricity cogeneration added.

Assumptions were the same as for the generic dam (Table 6-5) except that a specific scheme size was used, details of sugar cropping were added, a sugar mill was added (with associated extra streams of costs and benefits), and water supply was assumed to be 85% reliable with 77% of the full water yield available on average in the other 15% of years (Table 6-16). Although some specific values had to be assumed for the purposes of the analysis, these should be considered as roughly indicative, and the emphasis was on the relative comparison between options rather than absolute values of results. Electricity cogeneration in remote locations is particularly difficult in this regard, given how site-specific it would be. Rough costs are provided in the assumptions below, which included a $20 million grid-connection cost. Wholesale electricity prices on the National Electricity Market (NEM) have more than doubled in the past 5 years, averaging about $90/MWh in 2017 and projected to be about $80/MWh in 2018 (AEMO, 2017). Renewable energy certificates (RECs) traded at about $85 per large-scale generation certificate (LGC, in units of MWh) in 2017, but the future of RECs is uncertain. Given the uncertainty in electricity prices over the life of the project, analyses used a conservative electricity price of $90/MWh, but also used a higher price of $165/MWh for comparison.

Table 6-16 Assumptions used for incorporating a sugar mill into an irrigation scheme

Two options for integrating a mill were explored. Cogen = cogeneration of electricity from bagasse (fibre); CCS = commercial cane sugar. Water reliability was assumed to be 85% with a mean of 77% of the full water yield available in the other 15% of years.

ITEM	UNITS	6-mo SEASON SUGAR ONLY	6-mo SEASON + COGEN
Scheme size			
Scheme area	ha	50,000	50,000
Capital costs of water and land development†	$ million	1,000	1,000
Capital costs per ha for water and land development†	$/ha	20,000	20,000
Cropping			
Mean area under cropping (1 in 5 year fallow)	%	80	80
Crop applied irrigation water (before application losses)	ML/ha	10	10
Crop yield (excluding fallow years)	t cane/ha	120	120
Sugarcane CCS (sugar content mill can extract from cane)	%	15.0	15.0
Sugarcane fibre content (affects rate mill can crush cane)	%	15.0	15.0
Farm variable costs of growing crop	$/ha	1,100	1,100
Farm variable costs of harvesting crop	$/t cane	8.00	8.00
Cane price (industry formula based on sugar price)	$/t cane	44.55	44.55
Processing			
Length of crushing season	month	6	6
Mill capital cost (including connection to grid for cogen)	$ million	**481**	**716**
Mill throughput rate	t/h	1,214	1,214
Mill reliability (% time operational)	%	90	90
Cane transport costs (farm to mill)	$/t	3	3
Processing costs	$ million/y	34	35
Sugar transport costs (mill to port)	$/t	50	50
Raw sugar price	$/t	450	450
Net exported electricity generation (per t bagasse)	MWh/t	**na**‡	0.5
Electricity transmission losses	%	**na**	5.0
Electricity sale price	$/MWh	**na**	90 and 165

Source: Details for mill processing costs provided in companion technical report on socio-economics (Stokes et al., 2017).
†Water supplier development costs of $20,000/ha equate to a dam cost of $650/ML/year yielded at the dam wall (with 85% reliability), assuming overall system efficiency of 55% (18 ML/ha/year applied irrigation water at dam wall) and an additional $10,500/ha supplier development costs.
‡na = not applicable

Results for both options showed that proportional increases in revenues from processed versus unprocessed products (54% extra revenue for sugar processing only, to 60% and 81% for sugar processing and cogeneration assuming electricity prices of $90 and $165/MWh, respectively) exceeded the proportional increases in scheme capital costs from adding a mill (37% for sugar processing only, to 55% with cogeneration) (Table 6-17). Accordingly, scheme financial returns increased substantially from a level that was unlikely to be viable at the farm gate (IRR = 4.0%) to an IRR of 5.1% with milling (with cogeneration) and an IRR of 6.6% at the higher electricity prices (including LGCs). The latter level might start to become attractive to investors if a location with the right mix of characteristics could be found with more favourable costs and prices than those used in these rough assumptions, and if there was greater certainty in pricing of renewable energy generation.

Adding a mill without cogeneration made little improvement to financial returns beyond those at the farm gate without processing (IRRs of 4.2% and 4.0% respectively). Cogeneration of electricity would likely be required to make an irrigated sugarcane scheme viable. However, given the complexity and uncertainty associated with doing this in a greenfield remote location, it would be important to determine costings and risks in detail on a case-by-case basis.

Table 6-17 Comparison of financial performance of an irrigation scheme with and without a sugar mill included

Two options for integrating a mill were explored. Cogen = cogeneration of electricity from bagasse (fibre); IRR = internal rate of return. Given the uncertainty in wholesale electricity prices, the comparison is repeated at the bottom of the table for an alternate, higher electricity price (including large-scale generation certificates for renewable energy).

PERFORMANCE METRIC	UNITS	6-mo SEASON SUGAR ONLY	6-mo SEASON + COGEN
Scheme from dam to farm gate			
Revenue from sugarcane	$ million	214	214
Total capital cost of development	$ million	1297	1297
Scheme IRR (farm gate)	%	4.0	4.0
Scheme from dam to port (including processing, applies to both electricity prices below)			
Revenue from raw sugar	$ million	324	324
Revenue from molasses	$ million	6	6
Total capital cost of development	$ million	1778	2013
Scheme comparison: Processing vs farm gate (price for cogenerated electricity = $90/MWh)			
Revenue from electricity (to node, after losses)	$ million	0	31
% extra capital spent	%	37	55
% extra revenue generated	%	54	69
Scheme IRR (to port)	%	4.2	5.1
Scheme comparison: Processing vs farm gate (alternate price for cogenerated electricity = $165/MWh)			
Revenue from electricity (to node, after losses)	$ million	0	56
% extra capital spent	%	37	55
% extra revenue generated	%	54	81
Scheme IRR (to port)	%	4.2	6.6

Other synergies that could also be considered to improve scheme revenues or reduce costs would include: sequential cropping (increasing net farm revenue by producing more than one crop from the same field each year), local use of by-products (such as feed supplements for livestock), including small-scale, high-value crops in the mix of farms in a scheme; expanding the scale of a scheme with extra dryland/opportunistic cropping around the irrigated core; improving transport infrastructure and supply chains (reducing the disadvantages of remote locations); generating hydro-electric power; and integrating farming industries (savings from synergies). Many of these options are untested, so location-appropriate details would need to be developed and proven before they could be seriously considered. Indirect costs and benefits beyond the irrigation scheme could also be important when considering public investment in new water infrastructure. Regional economic benefits are covered in the next section, while non-market impacts are covered in Chapters 3 and 7, but are not converted to dollar values.

6.4 Regional-scale economic impact of irrigated development

A water storage development scheme to promote irrigated agriculture or aquaculture could provide economic benefits to the Mitchell catchment and broader region in terms of both increased economic activity and jobs. The size of the total economic benefits experienced would depend on the scale of the development, the type of agriculture that is established, and how much spending from the increased economic activities occurs within the region. Regional economic impacts would be an important consideration for evaluating potential new water development projects.

It was estimated that each dollar spent on construction within the Mitchell catchment generated an additional $1.22 of indirect benefits ($2.22 total regional benefits including the direct benefit of each $1.00 spent on construction). Each dollar of direct benefit from new agricultural activity was estimated to generate an additional $0.96 to $1.10 in regional economic activity (depending on the particular agricultural industry).

If $2 billion capital was spent on developing an irrigated agricultural scheme within the Mitchell catchment, and 50% of this capital cost was spent locally, the one-off total economic activity generated from this construction within the catchment and surrounding region would be $2.22 billion (from Table 6-21). Assuming this development directly enabled an extra $100 million of output per year on a continuing basis through the lifetime of the irrigation scheme from irrigated cropping, then the region would benefit from $210 million of economic activity recurring annually (from Table 6-19) and generate about 1000 full-time equivalent jobs (from Table 6-20).

There would be additional national benefits from expenditure flowing to other regions, and the stabilising effect of geographic diversification on agricultural production in the face of local disruptions, such as climate variability or regional water reforms.

The full, catchment-wide impact of the economic stimulus provided by an irrigated agriculture or aquaculture development project extends far beyond the impact on those businesses and workers directly involved in either the short term (construction phase) or longer term (operational phase). Those businesses directly benefitting from the project would need to increase their purchases of the raw materials and intermediate products used by their growing outputs. Should any of these purchases be made within the surrounding region, then this provides a stimulus to those businesses from which they purchase, contributing to further economic growth within the region. Furthermore, household incomes increase as a result of those local residents who are employed (as a consequence of the direct and/or production-induced business stimuli). As a proportion of their additional income is spent in the region, this expenditure further stimulates the economic activity within the region. Accordingly, the larger the initial amount of money spent within the region, and the larger the proportion of that money re-spent locally, the greater the overall benefits that will accrue to the region.

The size of the impact on the local regional economy can be quantified by regional economic multipliers (derived from I–O tables that summarise expenditure flows between industry sectors and households within the region), where a larger multiplier indicates larger regional benefits. These multipliers can be used to estimate the value of increased regional economic activity likely to flow from stimulus to particular industries, focusing here on construction in the short term and different types of agriculture in the longer term.

It is also possible to estimate the increase in household incomes in the region. From this, an estimate can be made of the approximate number of jobs represented by the increased economic activity (including both those directly related to the increase in agriculture, and those generated indirectly within other industries in the region).

Not all of the expenditure generated by a large-scale development will occur within the local region. The greater the leakage (i.e. the amount of direct and indirect expenditure made outside the region), the smaller the resulting economic benefit that will be enjoyed by the region. Conversely, the more of the initial spend and subsequent indirect spend that is retained within the region, the greater the economic benefit and the number of jobs created within the local region. However, a booming local economy can also bring with it a range of issues that can place upward pressure on prices (including materials, houses and wages) in the region, negating some of the positive impacts of the development. If some of the unemployed or underemployed people within the Mitchell catchment could be engaged as workers during the construction and/or operational phases of the development this could reduce pressure on local wages and reduce the leakage resulting from the use of fly-in fly-out (FIFO) or drive-in drive-out (DIDO) workers, retaining more of the benefit from the project within the local region. Census 2016 data showed an unemployment rate of 11.2% within the Mitchell catchment, indicating local workers may be available within the region.

The overall regional benefit created by a particular development depends on both the one-off benefits from the construction phase and the ongoing annual benefits from the operational phase. The benefits from the operational phase may take a number of years to reach the expected level, as new and existing agricultural enterprises learn and adapt to make full use of the new opportunities presented by the development. It is important to note that the results presented here are based on illustrative scenarios incorporating broad assumptions, are derived from an I–O model developed for an I–O region that is larger than the Mitchell catchment study area, and are subject to the limitations of the method.

6.4.1 ESTIMATING THE SIZE OF REGIONAL ECONOMIC BENEFITS

To develop regional multipliers for the Mitchell catchment, it was necessary to use available information and models for the Far North Queensland input–output (FNQ I–O) region (Office of the Government Statistician Queensland Government, 2004), within which the Mitchell catchment predominantly sits. For more detail, see companion technical report on socio-economics (Stokes et al., 2017) and (Figure 6-2). Additional data are presented to show how economic circumstances of the Mitchell catchment compare to the larger I–O region (Table 6-18). The FNQ I–O table captures economic activity across a large and varied region (the FNQ I–O region comprises a mix of urban, rural and remote areas, including the city of Cairns, the islands of the Torres Strait and Cape York), whereas the Mitchell catchment itself is less diverse, contains no major city, and has a smaller economy overall. The economic impact within the catchment is therefore likely to be smaller than that estimated here.

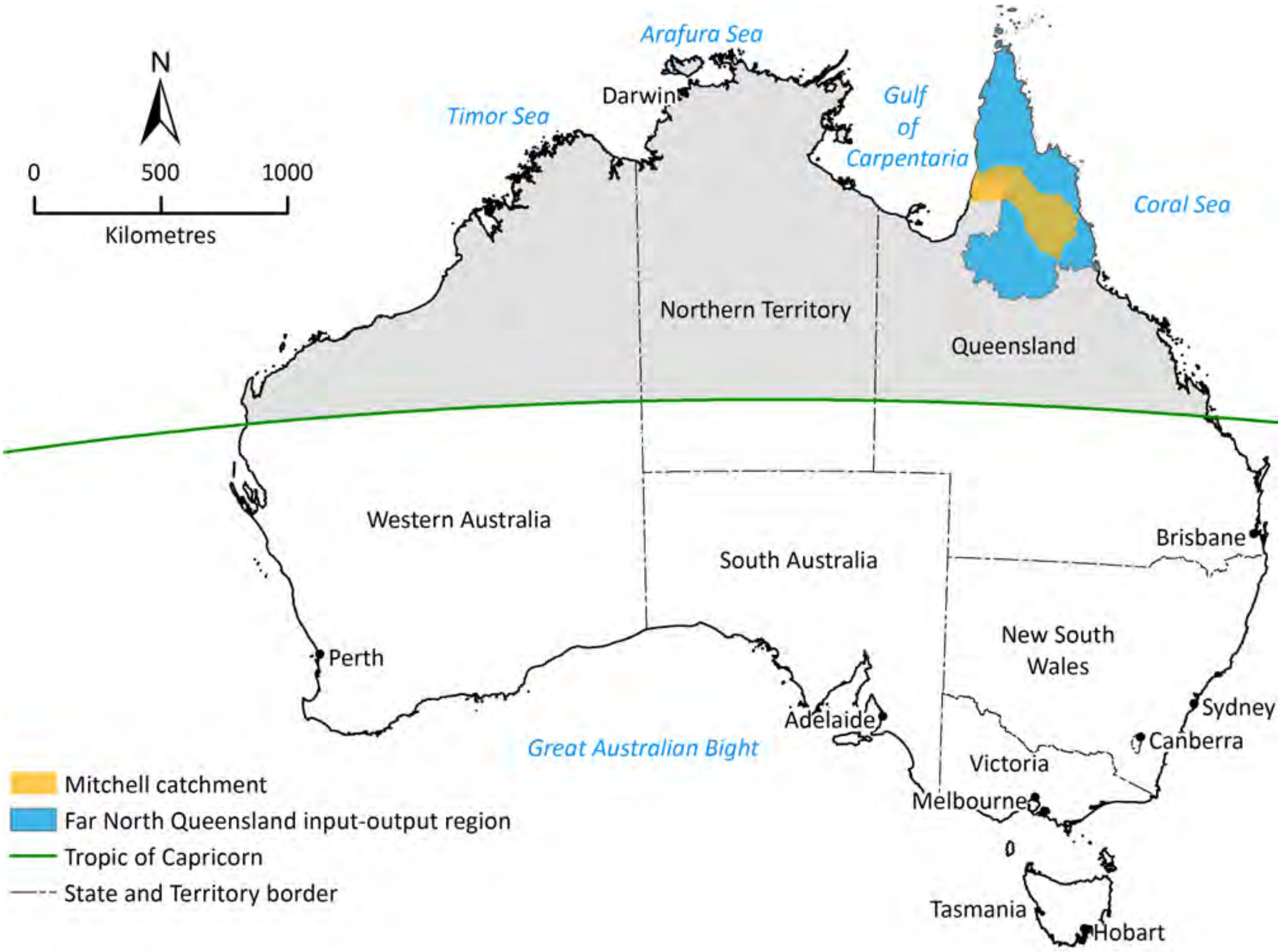

Figure 6-2 Far North Queensland input–output region relative to the Mitchell catchment

Table 6-18 Key 2016 data comparing the Mitchell catchment with the Far North Queensland input–output region

INDICATOR	MITCHELL CATCHMENT	FAR NORTH QUEENSLAND
Land area (ha '000)†	7,153	27,222
Population‡	6,365	272,580
% male‡	57.6%	50.0%
% Indigenous‡	25.8%	15.2%
Median age‡	42	38*
Median household income§	$51,272/y	$63,548/y††

†Data sourced from ABS (2017)
‡Data sourced from ABS (2016a)
§Data sourced from ABS (2016b)
*The median age for Far North Queensland has been estimated based on the weighted average of the median age in the component ABS sub-divisions (Cairns SA4 region and Far North SA3 region), weighted by total population, as ABS no longer reports data for the Far North Queensland I–O region.
††The median household income for Far North Queensland has been estimated based on the weighted average of the median household incomes in the component sub-divisions, weighted by number of households, as ABS no longer reports data for the Far North Queensland I–O region.

Wide variations can be seen in the size of the multipliers for different industries within the FNQ I–O region (Figure 6-3). Those industries with larger local regional multipliers would be expected to benefit more from development within the I–O region. For example, the 'Beef cattle' industry generated a smaller multiplier than 'Wholesale and retail trade', but a larger multiplier than 'Mining'. However, a simple comparison of I–O multipliers can be misleading when considering different options for regional investment because some impacts provide a short-term, one-off benefit (e.g. the construction phase of a new irrigation development), while others provide a sustained stream of benefits over the longer term (e.g. the production phase of a new irrigation scheme). A rigorous comparison between specific regional investment options would require NPVs of the full cost and benefit streams to be calculated.

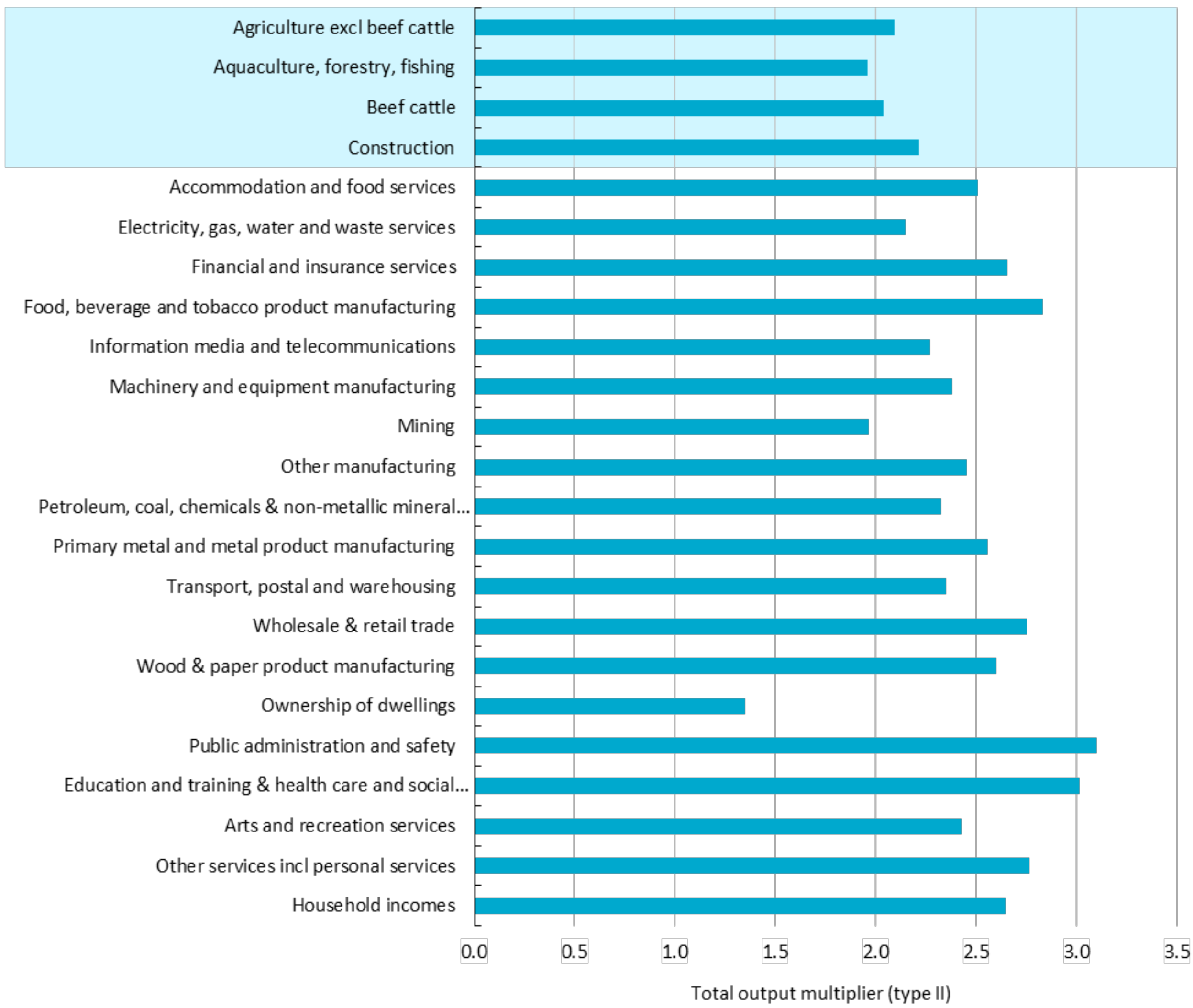

Figure 6-3 Multipliers for each industry within the Far North Queensland input–output region
Shaded box highlights the multipliers for industries (in agriculture and construction) used to estimate regional economic benefits below. Multipliers used here (Type II) combine both the initial direct expenditure in a particular industry and the knock-on benefits to other businesses and industries along the supply chain. For detail on the development of multipliers see the companion technical report on socio-economics (Stokes et al., 2017).

6.4.2 INDIRECT BENEFITS DURING THE OPERATIONAL PHASE OF A DEVELOPMENT

Impacts of development on the I–O region are presented for four scales of increase in gross economic output ($25, $50, $100 and $200 million/year, indicative of potential outcomes) in each of three categories of agricultural activity ('Beef cattle', 'Agriculture excluding beef cattle', and 'Aquaculture, forestry and fishing'). Impacts are shown as the total increased economic activity (Table 6-19) in the FNQ I–O region and the associated estimate of increase in employment (based on median incomes in the I–O region) (Table 6-20). Note that all results scale linearly as the economic output of each type of agricultural activity increases.

Table 6-19 Estimated regional economic impact per year resulting from four scales of direct increase in agricultural output (rows) for each of three different categories of agricultural activity (columns) in the Far North Queensland input–output (FNQ I–O) region

The value of increased agricultural economic activity can be calculated by multiplying the new area under irrigation by the mean increase in farm revenue received for the new (versus previous) agricultural produce.

DIRECT INCREASE IN AGRICULTURAL OUTPUT PER YEAR ($ MILLION)	TOTAL VALUE OF INCREASED ECONOMIC ACTIVITY IN FNQ I–O REGION – DIRECT, PRODUCTION INDUCED AND CONSUMPTION INDUCED ($ MILLION)		
	Type of agricultural development		
	Beef cattle	Agriculture excluding beef cattle	Aquaculture, forestry & fishing
25	51.0	52.4	48.9
50	102.0	104.8	97.9
100	203.9	209.5	195.7
200	407.9	419.0	391.4

As can be seen from the economic impacts (Table 6-19), an irrigation scheme that promotes 'Agriculture excluding beef cattle' could have a slightly larger regional impact in the FNQ I–O region than a scheme promoting 'Beef cattle' or 'Aquaculture, forestry and fishing'. These differences result from the different industry multipliers estimated for the FNQ I–O region (Figure 6-3).

Table 6-20 Estimated number of full-time equivalent jobs from four scales of increase in agricultural output (rows) for each of three different categories of agricultural activity (columns) in the Far North Queensland input–output (FNQ I–O) region

DIRECT INCREASE IN AGRICULTURAL OUTPUT PER YEAR ($ MILLION)	TOTAL NUMBER OF ADDITIONAL JOBS IN FNQ I–O REGION – DIRECT, PRODUCTION INDUCED AND CONSUMPTION INDUCED		
	Type of agricultural development		
	Beef cattle	Agriculture excluding beef cattle	Aquaculture, forestry & fishing
25	189	253	223
50	378	506	445
100	756	1012	890
200	1511	2023	1780

The results for employment (Table 6-20) are closely related to those for impacts on regional economic activity, but the two measures do reveal some differences. These additional full-time equivalent jobs arising in the FNQ I–O region may require additional community infrastructure (schools, health services etc.) if workers move to fill these jobs from other parts of the country, resulting in population growth within the FNQ I–O region. However, should these additional jobs be filled by currently unemployed or underemployed local people, then additional infrastructure would not be necessary.

6.4.3 INDIRECT BENEFITS DURING THE CONSTRUCTION PHASE OF A DEVELOPMENT

While initially the building of new infrastructure (on-farm and off-farm development, including construction of related supporting infrastructure such as roads, schools and hospitals) comes at a cost, the additional expenditure within a region (which puts additional cash into people's and businesses' pockets) would increase regional economic activity. This creates a fairly short-term economic benefit to the region during the construction phase, provided that at least some of the expenditure is within the region and is not all lost from the region due to leakage.

The proportion of expenditure during the construction phase that would be spent within the region depends on the different costs, including for labour, materials and equipment. For labour costs, it is likely that the wages will be paid to workers sourced from within the region and from elsewhere, with the likely proportion of labour costs relating to each source of workers being dependent on the availability of appropriately skilled labour within the region. For example, a highly populated region (more than 100,000 people) with a high unemployment rate (more than 10%) and skilled labour force is likely to be able to supply a large proportion of the workers required from within the region. However, a sparsely populated region with a low unemployment rate (less than 5%) is more likely to need to attract many workers from outside the region, either on a FIFO/DIDO basis or by encouraging migration to the region. Similarly, for materials and equipment, some regions may be better able to supply a large proportion of these items from within the region whereas construction projects in other locations may find they are unable to source what they need locally and instead import a significant proportion into the region from elsewhere.

Based on a review of different dam projects across the country, it would appear that the proportions of local construction spend sourced within a region (as opposed to being imported, which has no impact on the regional economy) vary significantly. Thus, analyses considered three levels for the proportion spent locally: 65% (low leakage), 50% and 35% (high leakage). However, it should be noted that for a very remote region, the potential exists for leakage to be higher than 65%.

Table 6-21 shows estimates of the regional economic benefit of the construction phase of a new development for five scales of scheme capital cost ($0.25 billion to $4 billion) and the three levels of leakage noted above.

Table 6-21 Estimated regional economic benefit of the construction phase of a development designed to promote an irrigated agricultural development within the Far North Queensland input–output (FNQ I–O) region

SCHEME-SCALE CAPITAL COST ($ BILLION)	TOTAL REGIONAL ECONOMIC ACTIVITY WITHIN FNQ I–O REGION AS A RESULT OF THE CAPITAL COST OF THE SCHEME ($ BILLION)		
	Proportion of total construction capital costs made locally within the I–O region		
	65%	50%	35%
0.250	0.36	0.28	0.19
0.500	0.72	0.55	0.39

SCHEME-SCALE CAPITAL COST ($ BILLION)	TOTAL REGIONAL ECONOMIC ACTIVITY WITHIN FNQ I–O REGION AS A RESULT OF THE CAPITAL COST OF THE SCHEME ($ BILLION)		
1.000	1.44	1.10	0.78
2.000	2.88	2.22	1.55
4.000	5.76	4.43	3.10

These results show that the size of the regional economic benefit experienced increases substantially as the proportion of scheme construction costs spent within the region increases. Given the proximity of potential Mitchell catchment dam sites to Cairns, leakage may be towards the middle of the range examined. For example, if $2 billion was spent on construction for a new dam project and only 50% of that was spent within the FNQ I–O region, the construction multiplier (2.22, Figure 6-3) would only apply to the $1 billion spent locally, to give an overall regional economic benefit of $2.22 billion (with additional benefits flowing to other regions where the remaining $1 billion was spent).

6.5 References

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7 Ecological, biosecurity, off-site and irrigation-induced salinity risks

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Chapter 7 discusses a range of potential risks to be considered before establishing a greenfield agriculture or aquaculture development. These include the ecological implications of altered flow regimes, a range of biosecurity considerations, off-site impacts from sediments, nutrients and agropollutants, irrigation drainage and aquaculture discharge water and irrigation-induced salinity.

The key components and concepts of Chapter 7 are shown in Figure 7-1.

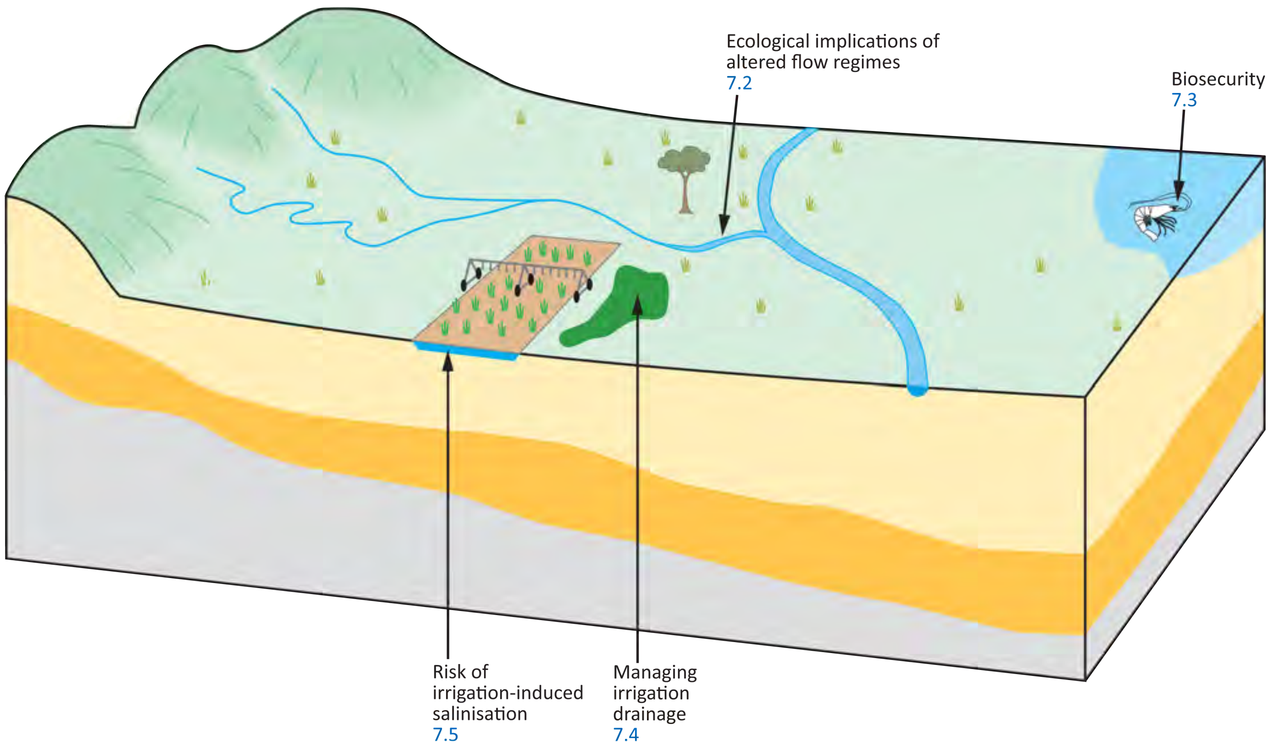

Figure 7-1 Schematic diagram of the components where key risks can manifest when considering the establishment of a greenfield irrigation or aquaculture development

7.1 Summary

This chapter provides information on the ecological, biosecurity, off-site and irrigation-induced salinity risks to the Mitchell catchment from greenfield agriculture or aquaculture development. It is principally concerned with the risks from these developments to the broader environment but also considers biosecurity risks to the enterprises themselves.

7.1.1 KEY FINDINGS

Ecological implications of altered flow regimes

Although irrigated agriculture in Australia typically occupies a small percentage of a catchment area (i.e. <3%), it can potentially use a large proportion of the water (i.e. greater than 30%). Consequently, it was important for the Assessment to consider ecological changes to near-shore marine, estuarine, freshwater and riparian ecosystems that may result from changes in streamflow following water resource development for irrigation and other uses. It should be noted, however, that several other human-related factors can also impact on these ecosystems, including grazing, fire, disease, invasive species and changes in water quality. These factors are discussed qualitatively in the companion technical reports on ecology (Pollino et al., 2018a, 2018b).

This section provides an overview of outcomes from the ecology asset analysis, considering impacts of potential dams and water harvesting. It was found that the sensitivities of ecological assets to changes in flow vary. Vulnerabilities of assets change depending on their location in the catchment, the type and size of the development, volumes of water extracted and timing of water extraction. The sensitivity of assets to impacts also varies according to their dependencies on different parts of the flow regime.

The Mitchell catchment is largely intact in terms of the continuity of its plant and animal communities and the ecological processes that support them. The highly seasonal flows underpin river-floodplain productivity and provide critical habitats for species, including freshwater sawfish, a barramundi fishery and the extensive Northern Prawn Fishery, one of the most valuable fisheries in the country. The catchment supports significant wetland habitats and discharges into the Gulf of Carpentaria.

In the Mitchell catchment, the introduction of the potential Pinnacles dam causes dramatic changes in flow, with localised catastrophic impacts on migratory fish, including sawfish and barramundi, and on waterhole habitats. Downstream, these changes are moderated by flows from joining tributaries, such that only minor changes occur to the habitat of species near the mouth of the Mitchell River. Other potential dams analysed as part of the Assessment have considerably less impact on the habitat of near-shore marine and freshwater species than the potential Pinnacles dam, although all dams result in dramatic changes in flow in the reach immediately below their dam wall. This in part highlights the ecological importance of the Mitchell River relative to its major tributaries, the Palmer, Walsh and Lynd, which are more ephemeral in nature than the Mitchell River. With both the potential Pinnacles and Rookwood dams in combination, moderate changes to the habitat of some species, including the freshwater sawfish, occur along the Mitchell River below its confluence with the Palmer River. Major changes to the habitat of species occur along the Walsh River near its confluence with the Mitchell River, and below the

Rookwood dam. Dams and re-regulating structures such as weirs are likely to impact on the passage of migratory fish, although potentially less so for sawfish where dams are above their mapped ranges.

Water harvesting typically causes less disruption to the high- and low-flow extremes than major instream dams and as a consequence the impact to habitat of species is generally lower, particularly if pumping/diversions only commence at a high minimum-flow threshold (i.e. 1800 ML/day). High minimum-flow thresholds, however, reduce the reliability of extracting a given volume of water. Under the water harvesting scenarios examined as part of the Assessment, changes to the habitat of near-shore marine and estuarine species are minor, except for whole-of-system extraction volumes of less than 600 GL/year with a high flow threshold, where no changes are evident. Thereafter, for extraction volumes between 600 and 6000 GL, minor changes to habitat occur. Elsewhere in the Mitchell catchment water harvesting with a high flow threshold results in no change or minor change to habitats of freshwater species, except in some reaches when the whole-of-system extraction equals or exceeds 3600 GL/year. Under a low flow threshold, moderate impacts to habitat important to freshwater species occurs with whole-of-system extraction volumes of 1200 GL and higher, with the impacts becoming major for extraction volumes greater than 4800 GL/year.

Biosecurity considerations

Compared with many other countries, Australia has many advantages in terms of the opportunity to mitigate risks from pests and disease due to its isolation and sound regulatory processes. However, there have been a number of recent disease outbreaks, such as the disease of bananas, Panama disease tropical race 4, which highlight the risks to enterprises and to industries. The recent discovery of white spot syndrome virus in south-east Queensland prawn farms similarly shows the potential for disease to damage whole industries and to have a negative impact on industries which depend on wild catch. Man-made pathways include road transport, ships and planes, and the 'carriers' (e.g. humans, animals, plants, machinery) that facilitate the movement and incursion of new pests, diseases and weeds. In the short to medium term, biosecurity risks to the Mitchell catchment are most likely to come from within Australia and, in particular, from adjacent or climatically similar parts of the country, although wind dispersal from countries to the north is also possible. The warmer, north Australian environment is more favourable than temperate climates for insects and pathogens to adapt and multiply with the introduction of a new food source (e.g. a crop). However, the environment also favours beneficial organisms that prey on pest species. A range of macro-pests also pose a risk, such as feral pigs. Pathogens pose a constant risk to aquaculture enterprises. In some cases management actions aim to prevent the introduction of the pathogen to the enterprise, in other cases the pathogen is present in the farmed population and needs to be managed through good husbandry practices. There is also potential for disease in farmed populations to escape into wild populations. Similarly, irrigated agriculture has the potential to introduce weeds into the broader environment.

Sediment, nutrients and agropollutant loads to receiving waters

Agriculture can affect the water quality of downstream freshwater, estuarine, and marine ecosystems. The principal pollutants from agriculture are nitrogen, phosphorus, total suspended solids, herbicides and pesticides. A relative-risk assessment approach was used to determine potential surpluses of these. Nitrogen use varied considerably but was high for bananas and relatively high for sugarcane. Conversely, the nitrogen surplus was low or even negative in the case of Jarrah grass. Phosphorus surplus also varied substantially but was very high for crops such as bananas and watermelon that have high phosphorous inputs and a low quantity of phosphorous in the harvestable product. Conversely, the phosphorous surplus was low or even negative for crops such as chickpea, maize and sesame. Some crops, such as bananas, have high pesticide, herbicide and fungicide application rates while other crops such as rice or mangoes have much lower application rates. Determining herbicide and pesticide surplus is difficult, especially since technologies are changing rapidly and many newer chemicals have much lower application rates, but their active ingredients are relatively more potent than older chemicals. Nitrogen losses were also examined using a different approach, through simulation. Losses via runoff were highly dependent on the amount of runoff, which is highly dependent on rainfall amount and intensity. Simulated sediment loss showed that the use of a cover crop could minimise soil loss and therefore the amount of sediment released into water bodies downstream.

Irrigation-induced salinity

The gently undulating plains and rises with cracking clay soils (SGG 9) developed on fine-grained sediments of the Great Artesian Basin at Wrotham Park in the centre of the Mitchell catchment show considerable potential for irrigated agriculture. However, field work indicated considerable levels of salt in this landscape where salts may mobilise and cause secondary salinity if a watertable rises close to the surface, resulting in lost crop productivity. Other soils considered to be suitable for irrigated agriculture in the Mitchell catchment were considered to have a lower salinity risk.

Under irrigation, the soils on the upper slopes of these gently undulating plains are essentially non-saline in the rooting zone and salinity only becomes apparent at depths greater than 2 m. With application of good quality water these soils can be successfully irrigated with careful management of water rates to avoid waterlogging and ponding (and possible water erosion). The sites on lower slopes, however, contain higher levels of salt and there is potential for salt to become an environmental problem and cause production losses unless carefully managed.

The watertable level depends on the initial depth to the watertable, recharge from rain and irrigation, size of the irrigation area, management practices and distance to the river. The Assessment indicates that watertable levels under small neighbouring irrigation developments (less than 500 ha in area) are not likely to interact in the next 100 years if the developments are placed at least 1 km apart. The watertable level is most likely to rise with high recharge rates and in soils with low saturated hydraulic conductivity. Proximity to rivers considerably reduces irrigation-induced rise in watertable level by increasing groundwater discharge. It may take many decades for watertable level to respond fully to irrigation development, especially if the cultivated area is large or far from the river. It is important to note, however, these watertable level and groundwater discharge results are under ‘idealised’ conditions and that the risk of secondary salinisation and watertable rise at a specific location can only be properly assessed by undertaking detailed field investigation.

7.1.2 INTRODUCTION

The range of environmental changes that could potentially occur as a result of water and irrigation development is as varied as the number of developments that could be proposed. Furthermore, water and irrigation development can result in complex and in some cases unpredictable changes to the surrounding environment and communities. For instance, prior to the construction of the Burdekin Falls Dam, the Burdekin Project Committee (1977) and Burdekin Project Ecological Study (Fleming et al., 1981) concluded that the dam would improve water quality and clarity in the lower river and that para grass (*Brachiaria mutica*), an invasive weed from Africa that was then present at relatively low levels, could become a useful ecological element as a result of increased water delivery to the floodplain. However, the Burdekin Falls Dam has remained persistently turbid since construction in 1987, greatly altering the water quality and ecological processes of the river below the dam and the many streams and wetlands into which that water is pumped on the floodplain (Burrows and Butler, 2007). Para grass and more recently hymenachne (*Hymenachne amplexicaulis*), an ecologically similar plant from South America, have become serious weeds of the floodplain wetlands, rendering innumerable wetlands unviable as habitat for most aquatic biota that formerly occurred there (Tait and Perna, 2000; Perna, 2003, 2004).

Thus, there are limitations to the specific advice that can be provided in the absence of specific development proposals and for this reason this section provides general advice on those considerations or externalities that are most strongly affected by water resource and irrigation developments. It is not possible to discuss every potential change that could occur. For this reason, the chapter is structured as follows:

- Section 7.2, ecological implications of altered flow regimes; examines how river regulation affects inland and freshwater assets in the Mitchell catchment and marine assets in the near-shore marine environment.
- Section 7.3, biosecurity considerations; discusses the risks presented by disease, pests and weeds to an irrigation development and the risks new agriculture or aquaculture enterprise in the Mitchell catchment may present to the wider industry and broader catchment.
- Section 7.4, sediment, nutrients and agropollutant loads to receiving waters; examines water quality resulting from agriculture and aquaculture enterprises and discusses agricultural or other chemical containment risks to downstream aquaculture enterprises.
- Section 7.5, irrigation-induced salinity; examines the risk of irrigation-induced salinity to an irrigation development and the downstream environment in the Mitchell catchment.

Other externalities associated with water resource and irrigation development discussed elsewhere in this report include:

- The direct impacts of the development of a large dam and reservoir on:
  - Indigenous cultural heritage (Section 3.5)
  - the movement of aquatic species (Section 5.3)
  - terrestrial ecosystems and species within the reservoir inundation area (Section 5.3).

The externalities listed above are rarely factored into the ‘true costs’ of water resource or irrigation development, and the reality is that even in parts of southern Australia where data are abundant, it is very difficult to express these ‘costs’ in monetary terms as perceived changes are strongly driven by values, which can vary considerably within and between communities and fluctuate over time. For this reason, the material in this chapter is presented as a standalone analysis to help inform conversations and decisions between communities and government.

It is important to note that this chapter is primarily focused on key risks from irrigated agriculture and aquaculture, although the section on biosecurity considers both risks to the enterprise and risks emanating from the enterprise into the broader environment. Other risks to irrigated agriculture and aquaculture are discussed elsewhere in this report and include risks associated with:

- flooding (Section 2.5)
- regulatory delays (Section 3.6)
- erosion (captured in the land suitability analysis described in Section 4.3)
- sediment infill of large dams (Section 5.3)
- reliability of water supply (sections 5.3 and 6.3)
- timing of runs of failed years on the profitability of an enterprise (Section 6.3).

Material within this chapter is largely based on (and further information can be found in) the companion technical reports on agricultural viability (Ash et al., 2018), aquaculture viability (Irvin et al., 2018), hydrogeological assessment (Taylor et al., 2018) and two companion technical reports on ecology (Pollino et al., 2018a, 2018b).

7.2 Ecological implications of altered flow regimes

7.2.1 INTRODUCTION

As outlined in Chapter 2, the Mitchell catchment is characterised by distinct wet and dry seasons, with significant variability year to year in annual rainfall. Most rivers only flow during the wet season and freshwater and marine ecosystems of northern Australia have adapted to this seasonal variability. Changes in flow as a consequence of new water resource developments have the potential to impact on these ecosystems depending upon the location, scale and nature of regulation. This section assesses the potential ecological impacts arising from changes in flow as a result of:

- major instream dams (Section 5.3)
- water harvesting (Section 5.3), where water is pumped or diverted from a major watercourse into an offstream storage, usually a ringtank.

As described in Section 5.3, major instream dams are efficient at capturing water. However, they can dramatically change the flow patterns downstream of the dam wall. With distance downstream of the dam and the point of irrigation extraction, the seasonality of streamflow may increasingly resemble the natural pattern and the amount of water extracted as a proportion of total streamflow decreases. Water harvesting typically causes less disruption to the high- and low-flow extremes than major instream dams. This is because during high-flow events mechanical pumps can only physically extract so much water, which is usually a small volume in relation to the volume of the flows. At low flows, pump-take thresholds constrain water take, where pumping only commences when the flow in the river is above a certain ‘threshold’ discharge. While a lower threshold results in an irrigator being able to extract their full allocation of water at a higher degree of reliability, it reduces the protection of low flows for the environment.

This section evaluates the potential impact of changes in flow on freshwater and marine ecological assets that may result from these two water resource development options (Scenario B). Some analyses also include assessment under wet and dry extreme climate change projections (Scenario C), and assessment of climate change projections with potential developments (Scenario D). Assets are defined as important habitats, species or functional groups that are of conservation, cultural, commercial or recreational value or that support ecological function. The outputs are intended to examine the sensitivity of freshwater and marine ecological assets to potential changes at locations within the catchment where the asset is located and to assist any future decisions on environmental flows.

Environmental flows are used to describe the quantity, timing and quality of water flows required to sustain freshwater, estuarine and coastal ecosystems. While simple 'rules of thumb' approaches to defining environmental flows are desirable, they have no empirical basis and can put the integrity of ecosystems at risk (Arthington et al., 2006). Contemporary methods for defining environmental flows require the development of relationships between components of flow and ecological responses (Poff et al., 2010). This report develops such relationships to evaluate the impacts of flow alteration.

Unless specified elsewhere, the material presented in Section 7.2 has been summarised from the companion technical report on ecology (Pollino et al., 2018b).

Contextual information

Water-dependent ecological assets are sensitive to changes in flow, being sustained by either surface water or groundwater flows or a combination of these. Priority assets have been selected in the Mitchell catchment to represent potential impacts to ecology as a consequence of surface water developments. To assess impacts, knowledge of the distribution and drivers of change of assets was synthesised and potential impacts of altered flows to assets assessed using quantitative and qualitative methods. By using these scenarios, the sensitivity of assets to changes to flow as a consequence of different types of flow changes was evaluated.

A two-tiered approach was used for analysis.

- The first tier evaluated changes in flow throughout the catchment where assets are known to be located. The components of the flow that are important to the asset were identified and the potential for these to change were evaluated. This was done by comparing 'important' components of flow (referred to as flow metrics) under Scenario B to the same components of flow under Scenario A and calculating the mean change, with the scale of change ranging from 0 and 100%.
- A subset of these assets proceeded to a second tier of analysis that provided a more detailed assessment of potential impacts. This was only undertaken for those assets for which there was a sufficient body of literature available to develop quantitative models (for more information see the companion technical report on ecology (Pollino et al., 2018b)).

Several other factors can also impact ecological systems such as water quality, access to groundwater, soil characteristics, physical changes (e.g. grazing impacts), fire, disease and invasive species. However, this analysis solely focuses on ecological changes that may result from changes in flow regimes. Other factors are discussed in Pollino et al. (2018a) but not evaluated.

A subset of hydrological model nodes was selected for assessment, representing locations in the Mitchell catchment. These nodes were selected based on observational records of the location of assets within the catchment, and the likelihood that the nodes would experience changes in flow (Figure 7-2).

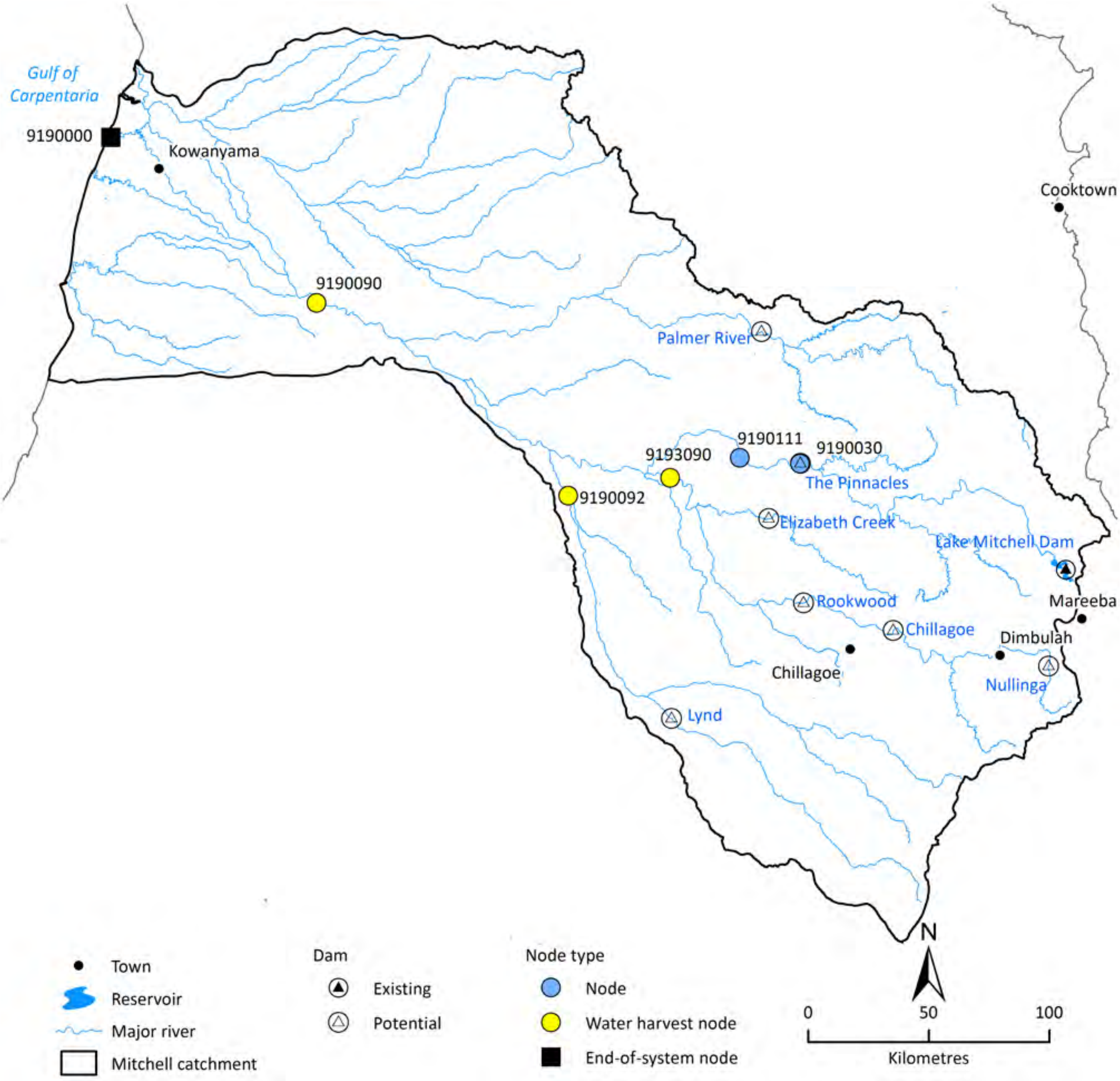

Figure 7-2 Map of the Mitchell catchment showing the location of potential water development sites and nodes used for the ecological assessment

Scenario A incorporates historical climate and current levels of development. This is the 'baseline' scenario against which other scenarios were compared.

Under Scenario B, water is extracted at different locations within the catchments and the Assessment examined how the reliability of extraction is affected by a variety of pump-related variables and other uses (Hughes et al., 2018). It also involved using major dams to store water within a catchment (Petheram et al., 2017).

Under Scenario B water harvesting (Scenario B-WH), the ecological analysis considered seven whole-of-system annual extraction volumes (300, 600, 1200, 2400, 3600, 4800 and 6000 GL) at a low pump-take threshold (LT; 200 ML/day) and at a high pump-take threshold (HT; 1800 ML/day).

Under Scenario B major dams (Scenario B-D), the impacts of seven potential dams on streamflow were either calculated individually (Scenario B-D-I) or in combination (Scenario B-D-C). These potential dams are:

- the Pinnacles dam site on the Mitchell River
- the Rookwood dam site on the Walsh River
- the Palmer dam site on the Palmer River
- the Lynd downstream dam site on the Lynd River
- the Chillagoe dam site on the Walsh River
- the Elizabeth Creek dam site
- the Nullinga dam site on the Walsh River.

Potential changes under scenarios Cwet and Cdry are examined (Scenario C), as are potential changes under a projected future climate and potential development (Scenario D). Scenarios are described in Section 1.4.

Categories of impact used in the scenario analysis are:

- no change – no changes are likely to be measurable (mean change in flow metrics is less than 10%)
- minor change – minor changes that are unlikely to be measurable (mean change in flow metrics is between 10 and 30%)
- moderate change – measurable changes but without major changes to ecosystem structure or function (mean change in flow metrics is between 30 and 60%)
- major change – significant changes to ecosystem structure or function, no longer supporting habitat or species (mean change in flow metrics is between 60 and 90%)
- extreme change – complete change of ecosystem structure and function (mean change in flow metrics is greater than 90%).

The remainder of this section is structured as follows:

- Section 7.2.2 provides a summary of changes to assets using the first-tier approach at selected locations across the study area.
- These results form the basis of interpretation and discussion in sections 7.2.3 to 7.2.5.
- Combined with the second-tier approach, further results are discussed in sections 7.2.4 and 7.2.5.

7.2.2 CHANGE IN COMPONENTS OF FLOW SPECIFIC TO KEY ECOLOGICAL ASSETS AND HABITATS IN THE DARWIN CATCHMENTS

To analyse the potential for ecological change arising from potential water resource development, relative changes in streamflow under scenarios A, B and C were assessed at six locations in the Mitchell catchment. Data from select sites, corresponding with streamflow nodes, are presented here.

The locations for which results are presented in this section are shown in Figure 7-2. Results are presented for streamflow nodes 9190000, 9190090, 9190092, 9190111, 9190030 and 9193090 from the coast (end-of-system) to inland (Figure 7-3, Figure 7-4, Figure 7-5, Figure 7-6, Figure 7-7, Figure 7-8, respectively). The figures in this section present a summary of information on aspects of change in volume and timing of streamflow specific for each species at each node under Scenario A. The greatest changes occur at nodes immediately downstream of dams. It should be noted that the modelled changes (i.e. the results of this analysis) are based on the output of hydrological model simulations, and that the modelled flows may vary from those reported here depending upon the specific details of a development (e.g. whether water is being released directly from the dam into a channel/pipe or released down the river), particularly in river reaches immediately downstream of a dam. Consequently, these results can be considered as indicative of the likely magnitude of change and should not be used as a substitute for a detailed ecological analysis of a specific development proposal.

Each figure in Section 7.2.2 corresponds to a specific node in the river model (Hughes et al., 2018). The proximity of assets to each river model node was determined, and only assets in close proximity to a node were assessed at that node. Scenarios for water harvesting (Scenario B-WH) and dams (Scenario B-D) are presented on the *x*-axis and assets are listed on the *y*-axis. Each number represents the percentage difference between Scenario B and Scenario A, ranging from 0 to 100%. The percentage difference is calculated as the mean of change of those flow components considered important to each asset relative to Scenario A. The larger the mean percentage difference between scenarios B and A, the larger the potential for ecological change to assets. The intensity of the colour in Figure 7-3 to Figure 7-8 illustrates the magnitude of the percentage difference in flow components.

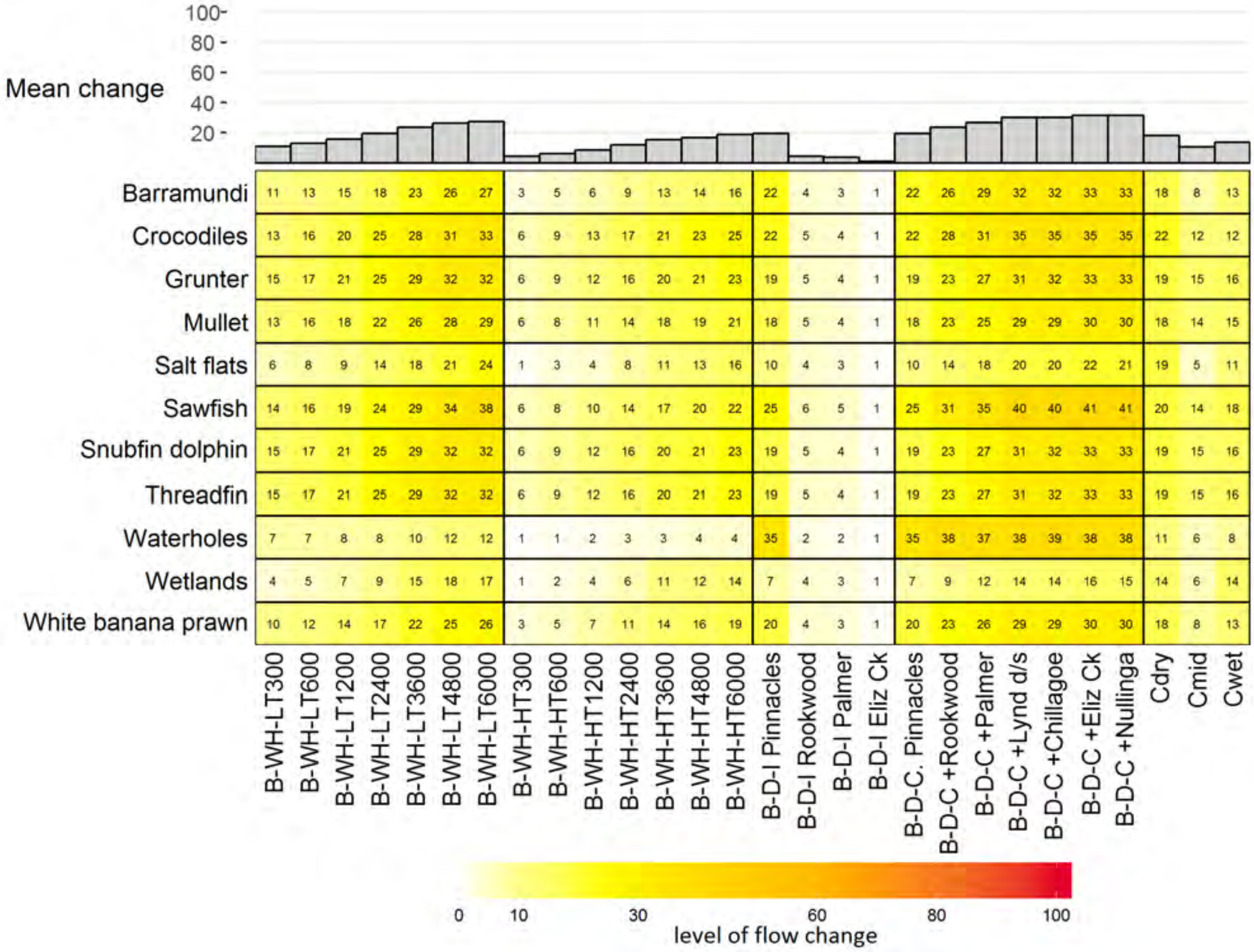

Figure 7-3 Assessment of change in flow metrics for assets at assessed location 9190000 in the Mitchell catchment
The intensity of the colour represents the variability of the scenario evaluated relative to Scenario A. Water harvesting scenarios are designated by an 'LT' or 'HT' where 'LT' and 'HT' represent low (200 ML/day) and high (1800 ML/day) extraction thresholds for water harvesting, respectively. The pump rate was assigned such that the allocated volume could be extracted in 20 days. The values in the water harvest label correspond to the total extraction in the Mitchell catchment. B-D-I denotes the results are for a single dam. B-D-C denotes the results are for a combination of dams, starting with the Pinnacles dam site on the Mitchell River and incrementally adding each dam to the right. Numbers in cells represent mean percentage change in flow metrics for an asset (between Scenarios B and A). The bar graph at the top shows mean of the mean change across all assets. This node represents end-of-system.

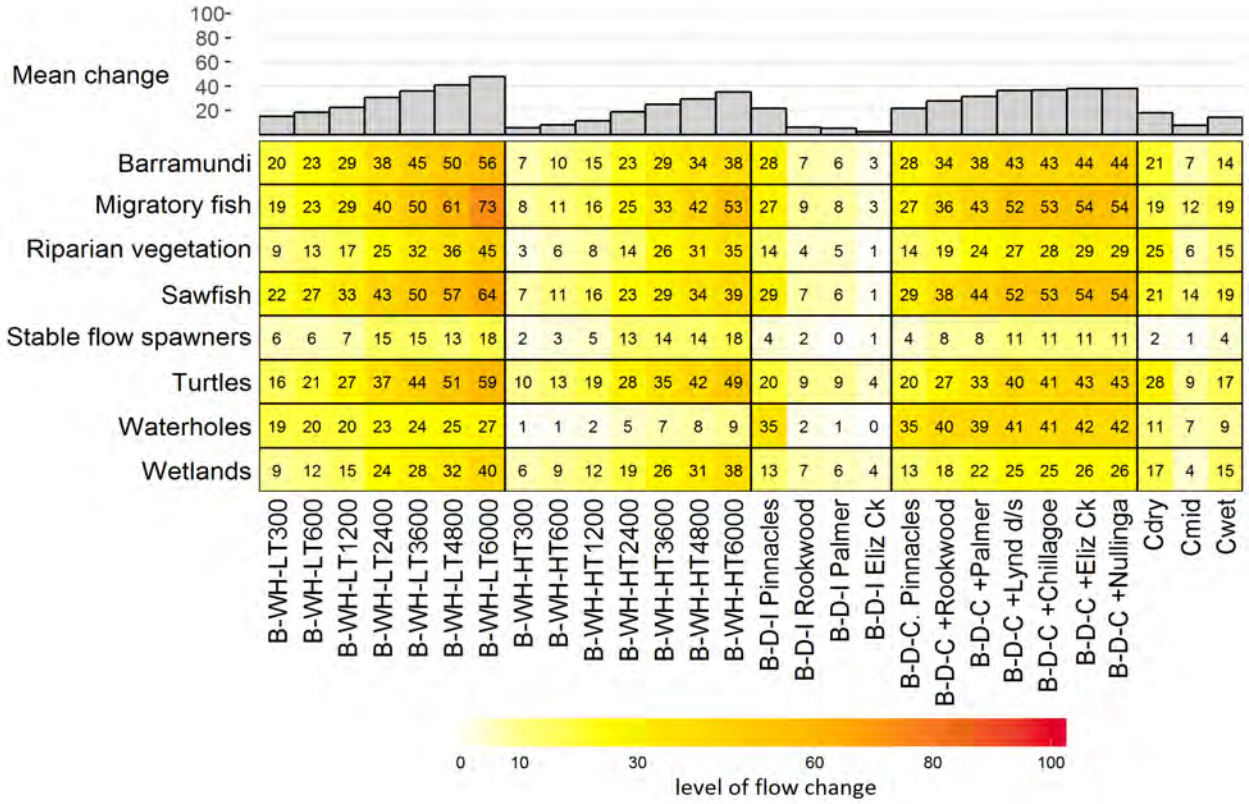

Figure 7-4 Assessment of change in flow metrics for assets at assessed location 9190090 in the Mitchell catchment
Refer to caption note in Figure 7-4 for figure explanation.

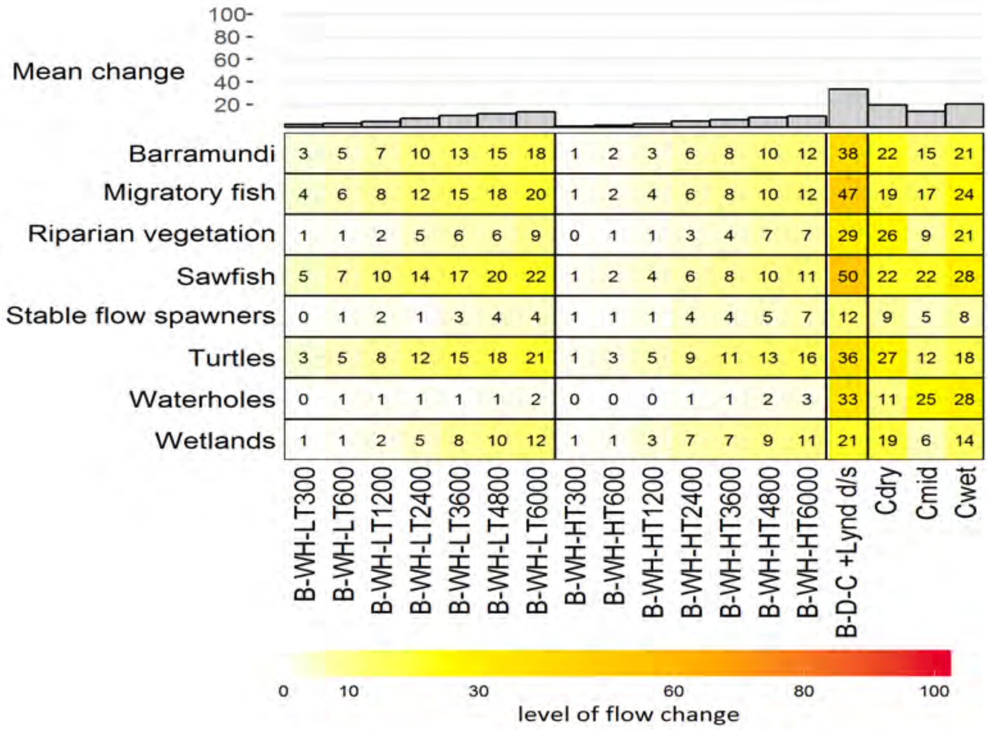

Figure 7-5 Assessment of change in flow metrics for assets at assessed location 9190092 in the Mitchell catchment
Refer to caption note in Figure 7-4 for figure explanation.

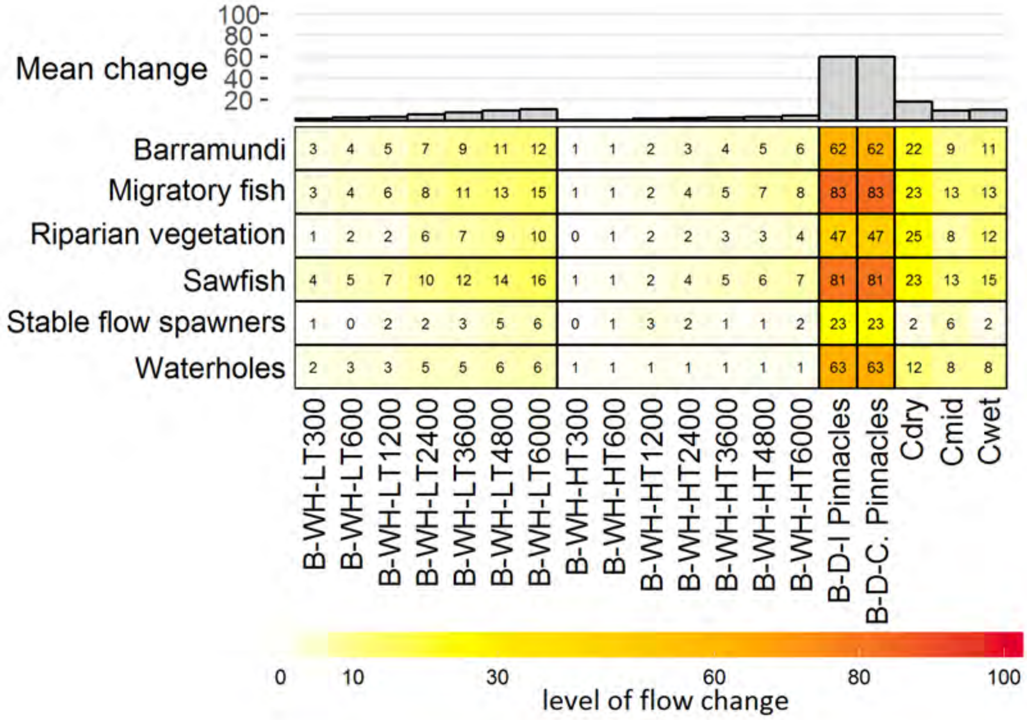

Figure 7-6 Assessment of change in flow metrics for assets at assessed location 9190111 in the Mitchell catchment
Refer to caption note in Figure 7-4 for figure explanation.

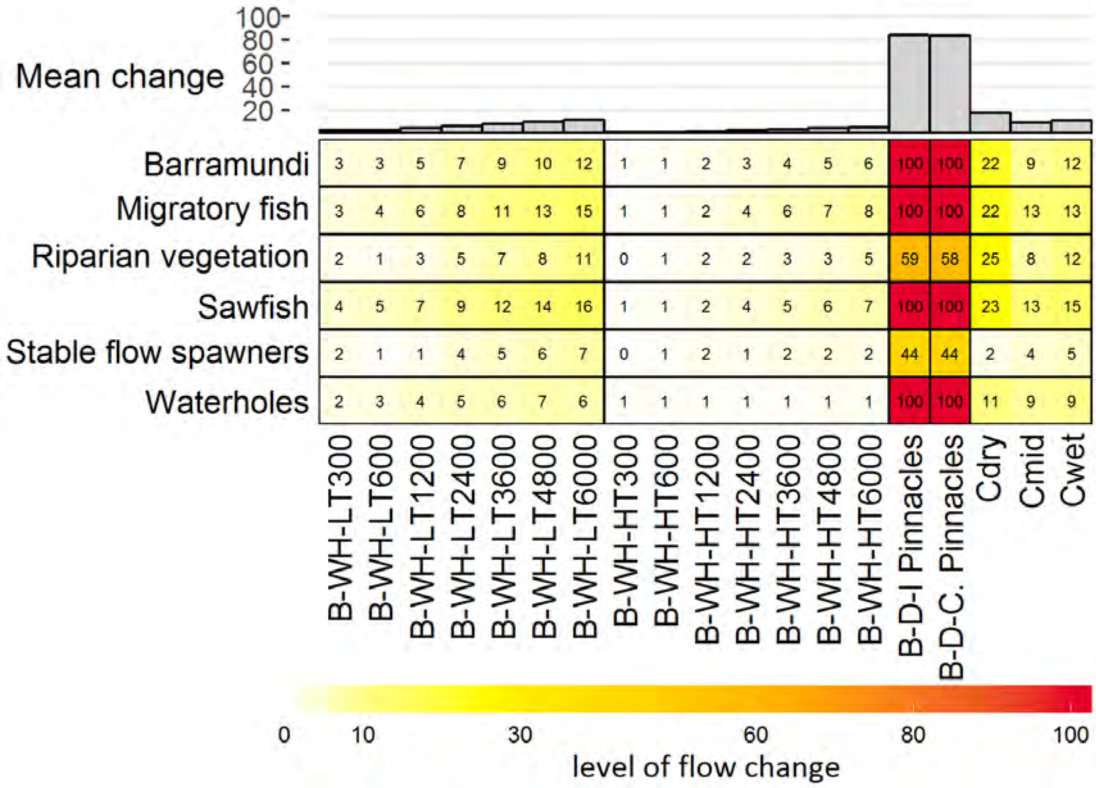

Figure 7-7 Assessment of change in flow metrics for assets at assessed location 9190030 in the Mitchell catchment
Refer to caption note in Figure 7-4 for figure explanation.

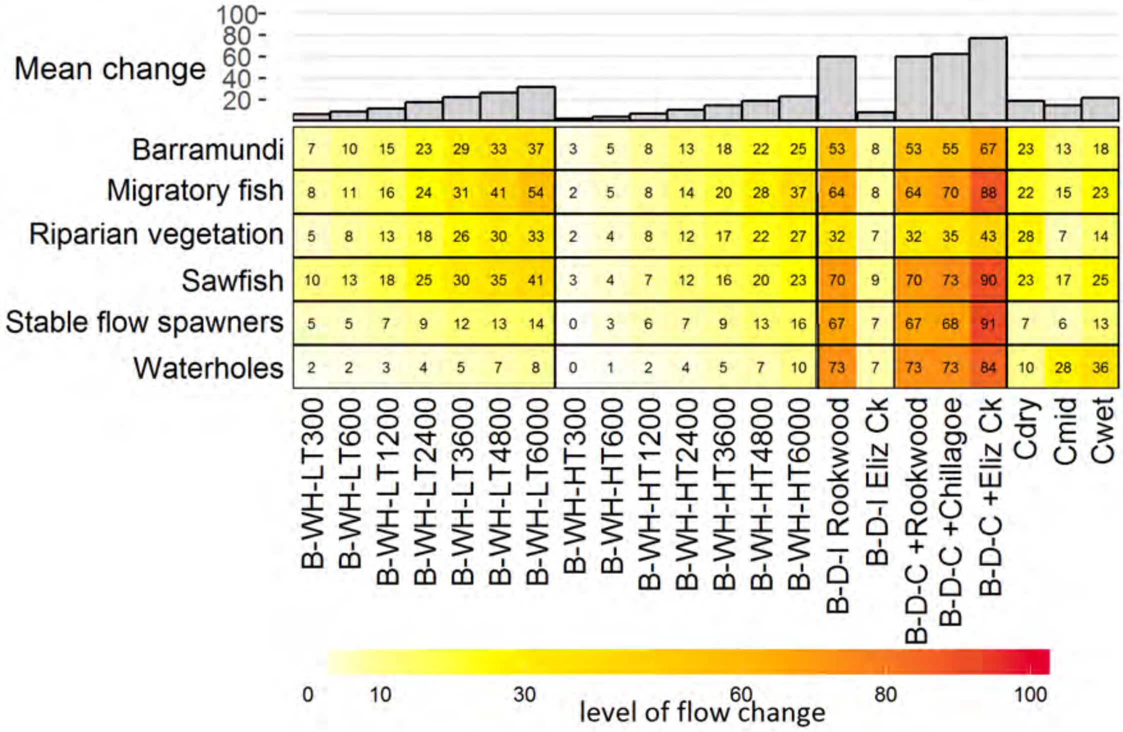

Figure 7-8 Assessment of change in flow metrics for assets at assessed location 9193090 in the Mitchell catchment
Refer to caption note in Figure 7-4 for figure explanation.

7.2.3 CHANGE IN MARINE ASSETS

Marine fish

Grunter and threadfin are the most sensitive species of the marine fish to changes in flow arising from potential dam and water harvesting developments, followed by mullet (Figure 7-3). Changes are greatest under the low pump-take threshold (LT) pumping options. Under Scenario B-WH, for extraction of up to and including the 3600 GL extraction volume, impacts are minor for all marine fish. The 4800 GL and 6000 GL water harvest scenarios show moderate changes to grunter and threadfin.

Under Scenario B-D-I, the potential Pinnacles dam has a minor impact on the components of flow relevant to marine fish (Figure 7-3). Other individual dams result in no change to the components of flow relevant to marine fish at the river end-of-system. Under Scenario B-D-C impacts to grunter and threadfin are moderate with the addition of the potential Rookwood, Palmer and Lynd dams and moderate for mullet with the further addition of the potential Chillagoe and Elizabeth Creek dams.

Marine fish were assessed at the end-of-system node (9190000) (Figure 7-2). This part of the Mitchell catchment represents estuarine habitats, which have high primary productivity and dynamic food webs supporting abundant and diverse fish and crustacean species (Halliday et al., 2012). The annual monsoon season is a critical time period for many fish species, including estuarine-dwelling species. The late dry season to early wet season is a critical period for recruitment and survival, with catchment flows reducing salinity in the estuary allowing for optimal growth and feeding of adults and juveniles (Humphries et al., 1999). Below is an overview of changes to grunter, mullet and threadfin salmon.

Adult grunter spawn in the estuary. They prefer brackish habitats, which are sustained by late dry-season flows. Grunter reproduce in the late dry and wet season, and the estuary habitat becomes abundant with juvenile fish. Grunter are an important predator in estuary habitats, and they structure fish populations in estuaries as a result. Changes in the volume of wet-season flows to the estuary would restrict grunter breeding and feeding habitat. Changes in late dry-season and wet-season flows could potentially affect the population of grunter in the estuary if changes occurred on an annual basis.

Mullet use both estuary and freshwater environments. Adult mullet spawn in estuaries and juvenile mullet migrate to the river during the late dry-season flows; flows are needed to reconnect the estuary and river channel for migration to occur (De Silva, 1980; Grant and Spain, 1975; Halliday and Robins, 2005; Kailola et al., 1993). Given the reduction in late dry-season flows, it is possible that the timing of connection is delayed, reducing the opportunities for mullet to migrate when flows are not at a high velocity. This could strand juveniles in the estuary in less optimal habitats for growth.

Adult threadfin salmon spawn in the estuary (Halliday and Robins, 2005) with juveniles abundant in the estuary in the late dry season (Halliday et al., 2012). Prey species for fish are also abundant in the late dry period, with prey coming downstream from the river. With reduced-size pools in the estuary in the late dry season, predation of juvenile fish is higher. Reduced food availability and increased predation could decrease the population size of juvenile fish, including the threadfin salmon.

Snubfin dolphin

Changes to the flow metrics most relevant to snubfin dolphin range from minor up to 3600 GL and moderate up to and including 6000 GL under Scenario B-WH LT (Figure 7-3). Under Scenario B-WH HT, impacts range from no change to minor change. Under Scenario B-D, impacts to the flow metrics relevant to snubfin dolphin from the Pinnacles dam are minor, increasing as dams are added incrementally. Impacts increase to moderate considering the cumulative changes with the addition of the Rookwood, Palmer and the Lynd dams. End-of-system components of flow relevant to snubfin dolphin do not change for individual dams, other than the Pinnacles dam, which results in a minor change.

Snubfin dolphin were assessed at the end-of-system node (9190000) (Figure 7-2). The snubfin dolphin is an estuarine- and embayment-dwelling species of conservation significance and, until recently, considered a different species from the Irrawaddy dolphin (Palmer et al., 2011). Their occupation of marine habitats is exclusively near-shore and while they are found in upper estuary freshwaters, they do not venture into riverine habitats. The dependence of snubfin dolphin on river flows and habitats in the Mitchell catchment is via the dynamics of the annual monsoon driving a complex food web. There is very limited information available on snubfin dolphins.

In the dry season, waterhole habitats in the estuary are affected. Dry-season flows are important for maintaining the quality of habitat in waterholes and for the recruitment, growth and survival of key prey species for snubfin dolphin, which recruit in estuarine and riverine habitats during September to December annually. The cumulative impacts of new developments over consecutive years will likely result in habitat loss in the estuary for snubfin dolphin. These changes are based on modelled flows and changes may vary depending upon the specific details of a development.

Crocodiles

Changes to the flow metrics relevant to crocodiles range from minor to moderate under Scenario B-WH LT, with changes being moderate from extraction volumes exceeding 4800 GL (Figure 7-3). Impacts range from no change to minor change under Scenario B-WH HT. Under Scenario B-D, impacts are minor with the addition of the potential Pinnacles dam, increasing to moderate with the addition of the potential Rookwood and Palmer dams.

Crocodiles were assessed at the end-of-system node (9190000) (Figure 7-2). Flows are critical to support breeding and nesting of crocodiles, which span the wet season. Inundated areas provide suitable habitat for crocodiles. If the size or number of inundated areas increases, it could provide an opportunity for juveniles to access a greater range of habitats. This could result in a greater food supply that could boost the growth rate of crocodiles and enable them to outcompete predators. If inundated areas decrease in size or number, it may limit the growth rate of juveniles.

Change in flow characteristics could potentially reduce the available nesting sites available to crocodiles in the wet season. Over time, reduced breeding could decrease the population size of crocodiles in the catchment. These changes are based on modelled flows and changes may vary depending upon the specific details of a development.

White banana prawns

Past assessments have shown the relationship between flows at the end of a river system and the catch of white banana prawns (Bayliss et al., 2014). Analysis of white banana prawn data from the Mitchell catchment indicate that catches in this catchment are likely to be minimally affected by Scenario B-WH and Scenario B-D. It found that a reduction in annual streamflow of 20% from the Mitchell catchment may reduce the median annual prawn catch across the whole Northern Prawn Fishery by about 2.5%, though the median annual reduction in some regions could be as high as 11% with percentage reductions in some low-flow years higher (see companion technical report on modelling the influence of streamflow on prawn catch, Shao et al., 2018). However, river flows are only able to partially explain the catch of white banana prawns in the Mitchell catchment. This suggests that other variables that affect the distribution, growth and survival of white banana prawns (including temperature, salinity, food availability and habitat availability) are not captured by the methods of Bayliss et al. (2014). These factors are important for the recruitment of white banana prawns and should be considered in future assessments. These changes are based on modelled flows and may vary depending upon the specific details of a development. For more information on this analysis see the companion technical report on ecology (Pollino et al., 2018b).

Salt flats

Salt flats were assessed at the end-of-system node (9190000) (Figure 7-2). At the end-of-system, flood flows expand the available habitats. Overbank floods inundate salt flats and other coastal habitats adjacent to the estuary. These are colonised by a range of fish and crustacean species. When salt flats are inundated a spike in primary productivity occurs, and this contributes to the overall dynamic production in estuaries during the monsoon season (Burford et al., 2016). Overall, changes in flow metrics relevant to salt flats range from no change to minor impacts (Figure 7-3). These changes are based on modelled flows and changes may vary depending upon the specific details of a development.

7.2.4 CHANGE IN INLAND AND FRESHWATER ASSETS: HABITATS

Floodplain wetlands

Inputs to the wetlands analysis were from the inundation modelling undertaken in the Mitchell catchment as documented in the companion technical report on flood mapping and modelling (Karim et al., 2018).

The Mitchell catchment supports some of the most ecologically diverse aquatic systems in Australia (Close et al., 2012) with a mixture of ephemeral, semi-permanent and permanent wetlands (Australian Nature Conservation Agency, 1996). Riverine flows establish connections between the river channel and surrounding wetlands. These need to be of sufficient magnitude and duration to facilitate movement and recruitment of aquatic biota between the main channel habitat and the floodplain wetlands.

An analysis of the impact of future climate projections and potential dam developments on the connectivity of 65 wetlands on the floodplain of the Mitchell catchment was undertaken. This analysis considered (i) wetlands with no connection to the main river channel; (ii) wetlands that have one or more connections to the main river channel, with a mean connection period of less than 21 days; and (iii) wetlands that had a single connection event to the main river channel that generally persisted for more than 21 days. Connectivity was analysed for low and high annual exceedance probabilities (AEP), representing low and high flood frequencies, of whether a flood is likely to be exceeded in a given year.

Under Scenario A, for flood events that occur on average once every 2 years (AEP 1 in 2), 65% of wetlands in the Mitchell catchment have no connection to the main river channel, and only 6% have extended periods of connection (>21 days) (Table 7-1). Wetlands with extended periods of connection occur low on the floodplain, which allows connection to be maintained for longer as the flood peak passes. The remaining wetlands are intermittently connected for variable periods with a mean duration of less than 21 days (Table 7-1).

Compared to Scenario A, Scenario Cwet has a greater proportion of wetlands connected intermittently, while the number of wetlands with extended periods of connection is similar (Table 7-1). Under Scenario Cdry, the proportion of wetlands with no connection to the main river channel increases, with a corresponding decrease in wetlands with intermittent connectivity. Importantly those wetlands low on the floodplain that had extended periods of connection under Scenario A are likely to become disconnected from the floodplain under Scenario Cdry (Table 7-1).

Under Scenario B-D with the potential Pinnacles dam, 91% of the wetlands have no connection to the main river channel and only 2% are connected for more than 21 days (Table 7-1). Under Scenario Dwet the percentage of wetlands connected to the main river channel is similar to that under Scenario A (Table 7-1).

Table 7-1 Percentage of wetlands connected to the main river channel in the Mitchell catchment for a flood event of AEP 1 in 2

SCENARIO	% WETLANDS WITH NO CONNECTION	% WETLANDS CONNECTED <21 DAYS	% WETLANDS CONNECTED >21 DAYS
Scenario A	65	29	6
Scenario B-D	91	8	2
Scenario Cwet	42	51	8
Scenario Cdry	63	37	0
Scenario Dwet	63	31	6
Scenario Ddry	94	5	2

AEP = annual exceedance probability

Under Scenario A, for flood events that occur on average once every 10 years (AEP 1 in 10), 69% of wetlands have either intermittent connectivity (<21 day) or extended periods of connectivity (>21 days). The remaining wetlands (31%) have no connection (Table 7-2). A similar pattern of connectivity occurs under Scenario Cwet (Table 7-2). In contrast, under Scenario Cdry 63% of wetlands are not connected and 8% of wetlands have periods of connectivity longer than 21 days (Table 7-2).

Under Scenario B-D, the potential Pinnacles dam has a similar influence on wetland connectivity as Scenario Cdry with 68% of wetlands not connected to the main river channel and only 8% of wetlands having connectivity longer than 21 days (Table 7-2). Under Scenario Dwet this pattern was the same (Table 7-2). In contrast, under Scenario Ddry the percentage of wetlands no longer connected (86%) increases with losses of those wetlands connected intermittently (Table 7-2).

Table 7-2 Percentage of wetlands connected to the main river channel in the Mitchell catchment for a flood event of AEP 1 in 10

SCENARIO	% WETLANDS WITH NO CONNECTION	% WETLANDS CONNECTED <21 DAYS	% WETLANDS CONNECTED >21 DAYS
Scenario A	31	46	23
Scenario B-D	68	25	8
Scenario Cwet	29	45	26
Scenario Cdry	63	29	8
Scenario Dwet	68	25	8
Scenario Ddry	86	6	8

AEP = annual exceedance probability

Under Scenario A, for flood events that occur once every 26 years (AEP 1 in 26), all wetlands are connected with most wetlands having intermittent connections <21 days and those wetlands lower on the floodplain having extend periods of connection (Table 7-3). Under Scenario Cwet, this pattern remains the same (Table 7-3). In contrast, under Scenario Cdry the number of intermittently connected wetlands decreases, with 31% of these wetlands no longer connected. Wetlands with extended periods of connection under Scenario A experience little change under future climate and/or development scenarios (Table 7-3).

Under Scenario B-D, the potential Pinnacles dam reduces the percentage of wetlands with an intermittent connection, with 43% of wetlands having no connectivity (Table 7-3). Under Scenario Dwet, 28% of wetlands have no connection (Table 7-3). In contrast, under Scenario Ddry, the percentage of wetlands with no connection is 57% (Table 7-3). Importantly the number of wetlands with extended periods of connection remains relatively unchanged (Table 7-3).

Table 7-3 Percentage of wetlands connected to the main river channel in the Mitchell catchment under a flood event of AEP 1 in 26

SCENARIO	% WETLANDS WITH NO CONNECTION	% WETLANDS CONNECTED <21 DAYS	% WETLANDS CONNECTED >21 DAYS
Scenario A	0	92	8
Scenario B-D	43	49	8
Scenario Cwet	0	92	8
Scenario Cdry	31	63	6
Scenario Dwet	28	65	8
Scenario Ddry	57	37	6

AEP = annual exceedance probability

The potential Pinnacles dam has the potential to alter wetlands becoming disconnected and permanently dry. The disconnection of wetlands from the main river channel under Scenario B-D (potential Pinnacles dam) is amplified under the Scenario Ddry but is less pronounced under Scenario Dwet.

Under small, moderate and large flood events, wetlands that are closest to the river remain connected and wetlands further from the river become permanently disconnected and remain dry (Walker and Thoms, 1993; Ward and Stanford, 1995). Increasing dryness is likely to lead to loss of aquatic biota and result in a more terrestrial landscape. If the period a wetland remains dry exceeds 10 years, there will be a substantial loss of resilience with many biota adapted to periodic wetting and drying by surviving as dormant propagules becoming lost (Nielsen et al., 2013).

Inchannel waterholes

The Mitchell catchment is highly seasonal with high wet-season and low dry-season flows. During the dry season, waterholes are important habitat that provide refuge for aquatic species and sources of water for other flora and fauna. As the dry season progresses, a reduction in the total area of waterholes occurs with the loss of smaller waterholes (Close et al., 2012; Pollino et al., 2018b) with many aquatic species, including a high diversity of fish species, turtles and sawfish, finding refuge within these waterholes. While waterholes have a relatively small contribution by area, it is from these refuge habitats that recolonisation of the river habitat occurs during the wet season (Lymburner and Burrows, 2008).

Maintaining the quality of waterhole habitats during periods of low flow is crucial for the local persistence of many of aquatic species (Department of Environment and Resource Management, 2010). Lower dry-season flows resulting in longer periods of low flows due to water resource development threaten to reduce the habitat value of waterholes. This can occur due to the loss of waterholes within the landscape and also decreases in the habitat quality and condition of the waterholes that remain (Department of Environment and Resource Management, 2010). In highly seasonal catchments such as the Mitchell catchment, increases in flow or longer water persistence due to dam releases or weirs during the dry season can also have impacts on waterholes as the fauna of the region are adapted to the annual cycle of low-flow and high-flow periods. Over the dry season, flow pulses within a river, groundwater input and local rainfall can replenish waterholes.

Modification of the duration or timing of low-flow or cease-to-flow periods threatens to change the ecological character of waterholes in the Mitchell catchment. During cease-to-flow events, where no surface water enters waterholes, species lose migration and movement pathways, and water quality often deteriorates. During periods of low flow, waterhole area is reduced, resulting in the loss of important 'glide' and riffle habitat, or potential loss of entire waterholes. The location of individual waterholes within the catchment is an important contributing factor to the duration of the cease-to-flow period, with waterholes in the upper Mitchell River more likely to undergo prolonged periods of disconnection under current conditions.

In the Mitchell catchment, changes to waterholes by water harvesting (Scenario B-WH) and dams (Scenario B-D) are considered. Water harvesting is found to reduce flows at downstream nodes, although there are no changes in the mean number of cease-to-flow days across scenarios. The impact to low flows, and hence waterholes, is minimised by the high pump-take threshold (HT), with minimal impact to low-flow periods.

Although water harvesting causes minimal changes to the duration of the cease-to-flow periods, it was associated with a small reduction in the total area of waterholes, due to a reduction in dry-season flows (Table 7-4). This would result in some loss of important glide or riffle habitat on the edge of or between waterholes and in some locations where the disconnection from habitat structure occurs, such as bank overhangs and tree roots. This impact is reduced under Scenario B-WH HT. Limiting water harvesting leading up to and during periods of low flow and maintaining dry-season pulses and first wet-season flows would provide protection to waterholes within the Mitchell catchment. The water harvest volume and pump rate (Section 5.3) has little influence on waterhole area in the Mitchell catchment.

Table 7-4 Waterhole area by scenario, shown as mean minimum dry-season waterhole area
Node 9190111 is located just downstream of water harvesting and node 9190000 is located near the river mouth.

NODE	UNIT	SCENARIO A	SCENARIO B-WH LT	SCENARIO B-WH HT	SCENARIO Cdry	SCENARIO Cmid	SCENARIO Cwet
9190111	Area (ha)	1.0	1.0	1.0	0.6	0.8	1.3
	% change	0	–1.9%	0.0%	–41.2%	–26.4%	28.2%
9190000	Area (ha)	39.9	39.1	39.9	37.1	38.0	41.8
	% change	0	–2.0%	0.0%	–7.0%	–4.7%	4.9%

Potential dams (Scenario B-D) in the Mitchell catchment result in substantial changes in cease-to-flow days, with increases from no cease-to-flow days to a mean of 230 days/year (Table 7-5). Such changes would likely have severe impacts on waterhole ecology, including affecting migration and movement pathways in affected reaches, and have impacts on water quality and other habitat characteristics. In the cumulative dam assessment, changes to cease-to-flow periods in the Mitchell catchment are greatest in reaches close to the upstream dams (e.g. node 9190111) and have comparatively reduced but noticeable effects further downstream towards the river mouth (e.g. node 9190091). The end-of-system reach is unaffected by cease-to-flow periods from dams (Table 7-5) but is still affected by changes to important low flows during the seasonal dry period.

Table 7-5 Annual mean number of cease-to-flow days at selected nodes in the Mitchell catchment
Node 9190111 is located just downstream of a dam and node 9190000 is located near the river mouth.

NODE	SCENARIO A	PINNACLES	ROOKWOOD	PALMER	LYND D/S	CHILLAGOE	ELIZABETH CK	NULLINGA
9190111	0	232	232	232	232	232	232	232
9190000	0	0	0	0	0	0	0	0

The cumulative dam scenario (Scenario B-D-C) results in the greatest impact on waterholes with dry-season waterhole area severely reduced, with impacts extending downstream. At the most downstream reach (9190000) the dry-season waterhole area is reduced by over 65% by the initial dam and by over 75% when all seven dams are considered (Table 7-6). Such large losses of habitat area would result in substantial impact to plants and animals that depend upon waterholes as refuge habitat during the annual dry period.

Table 7-6 Waterhole area at the end-of-system reach by cumulative dams shown as annual mean dry-season minimum waterhole extent

NODE	UNIT	SCENARIO A	PINNACLES	ROOKWOOD	PALMER	LYND D/S	CHILLAGOE	ELIZABETH CK	NULLINGA
9190000	Area (ha)	39.9	12.9	12.0	10.9	10.1	10.1	9.8	9.8
	% change	0	–67.7%	–69.9%	–72.6%	–74.6%	–74.6%	–75.5%	–75.5%

Riparian vegetation zones

Riparian vegetation is adjacent to watercourses. Riparian zones are highly diverse, dynamic and complex, and because they depend on flood processes they are highly vulnerable to disturbances. The riparian zones of northern Australia have evolved with periods of high flow and may change if such flows are not appropriately managed (Pettit et al., 2016). The inputs to this analysis are from inundation modelling within the Mitchell catchment (Karim et al., 2018).

A major riparian vegetation type in the Mitchell catchment is the '*Melaleuca* species woodland-open forest on sands in channels and on levees' which is dominated by *Melaleuca leucadendra* and/or *Melaleuca argentea* fringing forests and woodlands and *Eucalyptus camaldulensis* (regional ecosystem (RE) class 2.3.24). It has a biodiversity status listed as 'of concern' and is a valuable refuge for some fauna and flora, including providing habitat for sawfish (Queensland Government, 2017). This RE class is subject to invasion by rubber vine (*Cryptostegia grandiflora*) and water hyacinth (*Eichhornia crassipe*) and grazing pressure (Queensland Government, 2017).

The vegetation RE class 2.3.24 was selected as representative of riparian vegetation to determine the likely impact of each of the scenarios by analysing inundation patterns. The larger floods (Figure 7-9c) show a smaller impact between the scenarios compared to the smaller floods (Figure 7-9a). The Scenario Ddry shows the largest decrease in area inundated from Scenario A for floods of all magnitudes, while Scenario Cwet shows an increase in inundated vegetation area for the smaller floods. The development scenarios (scenarios B, Ddry and Dwet) generally show a decrease in the inundated area compared to Scenario A (except for 'Scenario Cwet' for the smaller flood; Figure 7-9).

The alteration of the flow regime caused by development and/or a future drier climate, which in turn leads to a reduced area of inundation, will likely increase the success of invasive species, including rubber vine and water hyacinth, identified as threats to this RE class.

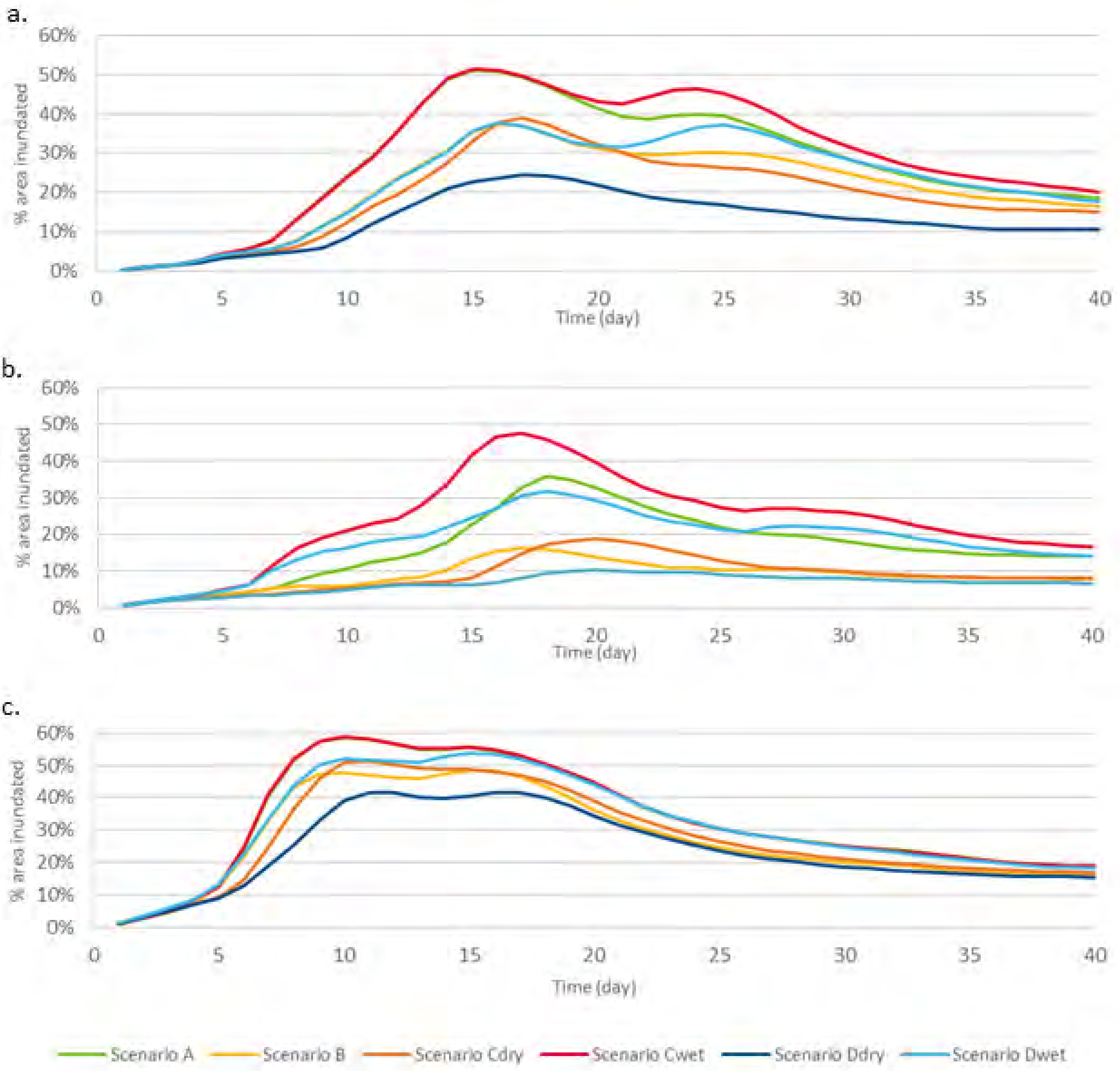

Figure 7-9 Change to percentage of area of riparian vegetation inundated for small, moderate and large flood event under scenarios A, B, C and D

Flood events are of magnitude (a) AEP 1 in 2, (b) AEP 1 in 10 and (c) AEP 1 in 26.

7.2.5 CHANGE IN INLAND AND FRESHWATER ASSETS: FISH

Stable flow spawners

Stable flow spawners are a functional group of fish that spawn in the dry season, in association with stable flows (low flow, baseflow and cease-to-flow). The species in the group include the freshwater longtom (*Strongylura krefftii*); mouth almighty (*Glossamia aprion*); bony herring (*Nematalosa erebi*); barred grunter (*Amniataba percoides*); flyspecked (*Craterocephalus stercusmuscarum stercusmuscarum*) and freckleheaded (*Craterocephalus lentiginosus*) hardyhead; and the eastern (*Melanotaenia splendida splendida*), chequered (*Melanotaenia splendida inornata*) and western (*Melanotaenia australis*) rainbowfish. Stable flow spawners were assessed at nodes 9190090, 9190092, 9190111, 9193090 and 9190030 (Figure 7-2). Stable flow spawners are an important fish species group in river ecosystems. They are typically small and sedentary, and prey for a range of larger species, such as barramundi. Despite stable flow spawners not requiring high flows to initiate spawning, recruits do benefit from exploiting the nutrient-rich floodplains during the wet season and they require flows for habitat maintenance and condition.

A reduction in the extent of inundation would increase competition between species because of the decrease of available resources and space. Overbank floods in the wet season provide dispersal routes for fish species to migrate to exploit the nutrient-rich inundated floodplains (Karim et al., 2012). Wet-season floods also inundate important offchannel habitats that function as refugia habitat in the dry season (Karim et al., 2012; King et al., 2015; Pusey et al., 2004). Changes in 'condition' are described as changes in the area, quality and persistence of habitat for species. Changes in habitat condition can affect recruitment rates, dispersal and range, body condition and persistence of stable flow spawners.

Tier 1 screening analysis indicates that under Scenario B-WH, for important flow metrics to stable flow spawners at node 9190090 there is no change for extraction volumes up to 1200 GL and minor change for extraction volumes greater than 1200 GL. At 9193090, for the LT, changes are minor for extraction volumes between 2400 and 6000 GL, and for the HT are moderate for extraction volumes between 3600 and 6000 GL. Changes in flow of concern are the number of zero-flow days, timing of minimum flows and duration of overbank flows.

Under Scenario B-D-C, for the combined potential Pinnacles, Rookwood, Palmer and Lynd dams, the components of flow relevant to stable flow spawners at nodes 9190090 and 9190092 show minor changes. No change is observed for any of the individual dams (Scenario B-D-I). Under Scenario B-D-I, for the Pinnacles dam the components of flow at node 9190111 show only minor changes. Under Scenario B-D-I at node 9193090, there are major changes in components of flow relevant to stable flow spawners, with the potential Rookwood dam on the Walsh River. The changes are extreme under Scenario B-D-C, which includes the potential Rookwood, Chillagoe and Elizabeth Creek dams, which would cause the habitat for stable flow spawners to no longer be suitable. Under Scenario B-D-I for the potential Pinnacles dam, the components of flow relevant to stable flow spawners at node 9190030 show moderate change.

Further analysis (Tier 2) was undertaken at nodes 9190090, 9190110 and 9193090 for water harvest scenarios and 9190090, 9190092, 9190111 and 9190030 (Figure 7-2) for dam scenarios, given the frequency of mapped occurrences of stable flow spawners in the Mitchell catchment. This analysis shows a substantial decline in condition of the stable flow spawners, longtom and barred grunter as a consequence of Scenario B-WH. Increasing volumes of flow extraction in Scenario B-WH result in the greatest change. Scenario B-WH for the HT shows little change for longtom and barred grunter. The mouth almighty, hardyheads and rainbowfish also show a loss in condition with increased flow extractions, although the response was not as dramatic.

Stable flow spawners show some decline under select dam scenarios, with changes being greater than under Scenario B-WH or Scenario C. This is evident at node 9190030, immediately downstream of the potential Pinnacles dam. At node 9190111, which is downstream of node 9190030, there is a decline in habitat for the potential Pinnacles and Rookwood dams.

Changes downstream of dams would negatively affect the habitat maintenance and persistence of stable flow spawners, altering the connection and disconnection periods of offchannel and main channel habitat. A reduced connection period could hinder the ability of stable flow spawners to migrate to suitable dry-season refugia habitat. Stable flow spawners would remain in main channel habitats where competition and predation effects would be greater. In contrast, an increased connection period (permanency of water in a previously ephemeral reach) could facilitate the dispersal of species that would normally not occupy offchannel habitats. This could alter fish assemblage structures and increase competition and predation.

Migratory fish

A fish group vulnerable to inchannel barriers and changes to flows is freshwater migratory fishes. Migratory fish are distributed throughout the Mitchell catchment. While there are many species in this group, barramundi (*Lates calcarifer*), bull shark (*Carcharhinus leucas*), black catfish (*Neosilurus ater*) and Hyrtl's tandan (*Neosilurus hyrtlii),* sooty grunter (*Hephaestus fugilinosus* and *H. jenkinsi*), freshwater longtom (*Strongylura kreffti*) and spangled perch (*Leiopotherapon unicolor*) are used here for analysis.

Migratory fish were assessed at nodes 9190090, 9190092, 9190111, 9193090 and 9190030 (Figure 7-2). Tier 1 screening analysis found that under Scenario B-WH some changes in habitat for migratory fish occur. Changes in important flow metrics for migratory fish at node 9190090 are minor up to and including extraction volumes of 1200 GL for the LT, becoming moderate up to 3600 GL and major at 6000 GL. Changes are minor, becoming moderate at extraction volumes greater than 3600 GL for the HT. Changes in important flow metrics range from no change to minor changes at nodes 9190092, 9190111 and 9190030. Changes at node 9193090 are minor between 600 GL to 2400 GL for the LT and moderate in remaining extraction volumes. Changes range from no change to minor change for the HT.

Under Scenario B-D-I at node 9190090, minor changes to habitat of migratory fish occur with the introduction of Pinnacles dam, increasing to moderate changes under Scenario B-D-C with the addition of the Rookwood dam on the Walsh River and for the remaining potential dams. Other potential dams when assessed individually (i.e. Scenario B-D-I) result in no change to important flow metrics for migratory fish at this location. At node 9190092, under Scenario B-D-I there are moderate changes in flow metrics with the introduction of a potential dam on the Lynd River (Figure 7-5).

Under Scenario B-D-I at node 9190111, major changes to flow metrics occur with the introduction of the potential Pinnacles dam (slightly upstream of Pinnacles dam site). Major changes would have substantial impacts on the habitat for migratory fish. Immediately below the potential Pinnacles dam (i.e. below the spillway), at node 9190030, extreme changes in flow metrics relevant to migratory fish are observed, which would result in the habitat no longer being suitable for migratory fish. However, it should be noted that under this particular model configuration it was assumed that all water released from the dam was released into a channel not down the river. Had water from the dam been released down the river the impact would be moderated to some extent.

Detailed flow analysis

Further analysis (Tier 2) was undertaken at nodes 9190090, 9190110 and 9193090 under Scenario B-WH and 9190090, 9190092, 9190111 and 9190030 under Scenario B-D. Analysis shows a decline in habitat of migratory fish. Increasing volumes of flow extraction under Scenario B-WH show increasing change in habitat with increased volumes of water extracted. Under Scenario B-D, the introduction of the potential Pinnacles dam results in a decline in habitat for freshwater fish species Hyrtl's tandan, black catfish, sooty grunter and spangled perch at nodes 9190030 and 9190111.

Dams compromise the movement of fishes, preventing access to distant or adjacent habitats, and their breeding cues (Roscoe and Hinch, 2010). Migratory fish are actively moving on the decreasing flows of the wet season and a subset would be using early wet-season flows to spawn and recruit. The potential dams in the Mitchell catchment will have localised impacts by limiting movement within the river channel. These changes could influence the structure of fish communities.

The location corresponding to node 9190090 is thought to be particularly important for migratory fish, as it connects to the floodplain and estuarine habitats. With the cumulative addition of dams, there is potential for extensive changes in habitats for migratory fish. At the end-of-system node (9190000) there are major shifts relevant to large-bodied species, such as sawfish, barramundi and bullsharks.

Overbank floods in the wet season provide dispersal routes for fish species to migrate and exploit the nutrient-rich inundated floodplains (Karim et al., 2012). Reduced dry-season flows may limit the movement of migratory fish into high primary-productivity estuarine habitats that support productive food webs and high growth rates as river connectivity is required to access these habitats (King et al., 2015). Reduced duration of high flows would also restrict the migration distance and window for migratory fish. In addition to changes in habitat, cues and productivity, dams are also a physical barrier. This would reduce the movement of migratory fish through the catchment.

Barramundi

The barramundi is a large fish that occurs throughout northern Australia in rivers, lagoons, swamps and estuaries and is arguably the most important fish species to cultural, recreational and commercial fisheries. Barramundi is found extensively throughout the Mitchell catchment. Barramundi has the potential to be affected by barriers to movement and changes in the flow regime. Spawning occurs in estuaries, juveniles migrate up rivers and the first few years of a barramundi's life are spent in freshwater habitats. In the dry season, barramundi use permanent waterholes as a refuge.

Barramundi were assessed at six nodes: 9190000, 9190090, 9190092, 9190111, 9193090 and 9190030 (Figure 7-2). Tier 1 screening analysis indicates that Scenario B-WH results in some changes to the habitat for barramundi. Changes in flow metrics of importance to barramundi at the end-of-system node (9190000) range from no changes to minor changes. Changes at node 9190090 are minor up to and including 1200 GL, becoming moderate up to 6000 GL for the LT. Changes are moderate between 600 and 2400 GL, becoming moderate for remaining extraction volumes under the HT. Changes range from no change to minor changes at nodes 9190092, 9190111 and 9190030. Changes at node 9193090 are minor up to 3600 GL and moderate in remaining scenarios for the LT, with changes ranging from no change to minor for the HT.

Under Scenario B-D-C at the end-of-system node (9190000), changes are minor up to the addition of the fourth potential dam, the Lynd dam. The remaining potential dams result in a moderate change. Under Scenario B-D-I, Pinnacles dam results in a minor change to flow metrics of importance to barramundi at the end-of-system.

Under Scenario B-D-I at node 9190090, minor changes to the habitat of barramundi occur with the introduction of the potential Pinnacles dam, increasing to moderate under Scenario B-D-C with the addition of the Rookwood dam on the Walsh River and the remaining dams. At node 9190092, moderate changes occur with the introduction of the potential dam on the Lynd River.

Under Scenario B-D-I at node 9190111, major changes to flow metrics important to barramundi occur with the introduction of the potential Pinnacles dam. Under scenario B-D-I and B-D-C at node 9193090, moderate changes to flow metrics occur with the introduction of the Rookwood dam on the Walsh River, increasing to major changes with the addition of the Elizabeth Creek dam. Major changes would have substantial impacts on the habitat for barramundi.

Immediately below the potential Pinnacles dam (i.e. below the spillway), at node 9190030, extreme changes in flow metrics relevant to barramundi occur, which would result in the habitat no longer being suitable for barramundi. However, it should be noted that under this particular model configuration it was assumed that all water released from the dam was released for irrigation into a channel not run down the river. Had water from the dam been released down the river the impact would be moderated to some extent.

Detailed flow analysis

Further analysis (Tier 2) was undertaken at nodes 9190090, 9190110 and 9193090 under Scenario B-WH and 9190090, 9190092, 9190111 and 9190030 under Scenario B-D. The decrease in the condition scores of barramundi with increasing water extraction indicates the potential to negatively affect the populations of barramundi over time (Figure 7-10). The introduction of the Pinnacles dam in the Mitchell catchment results in a substantial modelled decline in habitat at nodes 9190030 and 9190111 (Figure 7-11). However, it should be noted that under this particular model configuration it was assumed that all water released from the dam was released for irrigation into a channel not run down the river. Had water from the dam been released down the river the impact would be moderated to some extent.

Water harvest scenarios have the potential to reduce dry-season flows and the duration of wet-season flows. Dam scenarios increase the duration of low-flow periods in the dry season. In the dry season, adult barramundi in near-shore marine habitats spawn and the juveniles migrate to estuaries and freshwater river reaches where they forage and grow for several years. Barramundi spawned during the late dry season move upstream to inchannel waterhole habitats as juveniles. Connectivity via river flows is required to access these habitats. Late dry-season flows are important to reconnect the estuary to the river channel and allow juvenile barramundi to move to riverine habitats. For inland juvenile barramundi, the loss of freshwater habitats may represent a critical bottleneck for barramundi populations in the catchment. Decreases in the extent, depth and productivity of waterholes would reduce the extent of dry-season habitat and food abundance. In addition to changes in habitat, cues and productivity, dams are also a physical barrier. Flow changes as a consequence of the potential dams are likely to have an impact on barramundi, with changes throughout the year, impacting on habitat. This is more evident in nodes close to potential dams. Dams compromise the movement of barramundi, preventing access to distant or adjacent habitats (Roscoe and Hinch, 2010).

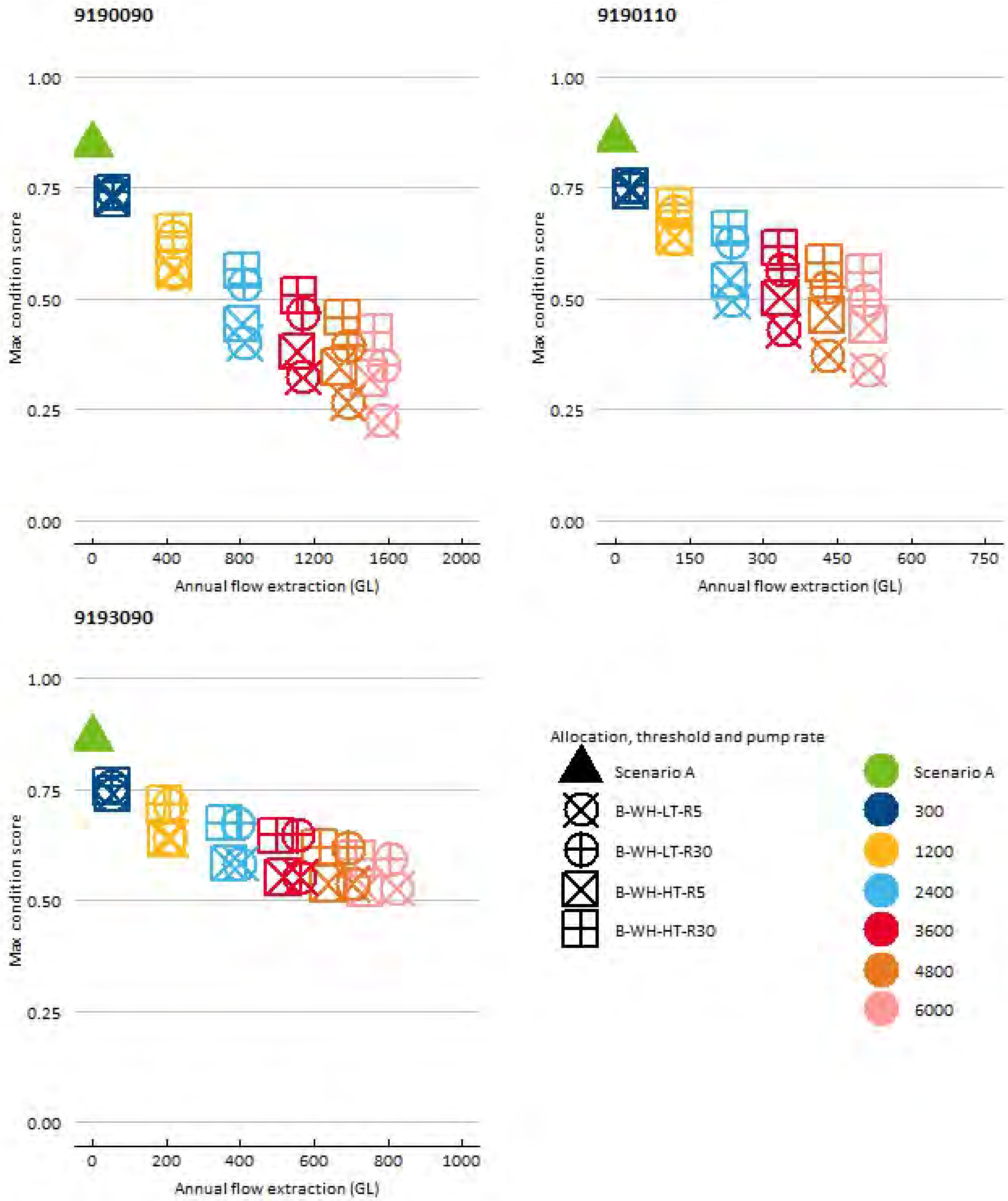

Figure 7-10 Maximum condition scores of barramundi, considering Scenario B-WH at nodes 9190090, 9190110 and 9193090, showing LT and HT scenarios

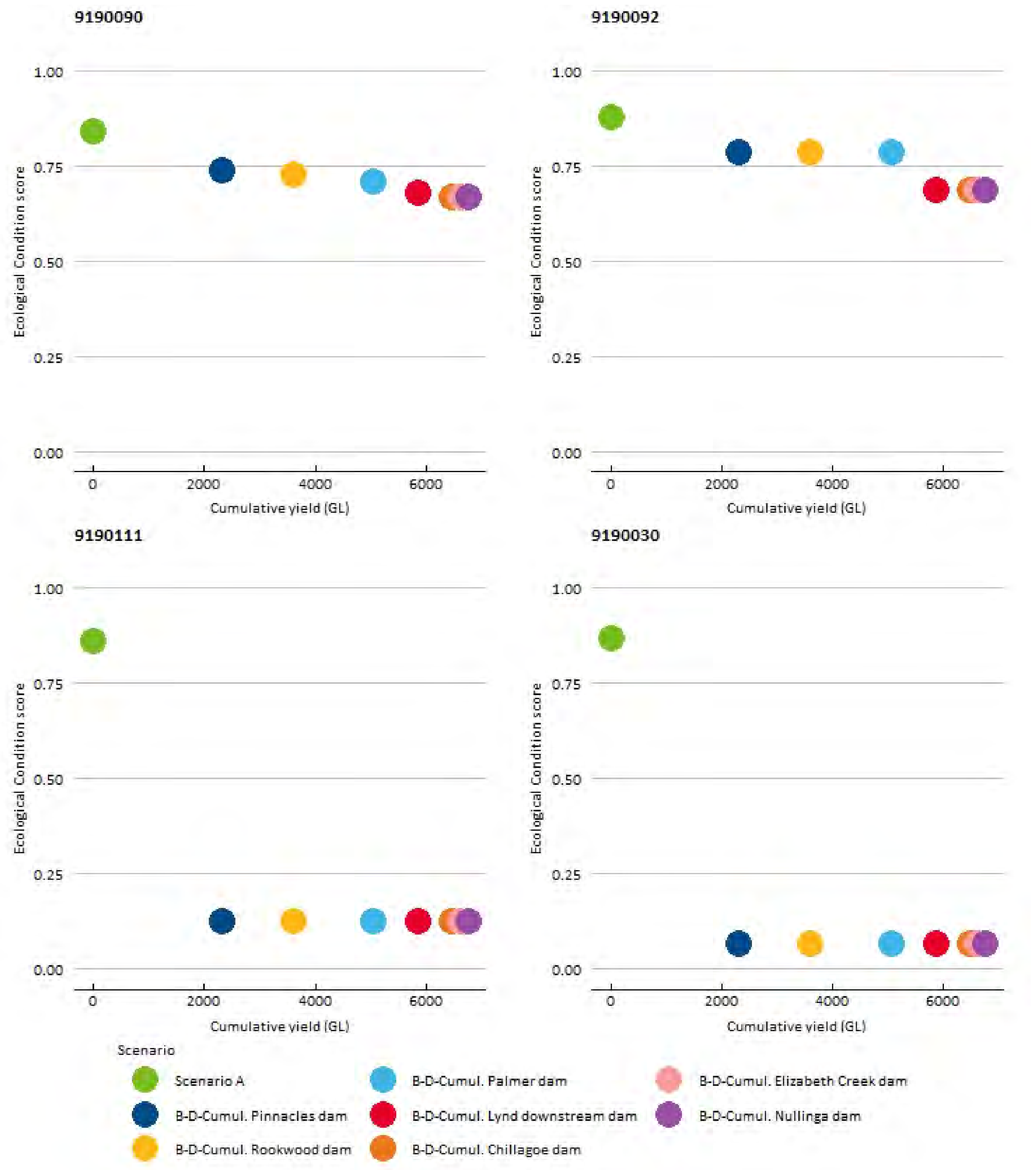

Figure 7-11 Maximum condition scores of barramundi, considering Scenario B-D-C at nodes 9190090, 9190092, 9190111 and 9190030

Sawfish

The freshwater sawfish (*Pristis pristis*) is distributed throughout the Mitchell catchment. Inchannel barriers along migration routes of the Mitchell catchment pose a threat to the freshwater sawfish. The freshwater sawfish has a marine adult phase while the juvenile phase is in estuaries and rivers, and juveniles and adults occupy large pools and waterholes of large rivers.

Sawfish were assessed at five nodes in the Mitchell catchment (nodes 9190000, 9190090, 9190092, 9190111 and 9193090) (Figure 7-2). Tier 1 screening analysis in the Mitchell catchment under Scenario B-WH results in some changes in habitat for sawfish. Changes to important flow metrics for sawfish at the end-of-system node (9190000) are minor up to and including an extraction volume of 3600 GL, increasing to moderate up to 6000 GL for the LT. Changes range from no change to minor change at the HT. Changes at nodes 9190090 are minor up to and including 600 GL, becoming moderate up to 4800 GL and becoming major at 6000 GL for the LT. For the HT, there are minor changes for 2400 and 3600 GL, ranging up to moderate changes for 4800 and 6000 GL. At 9110092, changes range between no change and minor change for the LT and HT. Changes range between no change and minor change at nodes 9190111 and 9190030. Changes at node 9193090 are minor up to 3600 GL and moderate in remaining scenarios.

Under Scenario B-D-I, the potential Pinnacles dam results in minor changes at nodes 9190000 (end-of-system) and 9190090. Under Scenario B-D-C these increase to moderate with the addition of the potential Rookwood dam on the Walsh River (Figure 7-2). Under Scenario B-D-I the introduction of individual dams other than Pinnacles dam results in no change to important flow metrics for sawfish at nodes 9190000 and 919090. Changes at node 9190092 are moderate with the introduction of the Lynd River dam.

Under Scenario B-D-I at node 9190111 (i.e. in the reach below the potential Pinnacles dam), major changes occur with the introduction of the potential Pinnacles dam. At node 9193090 major changes occur with the addition of the Rookwood dam on the Walsh River, increasing to extreme changes with the addition of the Elizabeth Creek dam. With the introduction of the Pinnacles dam at node 9190030, extreme changes occur immediately downstream. Major changes would have substantial impacts on the habitat for sawfish. Extreme changes would result in the habitat for sawfish no longer being suitable. However, it should be noted that under this particular model configuration it was assumed that all water released from the dam was released for irrigation into a channel not run down the river. Had water from the dam been released down the river the impact would be moderated to some extent.

Detailed flow analysis

Further analysis (Tier 2) was undertaken at nodes 9190090, 9190110 and 9193090 under Scenario B-WH and 9190090, 9190092, 9190111 and 9190030 (Figure 7-2) under Scenario B-D. Under Scenario B-WH at the lower-volume extractions there are minimal changes to the condition of sawfish. In contrast, high extraction would potentially have a substantial impact on the condition of sawfish. The decrease in condition for sawfish is proportional to the annual flow extracted (Figure 7-12). These changes have the potential to reduce sawfish populations over time.

Under Scenario B-D, there are substantial changes at nodes 9190111 and 9190030, with minimal changes at other assessment nodes (Figure 7-13).

Water harvest scenarios and potential dam scenarios led to reduced dry-season flows. Dam scenarios also increased the duration of low-flow periods. In the dry season, juvenile sawfish use inchannel waterholes in the lower to mid-reaches. With reduced flows, inchannel waterholes decrease in extent and depth, reducing habitat diversity and prey abundance within the waterholes. Inchannel waterholes act as refuge habitats that sustain freshwater sawfish during the dry season. Sawfish rely on the perennial nature and diversity of the instream pool habitats to survive, shelter and forage. Waterholes that have both deep-water pools and shallow bank and glide habitats are preferred as they support sheltering and feeding. In the late dry season, the water quality in waterholes declines and they are replenished by late dry-season flows that are also critical for maintaining habitat and production in estuaries. These late dry-season flows are at risk of change in the scenarios.

Under dam scenarios, flow changes also occur for wet-season flows. This has the potential to reduce sawfish reproduction and migration. Sawfish juveniles would be limited in their ability to migrate upstream to freshwater channel–pool and billabong habitats. Movement of sawfish downstream may be reduced due to decreased flood duration.

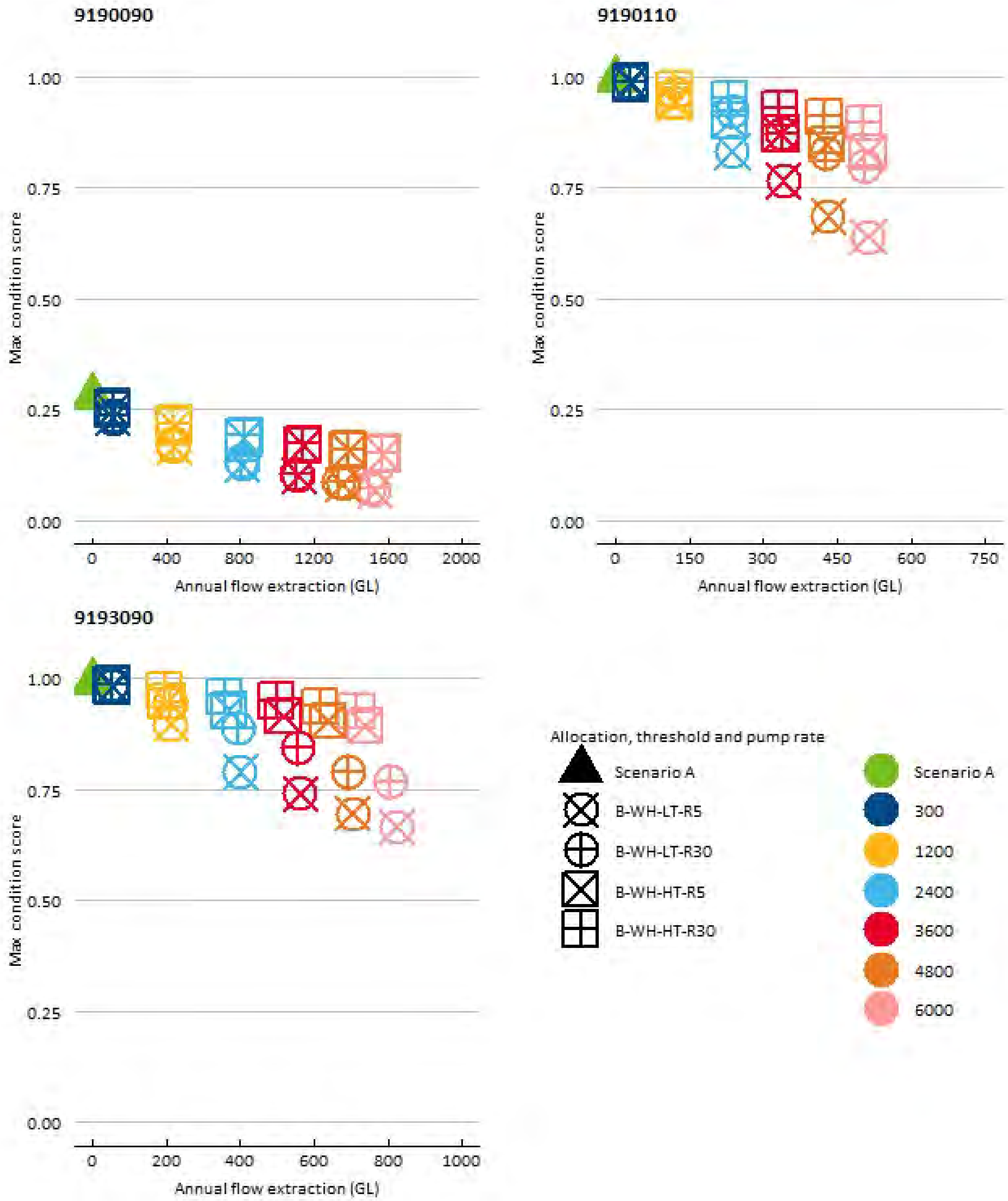

Figure 7-12 Maximum condition scores for sawfish, considering Scenario B-WH at nodes 9190090, 9190110 and 9193090

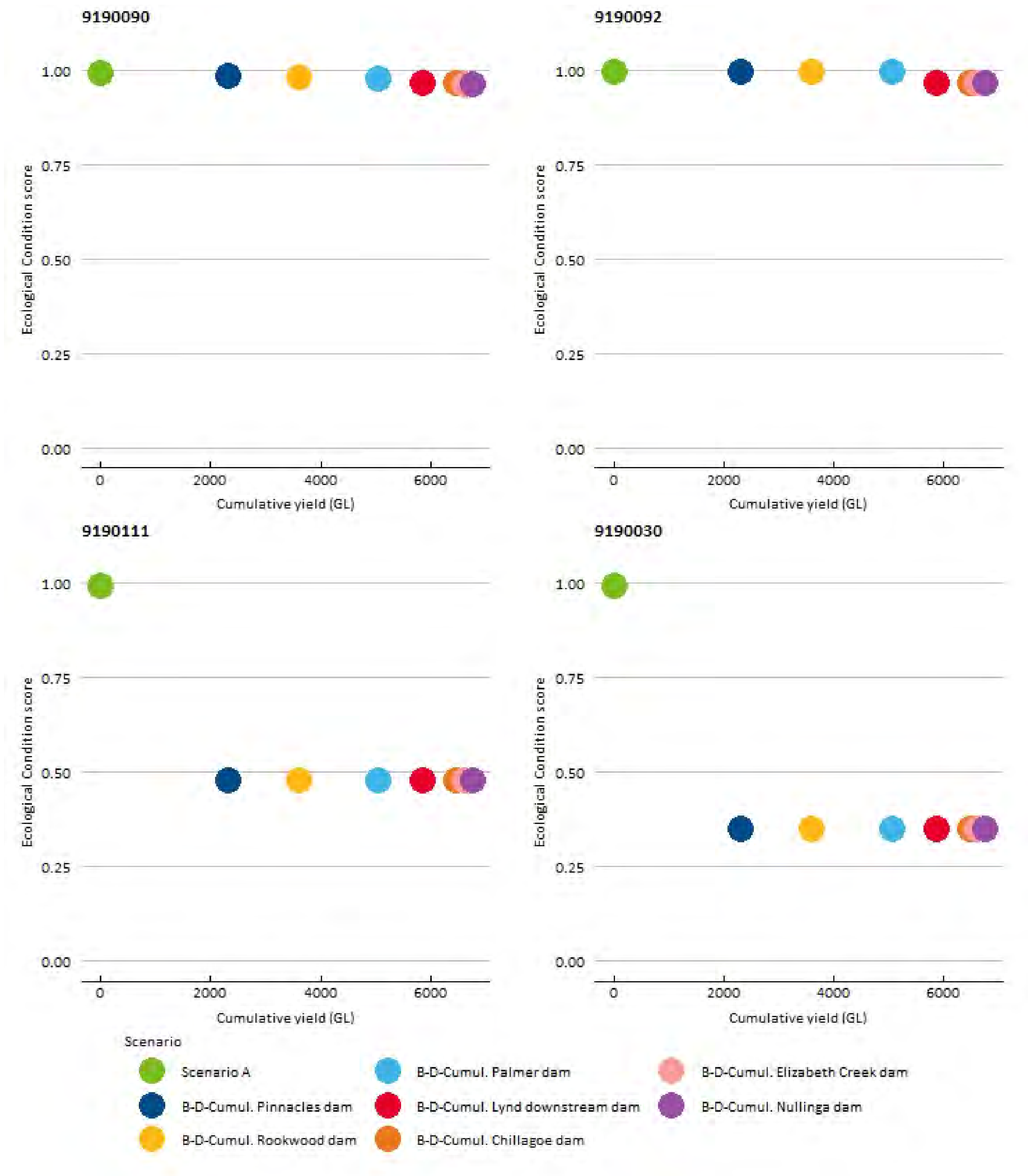

Figure 7-13 Maximum condition scores for sawfish, considering Scenario B-D-C at nodes 9190090, 9190092, 9190111 and 9190030

7.3 Biosecurity considerations

7.3.1 INTRODUCTION

Diseases and pests, due either to pathogens endemic to farming regions or introduced through translocations of animals from other regions, have had, and continue to have, major impacts on global agriculture and aquaculture production. For example, the resultant economic loss to global aquaculture industries alone was estimated to be US$6 billion/year (World Bank, 2014).

Compared with many other countries, Australia has many advantages in terms of the opportunity to mitigate risks from pests and disease through sound regulatory processes controlling translocation, technological knowledge and capability, and the greater geographic spread between farming operations in many regions. However, the recent discovery of the highly pathogenic white spot syndrome virus (WSSV) in south-east Queensland prawn farms has had a devastating effect on parts of the industry. There have also been serious outbreaks of diseases in agricultural crops in recent years across northern Australia, including green cucumber mottle mosaic virus on melons in the Katherine region in the NT; the fungal rice blast affecting rice production in the Ord, WA; Panama disease tropical race 4 affecting bananas in northern Queensland and the NT; and banana freckle in the NT. These serve as contemporary reminders of the impact that a pathogen can have at the point of infection as well as on an entire industry.

From a biosecurity point of view, risk is defined as the product of the likelihood of an invasion by a pest or pathogen and the impact that species will have. With both likelihood and impact there is a great deal of uncertainty and difficulty in making clear predictions.

This section examines biosecurity risk from an agriculture and aquaculture perspective, with the discussion structured around:

- the biosecurity risk to new farming enterprises in the Mitchell catchment
- the biosecurity risk that new farming enterprises in the Mitchell catchment may present to the broader industry across Australia.

Agriculture and aquaculture production systems can be threatened by generalist or specialised pests. The relative isolation of small areas of agriculture and aquaculture may, under some circumstances, provide some protection from certain pests and diseases but the opposite may also be the case; extensive areas of natural or less intensively managed vegetation may provide refuge for pests and diseases as well as beneficial organisms. For example, the Mitchell catchment is far removed from the WSSV outbreaks in prawn production systems in south-east Queensland but such isolation does not preclude the very real prospect of a biosecurity risk should such production systems be established there.

Generally, both dryland and 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 the pests that are of concern to them. This is especially the case for high-value crops. Less-intensive agricultural industries and environmental interests are likely to be in a less-favourable economic position when it comes to pest management. Irrigation and other intensive agricultural industries can thus increase the risks from pests faced by less-intensive industries and the natural environment.

Unless stated otherwise, material in the agriculture biosecurity (Section 7.3.2) and aquaculture biosecurity (Section 7.3.3) sections have been summarised from the companion technical reports on agricultural viability (Ash et al., 2018) and aquaculture viability (Irvin et al., 2018), respectively.

7.3.2 AGRICULTURAL BIOSECURITY

Irrigated agriculture in the Mitchell catchment will be exposed to existing and new diseases, pests and weeds. Although a tropical environment is conducive to a wide range of diseases, pests and weeds, the long dry season and the loss of green vegetation that characterises the Mitchell catchment provide an unfavourable environment for many diseases, pests and weeds and act as a natural break to their year-round persistence. However, areas of irrigation with year-round green foliage may increase the risk of insect pests and diseases persisting throughout the year. Further, new incursions are more likely because of increased human activity and the transport of new vectors on equipment, people or through seeds.

In the short to medium term, biosecurity risks to the Mitchell catchment are most likely to come from within the country and, in particular, from adjacent or climatically similar parts of Australia. The catchment already experiences impacts from introduced plants that are widespread in northern Australia. Not all parts of the catchment are equally vulnerable. Important pathways for dispersal of invasive species include existing road and river corridors. In northern Australia, riparian zones are vulnerable to invasion by many different non-native plants because these zones are relatively moist, have generally higher nutrient levels and experience naturally high levels of disturbance.

New risks will mostly be associated with insect pests and diseases. Understanding and managing this increased risk will be important. For this catchment, the types of pests and diseases that provide a risk to the various agricultural industries that could be established are many and varied. Annual weeds are a risk to crop production but they can generally be controlled through herbicides, use of cover crops and stubbles, and cultivation. They tend to not be an acute problem like pests and diseases and thus represent an ongoing management challenge rather than a threat to viability. For example, ongoing weed management in sugarcane costs around $338/ha.

Identifying potential pest and disease problems that can occur in greenfield agricultural areas can be problematic. The warmer, north Australian environment is more favourable than temperate climates for insects and pathogens to adapt and multiply with the introduction of a new food source (i.e. a crop). However, the environment also favours beneficial organisms that prey on pest species. Production systems that recognise the ecological realities of the natural environment are recommended; the collapse of the cotton industry in the Ord in WA during the 1970s is one example of a failure to do this. Irrigating a number of crops each year in rotation can provide a year-round food source for pests and carry-over of pathogens between crops.

Biosecurity risks to new agricultural enterprises and the risks from these enterprises to the broader environment

This discussion examines pathways of entry to the Mitchell catchment and then specifically discusses disease, pests and weeds in turn.

Pathways of entry

Pathogens, pests and weeds can enter a catchment via man-made pathways or natural pathways. Man-made pathways include road transport, ships and planes, and the 'carriers' (e.g. humans, animals, plants, machinery) that facilitate the movement and incursion of new pests, diseases and weeds. Published work has shown that the most likely human-facilitated pathway for bringing invasive species is either general trade, or live plant or animal trades. While it is not currently possible to determine the actual or relative risk to the Mitchell catchment from these forms of human-facilitated trade, it is possible to look at the historical rate of invasions (also referred to as incursions) in Australia. Studies have shown that the incursion rate in Australia for four orders of insects (beetles, bugs, flies, and moths and butterflies) has been about 15 species per year. Given the low human population in the Mitchell catchment it is not likely that this catchment will be exposed to regular incursions facilitated by humans. However, they do occur and can be very damaging, for example the green cucumber mottle mosaic virus in the NT.

Natural pathways include wind dispersal and river flow. Of these two modes, river flow is probably the higher risk as the headwaters of the Mitchell catchment are relatively densely populated and intensively farmed.

Another mode of entry to the Mitchell catchment is from pathogens and insects that arrive via the wind from Papua New Guinea or South-East Asia. Wind dispersal modelling undertaken in this Assessment shows that there is no risk of a fungal pathogen or insect pest landing in the Mitchell catchment from Sumatra, Java, or Bali (Table 7-7). The greatest risk of a fungal pathogen arriving to this region is from Papua, with Papua New Guinea and Timor-Leste presenting a lower risk. For insect pests, the only threat is from the coastal area of Papua. It should also be noted that these risks are only present for part of the year.

From mid-April to the beginning of September, the prevailing winds are generally southerlies through to easterlies (i.e. either blowing offshore or back towards Papua New Guinea). As a result, there are no arrivals from any points in South-East Asia to the Mitchell catchment during this period. In summary, the risk of arrival of fungal pathogens and insect pests directly from South-East Asia into the Mitchell catchment is small and restricted to a relatively narrow period.

Table 7-7 Proportion of simulations (1 per week = 52), in which a fungal pathogen or insect pest could have been transported from a location in South-East Asia to the Mitchell catchment

LOCATION	FUNGAL PATHOGEN	INSECT PEST
PNG (south coast)	0.04	0.00
PNG (mid-and north coast)	0.06	0.00
Indonesia (Papua – south coast)	0.15	0.02
Indonesia (Papua – mid- and north coast)	0.08	0.00
Indonesia (Java and Bali)	0.00	0.00
Indonesia (Sumatra)	0.00	0.00
Timor-Leste	0.06	0.00

PNG = Papua New Guinea

Threats to agriculture in the Mitchell catchment are not just from new arrivals from overseas but also from human-mediated dispersal from other areas within Australia. There are many different human-mediated vectors within Australia that have been shown to spread invasive species. These include tourists, livestock, vehicles, machinery, trains and transport containers. For example, the movement of cattle has been shown to spread the prickly acacia weed (*Acacia nilotica*) in western Queensland and parthenium weed (*Parthenium hysterophorus*) is spread by the movement of vehicles, machinery, livestock and stock feed. Those two examples are woody, perennial weeds that negatively affect extensive, pastoral operations as there is limited documentation of weed spread into irrigated cropping areas in northern Australia.

Pests

Pests are not limited to insects and pathogens, with macro-pests such as birds (cockatoo; galah, *Eolophus roseicapilla*; brolga, *Grus rubicunda*) and macropods (kangaroos and wallabies) considered a risk to introduced irrigated crops, particularly during the drier winter months when native food sources may be scarce. Locally developed and adaptive integrated pest and pesticide resistance management plans are an essential component of best practice and must be implemented pre-emptively.

More intensive land uses, such as irrigated agriculture, are associated with higher likelihoods of pest introduction and greater prospects for dispersal once pests are introduced. Aquaculture and irrigated agriculture entail more movement of materials and people and require more infrastructure than, for example, extensive, rangeland-based pastoralism. Roads and other transport corridors, pipelines, irrigation channels and powerlines, along with river corridors, are important transport routes and foci for invasions of pests. More vehicular traffic provides greater prospects for long-distance dispersal and agricultural machinery in particular is notorious for moving seeds around the landscape. The higher levels of disturbance that are almost inevitably associated with more intensive land uses will also promote invasion by certain kinds of species.

Pest animals are already present in the Mitchell catchment. Feral pigs (*Sus scrofa*) are perhaps the most apparent among terrestrial vertebrate pests and present some threat to agricultural enterprises. They are also destructive in natural environments, for example, through predation on nesting marine turtles on the beaches of the Gulf of Carpentaria, and through extensive damage to wetlands and associated vegetation. Pigs are a major problem in Queensland, and some 75% of their estimated population of 4 to 6 million is found in tropical north Queensland. Pigs can cause indirect damage, for example by carrying weed seed from watercourses to open country, and can cause direct and major physical damage to a wide range of crops and even to cultivated ground. Pigs have a daily water requirement, which means that during the dry season their range is generally restricted to watercourses and man-made water supplies, precisely the areas where crops are most prospective. Pig control is expensive and so selection of crops not attractive to pigs (e.g. cotton) is desirable where their numbers are high. Freshwater systems are also prone to invasions by non-native species including plants; vertebrates, such as the invasive fish tilapia; and invertebrates.

Weeds

The Mitchell catchment, along with other parts of northern Australia, is subject to invasion by a wide variety of weeds, many of them deliberately introduced (Cook and Dias, 2006). Some are more generally problematic while others are problematic for specific industries, sectors or land users. Riparian zones and other more mesic parts of the landscape are prone to a greater variety of weeds than elsewhere, but even drier parts of the landscape provide niches for some invasive species. Greater levels of disturbance, such as those that occur in association with any cropping system, provide opportunity for particular types of weeds.

Some plants associated with agricultural or more intensive pastoral developments can themselves become problematic for other land users. These could be the crop or pasture species themselves or commensals of the cropping and grazing systems. Such plants and other pests present particular threats to environmental assets. Olive hymenachne (*Hymenachne amplexicaulis*), a Weed of National Significance, is one example. It is present in Southedge Dam (Lake Mitchell), in the upper reaches of catchment, presenting the very real threat of downstream spread into riparian zones and coastal and other wetlands.

7.3.3 AQUACULTURE BIOSECURITY

Aquatic diseases are the main biosecurity risk to aquaculture and are caused by a range of pathogenic agents such as viruses, bacteria, fungi and parasites that have varying impacts across species, geographies, rearing systems and life stages.

Biosecurity risk to new aquaculture farming enterprises in the Mitchell catchment

This section briefly examines pathways by which pathogens could enter an operation in the Mitchell catchment. It then discusses disease and other biosecurity issues relating to the two main tropical farmed species, black tiger prawns (*Penaeus monodon*) and barramundi (*Lates calcarifer*). However, it should be noted that there are significant, and often different, experiences and issues posed by pathogens and disease for all Australian aquaculture industries.

Pathways of entry

The introduction of pathogens into aquatic farming systems comes from two main routes, the first being vertical transmission from parent to progeny, and the second being horizontal transmission from an infected environment, equipment, worker, or animal coming into contact with an uninfected animal during the rearing process. Horizontal transmission can occur through many vectors that harbour the pathogen such as the rearing water, other animals, dead tissues that are consumed, or animal faeces which are consumed or touched. Understanding the primary mode of transmission for each pathogen is critical to understanding how to mitigate disease risks. Applying preventative biosecurity measures that mitigate risks of all routes of transmission for all likely problematic pathogens is key to managing disease. Importantly, the existence of pathogens in the farming system does not necessarily equate to disease, and so disease management in aquaculture needs to both exclude those pathogens that can be excluded, and manage those pathogens that cannot be excluded.

Pathogens

As with all agricultural industries, there are a range of pathogens that pose risks to and may impact aquaculture. Fortunately, Australia is free of many of the aquatic pathogens that affect other aquaculture farming regions of the world.

For prawns, the disease agents that have most affected farming have been viruses. There are a large number of different viruses that can infect prawns, which vary significantly in their ability to cause disease and affect production. Fortunately, most of the highly pathogenic viruses are exotic to Australia. However, the recent discovery of the highly pathogenic WSSV in south-east

Queensland farms has led to investigations to determine whether WSSV is in fact endemic, or the result of an aberrant localised introduction (QDAF, 2017). Several endemic viruses can also have an effect on Australian prawn production, particularly when detrimental pond conditions, such as poor water quality, inflict environmental stress on the prawns and trigger disease episodes (QDPIF, 2006).

Bacteria pathogens can also reduce production, but are also often believed secondary to other stressors (QDPIF, 2006). Recently, syndromes caused by toxicity associated with bacteria have had significant impacts on prawn production both in Australia (*Penaeus monodon* mortality syndrome (QDAF, 2016)) and even more so overseas (acute hepatopancreatic necrosis disease (NACA, 2016)). Fungi and a range of other microbial and parasitic agents can also cause disease at various life stages and have a negative effect on the appearance of harvested prawn products, but have rarely affected Australian farming in recent decades due to better health and pond management practices.

For barramundi, a range of viral, bacterial, fungal and parasitic pathogens can also affect hatcheries and grow-out. The predominant viral pathogens of concern for barramundi farming in Australia are the nodaviruses, which can cause major mortalities in larval and juvenile barramundi. Bacterial diseases, such as streptococcosis, can also cause high mortalities in both fresh and marine farming systems. Vibriosis and other bacterial pathogens, which infect the gut (causing 'bloat') and the gills, also reduce production in fresh and marine waters but are typically secondary to other environmental and dietary stresses. Fungal diseases causing ulceration also periodically affect production in the freshwater and estuarine phases, and typically cause fish to become lethargic and prone to cannibalism. Parasitic protozoans residing in the skin and gills can increase in numbers at times and cause disease, and a blood protozoan has also been associated with major mortalities in sea-caged barramundi. In addition to these non-infectious diseases, particular deformities can reduce production, typically due to nutritional inadequacies in the diet.

A comprehensive knowledge of pathogen agents is essential for developing and implementing risk-based biosecurity measures to mitigate against disease impacts in aquaculture. Understanding of the diseases and disease agents that are likely present in various jurisdictions, or through the process of acquiring animal stocks, and which may have adverse effects, is also important in developing a biosecurity plan. Government departments have important roles in the ongoing surveillance of pathogens, in controlling translocation of stocks based on pathogen risks, and in undertaking investigations where potential disease episodes have been identified (Department of Agriculture and Fisheries Queensland, 2013)

Due to increasing awareness of pathogen risks and the need for biosecurity, and the increasing professionalism of farming operations, it is becoming more common for individual farms to undertake their own pathogen monitoring to minimise the disease risks to their operations. The key elements to effective biosecurity and disease management at the farm level are to access clean and healthy stock; to provide a clean and healthy rearing environment (e.g. good quality water); to provide an adequate quality and quantity of diet; and to control access to water, equipment and people that may introduce pathogens into the farming system.

Treatment actions once diseases are present typically provide few options, particularly for viral pathogens, and are also costly to implement and rarely as effective as prevention. Consequently, for aquaculture, the most important component of disease management is prevention. Important components of prevention are hygiene and biosecurity in the earliest hatchery stages of production, as well as decontamination processes between crops to ensure the environment is clean before the next crop is commenced. Another very important aspect of disease management is to maintain a quality rearing environment, as both the introduction of pathogens, and more importantly the increase of pathogens in the environment and their manifestation to a disease episode, is typically triggered by increased stress on the animals caused by a poor rearing environment.

Due to the rudimentary immune system of crustaceans, there is limited ability to manage the most serious diseases once established, and so pathogen management has typically focused on exclusion through pathogen screening of broodstock and postlarvae prior to stocking ponds. Some treatments for external bacterial and fungal pathogens are employed, particularly for broodstock, eggs and larvae within the hatchery (FAO, 2007). During the rearing of larvae, control of bacterial pathogens is typically focused on maintaining a good environment and through pre- and probiotics, with antibiotics used only in exceptional circumstances.

Biosecurity risks that new aquaculture farming enterprises in the Mitchell catchment may present to the broader catchment or industry

Risk to other aquaculture enterprises

A major risk pathway with the development of new and established marine aquaculture enterprises is associated with sharing of a water source (usually a river). The risk of contamination between enterprises is highest when there is limited distance (<2 km) between the location of the discharge point from one farm and the supply point of another farm.

Risk to wild populations

There is potential for disease transfer between aquaculture species (e.g. prawns and barramundi) and their respective wild populations. The main transfer routes are discharge waters containing disease or from infected animals (escapees) in discharge water or transferred by predatory vectors (e.g. seabirds). The potential impact of disease on wild populations will depend on pathogen volume, ability of the pathogen to survive without a host, proximity of a significant susceptible host population and the health and tolerance of the host to the disease. In general, susceptible animals in the wild occur only in low-density populations adjacent to land-based aquaculture operations.

The effect that exotic or endemic disease outbreaks from aquaculture have on wild stocks is difficult to evaluate. In Australia, impacts of disease transferred from aquaculture to wild populations have not been widely reported and are difficult to detect. In overseas countries where WSSV is endemic there is little evidence that the disease has any effect on wild prawn populations. In Australia, the response to a suspected outbreak of exotic disease (e.g. WSSV) involves the farm notifying the relevant authorities, isolation of affected ponds and preventing water flow from the ponds to the surrounding environment. The authority (e.g. Biosecurity Queensland) provides advice, which depending on the diagnosis may include destruction and disposal of stock and decontamination of the site. In the case of the recent WSSV discovery in south-east Queensland, a surveillance program commenced (post decontamination) that requires 24 months of no detection of infection in the wild before farming can recommence (DAF, 2018). Since the introduction of the surveillance program in Queensland only very small numbers of infected wild crustaceans have been detected, the vast majority sampled in the vicinity of the original discovery.

The discovery of exotic disease may have a larger impact on the fisher than the wild fishery. For example, in the case of WSSV in Queensland, local commercial and recreation prawn fishers have been constrained by a ban on the movement of uncooked prawns within a restriction zone, which stretches from Caloundra to the NSW border (DAF, 2018). If an exotic disease (e.g. WSSV) was to be identified in aquaculture enterprises located in the Mitchell catchment, commercial fishers operating in waters adjacent to the catchment would likely face similar restrictions in the movement of prawns.

Biosecurity regulatory impacts on development

The aquaculture industry is managed by numerous agencies at the local, state and federal levels of government. To date, significant development of marine aquaculture in northern Australia has in part been constrained by complex legislation and the absence of aquaculture-specific policy, particularly relating to biosecurity issues. A parliamentary inquiry into the development of northern Australia identified the regulatory environment as a serious impediment to major expansion of the prawn farming industry (Parliament of Australia, 2014).

In general, large areas of low-value land located away from populated coastal areas are likely to be suitable for freshwater ponds. In contrast, marine ponds require higher value coastal land, often located in close proximity to towns or regional centres. Compared to marine pond aquaculture, freshwater pond aquaculture is ranked as a low environmental risk option for development. There is no difference in the probability of marine or fresh pond water escaping containment and seeping into the groundwater or surrounding environment. However, marine water discharged into groundwater or freshwater bodies has greater potential to cause negative environmental and ecological impacts.

The approval process for an aquaculture licence is simple for freshwater pond-based farming. This is reflected in the number of licence approvals. For example, in Queensland in 2014–15 there were 158 development approvals for freshwater red claw production compared to 58 approvals for marine prawn production. The disconnection between the number of licence approvals and value of the respective industries ($1 million for red claw and $86 million for prawns) is due to the greater difficulty in obtaining an aquaculture licence for marine pond-based farming (Savage, 2016).

The approval process will vary depending on the state or territory and jurisdiction of water source. Specific details on the approvals required for a land-based aquaculture operation can be found at the website of the relevant authority. Two reviews undertaken in 2013 and 2014 by the Centre for International Economics (CIE) provide a good overview of the regulatory framework for aquaculture in Queensland (CIE, 2013, 2014). The 2014 CIE review provides a comparative assessment of Queensland with three southern jurisdictions, highlighting the degree of difference in regulatory approaches across jurisdictions (CIE, 2014).

7.4 Sediment, nutrients and agropollutant loads to receiving waters

7.4.1 INTRODUCTION

Agriculture can affect the water quality of downstream freshwater, estuarine and marine ecosystems. The principal pollutants from agriculture are nitrogen, phosphorus, total suspended solids, herbicides and pesticides (Lewis et al., 2009; Kroon et al., 2016; Davis et al., 2017). Losses via runoff or deep drainage are the main pathways by which agricultural pollutants enter water bodies. The climate, location (e.g. soils and topography), land use (e.g. cropping system) and management (e.g. conservation and irrigation practices) influence the type and quantity of pollutants lost from an agricultural system.

The development of agriculture in northern Australia has been associated with declining water quality (Lewis et al., 2009; Mitchell et al., 2009; De'ath et al., 2012; Waterhouse et al., 2012; Thorburn et al., 2013; Kroon et al., 2016). Since the 1850s it has been estimated that pollutant loads in north-eastern Australian rivers (typically those in which agriculture as a land use dominates) have increased considerably for nitrogen (2 to 9 times baseline levels), phosphorus (3 to 9 times), suspended sediment (3 to 6 times) and pesticides (~17,000 kg) (Kroon et al., 2016). Degraded water quality can cause a loss of aquatic habitat, biodiversity, productivity and ecosystem services. Increased nitrogen and phosphorus can cause planktonic blooms and weed infestation, increased hypoxia, and result in fish deaths. Suspended sediment can smother habitat and aquatic organisms, reduce light penetration and reduce dissolved oxygen levels. Pesticides may be toxic to habitats and aquatic organisms (Pearson and Stork, 2009; Brodie et al., 2013; Davis et al., 2017).

Water quality monitoring has been undertaken in specific areas of the Mitchell catchment. There is evidence that agricultural development within the Mitchell catchment has resulted in reduced quality of the water discharged from the Mareeba–Dimbulah Water Supply Scheme (MDWSS). Nutrient concentrations have been recorded to be two to ten times higher than the acceptable level in Cattle Creek and Two Mile Creek, with ammonia concentrations high enough to be acutely toxic to aquatic animals (Butler et al., 2008).

Northern Australian river systems are distinctive as they may have highly variable flow regimes, unique species composition, low human population densities and, in some cases, naturally high turbidity (Brodie and Mitchell, 2005). Primary influences on water quality include increased sediment loads associated with land clearing, grazing, agriculture and late dry-season fires, and nutrient pollution from agricultural and pastoral land use (Dixon et al., 2011).

Unless specified otherwise, material in sections 7.4.2 and 7.4.3 are summarised from the companion technical report on agriculture viability (Ash et al., 2018) and sections 7.4.4 and 7.4.5 are summarised from the companion technical report on aquaculture viability (Irvin et al., 2018).

7.4.2 AGRICULTURE POLLUTANT LOSSES AT THE PADDOCK SCALE

Two approaches were used to quantify the likely losses of key pollutants (nitrogen, phosphorus, total suspended solids, and chemicals such as herbicides, pesticides and fungicides) from potential agricultural development in the Mitchell catchment:

1. The first approach was a relative-risk assessment of the crops using potential nutrient surpluses arising from recommended tillage management and herbicide, pesticide and fungicide application rates in these cropping systems as indicators of risk of losses of the key pollutants.
2. The second approach involved a more detailed estimate of pollutant losses for some specific crops for agricultural development based on Agricultural Production Systems sIMulator (APSIM) simulations of the cropping systems for those crops.

Relative-risk assessment of pollutant losses

To estimate the risk of losses of nitrogen, phosphorus, total suspended solids and chemicals from a range of crops and cropping systems, information on a wide range of factors was collated or calculated including information on nutrient surpluses, number of tillage operations, and application rates of herbicides, pesticides and fungicides (Ash et al., 2018).

Central to the relative-risk assessment is nutrient surpluses, which occur when a greater amount of nutrient (e.g. nitrogen, phosphorous) is applied to the crop than is removed from the field in the harvested product. Nutrient surpluses are an indicator of potential nutrient losses from fields and have been used to assess the risk of nutrient discharges from agricultural areas in other parts of northern Australia (Thorburn and Wilkinson, 2013). The risk of herbicide, pesticide, fungicide and sediment losses was assessed from the amount of chemical applied and the number of tillage operations, respectively.

Nitrogen use varied considerably for crops assessed in the Mitchell catchment (Table 7-8). The nitrogen surplus was high for bananas and relatively high for sugarcane, which have high nitrogen inputs and a low quantity of nitrogen removed in the harvestable product. Conversely, nitrogen surplus was low for a number of crops or even negative in the case of Jarrah grass (*Digitaria milanjiana* cv Jarrah). A negative nitrogen surplus indicates that nitrogen inputs are less than the nitrogen in the harvestable product. In these instances, nitrogen from mineralisation of soil nitrogen would be required to meet crop nitrogen demands (Angus, 2001). It should be noted that efficiencies of use will be higher with split applications of nitrogen and where crop rotations or cover crops are used as part of the cropping system.

Table 7-8 Nitrogen (N) surplus for multiple crops grown in the Mitchell catchment based on risk assessment
Data calculated using APSIM output and values from literature (see the companion technical report on agricultural viability (Ash et al., 2018)).

CROP	N APPLIED TO CROP (kg/ha)	N FIXED (kg/ha)	TOTAL N INPUTS (kg/ha)	N IN HARVESTABLE PRODUCT (kg/ha)	N SURPLUS (kg/ha))
Banana	400	0	400	73	327
Chickpeas	6	87	93	92	1
Cotton	180	0	180	110	70
Jarrah grass (hay)	71	0	71	122	–51
Maize	180	0	180	142	38
Mungbean	23	65	88	85	3
Peanut	15	124	139	131	8
Rice	200	0	200	98	102
Rockmelon	107	0	107	37	70

CROP	N APPLIED TO CROP (kg/ha)	N FIXED (kg/ha)	TOTAL N INPUTS (kg/ha)	N IN HARVESTABLE PRODUCT (kg/ha)	N SURPLUS (kg/ha))
Sesame	89	0	89	85	4
Sorghum (grain)	170	0	170	133	37
Soybean	11	180	191	177	14
Sugarcane	200	0	200	70	130
Sunflower	150	0	150	83	67
Watermelon	107	0	107	48	59

Phosphorus surplus varied substantially for crops assessed in the Mitchell catchment (Table 7-9). The phosphorus surplus was very high for crops such as bananas and watermelon that have high phosphorus inputs and a low quantity of phosphorus in the harvestable product. Conversely, the phosphorus surplus was low or even negative for crops such as chickpea, maize and sesame. A negative phosphorus surplus indicates that phosphorus inputs are less than the phosphorus in the harvestable product. In these instances, phosphorus reserves in the soil are being depleted (Stewart and Tiessen, 1987).

Table 7-9 Phosphorus (P) surplus for multiple crops grown in the Mitchell catchment based on risk assessment
Data calculated using APSIM output and values from literature (see the companion technical report on agricultural viability (Ash et al., 2018)).

CROP	TOTAL P INPUTS (kg/ha)	P IN HARVESTABLE PRODUCT (kg/ha)	P SURPLUS (kg/ha)
Banana	101	9	92
Chickpea	11	9	2
Cotton	22	14	8
Jarrah grass (hay)	17	18	–1
Maize	19	27	–8
Mungbean	25	8	17
Peanut	33	11	22
Rice	28	20	8
Rockmelon	60	9	51
Sesame	3	18	–15
Sorghum (grain)	48	24	24
Soybean	22	18	4
Sugarcane	38	16	22
Sunflower	60	17	43
Watermelon	60	5	55

The total herbicide, pesticide and fungicide application rates per crop varied substantially for crops grown in the Mitchell catchment (Table 7-10). Some crops, such as bananas, have high pesticide, herbicide and fungicide application rates while other crops, such as rice or mangoes, have much lower application rates. It should be noted that this assessment is quite limited as it is simply reporting total amounts applied rather than the impact of the active ingredients. Many newer herbicides and pesticides have much lower application rates but their active ingredients are relatively more potent than older chemicals. For example, the pesticide chlorantraniliprole

(Alatacor, Dupont Chemicals) is a recent pesticide that is highly effective against caterpillars in pulse crops and is applied at a rate of just 70 g/ha.

Table 7-10 Herbicide, pesticide and fungicide application rates for multiple crops grown in the Mitchell catchment

CROP	TOTAL HERBICIDE APPLICATION (L/ha/CROP)	TOTAL PESTICIDE APPLICATION (L/ha/CROP)	TOTAL FUNGICIDE APPLICATION (L/ha/CROP)
Sorghum (grain)	5.5	0	0
Avocado	5.5	13.7	13
Banana	25.3	90	3.7
Cashew	2	6.4	0
Chickpea	8.4	0.1	2
Cotton	9.1	2.2	0
Jarrah grass (hay)	6	0	0
Maize	5.5	2	0
Mango Calypso	3	0.5	3.4
Mango KP	3	0.5	3.4
Mungbean	4	3.1	70.1
Peanut	4.1	0	13.2
Rice	3.5	1	0
Rockmelon	1.5	1.5	4.9
Sesame	3.8	0.14	0
Sugarcane	9.1	1.5	0
Sunflower	NA	0.8	0
Soybean	2.4	5	0
Watermelon	1.5	1.5	4.9

NA = data not available

The number of tillage operations varied substantially for crops grown in the Mitchell catchment. The greater the number of tillage operations, the greater the risk of loss of soil to the environment, which has the potential to end up as suspended sediment in waterways. As well, intensive tillage operations are likely to be more damaging than low-impact tillage operations. Thus, crops such as melons and bananas that have a high number of both total and intensive tillage operations pose the greatest risk. Crops such as rice and maize that have a low number of both total and intensive tillage operations pose the least risk.

Simulated pollutant losses

Simulated annual loss of nitrogen via runoff varied depending on crop, climate and soil (Figure 7-14a–d). Mean annual simulated loss of nitrogen was 1 kg/ha and the maximum annual loss was 16 kg/ha from a cotton crop on a Brown Sodosol (Figure 7-14c). In general, losses of nitrogen via runoff were higher in cotton than in other crops and tended to be higher for the Brown Sodosol than for the Grey Vertosol (Figure 7-14a–d).

Simulated annual losses of leached nitrogen were higher than losses via runoff and varied depending on crop, climate and soil (Figure 7-14e–h). Mean annual simulated nitrogen loss was 8 kg/ha and the maximum annual loss was 108 kg/ha from a sugarcane crop on a Brown Sodosol

(Figure 7-14e). In general, losses of leached nitrogen were higher in sugarcane than in other crops and tended to be higher for the Vertosol than for the Brown Sodosol (Figure 7-14e–h).

Simulated annual soil losses also varied according to crop, climate and soil (Figure 7-14i–l). Mean simulated annual loss was 6 t/ha and the maximum annual loss was 42 t/ha from a mungbean crop on a Brown Sodosol (Figure 7-14k). In general, soil loss from cotton, mungbean and sugarcane was higher than for forage sorghum and rice and soil loss tended to be higher for the Brown Sodosol than for the Vertosol.

Pollutant losses varied considerably based on rainfall as nitrogen loss via runoff and soil erosion are driven by frequency and intensity of rainfall, while nitrogen leaching is driven by water drainage. An example of these differences is a cotton crop simulated at Dunbar Station on a Grey Vertosol: annual rainfall was 559 mm in 2005 and 1440 mm in 2006. Simulated annual nitrogen losses through runoff were 0.05 kg/ha in 2005 and 0.9 kg/ha in 2006, while N leaching was 3 kg/ha in 2005 and 39 kg/ha in 2006, and soil losses were 1.1 t/ha in 2005 and 5.1 t/h in 2006 (data not shown). These results are based on a single annual crop and do not include a cover crop or other form of rotational cropping system. Cropping system implications are explored in the next section in the context of reducing pollutant losses.

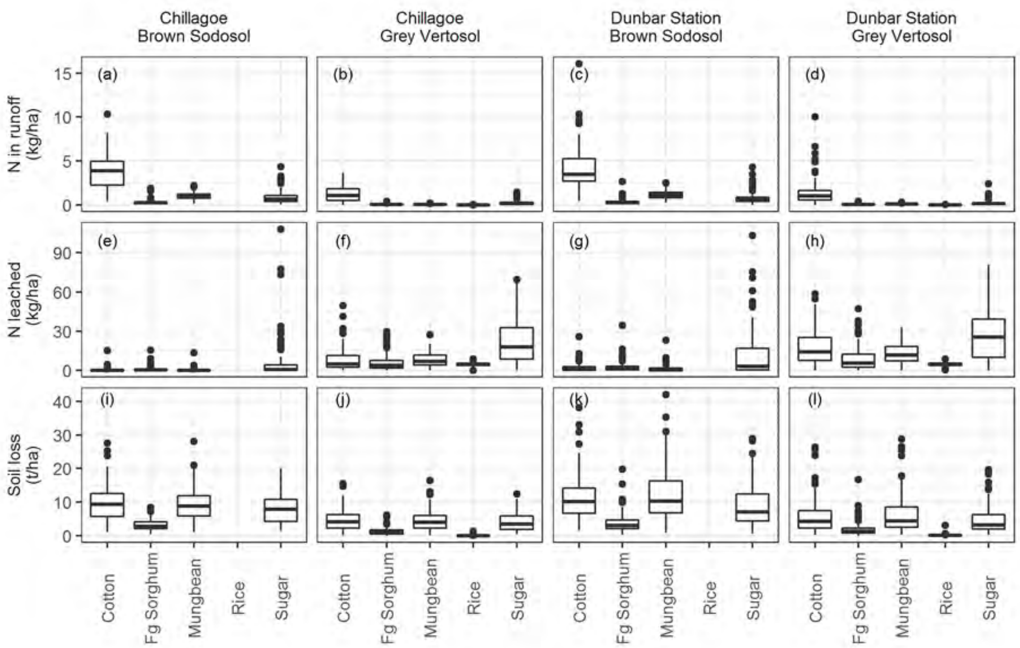

Figure 7-14 Simulated annual soil loss and nitrogen (N) losses via runoff or leaching at two locations and two soils for five crops in the Mitchell catchment over 125 years (1890 to 2015)
Note: (a) rice was only simulated on the Vertosol; (b) *y*-axes differ between rows.

Climate is also a driver of pollutant losses. Comparison of years with considerably different annual rainfall found nitrogen losses via runoff or leaching were greater in years with high rainfall than with low rainfall. Soil texture also plays a role in driving pollutant losses, with sandy soils more prone to nitrogen losses via leaching than clay soils (Gaines and Gaines, 1994). Future agricultural development could minimise pollutant losses by prioritising development on soils with lower potential for pollutant losses.

Reducing pollutant losses

There is a large body of literature that has investigated approaches to minimise pollutant losses from farming systems in Australia. Refining application rates of fertiliser to better match crop requirements and improving irrigation management are effective ways to minimise nitrogen losses (Brodie et al., 2008; Thorburn et al., 2008, 2011a, 2011b; Webster et al., 2012; Biggs et al., 2013; Thorburn and Wilkinson, 2013). Lower fertiliser application rates has reduced losses of nitrogen via leaching from banana crops Armour et al. (2013). The use of 'best management practices' including controlled traffic and banded application of herbicides can substantially reduce the loss of herbicides (Masters et al., 2013; Silburn et al., 2013). Furthermore, crop rotation, particularly the use of a cover crop, can minimise soil loss (Carroll et al., 1997; Dabney et al., 2001). In a simulated example of a cropping rotation that includes a summer cover crop, simulated annual soil loss was reduced from 6.5 t/ha for a single cotton crop to between 2.2 and 2.4 t/ha for a cotton–sorghum or cotton–soybean rotation (Figure 7-15). Nitrogen losses were little affected by the cropping system rotation but for all scenarios these losses were very low.

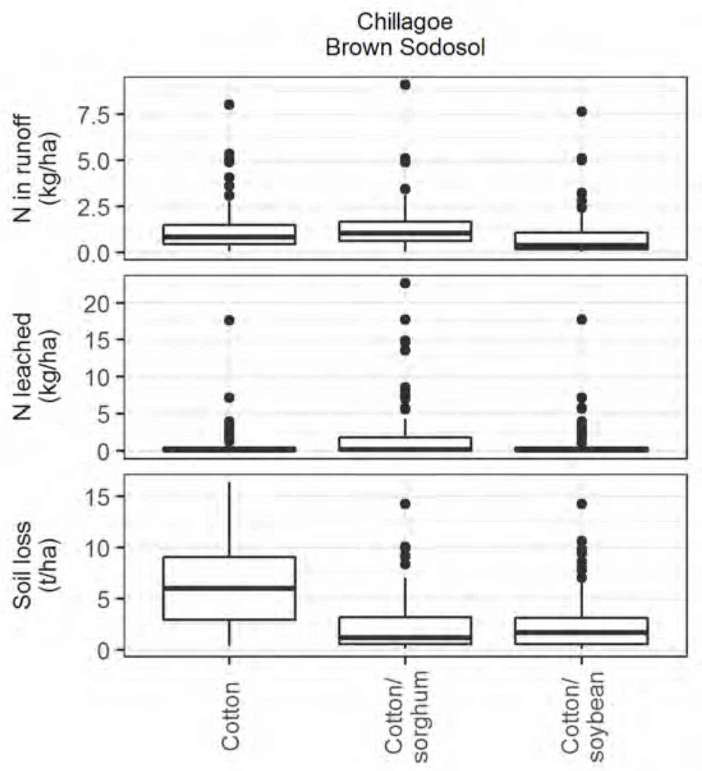

Figure 7-15 Simulated annual N losses via runoff or leaching and soil loss from Chillagoe climate station and a Brown Sodosol for a cotton crop, a cotton–sorghum crop rotation, and a cotton–soybean crop rotation for the Mitchell catchment

Simulation duration was 125 years (1890 to 2015).

7.4.3 MANAGING IRRIGATION DRAINAGE

Surface drainage water is water that runs off irrigation developments as a result of over-irrigation or rainfall. This excess water can potentially affect the surrounding environment by modifying flow regimes and changing water quality. Hence, management of irrigation or agricultural drainage waters is a key consideration when evaluating and developing new irrigation systems and should be given careful consideration during the planning and design process. Regulatory constraints on the disposal of agricultural drainage water from irrigated lands are being made more stringent as this disposal can potentially have significant off-site environmental effects (Tanji and Kielen, 2002). Hence, minimising drainage water through the use of best-practice irrigation design and management should be a priority in any new irrigation development in northern Australia. This involves integrating sound irrigation systems, drainage networks and disposal options so as to minimise off-site impacts.

Surface drainage networks need to be designed to cope with the runoff associated with irrigation, and also the runoff induced by rainfall events on irrigated lands. Drainage must be adequate to remove excess water from irrigated fields in a timely manner, and hence reduce waterlogging and salinisation, which can seriously limit crop yields. In best-practice design, surface drainage water is generally reused through a surface drainage recycling system where runoff tailwater is returned to an on-farm storage or used to irrigate subsequent fields within an irrigation cycle.

The quality of drainage water will vary depending upon a range of factors including water management and method of application, soil properties, method and timing of fertiliser and pesticide application, hydrogeology, climate and drainage system (Tanji and Kielen, 2002). These factors need to be taken into consideration when implementing drainage system water recycling and also when disposing of drainage water to natural environments.

A major concern with tailwater drainage is the agropollutants derived from pesticides and fertilisers that are generally associated with intensive cropping and are found in the tailwater from irrigated fields. Crop chemicals can enter surface drainage water if poor water application practices or significant rainfall events occur, after pesticide or fertiliser application (Tanji and Kielen, 2002). Tailwater runoff from pesticides and fertilisers can contain phosphate, organic nitrogen and pesticides that have the potential to adversely affect flora and fauna and ecosystem health, on land waterways, estuaries or marine environments. Tailwater runoff may also contain elevated levels of salts, particularly if the runoff has been generated on saline surface soils. Training of irrigators in responsible application of both water and agrochemicals is therefore an essential component of sustainable management of irrigation.

As tailwater runoff is either discharged from the catchment or captured and recycled it can result in a build-up of agropollutants that may ultimately require disposal from the irrigation fields. In externally-draining basins, the highly seasonal nature of flows in northern Australia does offer possibilities to dispose of poor-quality tailwater during high-flow events. However, downstream consequences are possible and no scientific evidence is available to recommend such disposal as good practice. Hence, consideration should be given to providing an adequate understanding of downstream consequences of disposing of drainage effluent and options must be provided for managing disposal that minimise impacts on natural systems.

7.4.4 CHEMICAL CONTAMINANT RISKS TO AQUACULTURE

Hundreds of different chemicals, including oils, metals, pharmaceuticals, fertilisers and pesticides (e.g. insecticides, herbicides, fungicides) are used in different agricultural, horticultural and mining sectors, and in industrial and domestic settings, throughout Australia. The release of these chemical contaminants beyond the area of target application can lead to the contamination of soils, sediments and waters in nearby environments. In aquatic environments, including aquaculture environments, fertilisers have the potential to cause nonpoint source pollution. This eutrophication is caused by nutrients that trigger excessive growth of plant and algal species, which then form hypoxic (low oxygen) ‘dead zones’ and potentially elevated levels of toxic un-ionised ammonia (Kremser and Schnug, 2002). This can have a significant impact on the health and growth of animals in aquaculture operations, as well as in the broader environment. For example, health indicators are lower in barramundi collected from agriculturally affected rivers in Queensland relative to those collected at more pristine sites.

Of concern to aquaculture in northern Australia are the risks posed to crustaceans (e.g. prawns and crabs) by some of the insecticides in current use. These insecticides can be classified based on their specific chemical properties and modes of action. The different classes of insecticides have broad and overlapping applications across these different settings.

The first class is organophosphate insecticides of which toxicity is not specific to target insects, raising concerns about the impacts on non-target organisms, such as crustaceans and fish. Despite concerns about human health impacts and potential carcinogenic risks, organophosphates are still one of the most broadly used insecticides globally and are still used in Australia for domestic pest control (Weston and Lydy, 2014; Zhao and Chen, 2016). Pyrethroid insecticides have low toxicity to birds and mammals, but higher toxicity to fish and arthropods. Phenylpyrazole insecticides are another class that also pose risks to non-target crustaceans (Stevens et al., 2011). Neonicotinoid insecticides are a class being used in increasing amounts because they are very effective at eliminating insect pests, yet pose low risks to mammals and fish (Sánchez-Bayo and Hyne, 2014). Monitoring data from the Great Barrier Reef catchments indicate that concentration of neonicotinoid insecticides in marine water samples is rapidly increasing with widespread use. One significant concern for aquaculture is the risk that different insecticides, when exposed to non-target organisms, may interact to cause additive or greater than additive toxicity.

An awareness and knowledge of the potential exposures, risks, and impacts that chemical contaminants may pose in a location is valuable when establishing and operating a commercial aquaculture enterprise, to ensure exposures are best mitigated. For the most vulnerable life cycle stages of production, such as the larval stages of rearing within the controlled hatchery environment, water treatment systems can be employed to mitigate risks of exposure to contaminants. However, for broadacre pond systems, the best approach is to understand the risks of exposure in an area, and ideally to establish farms in areas of lower exposure.

7.4.5 AQUACULTURE DISCHARGE WATER AND OFF-SITE IMPACTS

Discharge water is effluent from land-based aquaculture production. Discharge water is water that has been used (culture water) and is no longer required in a production system. In most operations (particularly marine), bioremediation is used to ensure that water discharged off farm into the environment contains low amounts of nutrients and other contaminants. The aim is for discharge waters to have similar physiochemical parameters to the source water.

Discharge water from freshwater aquaculture can be easily managed and provides a water resource suitable for general or agriculture-specific irrigation. Marine discharge water is comparatively difficult to manage, with limited reuse applications. The key difference in discharge management is that marine (salty) water must be discharged at the source, whereas location for freshwater discharge is less restrictive and potential applications numerous (e.g. irrigation). Specific water discharge guidelines vary with species and jurisdiction. For example in Queensland, water discharge policy minimum standards for prawn farming include minimum standards for physiochemical indicators (e.g. oxygen and pH) and nutrients (e.g. nitrogen, phosphorus and suspended solids) and total volume (EHP, 2013).

Management of water quality in ponds is a key component of aquaculture production. A consequence of water quality management is the requirement to discharge effluent water into the surrounding environment.

A large multidisciplinary study on intensive Australian prawn farming, which assessed the impact of effluent on downstream environments (CSIRO, 2013), found that Australian farms operate under world best practice in regards to the management of discharge water. The study found that discharge water had no adverse ecological impact on receiving water and that nutrients could not be detected 2 km downstream from the discharge point.

While Australian prawn farms are reported as being among the most environmentally sustainable in the world (CSIRO, 2013), location of the industry adjacent to the listed Great Barrier Reef and related strict policy on discharge has been a major constraint to expansion of the industry. Strict discharge regulation, which require zero net addition of nutrients in waters adjacent to the Great Barrier Reef, has all but halted expansion in the last decade. An example of the regulatory complexity in this region is the 14-year period taken to obtain approval to develop a site in the Burdekin shire in north Queensland (APFA, 2016). Over the last decade, increases in production have been due to improvements in production efficiency rather than any expansion of the industry footprint.

In a report to the Queensland Government (Department of Agriculture and Fisheries Queensland, 2013) it was suggested that less-populated areas in northern Australia, which have less conflict for the marine resource, may have potential as areas for aquaculture development. The complex regulatory environment in Queensland was a factor in the decision by Project Sea Dragon to investigate greenfield development in WA and NT as an alternative location for what would be Australia's largest prawn farm (Seafarms, 2016).

Today most farms (particularly marine) use bioremediation ponds to ensure that water discharged off-farm into the environment contains low amounts of nutrients and other contaminants. The prawn farming industry in Queensland has adopted a code of practice to ensure that discharge waters do not result in irreversible or long-term impacts to the receiving environment (Donovan, 2011).

Pump stations are used to distribute water around the farm (Figure 7-16). Marine water is pumped from a primary pump station located near the water source (usually a river) to a raised supply channel engineered to gravity-deliver water to the ponds. During production and at final harvest water is discharged from production ponds via gravity into a waste water channel. A secondary pump station is then used to pump the water from the waste water channel to the bioremediation pond. The role of the bioremediation process is to reduce suspended solids and nutrients (nitrogen and phosphorus) in the water to meet discharge water quality standards set by regulators. Water treated in the bioremediation pond is either recirculated to the production pond via a third pump station and the supply channel or discharged by gravity to the river. The specifications of each pump station are in keeping with the volume of water required to fill the ponds and to service water exchange requirements. Farm layout should be designed to minimise the chance of reintroducing discharged water to the ponds via the primary pump station. The location of the primary pump station and the discharge channel should be separated by as large a physical distance as practical. In general, best practice involves access of source water at high tide and discharge of water at low tide.

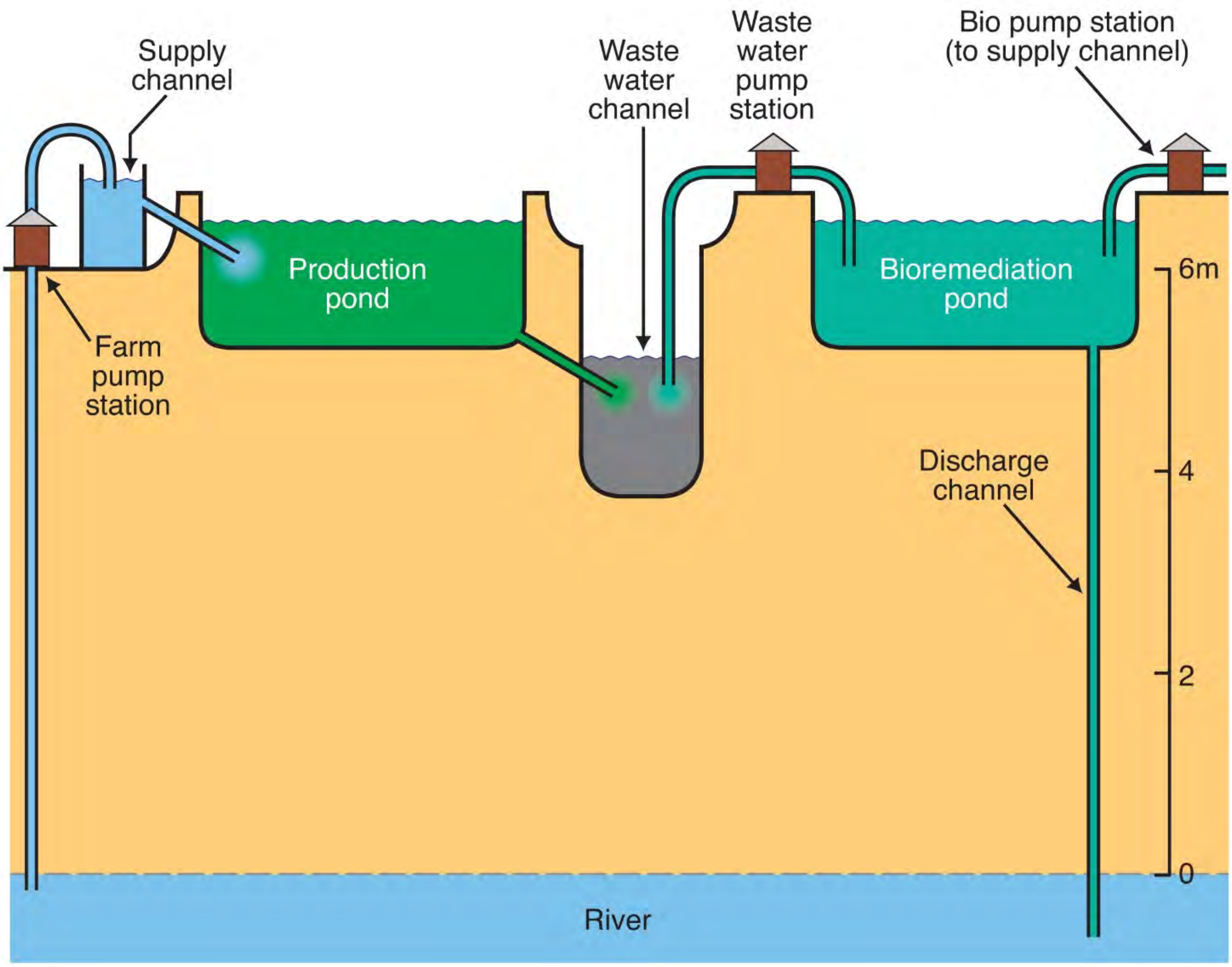

Figure 7-16 Cross-section of a marine aquaculture farm detailing optimal land elevation, water flow and discharge

The volume of water required to be discharged or possibly diverted to a secondary application (e.g. agriculture) is equivalent to the total pond water use for the season, minus total evaporative losses and the volume of recycled water used during production.

7.5 Irrigation-induced salinity

7.5.1 INTRODUCTION

Salts occur naturally in all soils and landscapes depending on climate; the salt store in the geology, soils and watertables; and landscape hydrology. Naturally-occurring areas of salinity or 'primary salinity' occur in the landscape with ecosystems adapted to these conditions. Any change to landscape hydrology, including clearing and irrigation, can mobilise salts resulting in environmental harm and agricultural productivity losses, a process referred to as 'secondary salinity'. Secondary salinity manifests itself in two main forms: that which occurs in irrigation regions and salinity occurring in dryland regions. The Assessment is concerned with irrigation-induced 'secondary salinity'.

In the case of irrigation-induced salinity, an increase in root-zone drainage following applications of irrigation water can provide a source of water to mobilise soluble salts stored in the soil. Root-zone drainage rates tend to be higher under coarser-textured soils (Petheram et al., 2002) and poor irrigation practices. In Australia, excessive root-zone drainage through poor irrigation practices, together with leakage of water from irrigation distribution networks and drainage channels, has caused the watertable level to rise under many intensive irrigated areas. Significant parts of all major intensive irrigation areas in Australia are currently either in a shallow watertable equilibrium condition or approaching it (Christen and Ayars, 2001). Where shallow watertables containing salts approach the land surface (in the vicinity of 2 to 3 m from the land surface), salts can concentrate in the root zone over time through evaporation. The process by which salts accumulate in the root zone is accelerated if the groundwater also has high salt concentrations.

The Mitchell catchment has moderate natural surface salinity occurring in drainage lines and at lower slopes of deeply weathered geologies in the south of the centre of the catchment. These areas are not considered suitable for irrigation development. Soils suitable for irrigation development in the Mitchell catchment tend to be either deep, free-draining loams (SGG 4.1, 4.2), sand or loam over sodic clay subsoils (SGG 8), or clays (SGG 9) (Section 2.3). Of the more suitable soils for irrigated agriculture the clay soils at Wrotham Park, at the centre of the catchment, were identified as having the highest salinity risk in the Mitchell catchment.

The survey undertaken for this reconnaissance salinity appraisal used an EM34 instrument able to measure to approximately 40 m in depth under favourable conditions (Reynolds, 2000). Through electromagnetic induction (EM), the electrical conductivity (ECa) patterns are used to differentiate between conductive/resistive layers in the profile, which equate to mineralogy (clay type), salinity, soil water content and rock.

This section is structured around the three basic requirements for salt to become an environmental problem: (i) a source of salt (Section 7.5.2), (ii) a source of water in which to mobilise the salt (Section 7.5.3), and (iii) mechanisms by which the salt is redistributed to locations in the landscape where it causes damage (Section 7.5.3).

7.5.2 POTENTIAL SOURCES OF SALT

Salt stores in the Mitchell catchment

The salts in the landscape are derived from salts delivered through rainfall, weathering of primary minerals and origin of the geology such as marine sediments. The amount of salts in the landscape (salt store) depends on the origin of salts, degree of geology weathering, climate (particularly rainfall), position in the landscape, landscape permeability (soils and rock) and watertable dynamics.

It should be noted that this section presents generalised results on soils suitable for irrigation development. The risk of secondary salinisation at a specific location in the Mitchell catchment can only be properly assessed by undertaking detailed field investigation.

The gently undulating plains and rises with cracking clay soils (SGG 9) developed on fine-grained sediments of the Great Artesian Basin at Wrotham Park in the centre of the catchment show considerable potential for irrigated agriculture (Figure 7-17). However, field work indicated a considerable salt store in the landscape where salts may mobilise and cause secondary salinity if a watertable rises close to the surface, resulting in lost crop productivity.

Figure 7-17 Gently undulating plains of deep, self-mulching, well drained, cracking clay soils (SGG 9) with high water storage need investigation for potential secondary salinisation on lower slopes as they have naturally high salt levels in the subsoil
Photo: CSIRO

Five sites were selected to represent the various landscape positions, as shown in Figure 7-18. Core samples were collected at the five sites for analysis while a geophysical survey using an EM34 instrument to measure EM was conducted at three of the sites (SAL1, SAL2 and SAL5).

A representation of the land surface is presented in Figure 7-19, which as a conceptual model highlights the subtle landscape features and positions of the sites. Stylised profile logs comprising distributions of saline and sodic properties, clay %, rock depth (if encountered) and main water flows (and relative strength) as recorded or interpreted from field and laboratory data are presented in the model. Upper slopes and plains (SAL1 to SAL3) are essentially non-saline with the EM measurements showing moderately conductive layers with low EM readings to approximately 5 m over high readings, which is consistent with the depth that bedrock was encountered. Lower slope positions (SAL4 and SAL5) have naturally very high salt levels at less than 1 m.

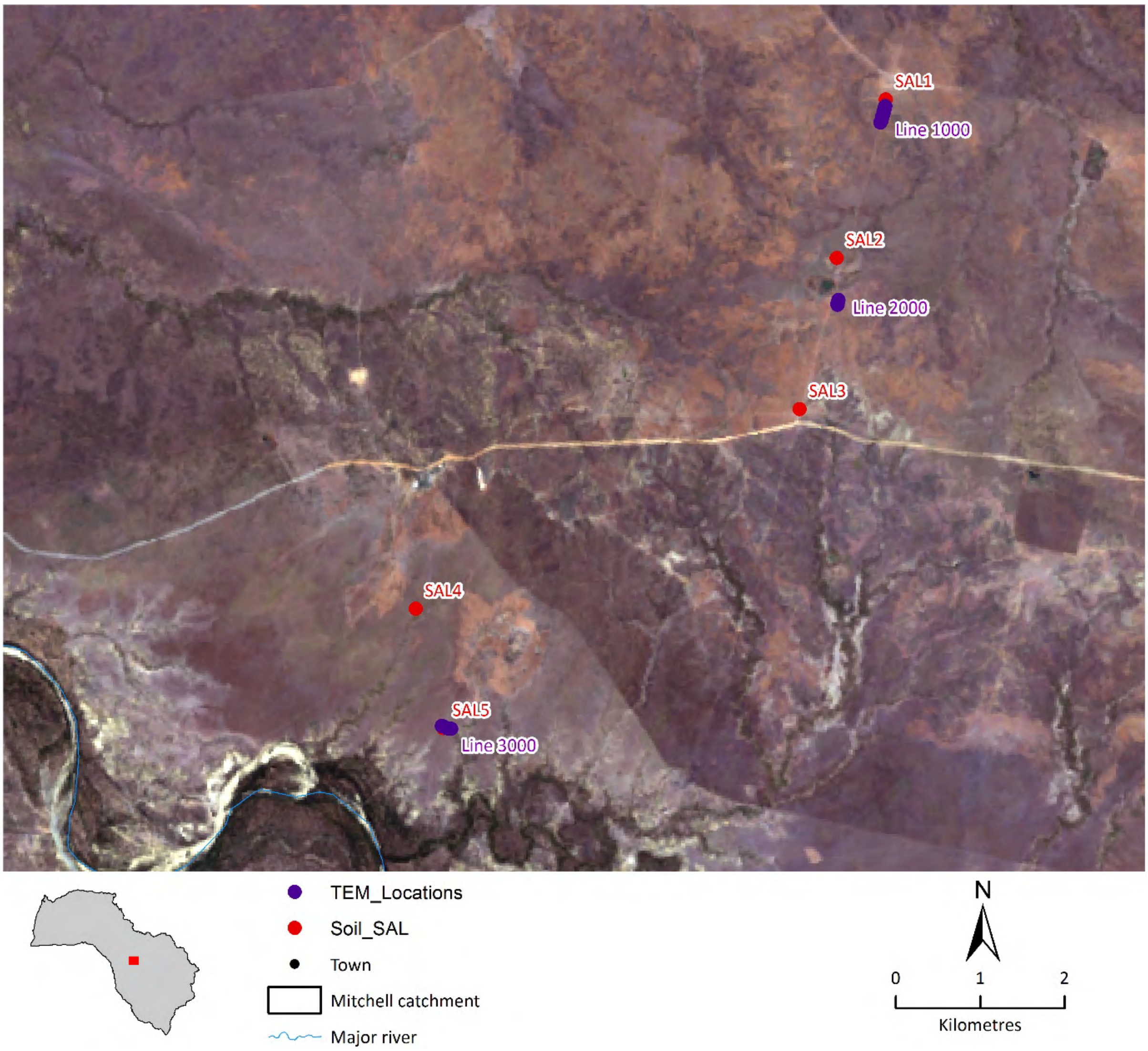

Figure 7-18 Study area site locations (red dots) and EM34 transects (blue dots)

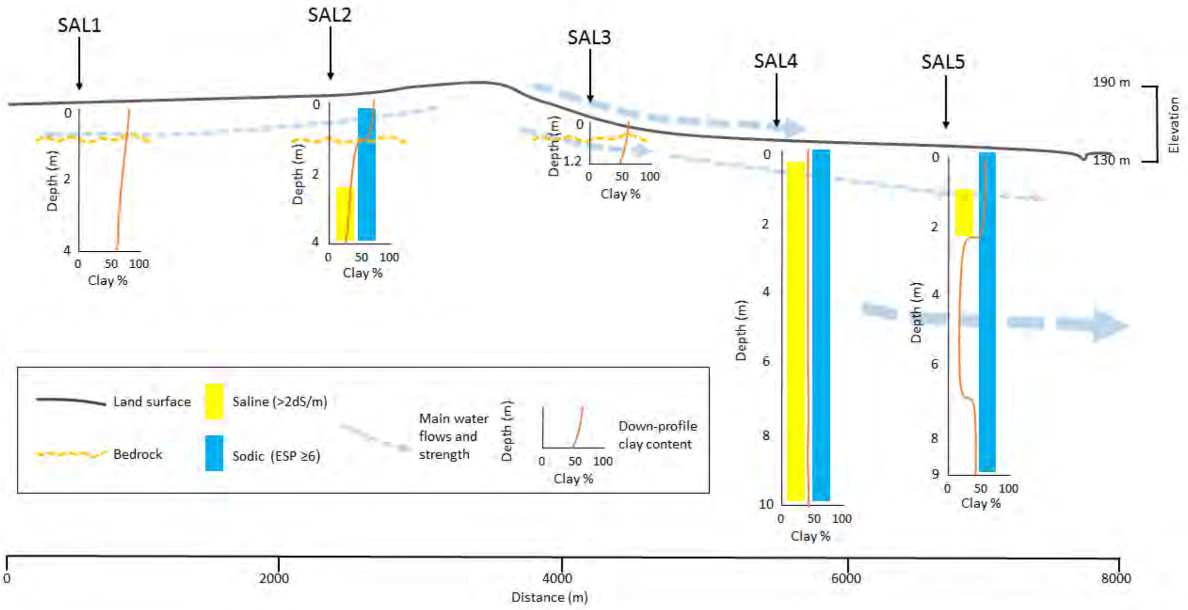

Figure 7-19 Study area cross-sectional conceptual model showing site positions, land surface elevation and landform, profile soil properties (EC, ESP, clay %, bedrock depth) and key water flows

The EM trace at SAL5 (Figure 7-20) shows distinctive conductivity lobes at depths of approximately 20 m and 30 m that may correspond to saline groundwater and/or lithological structure which is consistent with the EM traces of other sites.

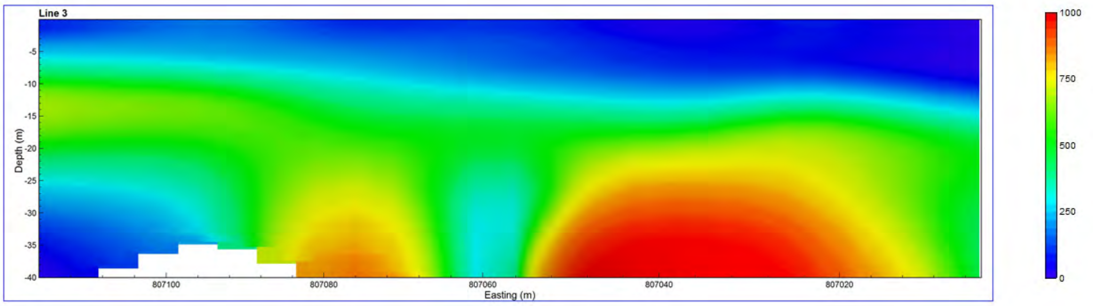

Figure 7-20 EC trace for site SAL5

Under irrigation, the soils on the upper slopes are essentially non-saline in the rooting zone and salinity only becomes apparent at depths greater than 2 m. With application of good quality water these soils can be successfully irrigated with careful management of water rates to avoid waterlogging and ponding (and possible water erosion). The sites are likely to be hydraulically connected by water throughflows, although rates are likely to be extremely slow.

The sites on lower slopes contain more salts. Given the landscape position and gradient, surface flow rates are likely to be high and throughflow rates moderate, which are likely to be sufficient over time to accumulate salts in lower landscape positions. This explains the saline-sodic conditions of SAL4 downslope. Here the throughflow rates (very slowly permeable) in the low-slope gradients are insufficient to off-set salt supplies from upslope with leaching rates downslope, hence salts accumulate in this zone. Down slope of this at SAL5, the loamy textures deeper than 2 m act as an internal drain for upslope salts due to the moderately permeable conditions and the maximum watertable level decreases as the distance to the river decreases because groundwater can be discharged to the river at a greater rate.

It is likely that the watertables on the lower slopes would take a relatively long period to rise to close to the surface. For additional information on groundwater in the Mitchell catchment see the companion technical report on hydrogeological assessment (Taylor et al., 2018).

Irrigation water as a potential source of salt

In many irrigation developments around the world, poor-quality irrigation water is the source of salt in salinisation. In the Mitchell catchment, however, the river water is relatively fresh and aquifers with potential for groundwater resource development are also relatively fresh, so are unlikely to be a source of salt. This is because the low levels of salt in the river water or groundwater would be leached through the soil profile before they could accumulate in the root zone to levels that adversely affect crop development. However, in some cases, certain levels of localised groundwater extraction from aquifers may result in the entrainment of poorer quality water from surrounding aquifers or aquitards over time, thereby reducing the overall quality of groundwater applied to crops. The potential for this to occur would require a site-specific investigation.

7.5.3 RISE IN WATERTABLE LEVEL AND CHANGES IN GROUNDWATER DISCHARGE DUE TO IRRIGATION DEVELOPMENT

The extent to which the watertable level rises close to the surface depends on:

- the initial depth to the watertable
- the amount of recharge (originating from root-zone drainage)
- the size of the irrigation area (thus dictating the total volume added to the landscape)
- the lateral distance to the river (which acts as a drainage boundary, thus reducing the height of the groundwater mound under irrigation)
- aquifer parameters, including the saturated hydraulic conductivity, aquifer thickness and specific yield.

The hydraulic conductivity and specific yield are hydraulic properties of a soil's ability to transmit water when submitted to a hydraulic gradient (e.g. difference in watertable level between two locations). The specific yield is the volume of water that could be allowed to drain from an aquifer under the forces of gravity and expressed as a proportion of the total volume of material in the aquifer.

In the Mitchell catchment, there is limited shallow groundwater data, and aquifer parameters typically need to be estimated from bore log information and generic relationships in the literature. The use of such relationships is made particularly challenging by the fact that saturated hydraulic conductivity is the most variable environmental parameter, its range varying by over 11 orders of magnitude. Typical values of saturated hydraulic conductivity and specific yield are provided in Table 7-11.

Table 7-11 Typical values of specific yield and saturated hydraulic conductivity

SOIL TEXTURE	SPECIFIC YIELD†	SATURATED HYDRAULIC CONDUCTIVITY‡ (m/day)
Gravel	0.25	3 to 30,000
Sand	0.20	0.3 to 300
Silt	0.18	0.00003 to 3
Clay	0.02	0.00000003 to 0.00003

†Adapted from Johnson (1967) and Carsel and Parrish (1988).
‡Adapted from Freeze and Cherry (1979).

An analytical modelling approach (Jolly et al., 2013) was used to evaluate the maximum (steady-state) rise in watertable level likely as a result of introducing new irrigation developments of varying areas situated at various distances from a river. A separate analysis was undertaken to investigate the time it takes the watertable to rise to its maximum level and how changes in groundwater discharge occur. It is important to note that these results are under 'idealised' conditions. The risk of secondary salinisation and watertable rise at a specific location in the Mitchell catchment can only be properly assessed by undertaking detailed field investigation.

Farm-scale developments

To investigate the sensitivity of the results to these parameters a range of likely values was selected (Table 7-12). Irrigation developments between 100 and 1000 ha in size are representative of irrigation developments on individual properties. Web-based applications are provided on the Assessment website that enable the user to assess the maximum rise and change in watertable level using parameter values specific to their area of interest. The results in this section are presented to illustrate general concepts.

Table 7-12 Likely range of values for parameters in farm-scale development in the Mitchell catchment

PARAMETER	SYMBOL	UNIT	VALUES	COMMENT
Distance from centre of irrigation area to river	*d*	km	0.5, 1.0, 2.0, 5.0, 10.0	River was assumed to be straight.
Circular irrigation area	*A*	ha	100, 250, 500, 1000	For radii of 564, 892, 1262 and 1784 m.
Recharge rate	*R*	mm/y	1, 10, 20, 50, 100, 200, 500	Recharge rate is related to the amount of water applied and the permeability of the soil. A recharge rate of 500 mm/y (or more) could occur under a ringtank.
Aquifer transmissivity (saturated hydraulic conductivity multiplied by aquifer thickness)	*T*	m^2/day	200, 500, 2000	Represents a constant saturated aquifer thickness (*h* = 10 m), and hydraulic conductivities (*K*) of 20, 50 and 200 m/day.
Specific yield	*Sy*		0.10 to 0.20	Specific yield does not alter the maximum height of the watertable. It affects the time over which the watertable rise occurs.

Maximum rise in watertable level

The maximum rise in watertable level increases with higher recharge rates and decreases with higher saturated hydraulic conductivity. Figure 7-21a shows that the effects of saturated hydraulic conductivity (and hence aquifer transmissivity) and recharge rates are linear but opposite and perfectly correlated. Hence, to simplify the presentation of results and reduce the number of variables, it is possible to report watertable level against recharge rate divided by the aquifer transmissivity.

Figure 7-21b shows the maximum watertable level expected for an irrigation area of 100 ha. This maximum level decreases as the distance to the river decreases. This is because, with the irrigation development located closer to the river, groundwater can be discharged to the river at a greater rate.

Figure 7-22 shows that the maximum watertable level increases in a non-linear manner as the distance to the river increases.

Figure 7-23 and Figure 7-24a show that the maximum watertable level increases as the irrigation area increases, and also as the recharge rate increases. For the combination of parameters considered for the Mitchell catchment, the highest point on the red line in Figure 7-24a shows the upper bound for watertable rise (h_{max} = 41.8 – 10 = 31.8 m, where 10 m is the initial watertable level), which represents the largest irrigation area (*A* = 1000 ha) located furthest from the river (*d*), with an aquifer having the lowest drainage capacity (highest *R*/*T*). Figure 7-24b presents the same results in a different way to highlight the effect of increasing the recharge area and distance to the river on watertable level.

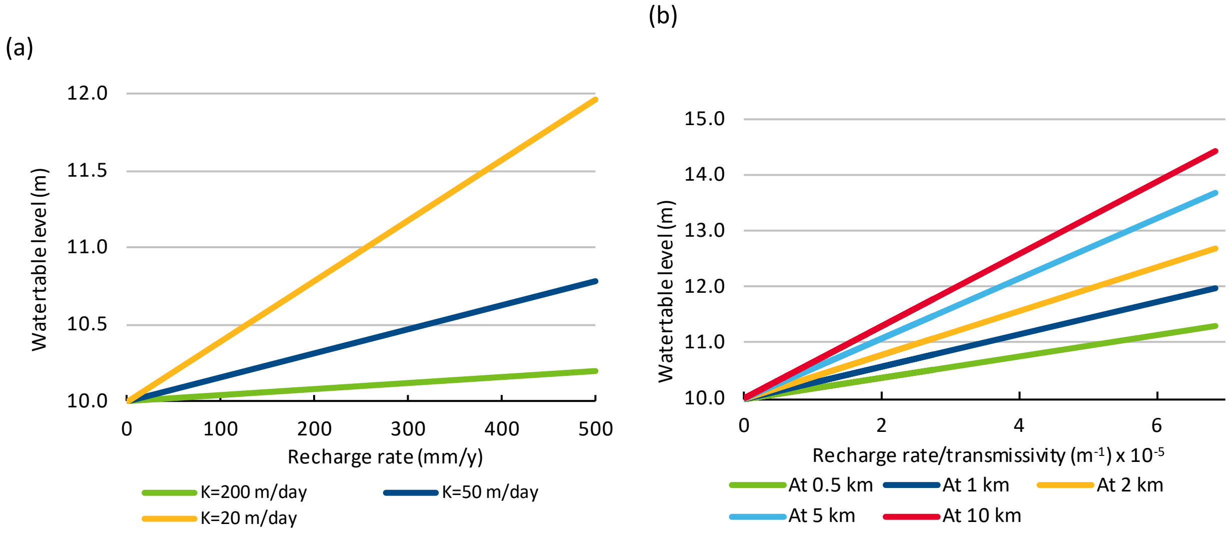

Figure 7-21 Steady-state watertable level for (a) various recharge rates and hydraulic conductivities (*K*) and (b) an irrigation area of 100 ha, at varying distances to the river

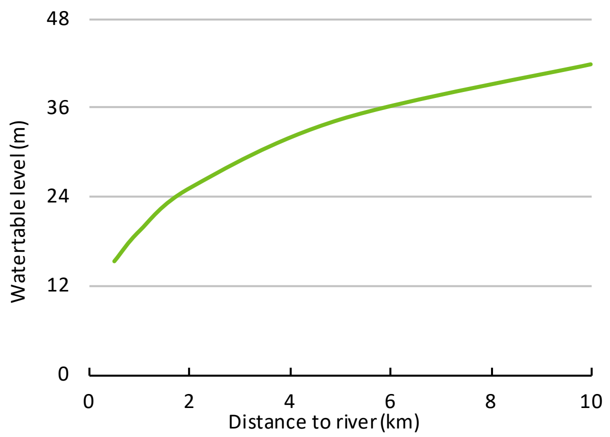

Figure 7-22 Steady-state watertable level for an irrigation area of 1000 ha, plotted against distance to the river

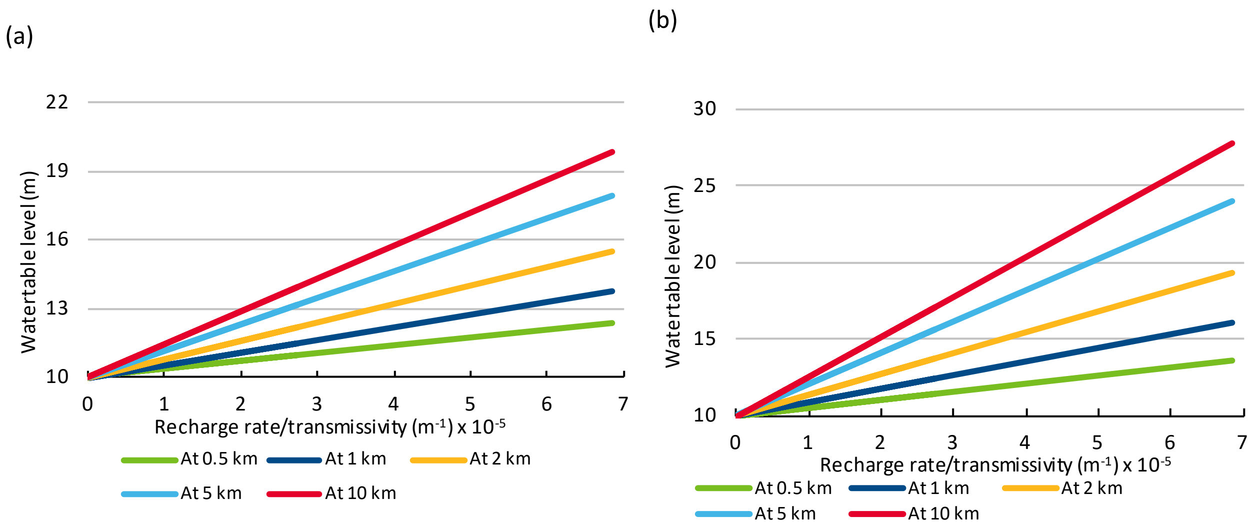

Figure 7-23 Steady-state watertable level at varying distances (*d*) to the river for an irrigation area of (a) 250 ha and (b) 500 ha

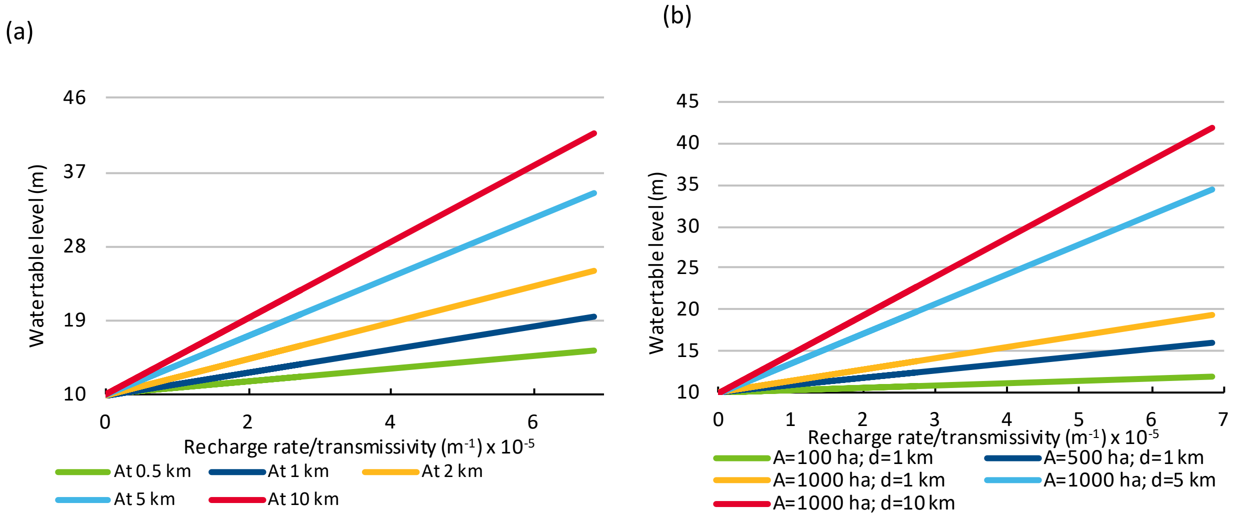

Figure 7-24 Steady-state watertable level at varying distances (*d*) to the river for (a) an irrigation area of 1000 ha and (b) various irrigation area and distance combinations

Changes in rise in watertable level over time

One of the challenges in managing groundwater is the time lag between a change in management and the response of the groundwater system. This analysis demonstrates how the watertable level rises over time until it achieves its maximum height. A key parameter for undertaking this analysis is the specific yield of the groundwater system. Figure 7-25 provides an example where the irrigation area is 100 ha and the recharge rate is 100 mm/year. For a given aquifer diffusivity (*D*) (i.e. aquifer transmissivity divided by specific yield), Figure 7-25 shows that after a change in recharge, the initial response of the groundwater system is identical regardless of the distance to the river (*d*). This is because the groundwater mound under an irrigation development forms before groundwater discharge to the river increases. When the groundwater mound reaches the river, the rate of the rise in watertable level starts to decline until the level reaches its maximum (i.e. under steady-state conditions). The watertable level takes longer to reach its maximum when the irrigation development is further from the river (Figure 7-25).

In Figure 7-25, for an aquifer diffusivity (*D*) with a high value of 200,000 m^2/day, the maximum watertable level is reached within about 13 years, whereas for the low value of 20,000 m^2/day, the maximum watertable level is reached in 30 to 100 years. The watertable level takes longer to reach its maximum when irrigation areas are larger and are located a greater distance from the river. With the most extreme combination of parameters from Table 7-12 (*d* = 10 km, *A* = 1000 ha, *R* = 500 mm/year, and *D* = 2000 m^2/day), it takes the watertable level about 270 years to reach approximately 90% of its rise.

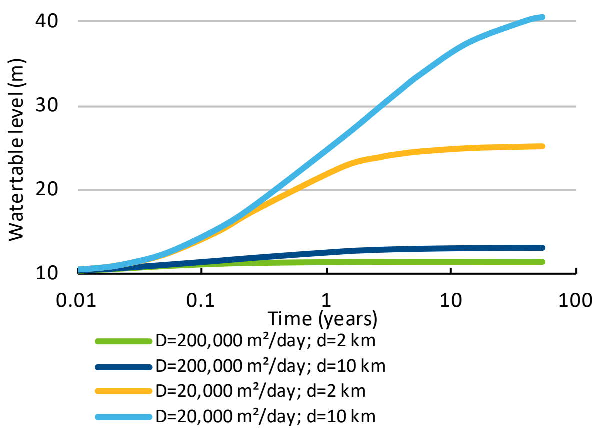

Figure 7-25 Watertable level for various aquifer diffusivities (*D*) and distances to river (*d*), for an irrigation area of 100 ha and recharge rate of 100 mm/year

Changes in groundwater discharge over time

Groundwater mounds under irrigation developments can result in increased groundwater discharge to nearby rivers. This can have important ecological implications.

The time taken for a groundwater mound to discharge to a nearby river depends on the aquifer diffusivity and the distance to the river. In Figure 7-26, the groundwater discharge to the river (i.e. flux response) is expressed as a fraction of the recharge. The increase in groundwater discharge to a river following an irrigation development can take many years to occur, particularly where the irrigation development is located a long distance from the river.

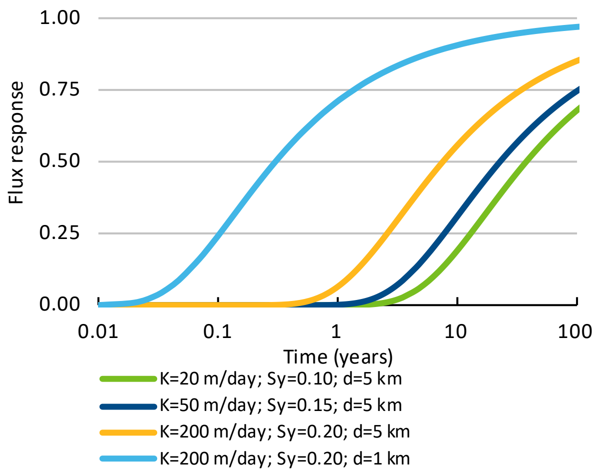

Figure 7-26 Flux response for different aquifer diffusivities, for different hydraulic conductivities (*K*), specify yields (*Sy*) and distances to river (*d*)

The flux response in Figure 7-26 is the groundwater discharge to the river, expressed as a fraction of the recharge. Because it is a fraction, it is unitless.

Interactions of groundwater as a result of neighbouring irrigation developments

The groundwater mounds that form under neighbouring irrigation developments have the potential to superimpose upon each other, resulting in higher groundwater levels than may otherwise occur. Figure 7-27 illustrates the variation in groundwater level beneath two small (500 ha) neighbouring irrigation developments at different distances of separation. Two sets of parameters are examined. The first assumes a saturated hydraulic conductivity of 1 m/day and a recharge rate of 65 mm/year (Figure 7-27a). The second assumes a saturated hydraulic conductivity of 20 m/day and a recharge rate of 130 mm/year (Figure 7-27b). Both assume the irrigation developments are 1 km from a river. The former is considered to be more representative of mosaic irrigation developments associated with offstream storages or groundwater extraction from an underlying aquifer in the Mitchell catchment. The results indicate that small-size irrigation developments (i.e. 500 ha) exhibit very little interaction during the first 10 years after development. Small interactions occur within a 100-year time frame, but interactions can be avoided when the developments are placed 1 km apart. Placing 500-ha irrigation developments at least 5 km apart excludes any interaction (i.e. under steady-state conditions).

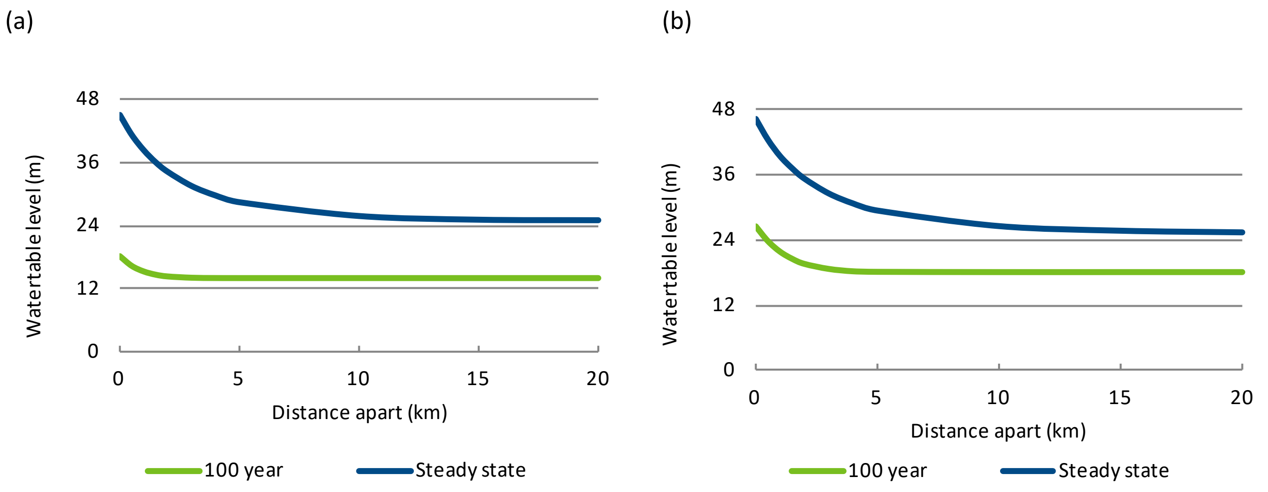

Figure 7-27 Variation in watertable level beneath two neighbouring 500-ha irrigation developments at different distances of separation
(a) Saturated hydraulic conductivity of 1 m/day, recharge of 65 mm/year and 1 km from river. (b) Saturated hydraulic conductivity of 20 m/day, recharge of 130 mm/year and 1 km from river.

Scheme-scale developments

This section illustrates how water levels may rise under a hypothetical scheme-scale irrigation development with parameters as shown in Table 7-13.

Table 7-13 Range of parameter values used in analytical groundwater model for a hypothetical scheme-scale development

AQUIFER PARAMETER	UNIT	VALUE	COMMENT
Aquifer thickness	m	12	na
Depth to groundwater	m	9	na
Distance of irrigation development boundary to river	km	1	na
Recharge rate	mm/y	67,118	Lower and higher estimate. Recharge as a result of both irrigation and rainfall
Saturated hydraulic conductivity (*K*)	m/day	1, 10, 100	Lower, middle and higher estimate, respectively
Specific yield		0.2	Only has bearing on rate of rise, not maximum rise

na = not applicable

Figure 7-28 indicates that under the low (1 m/day) and middle (10 m/day) values for saturated hydraulic conductivity, and under conditions where the depth to groundwater is 9 m below the ground surface, the watertable level under a 12,000-ha irrigation development reaches within 2 m of the ground surface in 10 to 25 years, depending on the recharge rate.

For the higher estimate of saturated hydraulic conductivity (100 m/day), the drainage capacity of the aquifer is higher, which results in a slower rise in watertable level. For the lower and higher recharge rates, the watertable level would approach to within 2 m of the ground surface in about 20 to 50 years.

In this hypothetical example any rise in watertable level is likely to mobilise soluble salts in the substrate and clay subsoils. This could potentially cause secondary salinisation when watertable level rises to within 2 m of the ground surface.

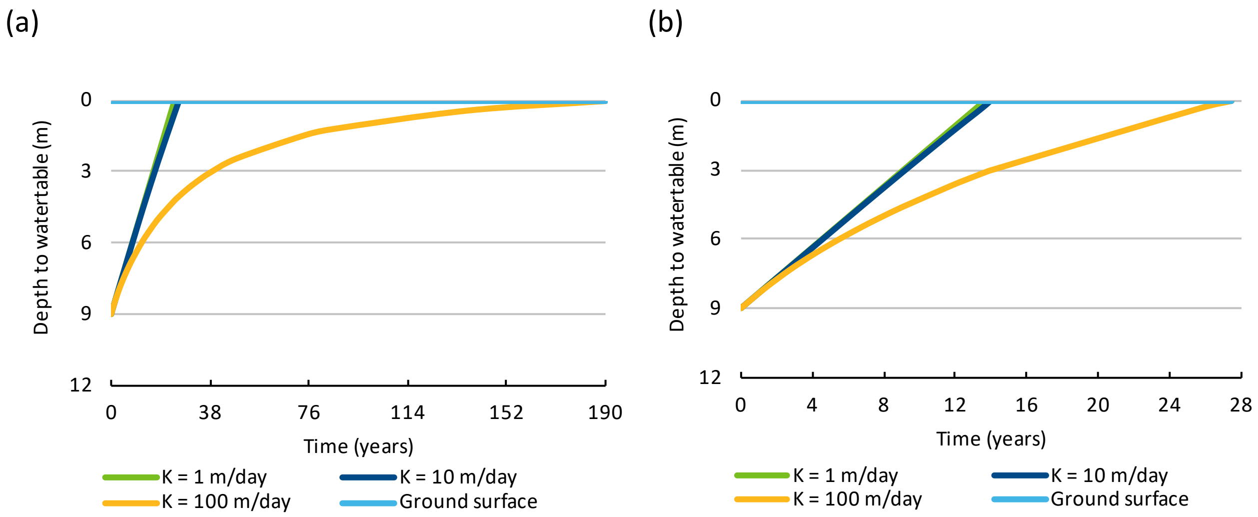

Figure 7-28 Change in depth to watertable for different values of saturated hydraulic conductivity (K)
(a) Low recharge rate of 67 mm/year and (b) high recharge rate of 118 mm/year.

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Appendices

Appendix A

Assessment products

More information about the Northern Australia Water Resource Assessment can be found at https://www.csiro.au/en/Research/Major-initiatives/Northern-Australia/Current-work/NAWRA. The website provides readers with a communications suite including factsheets, multimedia content, FAQs, reports and links to other related sites, particularly about other research in northern Australia.

In order to meet the requirements specified in the contracted 'Timetable for the Services', the Assessment provided the following key deliverables:

- Technical reports present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the activities of the Assessment has at least one corresponding technical report.
- Each of the three catchment reports (i.e. this report and another for the Fitzroy catchment and Darwin catchments) synthesises key material from the technical reports, providing well-informed but non-scientific readers with the information required to make decisions about the opportunities, costs and benefits associated with water resource development.
- A case study report, with case studies which show how information produced by the Assessment can be assembled to help readers 'answer their own questions'. They are also used to help readers understand the type and scale of opportunity for irrigated agriculture or aquaculture in selected parts of the Assessment area, and explore some of the nuances associated with greenfield developments in the study area. Case studies are provided for each study area.
- Three overview reports – one for each of the three study areas – are provided for a general public audience.
- Three factsheets provide key findings for each study area for a general public audience.

This appendix lists all such deliverables.

Please cite as they appear.

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Appendix B

Shortened forms

SHORT FORM	MEANING
AEM	airborne electromagnetics
AHD	Australian Height Datum
APSIM	Agricultural Production Systems Simulator
AWRC	Australian Water Resources Council
CGE	Computable General Equilibrium
CSO	community service obligations
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	digital elevation model
FTE	full-time equivalents
GAB	Great Artesian Basin
GCMs	global climate models
GCM-ES	global climate model output empirically scaled to provide catchment-scale variables
IPCC AR4	the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
IDAS	Integrated development assessment system
IQQM	Integrated Quantity-Quality Model – a river systems model
IRR	internal rate of return
Landsat TM	Landsat Thematic Mapper
MODIS	Moderate Resolution Imaging Spectroradiometer
NABSA	North Australia Beef System Analysis
NPV	net present value
NQIAS	North Queensland Irrigated Agriculture Strategy
NRM	natural resource management
ONA	the Australian Government Office of Northern Australia
OWL	the Open Water Likelihood algorithm
PAWC	plant available water capacity
PE	potential evaporation
RCP	representative concentration pathway
Sacramento	a rainfall-runoff model

SHORT FORM	MEANING
SALI	the Soil and Land Information System for Queensland
SLAs	statistical local areas
SRTM	shuttle radar topography mission
TRaCK	Tropical Rivers and Coastal Knowledge Research Hub
WRON	CSIRO’s Water Resource Observation Network

Units

MEASUREMENT UNITS	DESCRIPTION
BP	before present
GL	gigalitres, 1,000,000,000 litres
keV	kilo-electronvolts
kL	kilolitres, 1000 litres
km	kilometres, 1000 metres
kPa	kilopascal
Kt	kiloton
L	litres
m	metres
Ma	million years
MB	megabyte
mAHD	metres above Australian Height Datum
mEGM96	Earth Gravitational Model 1996 geoid heights in metres
MeV	mega-electronvolts
mg	milligrams

Data sources and availability

The Northern Australia Water Resource Assessment obtained a range of data for use under licence from a number of organisations, including the following:

- State of Queensland (Business Queensland)
  - Digital Cadastral Database - The Digital Cadastral Database (DCDB) contains the property boundaries and related property description of all land parcels in Queensland. It provides the base for searching, planning and analysing land related information and is primarily used by most local governments for these purposes.
    - Licence: Data downloaded via QSpatial as open data is provided under a Creative Commons CC-By licence.
    - https://www.business.qld.gov.au/running-business/support-assistance/mapping-data-imagery/data/digital-cadastral
- State of Queensland
  - Queensland's Regional Ecosystem Description Database
    - Licence: This work is licensed under a Creative Commons Attribution 3.0 Licence
    - Conditions of use statement: The database was developed using data compiled by the State of Queensland as represented by the Queensland Herbarium, Department of Environment and Science. While every effort has been made to ensure that the material contained in the database is accurate, the State of Queensland accepts no liability and gives no assurance in respect of its accuracy and shall not be liable for any loss or damage arising from the use of the database.
  - https://www.qld.gov.au/environment/plants-animals/plants/ecosystems/descriptions
- Australian Government (Geoscience Australia)
  - GEODATA Topo 250K Series 3 – spatial data for mapping
    - Licence: Creative Commons Attribution 3.0 Australia, http://creativecommons.org/licenses/by/3.0/au/, (c) Commonwealth of Australia (Geoscience Australia) 2014
    - https://data.gov.au/dataset/a0650f18-518a-4b99-a553-44f82f28bb5f
  - SRTM-derived 3 Second Digital Elevation Models Version 1.0
    - Licence: The 3 second DEMs were released under Creative Commons attribution licensing in ESRI Grid format
    - https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search?node=srv#/metadata/aac46307-fce9-449d-e044-00144fdd4fa6
  - GEODATA 9 second DEM and D8: Digital Elevation Model Version 3
    - Licence: Creative Commons Attribution 4.0 International Licence
    - https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search?node=srv#/metadata/a05f7892-d78f-7506-e044-00144fdd4fa6

- Esri
  - *World Imagery Map Service* – map service of satellite imagery for the world and high-resolution imagery for the United States and other areas around the world. Imagery is sourced from GeoEye IKONOS, Getmapping, AeroGRID, IGN Spain, IGP Portugal, i-cubed, USGS, AEX, Aerogrid, Swisstopo and by the GIS User Community.
    - https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9
- Atlas of Living Australia - a collaborative, national project that aggregates biodiversity data from multiple sources and is freely available and usable online.
  - https://www.ala.org.au/
- Australian Wetlands Database - online access to information on Australia's Ramsar wetlands and sites listed in the Directory of Important Wetlands of Australia, Australia's internationally and nationally important wetlands respectively.
  - http://www.environment.gov.au/water/wetlands/australian-wetlands-database

Glossary and terms

Anthropogenic: a human impact on the environment.

Aquifer: a permeable geological material that can transmit significant quantities of water to a bore, spring, or surface water body. Generally, 'significant' is defined based on human need, rather than on an absolute standard.

Aquitard (confining layers): a saturated geological unit that is less permeable than an aquifer, and incapable of transmitting useful quantities of water. Aquitards often form a confining layer over an artesian aquifer.

Artesian: a general term used when describing certain types of groundwater resources. Artesian water is underground water confined and pressurised within a porous and permeable geological formation. An artesian aquifer has enough natural pressure to allow water in a bore to rise to the ground surface. Subartesian water is water that occurs naturally in an aquifer, which if tapped by a bore, would not flow naturally to the surface. Artesian conditions refer to the characteristics of water under pressure.

Basement: the crust below the rocks of interest. In hydrogeology it means non-prospective rocks below accessible groundwater. Commonly refers to igneous and metamorphic rocks which are unconformably overlain by sedimentary beds or cover material, and sometimes used to indicate 'bedrock' (i.e. underlying or encasing palaeovalley sediments).

Benthic: the ecological region at the lowest level of a body of water such as an ocean or a lake, including the sediment surface and some sub-surface layers.

Current development: the level of surface water, groundwater and economic development in place as of 1 July 2013. The Assessment assumes that all current water entitlements are being fully used.

Development: see entries for 'current development' and 'future irrigation development'.

Discount rate: the percentage by which future cost and benefits are discounted each year (compounded) to convert them to their equivalent present value (PV)

Drainage division: the area of land where surface water drains to a common point. There are 12 major drainage divisions in Australia. At a smaller scale, surface water drainage areas are also referred to as river basins, catchments, or watersheds.

Drawdown: the lowering of groundwater level resulting from the extraction of water, oil or gas from an aquifer.

Ecosystem services: the contributions that ecosystems make to human wellbeing.

Eutrophication: the ecosystem response to the addition of artificial or natural substances, such as nitrates and phosphates, through fertilizers or sewage, to an aquatic system. One example is an 'algal bloom' or great increase of phytoplankton in a water body as a response to increased levels of nutrients.

Environmental flows: describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well being that depend on these ecosystems.

Flow regime: the entire pattern of flow in a river – from how long it lasts, to how frequently it flows and how large it is.

Fecundity: the potential reproductive capacity of an individual or population.

Fertigation: application of crop nutrients through the irrigation system (i.e. liquid fertiliser)

Future irrigation development: is described by each case study storyline (see chapters 8 to 10); river inflow and agricultural productivity are modified accordingly.

Geological basin: layers of rock that have been deformed by mega-scale geological forces to become bowlshaped. Often these are round or oblong with a depression in the middle of the basin.

Geological formation: geological formations consist of rock layers that have common physical characteristics (lithology) deposited during a specific period of geological time.

Groundwater (hydrogeology): water that occurs within the zone of saturation beneath the Earth's surface. The study of hydrogeology focuses on movement of fluids through geological materials (e.g. layers of rock).

Groundwater basin: a groundwater basin is a non-geological delineation for describing a region of groundwater flow. Within a groundwater basin, water enters through recharge areas and flows toward discharge areas.

Groundwater divide: a divide that is defined by groundwater flow directions that flow in opposite directions perpendicular to the location of the divide.

Groundwater flow (hydrodynamics): within a groundwater basin, the path from a recharge area to a discharge area is referred to as a groundwater flow system, where travel time may be as short as days or longer than centuries, depending on depth. The mechanics of groundwater flow – the hydrodynamics – are governed by the structure and nature of the sequence of aquifers.

Groundwater flow model: a computer simulation of groundwater conditions in an aquifer or entire groundwater basin. The simulations are representations based on the physical structure and nature of the sequence of aquifers and rates of inflow – from recharge areas – and outflow – through springs and bores. **Groundwater level:** in this report refers to the elevation of equivalent freshwater hydraulic head at 25 °C

Groundwater recharge and discharge: recharge occurs where rainfall or surface water drains downward and is added to groundwater (the zone of saturation). Discharge occurs where groundwater emerges from the Earth, such as through springs or seepage into rivers.

Hydrodynamics: the study of liquids in motion.

Internal rate of return (IRR): the discount rate at which the net present value (NPV) is zero.

Legume: pulse crop.

Lithology: the character of a rock; its composition, structure, texture, and hardness.

Net present value: a standard method for using the time value of money to appraise long-term projects by measuring the differences between costs and revenues in present value terms.

Palaeochannel: refers to the main channel of ancient rivers, sometimes called the 'thalweg', the lowest point of incision along the river bed where coarser sediments are commonly deposited. Former river channels that are recognised in the surface (from aerial or satellite images) or subsurface (typically in aerial electromagnetic surveys or drilling).

Permeability: a measurement describing the ability of any fluid (water, oil) to pass through a porous material. Values vary widely, with higher values corresponding to aquifers (i.e., highly permeable) and lower values corresponding to aquitards (i.e. less permeable).

Refugia: habitat for species to retreat to and persist in.

Regolith: weathered upper layer.

Residual value: calculated as the proportional asset life remaining multiplied by the original asset price.

Riparian: of, on, or relating to the banks of a watercourse. A riparian zone is the area of land immediately adjacent to a stream or river. Plants found within this zone are collectively known as riparian vegetation. This vegetation frequently contains large trees that stabilise the river bank and shade part of the river.

River reach: an extent or stretch of river between two bends.

Streamflow: is the flow of water in rivers and other channels (creeks, streams etc.). Water flowing in channels comes from surface runoff, from groundwater flow, and from water discharged from pipes. There are a variety of ways to measure streamflow – a gauge provides continuous flow over time at one location for water resource and environmental management or other purposes; it can be estimated by mathematical equations. The record of flow over time is called a hydrograph. Flooding occurs when the volume of water exceeds the capacity of the channel.

Triple-bottom-line: an accounting framework that incorporates three dimensions of performance: social, environmental and financial.

Watertable: the surface where the groundwater level is balanced against atmospheric pressure. Often, this is the shallowest water below the ground.

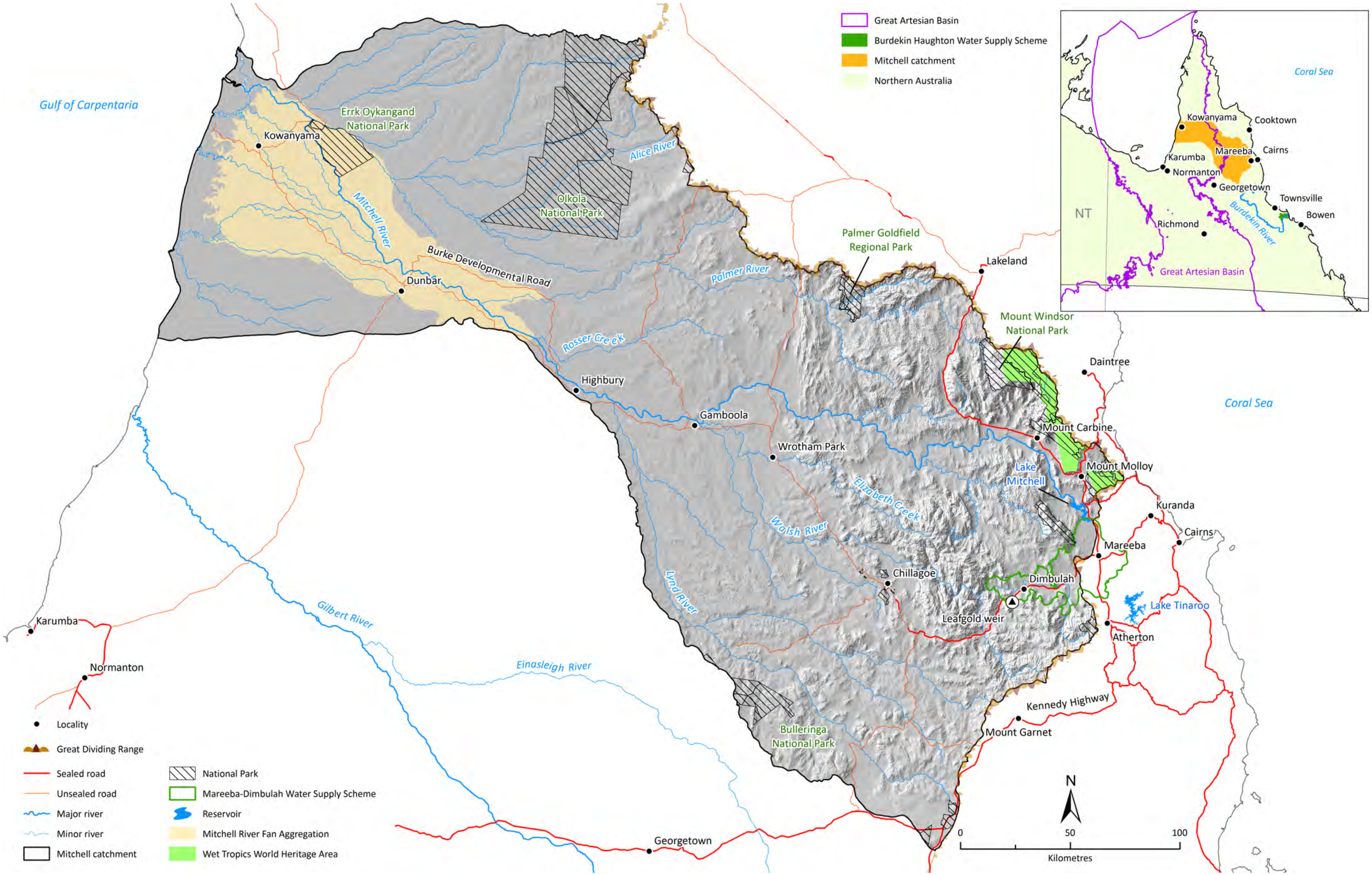
Appendix C

List of figures

List of tables

Appendix D

Detailed location map of the Mitchell catchment and surrounds



Great Artesian Basin
Burdekin Haughton Water Supply Scheme
Mitchell catchment
Northern Australia
Gulf of Carpentaria
Coral Sea
Kowanyama
Errk Oykangand National Park
Olkola National Park
Alice River
Mitchell River
Burke Developmental Road
Dunbar
Palmer River
Palmer Goldfield Regional Park
Lakeland
Rosser Creek
Mount Windsor National Park
Daintree
Highbury
Gamboola
Wrotham Park
Mount Carbine
Lake Mitchell
Mount Molloy
Elizabeth Creek
Walsh River
Kuranda
Cairns
Mareeba
Chillagoe
Dimbulah
Lynd River
Leafgold weir
Lake Tinaroo
Atherton
Karumba
Gilbert River
Normanton
Einasleigh River
Kennedy Highway
Mount Garnet
Bulleringa National Park
Georgetown
Locality
Great Dividing Range
Sealed road
Unsealed road
Major river
Minor river
Mitchell catchment
National Park
Mareeba-Dimbulah Water Supply Scheme
Reservoir
Mitchell River Fan Aggregation
Wet Tropics World Heritage Area
N
0
50
100
Kilometres
Cooktown
Townsville
Bowen
Richmond
NT
Burdekin River

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