Case studies for the Northern Australia Water Resource Assessment

A technical 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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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 DES, 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.

Parts of this report were reviewed by Dr Richard George (WA Government), Dr Mila Bristow (NT Government), Dr Fazlul Karim (CSIRO), Michael Quirk (Canegrowers), Dr James Kijas (CSIRO).

Photo

Harvesting a groundwater irrigated forage crop in the Fitzroy catchment, Western Australia. Source: CSIRO – Nathan Dyer
Director’s foreword

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

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

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

In response, CSIRO accessed expertise from across Australia to provide data and insight to support consideration of the use of land and water resources for development in each of these regions. While the Assessment focuses mainly on the potential for agriculture and aquaculture, the detailed information provided on land and water resources, their potential uses and the impacts of those uses are relevant to a wider range of development and other interests.

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The Northern Australia Water Resource Assessment (the Assessment) provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water and agricultural development in three priority regions shown in Preface Figure 1:

- Fitzroy catchment in Western Australia
- Darwin catchments (Adelaide, Finnis, Mary and Wildman) in the Northern Territory
- Mitchell catchment in Queensland.

For each of the three regions, the Assessment:

- evaluates the soil and water resources
- identifies and evaluates water capture and storage options
- identifies and tests the commercial viability of irrigated agricultural and aquaculture opportunities
- assesses potential environmental, social and economic impacts and risks of water resource and irrigation development.

*Preface Figure 1 Map of Australia showing three Assessment areas
Northern Australia defined as that part of Australia north of the Tropic of Capricorn. Murray–Darling Basin and major irrigation areas and large dams (> 500 GL capacity) in Australia shown for context.*
While agricultural and aquacultural developments are the primary focus of the Assessment it also considers opportunities for and intersections between other types of water-dependent development. For example, the Assessment explores the nature, scale, location and impacts of developments relating to industrial and urban development and aquaculture, in relevant locations.

The Assessment was designed to inform consideration of development, not to enable any particular development to occur. As such, the Assessment informs – but does not seek to replace – existing planning, regulatory or approval processes. Importantly, the Assessment did not assume a given policy or regulatory environment. As policy and regulations can change, this enables the results to be applied to the widest range of uses for the longest possible time frame.

It was not the intention – and nor was it possible – for the Assessment to generate new information on all topics related to water and irrigation development in northern Australia. Topics not directly examined in the Assessment (e.g. impacts of irrigation development on terrestrial ecology) are discussed with reference to and in the context of the existing literature.

Assessment reporting structure

Development opportunities and their impacts are frequently highly interdependent and, consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports most reliably informs discussion and decision concerning regional development when read as a whole.

The Assessment has produced a series of cascading reports and information products:

• Technical reports; that present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the ten activities (outlined below) has one or more corresponding technical reports.

• Catchment reports; that for each catchment synthesise key material from the technical reports, providing well-informed (but not necessarily-scientifically trained) readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture and other development options.

• Summary reports; that for each catchment provide a summary and narrative for a general public audience in plain English.

• Factsheets; that for each catchment provide key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable the reader to better access information that is not readily available in a static form. All of these reports, information tools and data products are available online at http://www.csiro.au/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.

Functionally, the Assessment adopted an activities-based approach (reflected in the content and structure of the outputs and products), comprising ten activity groups; each contributes its part to create a cohesive picture of regional development opportunities, costs and benefits. Preface Figure 2 illustrates the high-level links between the ten activities and the general flow of information in the Assessment.
What water and soil resources are available to enable regional development?

Preface Figure 2 Schematic diagram illustrating high-level linkages between the ten activities (blue boxes)
Activity boxes that contain multiple compartments indicate key sub-activities.
Executive summary

This report details six case studies, two in each of the three study areas. The case studies explore a range of scales of development and a wide variety of water sources, capture and storage options and different cropping opportunities. The case studies comprise:

- a barramundi aquaculture enterprise near Derby in the Fitzroy catchment
- a groundwater-based, irrigated, cotton – mungbean – forage sorghum rotation integrated into an existing beef enterprise in the Fitzroy catchment
- a large dam near Darwin supplying water for urban and agricultural use in the Darwin catchments
- groundwater and irrigated horticulture in the Darwin catchments
- water harvesting and mosaics of irrigated crops in the Mitchell catchment
- a large dam and an irrigated sugarcane and sugar mill development in the Mitchell catchment.

The case studies are illustrative only. They are designed to show how information from different disciplines could be used in an integrated way when considering potential development options, to provide a tangible means of exploring concepts of relevance to greenfield development in northern Australia. Importantly, the case studies are not designed to demonstrate, recommend or promote particular development opportunities being currently proposed, nor are they CSIRO’s recommendations on how development in the Fitzroy, Darwin or Mitchell catchments should unfold. They are, however, provided as realistic representations. That is, the case studies are ‘located’ in specific parts of the Assessment area, and use specific water and land resources and realistic intensification options.

The case studies show that there are soil and water resources that could potentially enable multiple small-scale developments or a single large irrigation development. In integrating the information there is an emphasis in this report on assessing the financial viability of each development and exploring factors that may have an impact on financial viability. However, it is recognised that economic considerations are just one aspect of decision-making for governments and communities, and that financial viability has not always been the major consideration in development decisions by Australian governments or communities in the past.

While each chapter starts with a summary specific to a particular case study, some overarching themes are presented as per the following.

- The diversity of opportunities in the three study areas, as highlighted in this report, illustrates that there is no one best water supply solution, and that all options (including farm-scale gully dams and managed aquifer recharge, which are not discussed in this report) may have an important role to play in maximising the cost-effectiveness of water supply.
- Strategies for minimising risk can be used to limit the potential for losses, such as staging developments during the initial learning phase of a greenfield development. However, not all forms of development lend themselves to staging. For example, large dam-based developments...
are typically more difficult to stage than groundwater developments that are more ‘modular’ in nature.

- Aquaculture enterprises could potentially generate an internal rate of return greater than 7% despite the remoteness of the study areas, assuming skilful operations and the existence of infrastructure that can enable year-round access for transporting supplies and produce.

- It was challenging to find a set of circumstances where broadacre crops – with ready markets and marketing infrastructure – could generate an internal rate of return greater than 7%.

- Industrial crops, i.e. cotton and sugarcane, have among the highest gross margins of crops with established markets. However, local processing facilities are essential for long-term financial viability. Third-party investment is typically required in order to build cotton gins or sugar mills. Plantings of large enough scale are required to make these investments in processing facilities viable. Vertical integration may be possible whereby the same investor, or investment facility, both grows the crop and builds, owns and operates the processing facility, and in this situation is more likely to be financially viable.

- Agricultural enterprises growing high-value produce (e.g. bananas, Asian vegetables, barramundi) can generate high gross margins and be highly profitable in northern Australia. However, these produce cannot be grown at scale without impacting on the domestic market price. For these crops (e.g. bananas and barramundi), a 10 to 15% reduction in market price is sufficient to render the enterprise unviable, i.e. resulting in negative gross margins. Success in high-value crops that, where there is price elasticity will require new market development, highlights the importance of developing international markets for high-value crops, establishing market access protocols and investing in infrastructure (e.g. cold storage and reefer handling facilities) to enable their export.

- It is more difficult to generate an internal rate of return of 7% for integrating irrigated forage from either stand and graze operations or hay production in a cattle enterprise. However, producing high-quality forage under irrigation potentially enables landholders to wean cattle at an early age and/or grow out young cattle to provide alternative markets to the live export trade. Consequently, motivations for some undertaking irrigation development may also be in ensuring the long-term viability of existing beef enterprises through market diversification, and hence lower internal rates of return (e.g. 3 to 5%) may be acceptable.

- The reliability with which water could be extracted and supplied to a crop was shown to have a large impact on the profitability of an enterprise. The reliability with which a water entitlement can be extracted decreases with increasing volume of water extraction across a catchment.

- Increasing revenue per hectare of developed land could assist in achieving higher internal rates of return. However, this can also result in higher risk. For example:
  - While a ‘vertically-integrated enterprise’ can result in a higher internal rate of return, such an enterprise inevitably becomes more complex and requires higher capital outlay, increasing the overall risk and consequently increasing the return sought by investors. The more complex and interdependent the parts of the enterprise, the more difficult it is to minimise risks through strategies such as staging development.
  - Double cropping has potential to enable an investor to generate a higher rate of return in some circumstances (e.g. low-cost, groundwater-based developments) but not all. In some types of development, the additional revenue from the second crop can be exceeded by the
cost of supplying the water required by that crop, and consequently double cropping is not a viable proposition (e.g. using water harvesting and offstream storage).

• Having multiple potential users of water is a way of spreading the risk of an investor being encumbered with a stranded asset. Typically, there are limited opportunities for mining and agriculture to share a dam because the volume of water required by agriculture far exceeds that for mining enterprises, and better soils (often alluvial) are usually geographically distinct from areas with mines (often ‘hard rock’ landscapes). The Darwin catchment does, however, present a unique opportunity across northern Australia for a water storage that could supply water for agriculture as well as high-security water for urban users.

• Conjunctive use of water offers a range of advantages:
  – For example, where groundwater and a smaller surface water resource are available for consumptive use at the one location, surface water could be used for irrigation solely during peak evaporative periods, thereby reducing the cost of groundwater infrastructure and pumping.
  – Although not explored explicitly, in reading the case studies, it is apparent that where surface water and a smaller groundwater resource are available for consumptive use at the one location, the groundwater could be used to start a crop prior to the first river flows of a wet season, and then surface water could be extracted and applied once the rivers start to flow sufficiently to enable a much larger scale of development than would be possible from groundwater alone.

• Even relatively modest scales of irrigation development (e.g. 2000 ha) face considerable regulatory and approval complexity and this can incur considerable costs under current approval processes, which vary across the three jurisdictions.

• Large developments in remote areas are likely to require considerable community support, hard infrastructure (e.g. schools, hospitals, housing, water treatment, energy, roads) and soft infrastructure (e.g. law enforcement, emergency services, education services). These costs have historically been borne by government. With a large and established regional population, the Darwin catchments offer considerable advantages over other parts of northern Australia in this regard.

• Large instream dams can result in large perturbations to streamflow, particularly in the reaches immediately downstream of the dam. Instream dams sited high in the catchment result in considerably less change in streamflow than dams sited in the mid-to-lower reaches, and also have less impact on the movement of aquatic species. Relative to large instream dams, water harvesting generally has lower impacts on aquatic systems.

• There is a high likelihood of unrecorded Indigenous cultural heritage sites being situated along water courses. Large instream dams are not a favoured form of development among Indigenous people in the Fitzroy, Darwin or Mitchell catchments.

For any developments in northern Australia, understanding how diverse stakeholder, investor and developer perspectives interact will be crucial in building and maintaining ongoing social licence-to-operate for future water and agricultural development.
## Contents

Director’s foreword .......................................................................................................................... i

The Northern Australia Water Resource Assessment Team .......................................................... ii

Preface ........................................................................................................................................ vi

Executive summary ......................................................................................................................... ix

1 Introduction ........................................................................................................................ 1
   1.1 Study area .............................................................................................................. 4
   1.2 Key concepts and terminology ............................................................................ 13

2 Barramundi aquaculture near Derby ................................................................................ 15
   2.1 Summary .............................................................................................................. 16
   2.2 Storyline for this case study example .................................................................. 17
   2.3 Case study and study area description ................................................................ 18
   2.4 Project costs ........................................................................................................ 26
   2.5 Project commerciality .......................................................................................... 31
   2.6 Project benefits ................................................................................................... 34
   2.7 Project risks ......................................................................................................... 36

3 Groundwater and an irrigated cotton–mungbean–forage sorghum rotation integrated into an existing beef enterprise .................................................................................. 38
   3.1 Summary .............................................................................................................. 39
   3.2 Storyline for this case study ................................................................................ 41
   3.3 Case study and study area description ................................................................ 46
   3.4 Case study costs................................................................................................... 58
   3.5 Project commerciality .......................................................................................... 64
   3.6 Project benefits ................................................................................................... 70
   3.7 Project impacts of groundwater extraction ........................................................ 71

4 Upper Adelaide River dam and multi-purpose use of water ............................................ 75
   4.1 Summary .............................................................................................................. 76
   4.2 Storyline for this case study ................................................................................ 77
   4.3 Case study and study area description ................................................................ 81
   4.4 Project costs ........................................................................................................ 88
   4.5 Project benefits ................................................................................................... 92
## Contents

4.6 Project commerciality ................................................................. 93
4.7 Project impacts ........................................................................ 97

5 Groundwater in the Wildman catchment and irrigated horticulture ............. 102
5.1 Summary ...................................................................................... 103
5.2 Storyline for this case study .......................................................... 104
5.3 Case study and study area description .......................................... 105
5.4 Case study costs ........................................................................ 119
5.5 Project commerciality ................................................................. 120
5.6 Project benefits .......................................................................... 122
5.7 Project impacts .......................................................................... 123

6 Water harvesting and irrigated crops ....................................................... 126
6.1 Summary ...................................................................................... 127
6.2 Storyline for this case study .......................................................... 128
6.3 Case study area and description .................................................. 131
6.4 Project costs ................................................................................ 147
6.5 Project commerciality ................................................................. 150
6.6 Project benefits .......................................................................... 152
6.7 Project impacts .......................................................................... 154

7 Dam on Mitchell River and irrigated sugarcane ............................................. 160
7.1 Summary ...................................................................................... 161
7.2 Storyline for this case study .......................................................... 163
7.3 Case study and study area description .......................................... 166
7.4 Project costs ................................................................................ 177
7.5 Project benefits .......................................................................... 182
7.6 Project commerciality ................................................................. 185
7.7 Project impacts .......................................................................... 186

References ......................................................................................... 192
# Figures

- Figure 1-1 The Fitzroy catchment showing general case study areas in red outline ............................... 5
- Figure 1-2 The Fitzroy catchment showing; (a) ecologically important areas: important wetlands, persistent waterholes, important bird areas and protected areas and (b) land use classification .................................................................................................................................... 6
- Figure 1-3 The Darwin catchments ........................................................................................................ 8
- Figure 1-4 The Darwin catchments showing; (a) ecologically important areas: important wetlands, important bird areas, monsoon vine forests and protected areas and (b) land use classification .................................................................................................................................... 9
- Figure 1-5 The Mitchell catchment ........................................................................................................ 11
- Figure 2-1 Schematic diagram of an aquaculture enterprise near Derby in the Fitzroy catchment ........................................................................................................................................... 15
- Figure 2-2 Supratidal flat on the coastal plain north of near Derby looking north. These marine hydrosol soils are permanently wet at depth .................................................................................. 18
- Figure 2-3 (a) Satellite image and potential maximum surface water extent and (b) soil generic group ................................................................................................................................................. 19
- Figure 2-4 Land suitability for marine aquaculture in (a) earthen ponds and (b) lined ponds .... 20
- Figure 2-5 Schematic of a marine aquaculture farm .............................................................................. 23
- Figure 2-6 Cross-section of a marine aquaculture farm detailing optimal land elevation, water flow and discharge .................................................................................................................. 24
- Figure 2-7 Breakdown of annual operating costs and capital development costs for a barramundi enterprise ........................................................................................................................................... 32
- Figure 2-8 Cumulative discounted cash flows for the first 20 years of operation of a barramundi enterprise ........................................................................................................................................... 33
- Figure 2-9 Sensitivity of financial performance of the case study farm to variation in costs, prices and other measures of farm efficiency ........................................................................................................ 34
- Figure 3-1 Schematic diagram illustrating the components of the case study for groundwater-based irrigation mosaics of cotton–mungbean–forage sorghum rotation ............................................................... 38
- Figure 3-2 Irrigated hay production near Fitzroy Crossing ...................................................................... 44
- Figure 3-3 Well-drained loamy soils (SGG4.1) and sands (SGG6.1) locally known as Pindan on extensive level to gently undulating plains of the lower Fitzroy catchment (Yeeda and Camelgooda land systems) ........................................................................................................ 44
- Figure 3-4 (a) Relief and potential maximum surface water extent and (b) satellite image and areas where the depth to the top of the interconnected Grant and Pool Sandstone aquifers is likely to be deeper than 300 m ........................................................................................................ 45
Figure 3-5 (a) Soil generic group and (b) agricultural versatility index maps............................... 51
Figure 3-6 Probability of exceedance of simulated production of cut hay (t/ha) for limited crop water demands of 1 to 5 ML/ha................................................................................................................................. 55
Figure 3-7 Probability of exceedance of soil water as a percentage of the DUL for seven sowing dates for (a) a red loam soil type and (b) a grey vertosol................................................................. 56
Figure 3-8 Probability of exceedance of periods of consecutive dry days (where rainfall is less than soil evaporation and surface zero to 15 cm less than 75% field capacity for 4 weeks in (a) January, (b) February and (c) March.......................................................................................... 57
Figure 3-9 Sum of equivalent annual cost of development assuming a 3% and 7% discount rate and annual overhead cost for cotton–mungbean–forage sorghum rotation.............................. 67
Figure 3-10 Sum of equivalent annual cost of development assuming a 3% and 7% discount rate and annual overhead cost for dry-season cotton................................................................. 68
Figure 3-11 Moderately suitable land with considerable limitations or better (i.e. Class 1, 2 or 3) on lighter soils that is potentially profitable at discount rates of 3% and 7% assuming an mean bore yield of 25 L/s and 50 L/s............................................................................................ 69
Figure 3-12 Modelled drawdown in groundwater level in the Grant Group and Poole Sandstone aquifers for a 20 GL/year extraction at six locations after (a) 5 years and (b) 20 years.............................................................................................................................................. 72
Figure 4-1 Schematic diagram illustrating the components of the case study for a large dam on the Adelaide River, urban water pipeline and irrigation development........................................ 75
Figure 4-2 (a) Satellite image and (b) relief and potential maximum surface water extent........ 80
Figure 4-3 (a) Soil generic group and (b) land suitability for rice (lowland) dry-season furrow-irrigated........................................................................................................................................ 82
Figure 4-4 Dryland hay on the Adelaide River alluvium downstream of Adelaide River town.... 83
Figure 4-5 Rice being grown at Tortilla Flats on the Adelaide River alluvial plain in the case study area........................................................................................................................................... 85
Figure 4-6 Upper Adelaide River dam on the Adelaide River looking upstream..................... 86
Figure 4-7 Assessment of change in flow metrics for assets at assessed location 81700050 in the Adelaide catchment.................................................................................................................. 98
Figure 4-8 Assessment of change in flow metrics for assets at assessed location 81700200 in the Adelaide catchment.................................................................................................................. 99
Figure 4-9 Assessment of change in flow metrics for assets at assessed location 81700001 in the Adelaide catchment.............................................................................................................. 100
Figure 5-1 Schematic diagram illustrating the components of the case study envisaging groundwater development for 500 ha of irrigated bananas at Wildman Station......................... 102
Figure 5-2 (a) Satellite image and (b) relief and potential maximum surface water extent...... 106
Figure 5-3 Well-drained deep loamy red soils at the Cashew farm, Wildman catchment........ 108
Figure 5-4 (a) Soil generic group and (b) land suitability for bananas under trickle irrigation .. 109
Figure 5-5 Mean daily temperature for the case study area.......................................................... 111
Figure 5-6 Long-term fortnightly climate variation in rainfall, maximum and minimum temperatures under the historical climate (1890 to 2015).......................................................... 113
Figure 5-7 Long-term fortnightly climate variation in solar radiation, relative humidity and vapour pressure deficit under the historical climate (1890 to 2015).......................................................... 114
Figure 5-8 Australian retail banana prices .................................................................................. 115
Figure 5-9 Distribution of wholesale Cavendish banana price in Melbourne and Adelaide markets in the 2012–2018 period............................................................................................... 116
Figure 5-10 (a) Surface geology and (b) basement geology in the Mary-Wildman rivers area . 117
Figure 5-11 Local aquifers targeted for groundwater-based irrigation development in the Wildman River case study area........................................................................................... 118
Figure 5-12 Modelled IRR for 500-ha banana development ...................................................... 122
Figure 5-13 Model groundwater drawdown for (a) shallow model layer and (b) deeper model layer assuming 3 GL/ha/year extraction at each development location ................................... 124
Figure 5-14 Change in monsoon rainforest patch transpiration rate and leaf area index with change in groundwater elevation (relative to no drawdown scenario)................................. 125
Figure 6-1 Schematic diagram illustrating the components of the case study for water harvesting and mosaic irrigation development.................................................................................. 126
Figure 6-2 (a) Relief and potential maximum surface water extent and (b) ringtank suitability130
Figure 6-3 Hard-setting Sodosol landscape occurring extensively on the alluvial plains and delta of the Mitchell River and its major tributaries ................................................................. 132
Figure 6-4 Grasslands on hard-setting Vertosols (cracking clays) of the Mitchell River delta ... 133
Figure 6-5 (a) Soil generic group and (b) agricultural versatility index map .............................. 134
Figure 6-6 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 ............................... 142
Figure 6-7 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 ............................ 143
Figure 6-8 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 end-of-system flow requirement of 1000 GL/year......................................................................................... 144
Figure 6-9 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 ....................................................... 156
Figure 6-10 80% annual exceedance 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........... 157
Figure 7-1 Schematic diagram illustrating the components of the case study example for a large dam and irrigation development ................................................................. 160

Figure 7-2 (a) Satellite image and (b) relief and potential maximum surface water extent upstream of the confluence of the Mitchell and Walsh rivers .................................................. 165

Figure 7-3 Gently undulating cracking clay plain upstream of the confluence of the Mitchell and Walsh Rivers .............................................................................................................. 167

Figure 7-4 Deep friable moderately well-drained cracking clay soil (SGG 9 vertosol) exposed in a gully in the mid-section of the Mitchell catchment ................................................. 167

Figure 7-5 (a) Soil generic group and (b) land suitability for spray-irrigated sugarcane upstream of the confluence of the Mitchell and Walsh rivers .................................................. 169

Figure 7-6 Long-term fortnightly climate variation in rainfall, maximum and minimum temperatures under the historical climate (1890 to 2015) .......................................................... 170

Figure 7-7 Long-term fortnightly climate variation in solar radiation, relative humidity (RH) and vapour pressure deficit (VPD) under the historical climate (1890 to 2015) ............... 171

Figure 7-8 Pinnacles dam site on the Mitchell River looking upstream .................................. 173

Figure 7-9 Assessment of change in flow metrics for assets at assessed location 9190111 ...... 188

Figure 7-10 Assessment of change in flow metrics for assets at assessed location 9190090 .... 189

Figure 7-11 Assessment of change in flow metrics for assets at assessed location 9190000 .... 189

Tables

Table 2-1 Key marine water quality parameters for barramundi aquaculture ....................... 21

Table 2-2 Land area and water requirements of example enterprise ........................................ 22

Table 2-3 Summary of capital development costs for an intensive barramundi enterprise with 30 ha of grow-out ponds .......................................................................................... 27

Table 2-4 Summary of overall annual operating costs for an intensive barramundi enterprise producing 624 t whole fish per year from 30 ha of grow-out ponds ............................. 28

Table 2-5 Summary of nursery costs and production parameters for a barramundi enterprise. 28

Table 2-6 Summary of feed costs and other growth parameters for barramundi grow-out ...... 29

Table 2-7 Packing costs and parameters for a barramundi enterprise .................................... 29

Table 2-8 Labour requirements and costs for a barramundi enterprise .................................. 30

Table 2-9 Utility charges for electricity for barramundi enterprise ........................................ 31

Table 2-10 Summary of overall long-term financial performance of the case study barramundi enterprise ................................................................................................. 32
Table 2-11 Estimated annual total increase in economic activity and jobs within the Kimberley region including the economic activity and jobs created by the barramundi aquaculture development itself ................................................................. 36
Table 2-12 Potential biophysical risks associated with the example aquaculture enterprise ..... 36
Table 3-1 Conveyance efficiency assumptions for the irrigation development associated with the groundwater in the Fitzroy catchment ................................................................................................................................. 53
Table 3-2 Yields and crop water demand for cotton, mungbean and forage sorghum hay at Fitzroy Crossing under irrigated conditions for a red loamy soil type ......................................................................................... 54
Table 3-3 Number of wet days per month where daily rainfall exceeds daily soil evaporation under the historical climate ......................................................................................................................... 55
Table 3-4 Farm-scale capital and operational costs .................................................................................. 59
Table 3-5 Indicative groundwater development capital costs .................................................................. 60
Table 3-6 Indicative groundwater development capital costs per ha ..................................................... 60
Table 3-7 Combined farm and water development costs for a 2000-ha irrigation development and 20 GL/year groundwater development ................................................................. 61
Table 3-8 Potential benefits of incorporating 1000 ha of forage sorghum and 2000 ha of cottonseed into a typical beef enterprise in the Fitzroy catchment ..................................................................................... 64
Table 3-9 Break-even gross margins required to meet capital costs and operation and maintenance costs of a 2000-ha irrigation enterprise for different groundwater resource configurations ................................................................................................................................. 66
Table 3-10 Gross value of production .................................................................................................... 70
Table 3-11 Estimated increase in agricultural output per year resulting from three physically plausible scales of irrigation development based on water harvesting and ringtanks ................. 71
Table 3-12 Modelled drawdown at seven reporting sites in the Grant Group and Poole Sandstone aquifer system for three extraction scenarios: 5, 10 and 20 GL/year ..................................................................................... 73
Table 4-1 Crop production parameters for dry-season rice and rainfed wet-season soybean ... 85
Table 4-2 Upper Adelaide River dam parameters ................................................................................... 87
Table 4-3 Conveyance and field application efficiency assumptions and water required to be released from Upper Adelaide River dam ..................................................................................... 88
Table 4-4 Pre-feasibility capital and operation and maintenance costs associated with Upper Adelaide River dam ..................................................................................................................... 89
Table 4-5 Order of magnitude capital and operation and maintenance costs of conveying water from the potential Upper Adelaide River dam to the potential Strauss water treatment plant ................................................................................................................................. 89
Table 4-6 Estimated capital costs and operation and maintenance costs associated with the 6000 ha (Option 1) and 9000 ha (Option 2) irrigation areas ...................................................................................... 90
Table 4-7 Farm-scale capital and operational costs ............................................................................... 91
Table 4-8 Summary of regional economic benefits of agriculture (recurring) arising from the irrigation development ................................................................. 92

Table 4-9 Summary of regional economic benefits of the construction phase for a case study of a large dam on the Adelaide River, water transfer infrastructure and scheme-scale and farm-scale irrigation development ................................................................................................................................. 93

Table 4-10 Scheme financial performance (IRR) and farm water pricing for different combinations of discount rate and values for urban water supply for a case study of 30 GL of high security water for Darwin and 6000 ha dry-season irrigated rice and wet-season rainfed soybeans ........................................................................................................................................ 95

Table 4-11 Scheme financial performance (IRR) and farm water pricing for different combinations of discount rate and values for urban water supply for a case study of 15 GL of high security water for Darwin and 9000 ha dry-season irrigated rice and 6000 ha of wet-season rainfed soybeans ........................................................................................................................................ 96

Table 4-12 Summary of other selected considerations impacted by the 6000 ha irrigation and dam development ........................................................................................................................................ 100

Table 5-1 Farm-scale capital and operational costs ................................................................................................................................. 120

Table 5-2 Estimated increase in agricultural output per year resulting from a 500-ha banana plantation at Wildman Station ........................................................................................................................................ 123

Table 6-1 Area of land with Class 1, 2, or 3 soils within 5 km of river reach ............................................................................................... 135

Table 6-2 Cropping season, median crop yield, median applied irrigation water, price, variable cost and median gross margin for selected field crops on Sodosols in the Mitchell catchment ........................................................................................................................................ 136

Table 6-3 Assumed dimensions for circular 4 GL ringtank ........................................................................................................................................ 138

Table 6-4 Streamflow metrics at selected gauging stations in the Mitchell catchment ................................................................................................................................. 140

Table 6-5 Indicative reliability of hypothetical irrigators extracting full entitlement for selected pump start thresholds ........................................................................................................................................ 141

Table 6-6 Effective volume after net evaporation and seepage for ringtanks of mean water depth 3.5 m under three seepage rates at Chillagoe ........................................................................................................................................ 145

Table 6-7 Efficiency assumptions for overhead irrigation development associated with water harvesting in the Mitchell catchment ........................................................................................................................................ 146

Table 6-8 Efficiency assumptions for furrow irrigation development associated with water harvesting in the Mitchell catchment ........................................................................................................................................ 146

Table 6-9 Indicative costs for a 4000-ML ringtank ........................................................................................................................................ 148

Table 6-10 Base costs for water harvesting irrigation development for 4000-ML ringtank and 500-ha development under spray irrigation ........................................................................................................................................ 148

Table 6-11 Capital costs for three scales of irrigated-cropping enterprise based on overhead irrigation ........................................................................................................................................ 149
Table 6-12 Capital costs for three scales of irrigated-cropping enterprise based on furrow irrigation ........................................................................................................................................................................ 149
Table 6-13 Break-even gross margins required to meet capital cost and operation and maintenance costs of irrigation enterprise .......................................................................................................................... 151
Table 6-14 Estimated increase in agricultural output per year resulting from three physically plausible scales of irrigation development based on water harvesting and ringtanks 154
Table 6-15 General discussion of potential non-flow-related ecological, social and cultural considerations with respect to small-scale water harvesting irrigation developments 159
Table 7-1 Crop production parameters for sugarcane and a mungbean fallow used in financial analysis .................................................................................................................................................................................... 172
Table 7-2 Modelled data under the historical climate at 919003 A ........................................................................................................................................................................................................................................ 173
Table 7-3 Pinnacles dam parameters ........................................................................................................................................................................................................................................................................ 174
Table 7-4 Conveyance efficiency assumptions for the irrigation development associated with the Pinnacles dam ........................................................................................................................................................................ 175
Table 7-5 Capital costs and operation and maintenance costs associated with Pinnacles dam on the Mitchell River ........................................................................................................................................................................ 178
Table 7-6 Order of magnitude capital costs and operation and maintenance costs associated with upgrading the Burke Development Road from Dimbulah to the Wrotham Park irrigation development .......................................................................................................................................................................................... 178
Table 7-7 Irrigation scheme development capital costs and operation and maintenance costs associated with Pinnacles dam ........................................................................................................................................................................ 178
Table 7-8 Farm-scale capital and operational costs for 70,000 ha of farmland growing sugarcane ........................................................................................................................................................................................................................................................................................................ 180
Table 7-9 Indicative capital and operating costs for a mill configured to suit the supply of sugarcane from the development ........................................................................................................................................................................................................................................................................................................ 180
Table 7-10 Community infrastructure requirements to support a 70,000 ha irrigation development near Chillagoe ........................................................................................................................................................................................................................................................................................................ 181
Table 7-11 Summary of assumptions on costs, prices and operations used for a case study of an integrated 70,000 ha sugar production scheme in the Mitchell catchment ........................................................................................................................................................................................................................................................................................................ 182
Table 7-12 Summary of outputs and revenue for a case study of an integrated 70,000 ha sugar production scheme in the Mitchell catchment ........................................................................................................................................................................................................................................................................................................ 183
Table 7-13 Summary of regional economic benefits of the construction phase for a case study of an integrated 70,000 ha sugar production scheme in the Mitchell catchment ........................................................................................................................................................................................................................................................................................................ 185
Table 7-14 Summary of scheme financial performance (IRR) for a case study of an integrated 70,000 ha sugar production scheme in the Mitchell catchment ........................................................................................................................................................................................................................................................................................................ 186
Table 7-15 Summary of other selected considerations impacted by the 70,000 ha irrigation and dam development ........................................................................................................................................................................................................................................................................................................ 190
Chapter 1 Introduction

The companion catchment and technical reports produced by the Assessment present material in a way that is essentially discipline, or subject, based. By contrast, the primary purpose of the case studies described in this report is to:

- show how information produced by different parts of the Assessment can be assembled to help readers address their own questions and information needs
- provide a pathway for the reader into the relevant technical reports
- help readers understand the type and scale of opportunity for irrigated agriculture and aquaculture in selected parts of the Assessment area and what individual developments might look like
- identify and explore considerations that become more apparent during the process of combining information from multiple disciplines.

The Assessment considered six case studies, two in each study area. Each case study forms a chapter of this report and each case study chapter includes:

- a storyline to set the scene and characterise the case study
- a description of the case study area, including soils, climate and water – drawing on material from Charles et al. (2016), Hughes et al. (2017), Hughes et al. (2018) and Thomas et al. (2018)
- a description of the configuration of the irrigation or aquaculture development – with reference to Ash et al. (2018a,b,c) and Irvin et al. (2018)
- an overview of the costs – drawing on material from Ash et al. (2018a,b,c), Benjamin (2018), Petheram et al. (2017) Stokes et al. (2017), Taylor et al. (2018a)
- an analysis of the project commerciality – using the financial analysis described by Stokes et al. (2017)
- a summary of the project benefits – using the methods described in Stokes et al. (2017)
- an overview of a selection of the project impacts – drawing upon the material presented in Pollino et al. (2018a,b) and Turnadge et al. (2018a).

While each case study has a similar structure, different case studies are used to highlight different considerations in establishing greenfield irrigation and aquaculture in northern Australia.

Importantly, the case studies are illustrative only. They are designed to show how information from different disciplines could be used in an integrated way when considering potential development options. Note that they are not designed to demonstrate, recommend or promote particular development opportunities that may be currently proposed, nor are they CSIRO’s recommendations on how development in the Fitzroy, Darwin or Mitchell catchments should unfold. They are, however, designed to be realistic representations. That is, the case studies are ‘located’ in specific parts of the Assessment area, and use specific water and land resources, and realistic intensification options.
It is also important to note that the detail of analysis provided in this case study report is not consistent with that required for a business case. For the purposes of brevity and readability, not all considerations important to greenfield water and agricultural development are discussed in each chapter. Furthermore, no on-ground investigations were undertaken specific to these case studies, and the analysis is based on information largely available from the catchment and technical reports. For example, other than the pre-feasibility major dam cost estimates (Petheram et al., 2017), on-ground investigations were not undertaken as part of the Assessment for the specific purpose of acquiring more accurate costing information. Consequently, the cost estimates presented in this report should be considered pre-feasibility. Similarly crop yields reported in these case studies, and which were used in the financial analyses, are modelled crop yields at full production potential (see Ash et al., 2018a,b,c). On-ground small scale trials and measurements would be required to locally parameterise agricultural production models to confirm the long-term yields. Risks of underperformance (e.g. due to poor planning, cyclones, pests), particularly at the commencement of a greenfield development, are acknowledged and are examined in the companion technical report on socio-economics, Stokes et al. (2017).

In summary, if these case studies were considered further, more detailed analysis and site-specific on-ground investigations should be undertaken, including an assessment of the potential for ecological and off-site impacts.

Report structure
The report is structured as follows.

Chapters 2 and 3 are case studies set in the Fitzroy catchment.

• Chapter 2 – barramundi aquaculture near Derby
  – This case study investigates the potential for an aquaculture enterprise to produce barramundi (*Lates calcarifer*) somewhere near Derby in the lower Fitzroy catchment.
  – The case study focuses on the production system required to produce barramundi for market and the costs and financial performance of such an enterprise in a remote location such as the west Kimberley.

• Chapter 3 – groundwater and an irrigated cotton – mungbean – forage sorghum rotation integrated into an existing beef enterprise
  – This case study investigates the potential to incorporate an irrigated crop-forage rotation based on groundwater into an existing beef enterprise. Developments would take the form of mosaics of irrigation situated to minimise cost and financial and ecological risk.
  – This case study highlights the opportunities and challenges of double cropping in northern Australia.
  – The case study also briefly discusses some of the challenges presented by the current approvals process.

Chapters 4 and 5 are case studies set in the Darwin catchments.

• Chapter 4 – Upper Adelaide River dam and multi-purpose use of water
This case study investigates the potential for a dam on the upper Adelaide River to supply water to meet future urban and industrial demand and supply water to irrigate 6000 ha of dry-season rice.

This case study highlights how a dam storing high-value urban water can improve the financial attractiveness of supplying water for agriculture.

• Chapter 5 – groundwater in the Wildman catchment and irrigated horticulture
  – This case study investigates the potential for an irrigation enterprise involving a groundwater development and 500 ha of irrigated bananas was investigated in the Wildman catchment, 200 km east of Darwin.
  – The case study examines the sensitivity in the viability of the enterprise to changes in price.
  – Potential impacts of groundwater pumping on groundwater dependent ecosystems are examined.

Chapters 6 and 7 are case studies set in the Mitchell catchment.

• Chapter 6 – water harvesting and mosaics of irrigated crops
  – This case study investigated water harvesting along the Palmer, Mitchell, Walsh and Lynd rivers in the Mitchell catchment.
  – The analysis focused on the gross margins required for investment in an irrigation development to be viable, rather than examining profitability with respect to one particular crop.

• Chapter 7 – large dam on the Mitchell River and irrigated sugarcane
  – In this case study, a potential irrigation development upstream of the confluence of the Mitchell and Walsh rivers was investigated. The development is based on a rotation of sugarcane and mungbeans, with a new sugar mill located on-site.
  – The case study investigates the capacity of the scheme to generate positive net revenues, based on a vertically integrated development that includes a new mill and is developed and operated by a single investor.

The remainder of this chapter provides an overview of the three study areas and then key concepts and terminology are explained.
1.1 Study area

1.1.1 THE FITZROY CATCHMENT

The Fitzroy catchment covers approximately 94,000 km² of the Kimberley region in northern WA (Figure 1-1). The Fitzroy River rises in the King Leopold Ranges and drains into King Sound and is more than 700 km long. With a median annual discharge of 4900 gigalitres (GL) the Fitzroy River has the largest discharge of any river in WA and the ninth largest median annual discharge of any river in Australia north of the Tropic of Capricorn (Petheram et al., 2014). The catchment uplands are drained by a number of major rivers, including the Hann, Leopold and Margaret rivers, with the Christmas, Cherrabun and Gee Gully creeks draining the lowlands. Elevation ranges from sea level in the west, to 125 mAHD in the centre of the catchment near Fitzroy Crossing, and reaches its highest point of 963 mAHD in the Durack Range on the eastern catchment boundary.

The catchment is characterised by a highly distinctive wet and dry season associated with the southern limit of the Australian summer monsoon. Mean annual rainfall decreases from north to south and is in the range of 1000 mm to 400 mm. Median annual potential evaporation in the catchment ranges from about 1900 to 2050 mm. Temperatures above 37°C are common from August to the start of the wet season.

There are two main population centres in the Fitzroy catchment: Derby and Fitzroy Crossing, with respective populations of 3511 and 1297 at the 2016 census, and 55 Indigenous communities (Department of Water, 2009), which combined make a total catchment population of about 7500 people. The Fitzroy catchment is characterised by a sparse road network (Figure 1-1) with the Great Northern Highway connecting Broome to the south-west and Kununurra in the north-east near the NT border. The administrative and commercial hub of the West Kimberley region is Broome, which lies on the coast approximately 100 km south-west of the Fitzroy River’s western catchment boundary. The distance from Broome to Perth (the capital city of WA) is 2240 km and internal distances in the catchment are long; Derby to Fitzroy Crossing is a distance of 260 km, to reach Halls Creek, just outside the eastern catchment boundary, is a further 290 km.

Most of the catchment is contained within three bioregions (Dampierland, Ord Victoria Plain, and Central Kimberley) but also contains parts of the Northern Kimberley and Great Sandy Desert bioregions. The main land use is pastoralism (95%), with nature conservation and Indigenous Protected Areas covering the remaining area (Figure 1-2). Areas of potential irrigation development are found on the deep sandy and loamy soils in the west and central areas of the catchment and the deep clay soils of the Fitzroy River alluvial plain and limestone geologies. Large areas of steep or shallow and/or rocky soils in the east and north of the catchment are unsuitable for irrigation development.
Figure 1-1 The Fitzroy catchment showing general case study areas in red outline
Figure 1-2 The Fitzroy catchment showing: (a) ecologically important areas: important wetlands, persistent waterholes, important bird areas and protected areas and (b) land use classification
1.1.2 THE DARWIN CATCHMENTS

The Darwin catchments span an area of approximately 30,000 km² and are comprised of four predominantly north-south draining catchments: the Finniss (9490 km²), Adelaide (7460 km²), Mary (8075 km²) and Wildman (4820 km²) catchments, as defined by the Australian Water Resources Council (AWRC) river basin boundaries (Figure 1-3). These rivers originate as incised channels in the southern uplands before broadening into alluvial plains and then extensive coastal and marine floodplains eventually flowing into the Arafura Sea. They lie in a broader area known locally as the ‘Top End’. Elevation ranges from sea level to the highest point of 385 m AHD on the plateau at the south-eastern boundary. Typically, the catchments are below 100 m AHD elevation with the higher areas along the southern boundary.

The Darwin catchments are characterised by a distinctive wet and dry season due to their location in the Australian summer monsoon. Mean annual rainfall over the 125-year historical period (1890 to 2015) over the Darwin catchments was 1423 mm and decreases from northeast to southwest.

The population of the Darwin catchments is about 140,000, of whom 98% live within the Greater Darwin area. The study area contains two very different settings: the ‘urban areas’ including Darwin and the surrounding suburbs (Greater Darwin area population was 136,828 as at the 2016 census), and the remaining ‘rural areas’. Outside the Darwin urban footprint, the Darwin catchments are characterised by a sparse road network of major roads (Figure 1-3) with the Stuart Highway being the main access to Darwin from the south. Distances across the study area are not great; Darwin to Pine Creek (just outside the southern catchment boundary) is 225 km.

The Darwin catchments fit mostly within the Darwin Coastal and Pine Creek bioregions but contain parts of the Daly Basin and Arnhem Plateau bioregions on the southern and eastern flanks respectively. Land use in the study area is dominated by conservation and natural environments (38%), and production from relatively natural environments (32%). Small areas of dryland agriculture, irrigated agriculture and plantations exist (Figure 1-4). A significant area is set aside for military training.
Figure 1-3 The Darwin catchments
Figure 1-4 The Darwin catchments showing; (a) ecologically important areas: important wetlands, important bird areas, monsoon vine forests and protected areas and (b) land use classification
1.1.3 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 1-5). 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 east of 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 (Figure 1-5). 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 vegetation. Conservation reserves are the second largest land use, but only cover 3% of the catchment (Figure 1-6). 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 (Figure 1-5) in the upper Walsh River catchment and irrigated cropping is dominated by sugarcane and horticulture, comprising about 0.3% of the study area.
Figure 1-5 The Mitchell catchment
Figure 1-6 The Mitchell catchment showing; (a) ecologically important areas: important wetlands, important bird areas and protected areas and (b) land use classification
1.2  Key concepts and terminology

1.2.1  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.

1.2.2  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 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. Key economic concepts
1.2.3 FINANCIAL TERMINOLOGY

A discounted cashflow framework was used to evaluate the commercial viability of irrigation developments. See companion technical report on socio-economics, Stokes et al., (2017) for more information.

**Discounted cashflow analysis**

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.

**Discount rate**

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.

**Internal rate of return**

The internal rate of return (IRR) is the discount rate at which the Net Present Value (NPV) is zero (and the benefit-cost ratio if 1). 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.

**Equivalent annual cost**

The equivalent annual cost (EAC) is the annual cost of owning, operating and maintaining an asset over its entire life. EAC allows comparison of the cost effectiveness of various assets with unequal lifespans.
This case study investigates the potential for an aquaculture enterprise to produce barramundi (*Lates calcarifer*) somewhere near Derby in the lower Fitzroy catchment (Figure 2-1). The case study focuses on the production system required to produce barramundi for market and the costs and financial performance of such an enterprise in a remote location such as the west Kimberley.

The drivers for establishment of a barramundi farm in this location are the potential biosecurity advantages, the tropical environment and growing conditions and the opportunity to provide employment to local people. Barramundi was chosen due to a long and successful farming history in Australia. This iconic species has proven commercially successful largely due to its suitability to culture tolerance of fresh or saltwater, high stocking densities, fast growth, market demand and price stability. Quality fingerling supply and dedicated feed producers enable farmers to produce a high quality, reliable product for both domestic and international markets.

The feasibility of this development was evaluated with respect to:

- the availability of suitable locations based on land suitability analysis, proximity to a marine water source and water suitability
- the farm layout of production ponds, bioremediation ponds, supply channel and waste water channel

**Figure 2-1 Schematic diagram of an aquaculture enterprise near Derby in the Fitzroy catchment**
• the production system, including sourcing fingerlings and specialist feed from interstate, nursery activity and size grading, aeration and power requirements, the grow-out phase, biosecurity and harvesting
• the capital costs of setting up the farm
• annual operating costs including nursery, feed, packing, transport, labour, electricity and overhead estimates
• farm financial analysis in terms of financial performance and net present value
• an estimate of regional economic benefits.

The enterprise investigated in this case study would be located within 2 km of a marine water source. The farm itself would be made up of 30 land-based production ponds (1 ha each) plus other areas such as bioremediation ponds and processing areas, giving a total farm size of 100 ha. The ponds would be earthen lined.

The production target of about 600 t/year (whole fish at harvest, before processing), would occur over a 2-year production cycle, where a partial harvest of smaller size fish occurs at the end of the first year, and the remaining fish are grown out for a further 12 months before harvesting at the end of the second year. Smaller fish would be marketed as whole, plate-sized fish while larger fish would be sold as fillets. Fingerlings would be sourced from interstate suppliers, as would specialist feed. The fish would be processed on site and trucked to Perth.

In presenting this case study example, no consideration is given to approval and ongoing regulatory obligations that will need to be addressed for any aquaculture development to proceed. These issues include, but are not limited to, legislation relating to land tenure, planning and infrastructure, cultural heritage, native title, vegetation management, wildlife protection, water resources, fisheries, and environmental protection. Each development would need to work through these approval processes on a case-by-case basis.

2.1 Summary

The case study concludes that suitable soil and water resources exist to locate a barramundi aquaculture enterprise in the lower Fitzroy catchment.

• The production target of about 600 t/year (whole fish at harvest, before processing) would occur over a 2-year production cycle. With a favourable climate and year-round fingerling availability, production and fingerling intake would continue throughout each calendar month.

• The case study concluded that only frozen products would be feasible for storage and transport and that the closest market of sufficient size was Perth. About 15 staff would be required to run the farm, with 5 of these being skilled.

• The operating expenses for barramundi production are very high relative to the initial costs of development and in this case study, annual operating costs exceeded the total initial capital costs. The highest costs are for feed and for electricity, each about a third of the overall annual operating costs.

• The financial analysis indicated that the barramundi enterprise modelled could be financially feasible, generating a net present value of $3.7 million (at a 7% discount rate) and an internal rate of return of just over 12%. 

16 | Case studies for the Northern Australia Water Resource Assessment
• The cumulated discounted cash flow for the enterprise suggests that the payback period for the enterprise would be about 12 years. However, the analysis also showed that substantial capital reserves would be required in the early years of establishing the production system as substantial operating expenses are incurred before revenue can be generated from the harvested product. The reserves required to get through the establishment period would exceed the initial capital costs of developing the enterprise (and therefore value of the enterprise’s total tangible assets).

• As might be expected, there is a high level of uncertainty in many of the parameter estimates for establishing a greenfield barramundi enterprise in such a location. A sensitivity analysis showed that the business would be particularly vulnerable to variations in the price received for produce (frozen whole fish and frozen fillets). A decline in produce prices of only 10% would render the enterprise unprofitable, whereas an increase of 10% would more than double its value in net present value terms. This suggests that negotiating a viable price with a stable buyer would be one way of ensuring that the enterprise did not become unprofitable unexpectedly.

2.2 Storyline for this case study example

In this case study, a potential aquaculture development near Derby was investigated, comprising a total of 30 ha of ponds. The development would enable barramundi to be supplied into the domestic market as whole plate-sized fish of about 1 kg, or as fillets from larger fish, about 3 kg. The drivers for establishment of a barramundi farm in this location are the potential biosecurity advantages, the tropical environment and growing conditions and the opportunity to provide employment to local people.

Barramundi was chosen due to a long and successful farming history in Australia. This iconic species has proven commercially successful largely due to its suitability to culture tolerance of fresh or saltwater, high stocking densities, fast growth, market demand and price stability (Irvin et al., 2018). Quality fingerling supply and dedicated feed producers enable farmers to produce a high quality, reliable product for both domestic and international markets.

By requirement the development would be adjacent to a suitable water supply, with saltwater intake and output pipelines located to allow operation at high tide. This would require 30 ha of production ponds (at 1 ha each) plus ancillary bioremediation ponds and associated infrastructure for a total of 100 ha. After Derby, the next nearest major town is Broome, 220 km by road.

The outline of this case study is as follows:

• Section 2.3 describes the case study and the study area including: soil and land suitability, water suitability and a description of the case study enterprise and management practices
• Section 2.4 outlines project capital and operating costs including nursery, feed, packing, transport, labour, electricity and overhead costs
• Section 2.5 discusses project commerciality including farm financial analysis, farm financial performance and sensitivity analysis
• Section 2.6 outlines the production potential and modelled regional economic benefits
• Section 2.7 considers project risks.
2.3 Case study and study area description

The general location for this case study, in the lower part of the catchment, was chosen because of the need to be close, within 2 km but preferably closer, to a marine water source for this enterprise type. Freshwater enterprises are likely to be located elsewhere in the catchment.

2.3.1 SOIL AND LAND SUITABILITY FOR INTENSIVE AQUACULTURE

Land suitability requirements for aquaculture in earth ponds include impermeable soils, slopes less than 5%, no rock, deep soils, and free from flooding. No lands in the Fitzroy River catchment (sufficiently near to tidal flows) meet all these requirements for earth ponds. Several land types meet the requirements except for flooding, which can be mitigated and managed if the economics allow. These include the marine plains subject to occasional tidal inundation adjacent to the coast (Figure 2-3), and the strongly sodic impermeable clay soils of the Fitzroy River alluvial plains.

The level (slopes <1%) marine tidal plains (salt pans and/or saline coastal flats) along the coast (Figure 2-2) are subject to occasional spring tides, rock free, very slowly permeable, poorly drained, grey clay soils with acid sulfate material at depth, but are subject to potential storm surge during cyclones. Fresh surface water is generally lacking but groundwater may be available.

The clay soils (usually cracking) of the Fitzroy River alluvial plains and tributaries are strongly sodic, impermeable, mainly moderately well-drained to imperfectly drained, rock free, level plains (slopes <1%) supporting grass lands and Eucalypt woodlands. The alluvial plains are frequently dissected by flood channels and are subject to regular flooding. Extensive back plains with few flood channels are subject to mainly shallow floods (<1 m deep) of short duration (about 1 week). However, these landscapes are at the upper extremity of estuarine flow and may not be economical for an enterprise that relies on marine water source. A land suitability map for marine aquaculture ponds near Derby is presented in Figure 2-4.

For the purposes of this case study example, land close to Derby was chosen and more detailed inundation and land suitability analysis would need to be conducted.

Figure 2-2 Supratidal flat on the coastal plain north of near Derby looking north. These marine hydrosol soils are permanently wet at depth
Supratidal flats are seldom inundated
Data used to develop the flood map were captured using MODIS satellite imagery. This figure illustrates the maximum percentage of MODIS pixels inundated between 2000 and 2015.

The method and rationale behind the land suitability analysis can be found in the companion technical report on land suitability (Thomas et al., 2018). The criteria included: distance to marine water; elevation; slope; pH, depth and clay content of the soil; risk of acid sulfate soils; permeability; rockiness and microrelief. These were combined into a five-level categorisation from

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**Figure 2-3 (a) Satellite image and potential maximum surface water extent and (b) soil generic group**

Data used to develop the flood map were captured using MODIS satellite imagery. This figure illustrates the maximum percentage of MODIS pixels inundated between 2000 and 2015.
‘Highly suitable with negligible limitations’ to ‘Unsuitable land with extreme limitations’ (Figure 2-4).

The land suitability map does not take into consideration flood risk or offsite impacts.

2.3.2 MARINE AND WATER SUITABILITY AND FRESHWATER REQUIREMENTS

The quality of seawater supply is critical for fish farming. Table 2-1 provides key water quality parameter ranges. In general, the local seawater source will be suitable for barramundi as the...
species is naturally distributed in the local waters. The salinity of the seawater fluctuates with season, decreasing during the wet season. The level of salinity fluctuation depends on the specific location of the water source, with less variability away from the coastline.

Table 2-1 Key marine water quality parameters for barramundi aquaculture

<table>
<thead>
<tr>
<th>WATER PARAMETER</th>
<th>RECOMMENDED RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity (ppt)</td>
<td>0 – 35</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>24 – 33</td>
</tr>
<tr>
<td>Dissolved oxygen (mg/L)</td>
<td>&gt;4</td>
</tr>
<tr>
<td>pH</td>
<td>7.0 – 9.0</td>
</tr>
<tr>
<td>Total suspended solids (mg/L)</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Ammonia total (mg/L)</td>
<td>&lt;1.0</td>
</tr>
</tbody>
</table>

Freshwater additions to seawater or the use of freshwater baths would typically only be used during the nursery components of the operation. This is due to the higher stress demands placed on the fingerlings during transport and regular grading/handling, making them more susceptible to potential disease pathogens. Salinity control or fish movement to a freshwater system can assist in alleviating some of these disease concerns. In addition to the production cycle, a quality source of freshwater would be needed for processing the barramundi prior to transporting to the market. This may be in the form of town, bore or rain water and will be used for ice, fish cleaning and wash-down. Freshwater sources containing high levels of heavy metals or other metals (e.g. iron and manganese); insecticides, pesticides and other toxins will compromise the quality and quantity of freshwater that can be utilised in the nursery phase as well as posing human health issues during processing. It may be that areas of production requiring untreated (non-town) freshwater will require high levels of pre-use water treatment and monitoring. A 30 ha barramundi farm would require about 500 ML/year of freshwater. The town of Derby has a licence to extract 800 ML/year from the Erskine Sandstone supplied by five bores. It is unknown if there is capacity to supply an additional 500 ML/year from these bores. If the potential aquaculture development was required to source its own freshwater, an additional two bores in the Erskine Sandstone could potentially supply the required water at an estimated capital cost of about $650,000. Water quality and the potential for sea water intrusion would need on-going monitoring. The majority of water samples taken from the Erskine Sandstone have been < 500 mg/L (companion technical report on hydrogeology, Taylor et al., 2018).

2.3.3 LEGISLATIVE AND REGULATORY CONSIDERATIONS

In presenting this case study example, no consideration is given to approval and ongoing regulatory obligations that will need to be addressed for any aquaculture development to proceed. These issues include, but are not limited to, legislation relating to land tenure, planning and infrastructure, cultural heritage, native title, vegetation management, wildlife protection, water resources, fisheries, and environmental protection. Each development would need to work through these approval processes on a case-by-case basis. However, agriculture enterprises in the
Fitzroy catchment may encounter fewer regulatory constraints than those in catchments in eastern Australia that drain into the Great Barrier Reef lagoon.

The companion technical report on legal, regulatory and policy, Macintosh et al., (2018), discusses the potential for government assessment and approval processes to cause project delays in aquaculture projects. It also discusses how in response to the potential for delays and regulatory uncertainty to deter investment the Western Australia Department of Fisheries established a program involving the creation of designated aquaculture zones. The zones are ‘investment ready platforms’, where strategic assessments and approvals are put in place, which minimise the need for individual project assessments and approvals (Macintosh et al., 2018).

### 2.3.4 OVERVIEW OF AQUACULTURE ENTERPRISE AND OPERATION

The intensive operation would consist of 30 ha of land-based ponds (Table 2-2), producing about 600 t/year of barramundi. The region selected provides adequate climate conditions to allow for pond stocking and production growth throughout the entire year. In the grow-out phase barramundi would be stocked at 2.4/m², with 800,000 fingerlings required every 2 years for the entire operation. Fingerlings would be sourced from domestic suppliers and managed through a series of nursery stages to provide adequate numbers and size ranges for stocking into each production pond.

#### Table 2-2 Land area and water requirements of example enterprise

<table>
<thead>
<tr>
<th>CRITERIA</th>
<th>INTENSIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total land area</td>
<td>100 ha</td>
</tr>
<tr>
<td>Total nursery production area</td>
<td>0.25 ha</td>
</tr>
<tr>
<td>Total production pond area</td>
<td>30 ha</td>
</tr>
<tr>
<td>Bioremediation pond area and discharge channel</td>
<td>3 ha</td>
</tr>
<tr>
<td>Sea water requirement to fill production ponds</td>
<td>450 ML</td>
</tr>
<tr>
<td>Seawater requirement (annual water exchange)</td>
<td>8 GL</td>
</tr>
</tbody>
</table>

#### Pond preparation

The 30 ponds would be 1 ha (100 m x 100 m) and 1.5 m deep (Figure 2-5). The ponds would be earthen lined using locally derived soil material. Preparing the pond before filling with seawater and stocking of barramundi is critical for successful farming. The pond base should be dry. Once operational, organic material from each previous crop should be removed to provide a stable soil environment.

A paddlewheel aeration system is installed prior to filling the pond. The role of the aeration system is to create a circular flow for concentrating waste into a central sludge pile within the ponds (for ease of later removal and to create larger areas of the pond bottom free of sludge) and to maintain oxygen levels (>4 mg/L) to ensure optimal conditions for fish growth and the stability of the mixed algal blooms. The number of paddlewheels operating would depend on the biomass
of the fish in the pond and the individual pond dynamics. Approximately 1 kW of aeration is required for every tonne of fish.

At high tide, seawater is delivered from the pump station to the supply channel. The role of the supply channel is to allow suspended solids in the source water to settle to the pond bottom. Seawater from the supply channel is gravity fed to the production pond. Waste water released from the production pond is gravity fed to the bioremediation ponds, prior to being recycled back to the production pond or returned to the seawater source via the discharge channel (Figure 2-6). Incoming water is filtered to remove the presence of fish and crustaceans.

![Figure 2-5 Schematic of a marine aquaculture farm](image)

**Management of the farm**

The production target of about 600 t/year (whole fish at harvest, before processing), would need to account for the averaging of a 2-year production cycle, where a partial harvest of smaller size fish occurs at the end of the first year, and the remaining fish are grown out for a further 12 months before harvesting at the end of the second year. This case study considered a production cycle in each 1 ha grow-out pond that involved stocking ponds at the start of each cycle with 24,000 fingerlings of which 10% die before harvest. Of the surviving fingerlings 11,600 are harvested as 1 kg fish at the end of the first year (11.6 t), and the remaining 10,000 fish are harvested as 3 kg fish at the end of the second year (30 t). This gives a total yield of 41.6 t over the 2-year production cycle (for a farm average of 20.8 t whole fish per ha of grow-out ponds per year, or 624 t/y total across the 30 grow-out ponds). With a favourable climate and year-round fingerling availability, production and fingerling intake would continue throughout each calendar month. To smooth out operations and cash flow between years, half of the ponds would begin their production cycles in the first year of production, and the other half of ponds would start the next year and remain 1-year offset from then on.
Fingerling supply

Fingerlings would be sourced from domestic suppliers based in Victoria and South Australia who provide year-round production into domestic and international markets. To ensure the fingerlings are healthy when stocked, the duration between packing at the hatchery and stocking in the nursery tanks would need to be under 14 hours.

Pellet-weaned barramundi of 20 to 25 mm in length would be transported from the hatchery in polystyrene boxes. Each box would contain a double-lined 20 L plastic bag with 10 L of pure oxygen injected water and approximately 1000 fingerlings.

Nursery

On arrival, 0.2 g fingerlings would be acclimated in nursery tanks by floating the plastic bags on the tank water surface for 30 minutes, followed by the slow addition of tank water to the bag before release. During the early nursery stages barramundi are highly cannibalistic. To reduce mortality rates, fish are regularly graded by size. Grading initially occurs twice weekly and is reduced to twice monthly by the end of the nursery period. Barramundi require a high protein feed (45 to 55%), formulated to their dietary requirement (Glencross, 2006). In the nursery system fish are fed 3 to 6 times per day, with the first at sunrise and the last at sunset. The nursery phase is
completed when the fish reach a weight of 120 g, after 84 days. A 10% mortality rate is expected during the nursery phase.

**Grow-out**

Twelve weeks after arrival as fingerlings, 120 g juveniles would be stocked into the production ponds. Fish would be stocked at a rate of 2.4 juveniles/m² or 24,000 per pond. Fish would be fed twice per day, with the size of the pellet increasing in proportion to fish size. Feed is a major cost of barramundi production. Approximately 1.5 kg of feed would be required to produce 1 kg of barramundi. Farm production levels of 624 t/year would therefore require 936 t/year of feed to support the operation. Due to the specialised nature of the pelleted diet and the quality and quantity of ingredients required, local or on-farm feed production is seen to be costly and highly impractical. As a result, the use of an Australian-produced barramundi feed would be required with transport from either Brisbane or Tasmania.

The target fish sizes at the 12- and 24-month harvests are 1 kg and 3 kg, respectively. As fish biomass increases, so does the requirement for water exchange and mechanical oxygen addition from paddlewheels. Just prior to the 12- and 24-month harvests in each production cycle, barramundi biomass peaks at 20 to 30 t/ha and 10 to 20 paddlewheels would be required in each pond to maintain optimal oxygen levels. Water exchange is primarily with saltwater which involves either the introduction of new water (5% daily) or recycling of existing water from the bioremediation pond back to the production pond. Freshwater can be added to manage high water salinity from evaporative losses. In most cases, water salinity is not managed and would increase with evaporation and decrease with rainfall and flooding. Strict regulation on the quality and volume of water which can be discharged means efficient use of water is standard industry practice.

Effective barramundi farm management involves maintaining water quality conditions within ranges optimal for growth and survival. This becomes progressively complex as the barramundi biomass and the quantity of feed added to the system increases. Critical to the commercial success of the operation is the employment of suitable staff across managerial, administrative and technical roles. The farm manager has the overall responsibility for production. Essential skills include understanding the interaction between biology, feed and water quality management as well as staff training and management.

**Biosecurity**

Effective management of pathogens in the production system is critical for any successful aquaculture operation. In barramundi farming, the key pathogens are viruses and bacteria, but also fungi and other microorganisms. The commercial impacts of pathogens can range from almost negligible to catastrophic, with the greatest impacts seeing widespread disease episodes that can destroy most of the stock, but also trigger emergency regulatory responses that can impact the enterprise beyond the current crop.

Pathogens can enter the systems in several ways, but most commonly through horizontal transmission pathways such as human or animal vectors and contaminated equipment.

Good farm management practices and effective biosecurity protocols and systems can mitigate risks. Biosecurity is typically easier to manage in the smaller and more-controlled production
systems (e.g. the nursery phase) and harder to manage in the larger and less-controlled open grow-out ponds. Optimal biosecurity requires using ‘clean’ fingerlings, with good husbandry and high levels of hygiene maintained through controlling access to the production systems, and by using reliable, ‘non-infected’ feeds.

The farm’s location in Derby presents significant biosecurity advantages. Its remoteness, especially from other aquaculture facilities will reduce the potential of vehicles, staff and contaminated equipment transferring disease onto site. Site-specific biosecurity considerations would also need to include:

- effective water filtration and treatment prior to entry and exit of the farm to reduce the potential of disease from entering or exiting the facility
- correct site selection (above wet-season flood zones) to prevent flooding and damage to farm and pond containment structures
- physical screening of discharge channels and a suitable pest (rodents, crabs, birds, crocodiles) management strategy to limit the potential of fish stocks and disease vectors escaping into native populations.

**Harvest method**

For the 12- and 24-month harvests, seine nets would be used to crowd the fish towards an accessible bank with supplementary aeration provided. Harvested fish would then be manually lifted or pumped to a saline ice slurry (for processing). Given a full production schedule, four ponds would need to be partially or fully harvested every seven weeks. Fish moved to the processing facility would then be graded by size and packaged whole or processed (filleted, gilled/gutted) according to target markets and packed accordingly in cold storage awaiting further refrigerated transport and distribution. The production facility would require the capacity to process and pack an average of 12 t/week.

**Pond management between production cycles**

Depending on waste water treatment methods and farm biosecurity protocols, at the end of the 2-year production cycle ponds would either be re-stocked with 120 g barramundi or complete a drain and dry-out period (left for a period to dry, waste matter removed, and the pond prepared for re-filling. The removed dry waste would then be applied to areas approved for reclamation or erosion prevention).

### 2.4 Project costs

The financial analysis of barramundi production was based largely on an enterprise financial model developed by the Queensland Government\(^1\). The model was adapted based on the case study details of the production system described above and the assumptions on costs and prices outlined below. In this section costs are divided into the initial capital costs of developing the farm and the ongoing costs of operating the enterprise, structuring the costs according to the

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breakdown used in the financial model and the production stages described above. The next section (Section 2.5) then uses these costs in the financial model to evaluate the commercial viability of the case study enterprise.

2.4.1 CAPITAL COSTS FOR AQUACULTURE ENTERPRISE DEVELOPMENT

The initial capital investment was costed based on a greenfield development, where all construction activities and assets were priced at their value delivered new in the year that barramundi production commenced. Subsequent replacement costs and salvage values of capital inputs were initially derived from Guy et al. (2014) but were amended to capture additional costs for material transport and installation that would be incurred in a remote location like Derby. At the end of each corresponding life span, the assets would be sold for their salvage value and replacements would be purchased. A straight-line depreciation was used across the life span of the input for tax deduction.

A summary of the overall capital costs of development is provided in Table 2-3. The biggest component of the development costs for a new barramundi farm is the ponds, including the related aerators, piping, channels, water treatment, electricity connections, cages, nets and other equipment required to grow and manage the fish. The land and buildings were the next biggest cost for the case study enterprise and included processing facilities, staff accommodation, a shed/office, cold room, nursery, and a $50,000 charge for connecting to the Derby local electricity network. Vehicles and other equipment such as pumps, generators, water monitoring equipment, a fish grading machine, and workshop tools would also be required to establish the farm.

Table 2-3 Summary of capital development costs for an intensive barramundi enterprise with 30 ha of grow-out ponds

If additional infrastructure is required to source freshwater it is estimated that drilling and groundwater pumping infrastructure would cost about $650,000. As shown in Section 2.5.3 inclusion groundwater supply infrastructure would have negligible impact on the outcomes of this analysis.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>COST ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land and buildings</td>
<td>840,000</td>
</tr>
<tr>
<td>Vehicles</td>
<td>75,000</td>
</tr>
<tr>
<td>Pond-related expenditure</td>
<td>2,502,000</td>
</tr>
<tr>
<td>Other infrastructure and equipment</td>
<td>181,500</td>
</tr>
<tr>
<td>Total capital cost</td>
<td>3,598,500</td>
</tr>
</tbody>
</table>

2.4.2 OPERATING COSTS

Total annual operating costs

A high-level breakdown of the total annual operating costs of the business is provided below. Note that operating expenses for barramundi production are very high relative to the initial costs of development and that annual operating costs (Table 2-4) exceed the total initial capital costs (Table 2-3) for this case study enterprise.

Fixed costs from overheads make up a relatively small proportion of the costs of aquaculture production (Table 2-4). Overheads included licences, permits, vehicle registrations, maintenance
and fixed supplies. The remaining costs are all variable costs that scale with the yield of fish produced from the farm each year. Further detail is provided below for variable costs at each stage of production.

**Table 2-4 Summary of overall annual operating costs for an intensive barramundi enterprise producing 624 t whole fish per year from 30 ha of grow-out ponds**

<table>
<thead>
<tr>
<th>OPERATING EXPENSE</th>
<th>COST ($/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nursery costs</td>
<td>246,447</td>
</tr>
<tr>
<td>Feed costs</td>
<td>1,927,603</td>
</tr>
<tr>
<td>Packing costs</td>
<td>110,200</td>
</tr>
<tr>
<td>Transport costs</td>
<td>598,276</td>
</tr>
<tr>
<td>Labour costs</td>
<td>632,611</td>
</tr>
<tr>
<td>Electricity costs</td>
<td>1,845,532</td>
</tr>
<tr>
<td>Overhead costs</td>
<td>86,988</td>
</tr>
<tr>
<td><strong>Total annual operating costs ($/y)</strong></td>
<td><strong>5,447,656</strong></td>
</tr>
</tbody>
</table>

**Nursery**

The average weight and length of fingerlings are used to determine the average cost of fingerlings, and these costs were based on prices from a private supplier (Musa, pers comm) (Table 2-5). The feed requirements in this nursery stage are adapted from suggested requirements based on feed pellet size (Schipp et al., 2007), with prices obtained from Ridley Agriproducts Pty Ltd. These prices are assumed to include transport costs of the feed and fingerlings. A 10% mortality rate during the nursery stage is assumed to cover loss from environmental factors and cannibalism.

**Table 2-5 Summary of nursery costs and production parameters for a barramundi enterprise**

<table>
<thead>
<tr>
<th>PARAMETER (UNIT)</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of stocked fingerling (mm)</td>
<td>20</td>
</tr>
<tr>
<td>Weight of stocked fingerling (g)</td>
<td>0.20</td>
</tr>
<tr>
<td>Price of fingerling ($)</td>
<td>0.23</td>
</tr>
<tr>
<td>Weight of harvested juvenile (g)</td>
<td>120</td>
</tr>
<tr>
<td>Feed conversion ratio (FCR) in nursery</td>
<td>1.0</td>
</tr>
<tr>
<td>Mortality rate (%)</td>
<td>10</td>
</tr>
<tr>
<td>Starter feed Usage (%)</td>
<td>Price ($/kg)</td>
</tr>
<tr>
<td>Start dust</td>
<td>2.6</td>
</tr>
<tr>
<td>1 mm Crumble</td>
<td>10.3</td>
</tr>
<tr>
<td>2 mm Crumble</td>
<td>10.3</td>
</tr>
<tr>
<td>3 mm Short cut</td>
<td>76.9</td>
</tr>
</tbody>
</table>

**Grow-out**

Feed is the dominant cost in producing barramundi (Table 2-6). Feed requirements were based on the feed conversion ratio noted above (1.5 kg of feed to produce 1 kg of fish weight gain). Feeds at different stages of production largely comprise similar nutrients, but larger pellets are used as fish
grow. Feed prices were also obtained from Ridley Agriproducts Pty Ltd and percentage requirements adapted from levels suggested by (Schipp et al., 2007).

Table 2-6 Summary of feed costs and other growth parameters for barramundi grow-out

<table>
<thead>
<tr>
<th>PARAMETER (UNIT)</th>
<th>PLATE-SIZED</th>
<th>LARGE-SIZED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight per fish at harvest (kg)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Death rate at grow-out (%)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Feed conversion ratio (FCR) at grow-out</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Grower feeds Usage (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 mm float</td>
<td>6.0</td>
<td>2.21</td>
</tr>
<tr>
<td>6 mm float</td>
<td>7.5</td>
<td>2.15</td>
</tr>
<tr>
<td>8 mm float</td>
<td>26.9</td>
<td>2.04</td>
</tr>
<tr>
<td>10 mm float</td>
<td>59.7</td>
<td>2.03</td>
</tr>
</tbody>
</table>

Processing and packing

Given the remoteness of Derby from the closest market for produce in Perth, only frozen products would be feasible for storage and transport. This case study assumed two types of products would be sold: frozen plate-sized fish that have been scaled, gilled (from the 12-month, 1 kg harvested fish), and frozen fillets (from gutted and scaled 24-month, 3 kg fish). The packing costs of the two products were based on the weight after packing with ice for transport to market (Table 2-7).

Table 2-7 Packing costs and parameters for a barramundi enterprise

<table>
<thead>
<tr>
<th>ITEM (UNIT)</th>
<th>FROZEN WHOLE</th>
<th>FROZEN FILLETS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight loss after processing (%)</td>
<td>11</td>
<td>52</td>
</tr>
<tr>
<td>Weight of fish per box (kg)</td>
<td>18.00</td>
<td>13.00</td>
</tr>
<tr>
<td>Gross weight of packed box (kg)</td>
<td>20.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Cost per styrofoam box ($)</td>
<td>5.90</td>
<td>3.75</td>
</tr>
<tr>
<td>Weight of ice per box (kg)</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Cost of ice ($/kg)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Number of plastic liners per box</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Cost of each plastic liner ($)</td>
<td>$0.05</td>
<td>$0.05</td>
</tr>
<tr>
<td>Label or logo ($)</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Total cost per box ($)</td>
<td>6.15</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Staff requirements and labour costs

This case study enterprise was estimated to require 1 staff member for every 2 ha of production ponds, for a total of 15 staff. This staff contingent was assumed to be made up of 1 farm manager, 4 skilled technicians, 7 low-skilled technicians/trainees, and the remainder were employed on casual basis during harvest and processing. Wages for each category were based on estimates for current industry wages and related on-costs as outlined in Table 2-8.
Table 2-8 Labour requirements and costs for a barramundi enterprise
Costs are for when the production system is in full operation.

<table>
<thead>
<tr>
<th>LABOUR COSTS</th>
<th>AVERAGE STAFF REQUIREMENTS</th>
<th>WAGE RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total on-costs (% of wages)</td>
<td></td>
<td>33.50%</td>
</tr>
<tr>
<td>Casual processing staff</td>
<td>3467 hours/year</td>
<td>$20.00/hour</td>
</tr>
<tr>
<td>Skilled technicians</td>
<td>4</td>
<td>$850/week</td>
</tr>
<tr>
<td>Low-skilled technicians</td>
<td>7</td>
<td>$500/week</td>
</tr>
<tr>
<td>Farm manager</td>
<td>1</td>
<td>$1,300/week</td>
</tr>
<tr>
<td><strong>Average annual labour costs ($/year)</strong></td>
<td></td>
<td>638,577</td>
</tr>
</tbody>
</table>

Market and transport costs

The closest major market is Perth, which is 2369 km (mostly along National Highway 95) from Derby and about 1.5 days travel time including rest stops. About 30 semi-trailer equivalents would be required to transport the processed fish to market. The travel cost to Perth using a semi-trailer is typically $0.535 per kg, but this would include the use of backloading. While backloading will reduce the transport costs, it will likely increase total travel time to market if the backloading is not available when needed. Using a dedicated refrigerated vehicle that is owned and operated by the farm, and available when needed (just-in-time) is therefore preferable. The cost of transport to Perth would be $0.657 per kg for this preferred option. The increased cost accounts for reduced vehicle km/year when it is only being used for the transport of barramundi. Upon arrival at a distribution centre or central market in Perth, the fish would be transported to the retail outlets, potentially with a total travel time between harvest and retail of less than 3.5 days. This would be similar to some fresh barramundi supply chains in eastern Australia (e.g. Brisbane).

An alternate option was considered for transporting fish to market via a 220 km or 2.5-hour trip to Broome, plus a 2.5-hour flight to Perth. The advantage of this option is that it would allow fresh (non-frozen) fish to be supplied. But at an estimated cost of $4.834 per kg, this option was too expensive to be financially viable.

Feed was assumed to be transported by road from a Brisbane-based producer across to Derby via a 3988 km route, at a cost of $0.518 per kg (assuming a Type 2 road train would be used for the journey west of Roma).

Power

There may be potential for electricity to be connected from existing power stations in the Derby region based on potential peak loads, station capacities and distances. Augmentation of the power stations may also be required based on energy demand for the enterprise, which was factored into the capital costs above.

Charges for electricity are outlined in Table 2-9. These rates may be overestimated as they do not consider potential bargaining for a lower-priced contract with the supplier for bulk rates.
Table 2-9 Utility charges for electricity for barramundi enterprise

<table>
<thead>
<tr>
<th>ELECTRICITY COSTS (UNITS)</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply charge (cents/day)</td>
<td>50</td>
</tr>
<tr>
<td>Cost per unit for first 1650 units (cents/kWh)</td>
<td>33.35</td>
</tr>
<tr>
<td>Costs per unit for 1651 units and thereafter (cents/kWh)</td>
<td>30.10</td>
</tr>
<tr>
<td>Average annual electricity costs ($/year)</td>
<td>1,845,532</td>
</tr>
</tbody>
</table>

2.5  Project commerciality

2.5.1  FARM FINANCIAL ANALYSIS

The farm-scale financial evaluation of the case study barramundi farm is based on the financial feasibility of the project to a prospective investor. This involves estimating the annual net returns from the farm to determine if the investment would yield a positive net value over the investment period. The analysis does not account for the full list of economic costs and benefits (e.g. non-monetary costs and benefits, monetary costs and benefits to anyone outside the business, or equity considerations of how costs and benefits are distributed) and focuses solely on the financial value from an investment perspective. The baseline analysis does not account for normal market fluctuations in costs of inputs and prices for produce, variations in fish production (such as suboptimal yields while learning and establishing barramundi production in a new location) or other sources of risk.

The financial feasibility is based on the net present value (NPV) of the farm. The NPV is the sum of all the annual net returns, or cash flows, discounted by a rate representative of the time value of earnings with a given risk preference for the entire operation period. In general, a positive NPV represents a financially feasible investment.

The NPV is expressed as:

\[
NPV = \sum_{t=0}^{N} \frac{CF_t}{(1+r)^t}
\]

where \(CF_t\) is the cash flow at time \(t\), \(r\) is the discount rate, and \(N\) is the years in which the NPV is calculated. The cash flows take into account all annual revenues less capital and operating costs, and tax payable for each year. Annual cash flows also account for an annual, compounding inflation of 2%. The enterprise was evaluated over the first 20 years of production with a discount rate of 7%.

As a supplement to NPV, the internal rate of return (IRR) is also estimated, which is the discount rate (\(r\) in the equation above) that returns an NPV of zero. This IRR can be used as an indicator of the feasibility of the project. If an investor views the risk of the proposed development as being particularly high, higher levels of return may be required to compensate for those risks.

2.5.2  FARM FINANCIAL PERFORMANCE

The summary results for the case study barramundi enterprise in Derby are presented in Table 2-10. These results assumed 100% reliability in the financial and production performance.
without fluctuation in productivity and prices, aside from the initial lags in the 2-year production cycle coming into full operation.

The financial analysis indicates that a barramundi enterprise in Derby that met the assumptions above could be financially feasible, generating an NPV of $3.7 million (at a 7% discount rate) and an IRR of 12.2%.

Table 2-10 Summary of overall long-term financial performance of the case study barramundi enterprise
Note that averages are over the first 20 years of operations, including the start-up years before all ponds are in full production (when costs and revenues are lower).

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNITS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs and revenue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital costs in year 0</td>
<td>$</td>
<td>3,598,500</td>
</tr>
<tr>
<td>Average annual operating costs ($/year)</td>
<td>$/y</td>
<td>5,447,656</td>
</tr>
<tr>
<td>Average annual yield (at harvest)</td>
<td>t/y</td>
<td>570.3</td>
</tr>
<tr>
<td>Average annual revenues</td>
<td>$</td>
<td>6,625,404</td>
</tr>
<tr>
<td>Performance measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPV (at 7% discount rate)</td>
<td>$</td>
<td>3,683,181</td>
</tr>
<tr>
<td>IRR</td>
<td>%</td>
<td>12.2</td>
</tr>
<tr>
<td>Average annual profit margin</td>
<td>$/kg</td>
<td>2.07</td>
</tr>
</tbody>
</table>

Feed and electricity were the biggest input costs for this enterprise, together accounting for about 70% of the overall annual operating costs (Figure 2-7). Transport costs accounted for 11% of the costs of production which, although a smaller cost, are higher than they would be for farms that are closer to market and would put Derby at a relative disadvantage. Capital costs of development were dominated by the costs of constructing and equipping the ponds (70%), and the building facilities required to support fish production and processing (23%) (Figure 2-7).

Figure 2-7 Breakdown of annual operating costs and capital development costs for a barramundi enterprise
Operating costs are per kg of fish at harvest, prior to processing.

The cumulative discounted cash flow for the enterprise shows that the payback period for the enterprise would be about 12 years (Figure 2-8). However, the cash flow also shows that substantial capital reserves would be required in the early years of establishing the production system as substantial operating expenses are incurred before revenue can be generated from the harvested product. The reserves required to get through the establishment period would exceed
the initial capital costs of developing the enterprise (and therefore value of the enterprise’s total tangible assets).

Figure 2-8 Cumulative discounted cash flows for the first 20 years of operation of a barramundi enterprise

2.5.3 SENSITIVITY ANALYSIS

The baseline financial analysis above was based on 100% reliability in the production and financial parameters specified in the assumptions. However, there is a high level of uncertainty in many of these parameters for establishing a greenfield barramundi enterprise in a new location, parameters would differ even between potential development sites in Derby, such as for flood mitigation, and would likely also vary over time. It is therefore prudent to consider the sensitivity of the baseline financial performance to variations from these assumptions. A sensitivity analysis was therefore conducted for key parameters contributing to enterprise performance in the financial model (Figure 2-9).

The sensitivity analysis shows that the performance of the enterprise is extremely sensitive to many of the assumptions about how the enterprise operates (Figure 2-9). Given this sensitivity, a narrow range was used to vary each parameter by only 10% above or below the original assumption. The business would be particularly sensitive to variations in the price received for produce (frozen whole fish and frozen fillets). A decline in produce prices of only 10% would render the enterprise unprofitable, whereas an increase of 10% would more than double its value (in NPV terms). Given this sensitivity, investing in a new barramundi farm in Derby would be a risky proposition unless the investor was able to have some control in setting produce prices (e.g. a contractual arrangement with a buyer).

In terms of operating costs, the enterprise was most sensitive to the two biggest input costs, feed and electricity. Improving the efficiency with which these inputs are used (such as the feed conversion rate) would be the largest contributors to making production viable.
2.6 Project benefits

2.6.1 PRODUCTION POTENTIAL

The case study enterprise analysed above was considered to produce 624 t/year of whole barramundi, of which 174 t was 1 kg plate-sized fish and 450 t was larger 3 kg fish. After processing this produced 155 t of frozen gilled and gutted plate-sized fish and 216 t of frozen fillets (from the larger fish) each year. The total gross value of this produce delivered to markets in Perth was estimated to be $7,258,320/year (once the production system was in full operation).

2.6.2 REGIONAL ECONOMIC BENEFITS

The full regional impact of the economic stimulus provided by any development project extends far beyond the impact on those businesses and workers directly involved in either the short or longer term. Those businesses directly benefitting from any project (in this case the barramundi aquaculture development) will need to increase their purchases of the raw materials and intermediate products utilised by their growing outputs; should any of these purchases be made within the region then this provides a stimulus to those businesses that they purchase from, contributing to further economic growth within the region. These are known as production-induced effects. Furthermore, household incomes increase due to local residents who are employed by either the direct and or production induced business stimuli; as a proportion of their additional income is spent in the region that further stimulates the economic activity. This economic activity is known as consumption-induced effect. Thus, the larger the initial amount of
money spent within the region, and the larger the proportion of that money that is respent locally, the greater the overall regional benefits will be.

One widely used approach that can estimate the total regional impact of a development project, including the direct activity of the project itself, plus all the production and consumption induced impacts on other businesses and households within the region, is to use input-output (I-O) analysis. The size of the production and consumption induced benefits is estimated using the regional multiplier, derived from I-O tables based on existing activity within the region; a larger multiplier indicates larger regional benefits.

The key output from the I-O models is the estimated value of the increased regional economic activity. However, the models also estimate the increase in household incomes in the region; from this an estimate can be made of the approximate number of jobs represented by this increased economic activity. Thus, I-O models can be used to estimate the impact of a barramundi aquaculture development scheme on employment, income and regional economic activity, encompassing all the direct and indirect impacts that will result.

The total economic impact on the Kimberley region (which includes the Fitzroy River catchment), including the activity of the barramundi aquaculture development itself and the production and consumption impacts on other businesses in the region that could result from this development, was estimated using I-O analysis. The baseline results for the generic analysis discussed above were included in the I-O model, representing an exogenous shock to demand of $7,258,320 to the aquaculture, forestry and fishing sector in the region (once the production system is in full operation). This figure represents the average annual revenue generated by the barramundi aquaculture development in the Fitzroy catchment. As can be seen from Table 2-11 this stimulus to the region would generate annual regional economic activity worth $13.1 million and would create around 79 new jobs in the region (including the activity and jobs of the barramundi aquaculture development itself).

Given the uncertainty of the parameters and prices incorporated within the generic analysis, sensitivity analysis was also used to estimate the regional impact should this baseline average annual revenue figure increase by 20% or reduce by 20%. The results of this sensitivity analysis are also shown in Table 2-11.
Table 2-11 Estimated annual total increase in economic activity and jobs within the Kimberley region including the economic activity and jobs created by the barramundi aquaculture development itself

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>ECONOMIC ACTIVITY ($)</th>
<th>NUMBER OF JOBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated total economic impact on region based on baseline case study analysis</td>
<td>13,112,374</td>
<td>79</td>
</tr>
<tr>
<td>Estimated total economic impact if baseline increased by 20%</td>
<td>15,734,849</td>
<td>94</td>
</tr>
<tr>
<td>Estimated total economic impact if baseline reduced by 20%</td>
<td>10,489,899</td>
<td>63</td>
</tr>
</tbody>
</table>

2.7 Project risks

Table 2-12 summarises several biophysical risks to the aquaculture enterprise and risks to the environment as a result of the enterprise. The likelihood of these risks becoming manifest would depend on the precise location of the development, its design features and the management system in place.

Table 2-12 Potential biophysical risks associated with the example aquaculture enterprise

<table>
<thead>
<tr>
<th>ECOLOGICAL AND SOCIAL CONSIDERATIONS</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation at farm location</td>
<td>This farm has a small footprint. Any development in the catchment would require an environmental impact assessment. Construction of ponds would likely result in minor loss of habitat and resources for resident and migratory fauna.</td>
</tr>
<tr>
<td>Acid sulfate soils</td>
<td>Acid sulfate soils are common in coastal area suitable for pond-based aquaculture. Appropriate management of acid sulfate soils during the construction is critical to the long-term viability of the operation.</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Ponds and channels are designed as containment structures. Risks associated with the construction of suboptimal containment structures include changes to groundwater quality water (e.g. increase in salinity and nutrients), local rise in groundwater level, waterlogging and vegetation dieback. If freshwater needs to be sourced from groundwater contained within the Erskine Sandstone the potential for sea water intrusion should be investigated and monitored.</td>
</tr>
<tr>
<td>Water quality – Production pond</td>
<td>The risk of mixed algal blooms is high. Nitrogen, phosphorus and suspended solids loads (feed, fish wastes) increase as the biomass in the pond increases. Under intensive operation, there is high risk of water being oxygen-depleted during the early morning hours during periods of hot weather.</td>
</tr>
<tr>
<td>Water quality – Discharge</td>
<td>Discharged water must meet minimum standards to comply with the farm’s specific aquaculture licence. Licensing criteria may include minimum standards for nitrogen, phosphorus, total suspended solids, chlorine, pH, dissolved oxygen and drugs and chemicals. Discharge of water to the marine environment is the major source of potential impact from operation. Elevated nitrogen and phosphorus (higher than receiving) has the potential to modify the surrounding habitat (e.g. mangrove growth, algal blooms).</td>
</tr>
<tr>
<td>Biosecurity/pathogens</td>
<td>Biosecurity measures are needed to mitigate disease risks that harmful pathogens pose to the production systems. While aquaculture ponds are not as amenable to high levels of biosecurity as are indoor or covered production systems, there are still practical measures that should be taken to mitigate disease risks in ponds. These include: sourcing clean seed stock; maintaining a healthy production environment; continual monitoring of animal health; and using means to control potential vectors that can spread disease, such as birds and crabs.</td>
</tr>
<tr>
<td>Escapees</td>
<td>Farm management practices reduce the risk of escapees. However, fish can enter natural waterways via water flow (e.g. discharge or flood) or predator movements (e.g. bird).</td>
</tr>
<tr>
<td>ECOLOGICAL AND SOCIAL CONSIDERATIONS</td>
<td>COMMENT</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td><strong>Terrestrial ecology</strong></td>
<td>The effect on terrestrial ecology requires site-based assessment, including examination of existing terrestrial flora and fauna databases. Animals that may access the resources provided by the pond environment include rodents and large reptiles (crocodiles).</td>
</tr>
<tr>
<td><strong>Pond ecology</strong></td>
<td>Aquaculture ponds provide an aquatic habitat with an abundant source of food (pellets and fish). Wild aquatic life (e.g. fish and crustaceans) are excluded from the ponds by screening source water. Resident and migratory birds are near impossible to exclude from the pond environment, and can impact on production and are a potential method for movement of fish between ponds and in to the natural waterway.</td>
</tr>
<tr>
<td><strong>Cultural Heritage environment</strong></td>
<td>Selection of farm location should consider the presence of any Indigenous and non-Indigenous heritage. This would include consultation with Traditional land owners to ensure development does not impact on cultural heritage.</td>
</tr>
<tr>
<td><strong>Flood risk</strong></td>
<td>The ponds should be capable of operating in all weather conditions. While flooding of low lying surrounding areas may occur during the wet season, the potential for pond inundation by flood waters should be considered low risk even during the largest of wet seasons due to correct site selection, pond bank elevations and suitable barriers to prevent ingress from king tides and additional flood waters.</td>
</tr>
</tbody>
</table>
3 Groundwater and an irrigated cotton–mungbean–forage sorghum rotation integrated into an existing beef enterprise

This case study investigated the potential to incorporate an irrigated crop-forage rotation based on groundwater into an existing beef enterprise. Developments would take the form of irrigated mosaics situated to minimise cost and risk. The analysis focuses on identifying broad locations where the ‘effective’ combined crop-forage gross margin exceeds the sum of the equivalent annual costs of development and annual overhead costs, and there are soils suitable for the intended land use.

Figure 3-1 Schematic diagram illustrating the components of the case study for groundwater-based irrigation mosaics of cotton–mungbean–forage sorghum rotation

The case study considers the feasibility of groundwater-based mosaics of irrigation in the Fitzroy catchment with respect to:

- the availability of soil suitable for irrigated agriculture that may also be trafficable during the wet season
- natural variations in mean bore yield, depth to the target water bearing geological unit and depth to hydraulic head (depth of the groundwater measured using a groundwater bore) of the interconnected Grant Group and Poole Sandstone aquifers
- the potential to implement a crop-forage rotation in the Fitzroy catchment and the capacity of the enterprise to generate positive net revenues
• the potential drawdown in groundwater levels as a consequence of the cumulative extraction of 120 GL of groundwater (<5% of recharge) from the interconnected Grant Group and Poole Sandstone aquifers

• approval costs and times.

The analysis of the irrigation development is presented at the farm scale, using results under two scenarios. Both scenarios use the same 125-year historical climate data (from 1890 to 2015). Scenario A uses historical climate and current development, whereas Scenario B uses historical climate and future irrigation development (i.e. an irrigation development based on utilising groundwater). All results in the Assessment, unless stated otherwise, are reported over the ‘water year’, defined as the period 1 September to 31 August. This allows each 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).

In presenting this case study, no consideration is given to legislative issues that may need to be addressed for any development of this scale to proceed. These issues include, but are not limited to, legislation relating to land tenure, planning and infrastructure, cultural heritage, native title, vegetation management, wildlife protection, water resources, fisheries, and environmental protection.

3.1 Summary

The case study concluded that sufficient soil and groundwater resources exist to potentially support 12,000 ha of irrigated land under a cotton–mungbean–forage sorghum rotation. The case study found:

• A cotton–mungbean–forage sorghum rotation under overhead irrigation is potentially feasible on the lighter soils. There are 880,000 ha of Class 3 land or better on the lighter soils in the Fitzroy catchment. Implementing this rotation on the heavier clay soils would be challenging due to lack of trafficability during the wet season.

• It is physically possible to extract 120 GL of groundwater (<5% of recharge) over the long term (i.e. 20 years) from the interconnected Grant Group and Poole Sandstone aquifers spread across six locations. At many, but not all locations, this regional-scale groundwater system is potentially the lowest cost, lowest risk and most flexible of the water supply options.

• This water could be used to potentially irrigate 12,000 ha of wet-season cotton (~0.1% of catchment) as part of a crop-forage rotation, which could produce a sufficient quantity of cotton to support a local cotton gin.

• Incorporating cotton seed and two cuts from 1000 ha of forage sorghum grown on station into an existing beef enterprise of 23,000 head of cattle was found to generate an additional $3.1 million in revenue from cattle sales, which is an effective gross margin of approximately $1550/ha when averaged over a 2000-ha development.

• The nearest existing cotton gin is at Emerald, a distance of 3500 km from Fitzroy Crossing, and without a cotton gin within the general area the ‘effective’ combined crop-forage gross margin for this rotation is $1400/ha, for which it is not possible to even achieve an Internal Rate of
Return (IRR) of 3% with an mean bore yield of 50 L/s, thus highlighting the need for many broadacre and industrial crops to have local processing facilities to be profitable.

- Assuming the existence of a cotton gin at Fitzroy Crossing and assuming cotton seed and forage are used as supplementary feed for cattle on the station the ‘effective’ combined crop-forage gross margin for this rotation would be about $3205/ha. Under a more likely potential development scenario of a cotton gin at Kununurra the effective combined crop-forage gross margin is estimated to be about $2580/ha. These gross margins are considerably higher than potential returns from a single crop and highlights the opportunity for a more diverse investment strategy in double cropping, which in most years is more likely to better meet the capital costs of development.

- Based on the areas where the ‘effective’ combined gross margin exceeds the equivalent annual cost of development and overhead costs, large parts of the Fitzroy catchment are potentially profitable at a discount rate of 3% where the mean bore yield exceeds 25 L/s and 7% where the mean bore yield exceeds 50 L/s (few long-term aquifer pump tests have been undertaken in the interconnected Grant and Poole Sandstone though tests at a two locations suggest yields between 25 and 50 L/s are potentially feasible). The more profitable locations appear to be south of the Fitzroy River.

- Under the scenario of the nearest cotton gin at Kununurra, approximately 280,000 and 660,000 ha of suitable land (i.e. ‘lighter’ soils and Class 3 or better) is underlain by the Grant and Poole Sandstone such that it may be possible to achieve an IRR of more than 3% for average yields of 25 and 50 L/s respectively, and 0 and 42,000 ha of suitable land is underlain by the Grant and Poole Sandstone such that it may be possible to achieve an internal rate of return of at least 7% for average yields of 25 and 50 L/s respectively. An on-ground assessment at each location would be required to determine the mean bore yield, as well as any potential risk of secondary salinisation (noting that natural surface salinity has been observed at the break of slope in lower landscape position of the sand plains in the Fitzroy catchment).

- A challenge in establishing a local cotton gin based on mosaics of irrigation is that cotton gins require a minimum of 6,000 – 10,000 ha of cotton to be viable, depending upon the reliability of production. Hence without third party support considerable coordination, cooperation and trust would be required between multiple landholders and potential gin financers/operators in order to establish a cotton industry in the Fitzroy catchment or ‘nearby’ Kununurra. In the Fitzroy catchment this would also require a coordinated release or allocation of a sufficient quantity of water by regulators to irrigate this area, and for irrigators to quickly learn how to grow high-yielding cotton so as to supply the gin with a sufficient volume of cotton to viably operate.

- There may be motivations for landholders in the Fitzroy catchment other than achieving a high commercial return on an irrigation development (e.g. 7% or greater). For example, incorporating cotton seed and forage sorghum into an existing beef enterprise may enable a station to grow out young cattle and provide alternative markets to the live export trade. Consequently, motivations for undertaking irrigation development may also be about ensuring the long-term viability of the existing beef enterprise and a lower discount rate (e.g. 3 to 5%) may be acceptable.

- The combined gross value of production of 12,000 ha of cotton–mungbean–forage sorghum rotation is about $84 million per year. This is calculated to result in an increase in regional
economic activity of about $130 million per year and potentially create an additional 490 direct and indirect jobs.

- The challenges in designing and implementing rotational cropping systems should not be underestimated. The rotation discussed in this case study would require on-ground trials, field measurements and further analysis before being implemented commercially.

- Modelled drawdown – within the Poole Sandstone aquifer and importantly not the Fitzroy River nor the shallow alluvial aquifer – ranged from 0.01 to 1.57 m after 20 years. Consequently, the impact to baseflows in the Fitzroy River are likely to be minor with such small modelled changes in the hydraulic gradient after 20 years. Furthermore, only three of the seven groundwater sites modelled occur in the vicinity of reaches of the Fitzroy River that have been characterised by the Assessment to have a medium to high likelihood of groundwater inflow.

- Based on the recent experiences of irrigation proponents in the west Kimberley, who were proposing developments smaller in scale than being considered here, it is likely that irrigation developments of the scale of 2000 ha would face considerable regulatory and approval complexity. The costs in dollars and time are difficult to estimate, however, it is possible that it could exceed the $200,000 used in the financial analysis in this case study by a factor of 5 to 10.

- Prior to any irrigation being developed, the area of interest would require more intensive assessment of potential ecological impacts based on the specifics of the proposal.

3.2 Storyline for this case study

This case study explores the viability of groundwater-based mosaics of irrigation in the Fitzroy catchment, and where the more viable opportunities are likely to be located. Water would be sourced from groundwater contained within the regional-scale interconnected Grant Group and Poole Sandstone aquifers. The groundwater would be used to irrigate moderate areas of land using centre pivots scattered across six locations in the Fitzroy catchment, where at each location about 20 GL/year would be extracted using a cluster of production bores. The use of groundwater from this regional-scale groundwater system potentially offers numerous advantages over alternative water sources in the Fitzroy catchment, such as water harvesting or groundwater from local-scale groundwater systems. These advantages include being able to optimally locate the development to:

- maximise agricultural production by locating irrigation on the better soils for agriculture
- minimise establishment costs and maximise profits by placing near existing infrastructure
- minimise risk by being able to avoid flood-prone areas
- maximise flexibility and minimise risk by always having water available at the time of planting as well as key stages of crop growth irrespective of the timing and reliability of rainfall and streamflow
- minimise the potential for environmental change by placing bore infrastructure away from areas of ecological and/or cultural concern and away from areas at higher risk of secondary salinisation.

The financial analysis detailed in this case study considers the operation and viability of incorporating an irrigated crop rotation into an extensive livestock enterprise at one of these
locations. It then assesses the cumulative impacts of extracting 120 GL/year (i.e. 20 GL/year from six nominal locations show in Section 3.7) from the interconnected Grant Group and Poole Sandstone aquifers. This volume is sufficient to support the 10,000 ha of cotton required for a local cotton gin to be viable, as well as irrigate a fodder crop, which could be harvested for hay (for supplementary feeding) or on which cattle could stand and graze.

Rotational cropping systems involve sequentially growing more than one crop per year to:

- achieve higher gross margins per hectare of land developed
- manage disease, pests and weeds
- minimise soil and nutrient losses
- reduce the need for inorganic nitrogen inputs.

Currently there are no rotational cropping systems operating in broadacre cropping in parts of northern Australia that are west of the Great Dividing Range, and the challenges in designing and implementing rotational cropping systems should not be underestimated. The rotation discussed in this case study would require on-ground trials, field measurements and further analysis before being implemented commercially.

Cotton is an attractive crop for inclusion in cropping systems in many parts of northern Australia, for a range of reasons including:

- It is suited to the climate of northern Australia and can be grown on a range of soils.
- Of all crops it has one of the highest returns, provided a cotton gin is close to the farm.
- Cottonseed (55% of raw cotton), a by-product of the milling, is a rich source of protein and can be used as a feed supplement for livestock with locally grown forages, making it attractive for producing an animal with a different market potential than live export, which currently dominates extensive grazing in the region, or it can be used as a high protein supplement in the breeding herd to lift reproductive performance.
- Cotton can be forward sold up to 3 years in advance, which can make it potentially lucrative where water is available at a high degree of reliability.
- Advances in genetically modified (GM) cotton have allowed the industry to substantially reduce insecticide and herbicide application. In recent years GM cotton has enabled Australian cotton farmers to use 89% less insecticide, 62% less residual-grass herbicide and 33% less residual-broadleaf weed herbicide. In addition to reducing the likelihood and severity of off-site impacts GM cotton also has potential health benefits to farm workers through handling fewer chemicals and considerably lower levels of stress during periods when insecticide would normally be applied.
- With growing awareness and concern about micro-plastics shed from synthetic clothing during washing and entering waterways and oceans (Welden 2017), future demand for natural fibres is likely to be strong.

Although cotton can be a high-gross margin crop, the raw product requires processing at a cotton gin to separate the fibres (lint) from the cotton seeds. In northern Australia, approximately 38% (range 35 to 40%) of the total unprocessed cotton mass is cotton fibre; about 55% is cotton seed and 5% is plant trash. Consequently there is considerable financial benefit in having a cotton gin in close proximity to the area in which the cotton is being grown. However, for a cotton gin to be
viable a minimum production is required, an often quoted number is 10,000 ha. However, of relevance to this case study where groundwater is available at 100% annual reliability, in the Burdekin district where water supply is also very reliable, it has been estimated that a minimum production of only about 50,000 bales per season – or 5500 to 7000 ha assuming a yield of 8 bales/ha of cotton – would be required to justify establishing a local gin. In this case study the commerciality of a cotton rotation is assessed based on (i) the nearest existing cotton gin at Emerald; (ii) assuming a cotton gin at Kununurra; and (iii) assuming a cotton gin at Fitzroy Crossing.

There are a number of reasons for including an irrigated fodder in a rotation system in a catchment such as the Fitzroy, for which the predominant land use is extensive grazing. Producing a high-quality forage under irrigation potentially enables the landholder to:

- wean cattle at an early age, thereby improving body condition of cows and enabling them to reconceive more easily, which can greatly enhance the number of calves produced
- grow out young cattle to provide alternative markets to the live export trade.

In irrigating a fodder crop, seasonal conditions will dictate the management option: during the wet-season when there is ample green pasture across the station to maintain the herd, irrigated forage is potentially best grown for hay or alternatively the paddock may be in a short rest phase as part of a rotational forage–broadacre cropping system. Irrigated forage can provide the most benefit during the dry season, either as hay or as stand and graze, when natural rangeland pasture is dormant and of low nutritional value. Small areas of groundwater based irrigated hay production already occurs in the Fitzroy catchment (Figure 3-2).

For the purpose of this case study each of the irrigation areas is assumed to be comprised of 2000 ha, totalling 12,000 ha across the six locations. With 20 GL potentially extracted at each location this is the equivalent to 10 ML/ha. It should be noted that double cropping at production potential across the full 2000 ha would require about 11.5 ML/ha after losses (depending upon the crops) in 50% of years.

Most of the more favourable areas for irrigated double cropping are on the deep permeable red, brown loamy soils (Figure 3-3) with a water-holding capacity of approximately 170 mm in the top 180 cm of the profile. As discussed in Section 3.3.2, in northern Australia it would be operationally easier to implement this cropping rotation system on these ‘light’ soils than the heavier clay soils, for which trafficability during the wet season is likely to be particularly challenging.

This case study examined:

- a potential rotation system that can be integrated into an existing beef enterprise and the extent to which this can be used to increase cattle turn-off at a younger age and increase reproductive capacity
- start-up costs and the impact on profitability of groundwater characteristics, depth to the target water-bearing geological unit, depth of hydraulic head and mean bore yield across a cluster of production bores at each irrigation area
- development approvals.
Figure 3-2 Irrigated hay production near Fitzroy Crossing
Photo: Nathan Dyer/CSIRO

Figure 3-3 Well-drained loamy soils (SGG4.1) and sands (SGG6.1) locally known as Pindan on extensive level to gently undulating plains of the lower Fitzroy catchment (Yeeda and Camelgooda land systems)
Photo: CSIRO.
Figure 3-4 (a) Relief and potential maximum surface water extent and (b) satellite image and areas where the depth to the top of the interconnected Grant and Pool Sandstone aquifers is likely to be deeper than 300 m. Data used to develop the flood map were captured using Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery. Figure (a) illustrates the maximum percentage of each MODIS pixel inundated between 2000 and 2016.
3.3 Case study and study area description

The approach employed in this case study to assist site selection was to overlay important areas of ecological consideration (e.g. persistent waterholes (Figure 3-4), groundwater-dependent ecosystems); flood inundation (Figure 3-4a), depth to the interconnected Grant Group and Poole Sandstone aquifers (Figure 3-4b), soil generic groups (SGG) (Figure 3-5a), and land suitability (Figure 3-5b). The better locations will have shallow depth to the target water-bearing geological unit (i.e. less than 300 m), lands suitable for the intended crops (i.e. Class 3 and better for all land uses), soils that do not have a high clay content and hence higher challenges with trafficability (SGG 2 (Dermosols on Fitzroy and Margaret river floodplain), 3 (Hydrogosols) and 9 (Vertosols)), and a ‘shallow’ hydraulic head, which influences the cost of pumping. Other factors in locating irrigation developments not explicitly considered in this analysis include proximity to existing infrastructure, and other factors that inevitably constrain development such as land tenure and existing legislation (e.g. tree clearing). It should be noted that the locations selected as part of this case study are broadly indicative of general areas (based on important attributes) where one could undertake irrigated agriculture and are not necessarily the best locations in the catchment. No on-ground assessment was undertaken at any of these locations.

3.3.1 HYDROGEOLOGY OF THE FITZROY CATCHMENT

Overview

In general, several aquifer (rocks and sediments in the subsurface that store and transmit groundwater) types exist in the Fitzroy catchment. These include:

- fractured rock
- sedimentary limestones and sandstones
- surficial sediments predominantly including alluvium.

All of the major aquifer systems in the Fitzroy catchment are found in the geological Canning Basin, which includes the Devonian reef complex, Grant Group, Poole Sandstone, Liveringa Group, Erskine Sandstone and Wallal Sandstone aquifers. Of these, the interconnected Grant Group and Poole Sandstone aquifers currently represent the greatest opportunity for future groundwater resource development over large parts of the catchment, and is the focus of this case study.

Unless otherwise stated, the material presented in Section 3.3.1 is based on findings described in the companion technical report on hydrogeological assessment (Taylor et al., 2018).

Interconnected Grant Group and Poole Sandstone aquifers

The Grant Group and Poole Sandstone aquifers are regionally extensive and are present in the subsurface across the entire western half of the Fitzroy catchment – also known as the Fitzroy Trough sub-basin of the Canning Basin (Figure 3-4). They host an interconnected regional-scale sandstone aquifer system across a very large area in the catchment (~40,000 km²), although a large portion of the aquifer system occurs at significant depth (i.e. several hundred metres), increasing the cost of drilling. The aquifer system occurs at shallow depths in the east and dips west towards the coast, and groundwater flow is generally from east to west. Recharge to the aquifer system occurs both at the outcrop and where it is shallow and only covered by surficial
sediiments, via infiltration of intense wet-season rainfall and some streamflow where the Fitzroy River traverses the outcrop zones (e.g. south of Fitzroy Crossing and south of Camballin). The aquifer system outcrops as small ranges in the east around Fitzroy Crossing, with more prominent outcropping ranges south of Noonkanbah and just east and west of Camballin (Figure 3-4). Away from the outcropping areas the aquifer system underlies the regionally-extensive Noonkanbah Formation, an aquitard that isolates the interconnected Grant Group and Poole Sandstone aquifer system at depth, thus preventing recharge and pressurising the groundwater in the Grant Group and Poole Sandstone aquifer system. In many places groundwater from the aquifer system is artesian or close to artesian, reducing the cost of pumping. Limited bore yield information exists, with only one pump test documented from the Grant and Poole sandstone aquifers. This test indicated a yield of at least 25 L/s and probably closer to 40 L/s (DWER, 2017). A second pump test, undocumented at the time of writing, indicated a yield of 30 L/s (pers comm. Harrington 2018). Groundwater in the aquifer is fresh in most places with low salinity (<800 mg/L) making the water suitable for a variety of uses.

Discharge from the interconnected Grant Group and Poole Sandstone aquifers occurs as a combination of upward leakage through the aquitard to overlying hydrogeological units, extraction of groundwater and possibly discharge to the ocean (Harrington et al., 2011). Currently, 517 ML/year is allocated from the aquifer, with the main purpose split between water supplies for Fitzroy Crossing and road construction, and smaller supplies for Indigenous communities and mining.

3.3.2 GRAZING AND CROPPING IN THE FITZROY CATCHMENT

Approximately 90% of the study area is under leasehold tenure, with 16 of the 44 stations in the Fitzroy catchment under Indigenous management or ownership. There are approximately 220,000 head of cattle in the study area.

This section provides some information on grazing properties in the Fitzroy catchment to provide context as to how irrigation may be incorporated into an existing beef enterprise. A range of broadacre crops suitable for irrigation in the Fitzroy catchment are then discussed.

Existing grazing enterprises in the Fitzroy catchment

The dominant beef production system that is employed across most of the Fitzroy 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 selection of operation type for any holding is largely determined through the interplay of land resource endowments, local climate, market opportunities and the requirements of other enterprises operated under common ownership and management. In a number of cases, variants of the cow-calf breeding system are conducted across geographically segregated holdings that are integrated under common ownership and management.

The highly seasonal rainfall and high inter-annual variability coupled with low fertility soils means that carrying capacity is relatively low compared to other parts of northern Australia, ranging from 8 adult equivalent (AE) per km² (e.g. frontage grass pastures) to 2.5 AE/km² in very poor pastures, such as hard spinifex hill pastures. Most of the sandier soils in the western half of the study area can support 2.5 to 4 AE/km² (Payne and Schoknecht, 2011). Pasture production occurs mostly in
the December to April period, where plant growth rates can be high. Very little pasture production occurs over the remainder of the year.

The low individual animal production rate means that annual turn-off rates are around 25% of the total herd size. It is challenging to fatten animals, so the emphasis is on breeding operations, which typically turn-off yearling animals (250 to 350 kg) that are exported live to Asia, with some being sent to south-west Western Australia for fattening on improved pasture or in feedlots.

To cope with low productivity per animal, holdings range from 100,000 ha to over 400,000 ha. Even with significant scale it can be difficult to generate a profit, with net earnings before interest and tax commonly either slightly negative or modestly positive. At the time of the Stockdale et al. (2012) and McLean et al. (2014) reports, prices for beef were very low at $1.40/kg to $1.75/kg live weight. Beef prices have more than doubled and returns have been considerably higher since 2015. However, land values have also been rising rapidly in the past few years on the back of renewed local and overseas interest in beef operations.

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). Irrigated pastures and forages may assist in meeting this goal.

It should be noted that while it is feasible to use a range of forage and legumes in Western Australia the pastoral land tenure restricts planting options. For more information on the existing grazing industry in the Fitzroy catchment and use of higher input, higher-productivity irrigated pastures to improve beef outputs and turn-off, see the companion technical report on agricultural viability (Ash et al., 2018a).

**Soil and land suitability**

Soils, landform and agricultural suitability are described for six locations in the Fitzroy catchment. The six sites are nominal, have ‘large’ areas of uniform soils and landform and are in the general vicinity of groundwater extraction locations modelled in the companion technical report on groundwater modelling (Dawes et al., 2018). This section briefly describes the spatial distribution of soil groups and soil attributes at the six locations based on field descriptions and mapping from the Assessment, as well as previous surveys conducted by the Western Australian Government in the study area (Figure 3-5). Management considerations are also summarised.

Site one east of Fitzroy Crossing (Figure 3-5b) comprises mainly alluvial plains and aeolian sand plains. Soils are dominated by red, brown and yellow loamy soils (Kandosols), sandy-surfaced texture contrast soils (Chromosols) and dark grey cracking clay soils (Vertosols).

The moderately permeable sandy-surfaced well-drained red and moderately well-drained brown to imperfectly drained yellow loamy soils (Kandosols) of the sand plains are predominantly very deep (>1.5 m) with low to moderate soil water storage (50 to 75 mm in the top 1 m). Active wind erosion occurs on the sand plains.

The sand or loam over friable clay (mainly Chromosols) are extremely minor and restricted to wind-deposited sand of the sandplains deposited over buried red clays.

The very deep (>1.5 m) moderately well-drained very slowly permeable alluvial clays with hard-setting structured surfaces (pedal Vertosols) on alluvial plains have a restricted rooting depth at less than 1 m due to very high salt levels in the subsoil. Soils have a high water-holding capacity
The clay soils have hard-setting scalded clay surfaces subject to moderate to severe wind erosion.

The Kandosols and Chromosols are suitable for wet- and dry-season spray-irrigated cotton, sugarcane, grain crops, pulse crops, forage crops and a range of horticultural crops. The clay soils are also suitable for furrow-irrigated cotton, sugarcane, grain crops, pulse crops and forage crops.

Site two west of Fitzroy Crossing comprises level aeolian sand plains with numerous east-west longitudinal sand dunes and numerous inter-dune clay pans. Soils are dominated by sandy-surfaced well-drained red and moderately well-drained brown loamy soils (Kandosols) on the inter-dune areas. Soils are predominantly very deep (>1.5 m) with low soil water storage (50 to 75 mm). Active wind erosion occurs on the sand plains.

Very deep sandy soils (Tenosols) occur extensively as well-drained red wind-deposited sand dunes. These highly permeable deep to very deep soils have very low soil water storage potential (30 to 50 mm in the top 1 m). Active wind erosion occurs on the sand dunes.

The inter-dune clay pans have predominantly seasonally wet scalded hard-setting texture contrast and clay soils often with surface salinity. The scalded surfaces are subject to moderate to severe wind erosion.

The Kandosols and some Tenosols are suitable for wet- and dry-season spray-irrigated cotton, sugarcane, grain crops, pulse crops, forage crops and a range of horticultural crops. However, the abundant sand dunes with very low soil-available water capacity that dissect the Kandosols that have a relatively high available water capacity makes efficient irrigation management difficult. In areas with clay pans, which are unsuitable for cropping, development potential is limited by the small size of individual usable areas due to a complex distribution of soils.

Site three south of the Fitzroy River is dominated by sand plains with very deep (>1.5 m) rapidly drained highly permeable red sandy soils (Tenosols) with very low soil water storage (30 to 50 mm). Minor very deep sandy soils (Tenosols) occur on the well-drained red wind-deposited sand dunes. Active wind erosion occurs on the sand plains.

The Tenosols are suitable for wet- and dry-season spray-irrigated cotton, sugarcane, grain crops, pulse crops, forage crops and a wide variety of horticultural crops.

Site four to the west of Fitzroy Crossing occurs as a gently undulating aeolian sand plain. Soils are very deep (>1.5 m) rapidly drained highly permeable red sandy soils (Tenosols) with very low soil water storage (30 to 50 mm in the top 1 m). Minor very deep sandy brown soils (Tenosols) occur on lower slopes. Active wind erosion occurs on the sand plains.

Seasonally-wet scalded hard-setting texture contrast and clay soils, often with surface salinity, occur on minor clay pans. The scalded surfaces are subject to moderate to severe wind erosion.

The Tenosols are suitable for wet- and dry-season spray-irrigated cotton, sugarcane, grain crops, pulse crops, forage crops and a wide variety of horticultural crops. The clay pans are unsuitable for development.

Site five is located on level aeolian sand plains with minor east-west longitudinal sand dunes and clay pans overlying Permian sandstone geologies. Sandstone rises and hills occur to the south, south-west and north.
Soils are very deep (>1.5 m) rapidly drained highly permeable red sandy soils (Tenosols) with very low soil water storage (30 to 50 mm in the top 1 m). Very deep sandy soils (Tenosols) occur on the well-drained red wind-deposited sand dunes mainly to the west of the site. Active wind erosion occurs on the sand plains. Clay pans with seasonally wet scalded hard-setting texture contrast and clay soils and surface salinity are associated with an old drainage depression dissecting the sand plain to the west of the site. The scalded surfaces of the clay pans are subject to moderate to severe wind erosion.

The Tenosols are suitable for wet- and dry-season spray-irrigated cotton, sugarcane, grain crops, pulse crops, forage crops and a wide variety of horticultural crops. The clay pans are unsuitable for development. The sand dunes with inter-dune clay pans have limited development potential due to the complex distribution of small usable areas.

Site six is located on a gently undulating Permian sandstone plain adjacent to level clay plains to the north-west of the site.

Soils on the gently sloping plains on Permian sedimentary sandstones are shallow to moderately deep red and brown loamy soils (Kandosols) with moderate to abundant rock fragments. These moderately permeable sandy-surfaced well-drained red and moderately well-drained brown soils are shallow to moderately deep (<0.5 to 1 m) with low to moderate (<50 to 75 mm in the top 1 m) soil water storage depending on soil depth and amount of rock fragments in the profile. Bare-scaled surfaces are common and subject to wind and water erosion. Some very shallow soils with rock outcrop may also occur.

The clay plains have slow permeability cracking clay soils (Vertosols) on level treeless plains. The deep to very deep (>1 m) moderately well-drained very slowly permeable clay soils with hard-setting pedal surfaces (pedal Vertosols) have a restricted rooting depth at less than 1 m due to very high salt levels in the subsoil resulting in a high water-holding capacity (100 to 125 mm). These clay soils frequently have small (<0.3 m high) gilgai. Minor rill and gully erosion are evident adjacent to stream channels.

The moderately deep to deep Kandosols are suitable for wet- and dry-season spray-irrigated cotton, sugarcane, grain crops, pulse crops, forage crops and a range of horticultural crops. Very shallow soils with very low available water capacity are not suitable for irrigated cropping. The clay soils are suitable for wet- and dry-season spray- and furrow-irrigated cotton, sugarcane, grain crops, pulse crops and forage crops.
Figure 3.5 (a) Soil generic group and (b) agricultural versatility index maps
Agricultural versatility index map does not consider flood risk, secondary salinity or water availability. High index values denote land that is likely to be suitable for more of the 14 selected land use options. Numbers correspond to soil descriptions provided in Section 3.3.2.
3.3.3 POTENTIAL ROTATIONAL CROPPING SYSTEMS IN THE FITZROY CATCHMENT

Overview
This case study examines the costs and benefits of introducing a sequential irrigated rotational cropping system of cotton–mungbean–forage at one of the six locations; for the purpose of this case study nominally a 450,000-ha extensive beef operation with 23,000 head of cattle.

For this rotation it is assumed that on each 2000-ha irrigation development, 2000 ha of cotton would be planted in late January to early February (i.e. before 10 February) and picked mid-June to July. Following the cotton, mungbeans would be sown on 500 ha of land by mid-August and harvested in early November. Of the remaining 1500 ha, approximately 1000 ha of a forage (i.e. forage sorghum) would also be planted in mid-August and baled regularly until the start of the rain in December. The remaining 500 ha would be sown to a dryland cover crop to protect the soil over the wet season until the next crop of cotton is planted the following year. Each year the fields under mungbeans, forage and cover crop would be rotated. This rotation and area of plantings have been matched to the nominal groundwater extraction volume (20 GL/year) with consideration of the efficiency of water delivery (Table 3-1) and crop water requirement (Table 3-2). With more water available per hectare the dryland cover crop could potentially be omitted, and a larger area of mungbeans could be planted, for example, in which case approximately 11.5 ML/ha would be required after losses in 50% of years.

One of the key challenges in implementing this rotation is associated with the timing of sowing and harvesting of sequential crops. Because mungbeans are very susceptible to rain at plant maturity, they need to be harvested prior to the early wet-season rains. To ensure mungbeans can be harvested prior to the rains in December cotton has to be planted during the wet season and before about 10 February. However, rainfall during this period can potentially cause trafficability problems where the use of planting equipment to sow a cotton crop is restricted or prevented entirely.

Good management is then required to ensure cotton could be quickly picked and mungbeans planted in close succession. However, GM cotton is resistant to glyphosate herbicides so additional time is required to adequately prepare the seed bed and plant the mungbeans. This involves the cotton stubble being tilled, irrigation being applied to germinate remaining cottonseed in the soil, and once the seeds have germinated the soil ploughed before planting the mungbeans. This process would take a minimum of 2 weeks and possibly 4 weeks. If there was a delay in planting the mungbeans then a forage could be planted instead.

After the mungbeans have been harvested and the final cut of the forage completed, in both instances the stubble would be retained and a dryland cover crop grown until planting the next cotton crop the following year to protect the soil from erosion during the wet season.

Another challenge in cropping new areas of northern Australia, such as the Fitzroy catchment, is the need to develop integrated pest management systems, incorporating biological controls. This is particularly important for double cropping where there is little break between crops, increasing the likelihood of insect populations building genetic resistance. Currently no integrated pest management systems exist for this part of Australia.
Overview of the Agricultural Production Systems sIMulator crop model configuration

The Agricultural Production Systems sIMulator (APSIM) crop model was used to analyse key aspects of the rotational cropping system, such as sowing and harvest dates, crop water use and crop yields. Soil water content output from APSIM was also used to investigate the risk associated with rainfall restricting trafficability of planting equipment to sow a cotton crop during the planning window (January to March). This was complemented by an analysis of ‘wet days’ each month, where daily rainfall exceeds daily soil evaporation.

The APSIM model was configured for a red loamy soil type of reasonable permeability. The model was configured to sow cotton within the planting window of between 1 and 10 February, assuming the soil is trafficable (i.e. where the soil water content of the top 15 cm is less than the field capacity of the soil). At least 10 days prior to sowing the cotton the soil was pre-irrigated to a depth of 60 cm, taking into consideration the quantity and timing of the preceding rainfall in early to mid-January. Nitrogen (N) fertiliser was applied at the time of sowing (150 kg/ha N) and again at 30 (100 kg/ha N) and 60 (50 kg/ha N) days after sowing. Irrigation was applied via overhead irrigation on a soil water deficit in response to rooting depth of the crop. Irrigation was stopped when the percentage of modelled open cotton bolls reached 65% (typically early to mid-June).

The modelled mungbean crop was sown on 15 August with irrigation water applied when the soil water content was in deficit by at least 31 mm in the top 90 cm. The modelled forage sorghum was sown on 15 August with 250 kg/ha of N fertiliser applied at sowing. Automatic harvesting of above-ground biomass for hay in the model occurs when biomass reaches 6.5 t/ha. Depending on seasonal conditions three to four cuts would be expected before mid-December. The modelled forage cuts ceased on 15 December, typically around the time the wet-season rains commence.

Crop water use, crop yield and field application efficiency

In this case study, it is physically possible to extract 20,000 ML of groundwater at each of the six 2000-ha potential development locations. Assuming a conveyance efficiency of 95% from bore to field and 85% field application efficiency under overhead irrigation, the overall efficiency is 80% (Table 3-1). These losses should be considered when planning irrigation systems and developing likely irrigated areas, and are impossible to completely avoid even under best-practice water management.

Table 3-1 Conveyance efficiency assumptions for the irrigation development associated with the groundwater in the Fitzroy catchment

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>EFFICIENCY (%)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-farm distribution efficiency</td>
<td>95</td>
<td>Representative of potential losses incurred in conveying water from pump to nearby pivot irrigation system.</td>
</tr>
<tr>
<td>Field application efficiency (overhead)</td>
<td>85</td>
<td>Representative of indicative loss under spray irrigation. Assumes majority of loss goes to deep drainage.</td>
</tr>
<tr>
<td>Overall efficiency</td>
<td>80</td>
<td>Product of the on-farm distribution and field application efficiencies.</td>
</tr>
</tbody>
</table>

Based on the APSIM results summarised in Table 3-2, if the full 2000 ha was cropped over an entire year (i.e. 2000 ha of cotton followed by 1000 ha of mungbeans and 1000 ha of forage sorghum) under the full rotation, approximately 17,700 ML of groundwater would be required,
before losses in median years. This exceeds the 20,000 ML of groundwater nominally used at each location in this case study. Consequently, priority for irrigation water is given to establishing the 2000 ha of cotton (median water use of 10,200 ML before losses) and 500 ha of mungbean (median water use of 2050 ML before losses). The 1000 ha of forage sorghum would require about 3400 ML/year before losses to achieve its full production potential. Prior to establishing the dryland cover crop on the remaining 500 ha, about 0.5 ML/ha would need to be applied to germinate any residual cottonseed in the soil. This totals 15,900 ML before losses or 19,380 ML after losses (i.e. The actual area of land planted to forage sorghum and dryland cover crops (nominally about 500 ha in this case study) will vary from one year to the next depending upon how much water the cotton uses in a particular year). Alternatively the risk of inter-annual climate variability on production could potentially be in part managed if the water extracted in a given year could exceed the annual allocation by a nominal percentage (e.g. 20% - Table 3-2) provided the average water use over a number of consecutive years did not exceed the annual allocation. Variability in annual groundwater pumping of this magnitude (over say 5 consecutive years) in a regional groundwater system such as the Grant and Poole sandstone is unlikely to be distinguishable from constant annual pumping due to the very large storage capacity of the aquifer. For the purpose of this exploratory case study median crop water demand values are used.

Figure 3-6 shows the probability of exceedance of simulated production of cut hay under limited water availability to meet crop water demand. For example, if available water for irrigation is less than 1 ML/ha, hay production is reduced to less than 7 t/ha in 50% of years compared to hay production of 12 t/ha with 3 to 4 ML/ha of applied irrigation. Depending on seasonal conditions and availability of 4 GL of groundwater for irrigation to meet crop water demand, a total area of 1000 ha per location sown to forage may produce between 7,000 and 16,500 t/year of total hay production in 90% of years. Three gross margins for cotton are provided in Table 3-2, the first for a gin at Emerald, then assuming a gin at Kununurra and lastly a gin at Fitzroy Crossing.

Table 3-2 Yields and crop water demand for cotton, mungbean and forage sorghum hay at Fitzroy Crossing under irrigated conditions for a red loamy soil type
Simulation results of cotton (bales/ha), mungbean (t/ha) and forage sorghum hay (t/ha) are presented as 20%, 50% (median) and 80% exceedance values. Crops have full access to irrigation and are irrigated on a deficit dependent on duration of crop, rooting depth and the requirement to minimise waterlogging in the cotton during critical stages of development. Gross margin does not include the operational costs associated with supplying water (e.g. groundwater pumping). Gross margin for cotton assumes local cotton gin.

<table>
<thead>
<tr>
<th>CROP</th>
<th>SEASON</th>
<th>UNIT</th>
<th>YIELD</th>
<th>CROP WATER DEMAND (ML/ha)</th>
<th>GROSS MARGIN ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton (bales/ha)</td>
<td>WS</td>
<td>bales/ha</td>
<td>12.2</td>
<td>5.8 5.1 4.4</td>
<td>$965/$1890/$2380*</td>
</tr>
<tr>
<td>Mungbean (t/ha)</td>
<td>DS</td>
<td>t/ha</td>
<td>1.9</td>
<td>4.4 4.1 3.7</td>
<td>$800</td>
</tr>
<tr>
<td>Sorghum hay (t/ha)</td>
<td>DS</td>
<td>t/ha</td>
<td>15.1</td>
<td>3.8 3.4 3.0</td>
<td>$900</td>
</tr>
</tbody>
</table>

* Gross margins assuming cotton gin is in Emerald/Kununurra/Fitzroy Crossing. If cotton seed is returned to the station and used as a nutritional supplement for cattle (i.e. rather than being sold at the gin) the gross margin for cotton reduces to about $350/ha, $830/ha, $1455/ha assuming the cotton gin is in Emerald, Kununurra and Fitzroy Crossing, respectively. This assumes the cotton seed can be backloaded to the station at 50% cost. In reality for the scenario of the cotton gin at Emerald quarantine restrictions may prevent cotton seed from being brought back into Western Australia from Queensland.
Figure 3-6 Probability of exceedance of simulated production of cut hay (t/ha) for limited crop water demands of 1 to 5 ML/ha

Plants opportunity
To investigate the risk associated with rainfall restricting trafficability of planting equipment to sow a cotton crop during the planting window (January to March), analysis was undertaken using:

• the long-term rainfall record for Fitzroy Crossing
• output on soil water content from APSIM.

The total number of rain days and days where rainfall exceeded soil evaporation for each month are presented in Table 3-3. Of particularly interest in this analysis is the planting window for wet-season cotton between January and March, and for the purposes of this case study that optimum sowing period before 10 February. The greater number of rain days during the months of January and February, the larger the risk associated with sowing during the optimum planting window for cotton. Freely draining soils and high evaporation during this period help increase chances of access onto cultivation areas shortly after rainfall events.

Table 3-3 Number of wet days per month where daily rainfall exceeds daily soil evaporation under the historical climate
The 20% exceedance and 80% exceedance values are listed in the table as 20% and 80%, respectively.

<table>
<thead>
<tr>
<th></th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>8.9</td>
<td>8.7</td>
<td>6.3</td>
<td>2.9</td>
<td>1.4</td>
<td>1.0</td>
<td>0.8</td>
<td>1.3</td>
<td>0.5</td>
<td>1.2</td>
<td>3.8</td>
<td>6.7</td>
</tr>
<tr>
<td>20%</td>
<td>12</td>
<td>11</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>80%</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Soil type and texture are key factors controlling how soon after a rainfall event machinery can operate in a paddock. For example, in many cases it is possible to operate farm machinery on well-drained sandy alluvial soils the day after rainfall, where it may take days to weeks to operate machinery on heavy textured clay soils following rainfall. This is one reason it is necessary to avoid the permanently wet soils (i.e. SGG 2) and heavier textured clay soils (e.g. SGG 9) for wet-season cropping in this case study. The APSIM model configured using a red loam soil type (SGG 4.1 and 4.2) and for contrast a heavier clay textured soil (SGG 9) was used to simulate the soil water...
content in the top zero to 15 cm at fortnightly intervals from 1 January to 31 March. Figure 3-7 shows the probability of exceedance of soil water as a percentage of drained upper limit (DUL) or field capacity of the top zero to 15 cm of the soil at seven potential sowing dates for a red loam soil and grey vertosol. The vertical dotted line represents the soil water content at 75% and 70% of the DUL, which is potentially indicative of the soil water content above which machinery may not be able to operate on red loam soil types (SGG 4.1 and 4.2) and heavier clay textured soil (SGG 9) respectively. The actual soil water content at which machinery can operate on these soils would need to be established based on field experiments and trafficability windows reassessed prior to implementing this rotation operationally.

Figure 3-7 Probability of exceedance of soil water as a percentage of the DUL for seven sowing dates for (a) a red loam soil type and (b) a grey vertosol
Vertical dotted line represents soil water of (a) 75% and (b) 70% of DUL.

Although consecutive ‘dry’ days when the paddocks are trafficable are not necessary, they are operationally convenient, particularly if contractors are used or there are large distances between machinery sheds and the paddocks. A single planter can plant approximately 200 ha of cotton per day if operated 23 hours a day, and hence it would take 10 days to plant 2000 ha, without any outages. Figure 3-8 presents the results of an analysis at Fitzroy Crossing of periods of consecutive days between January and March where daily rainfall is less than daily soil evaporation (considered as a ‘dry’ day). Results are presented on a weekly basis for each month.

While the number of rain days in January and February at Fitzroy Crossing are relatively low (i.e. less than 9 days in Table 3-3) and the surface soil water is potentially suitable for planting in 70% of seasons (Figure 3-7), opportunities for long consecutive days to complete crop establishment of large areas during February and March may be restricted in some seasons.
Irrigated forage

The potential benefits of incorporating an irrigated crop rotation into an existing beef extensive enterprise (Scenario B) were analysed using the Northern Australia Beef System Analyser (NABSA) model (Ash et al., 2015). NABSA is a whole-farm-scale dynamic simulation model that simulates beef cattle systems. See companion technical report on agricultural viability for NABSA modelling undertaken in the Fitzroy catchment (Ash et al., 2018a).

Under the potential rotation explored in this case study, whole cottonseed and forage sorghum would be used to improve the nutrition of the 23,000 cattle (baseline scenario) on the property. For a point of reference, the NABSA model was used to model the costs and benefits to the existing beef enterprise without irrigation (i.e. Scenario A), which would currently produce young animals for live export.

In undertaking the analysis the following assumptions were made:

- 2000 ha cotton is grown each year, producing on average 2716 t whole cottonseed
- 1000 ha of forage sorghum is grown each year, producing on average 12.5 t/ha.

The NABSA model was configured such that cottonseed is fed to the whole herd at a rate of 0.25 kg/head/day to weaners and 0.5 kg/head/day to all other animals (young females, breeders and steers). The whole cottonseed is fed out over the dry season, from May until November/December.

The forage sorghum is fed to the 1- to 2-year-old male cohort over the period it is grown (August to December). These animals also receive the 0.5 kg/head of cottonseed per day. The rationale for this feeding regime is that this cohort of males can be fed over the nutritionally stressed mid to late dry season (August to December), allowing them to grow at a high rate where they would normally be just maintaining or losing weight. The cattle then graze natural rangeland pasture over the following wet season and reach a target of 500 kg by the end of April, for sale at 28 to 30 months of age. These 500-kg cattle could be sold for finishing at a feedlot in the south or exported, depending on the import criteria of different countries. Under this scenario the herd size increases slightly from 23,000 to 24,000 cattle. This herd size is intentionally kept at no more than 24,000 head so that the rangeland pasture is not over utilised with negative feedback effects on long-term land condition. Because reproduction rates are higher with cottonseed being fed, breeding numbers need to be proactively reduced so that herd size does not increase under this favourable nutritional scenario.
Consequently, the NABSA modelling indicates that the major additional production benefits are not through a significant increase in herd size but due to an increase in animal weight and increase in weaning rate, which are largely due to the nutritional benefit of feeding breeders 0.5 kg/head/day of cottonseed over the dry season.

The cottonseed and forage sorghum produced annually by this rotation match well with the requirements of a herd of 23,000 to 24,000 cattle. In the more favourable years for cropping there may be a small surplus of cottonseed and forage.

3.3.4 CONFIGURATION OF WATER SUPPLY AND IRRIGATION DEVELOPMENT

A key factor influencing the number of bores required for the 2000-ha irrigation development is the peak water requirement of the rotation. Peak water requirement is the crop and soil evaporative demand at peak periods, and it is used to determine the system capacity. System capacity is the volume of water that the groundwater bores and the irrigation application systems need to be able to supply to match the peak water requirement, taking into consideration the field application efficiency (in this case assumed to be 85%) and the proportion of time the system is in operation, referred to as the pumping utilisation ratio (PUR).

For the purposes of this case study the peak water demand is calculated as the highest 3-day mean evaporation from the crop and soil.

\[ \text{System capacity} = \frac{\text{peak water requirement}}{\text{application efficiency} \times \text{pumping utilisation ratio}} \]  

In this case the application efficiency is assumed to be 85% (Table 3-1) and the PUR is assumed to be 85% (i.e. the pump and irrigation systems will be operational at least 20.5 hours in a 24-hour period). Based on the APSIM modelling, the peak water requirement occurs under 2000 ha of cotton at about 9 mm/day. This gives a system capacity of about 13 mm/day (rounded up). Although the peak evaporative demand typically occurs during October and November, at this time only 1500 ha of land is under irrigation and the forage crop is being regularly cut so is not transpiring at its potential.

Hence, to supply sufficient water to irrigate 2000 ha of cotton during periods of peak water demand requires the groundwater bores to be able to supply about 260 ML in a 24-hour period. Assuming a cluster of bores has a mean yield of 10 L/s, 25L/s, 50 L/s and 75 L/s this means 300, 120, 60 and 40 bores, respectively would be required to service the 2000-ha irrigation development and meet the peak evaporative demand.

3.4 Case study costs

3.4.1 FARM-SCALE COSTS

This section concerns farm-scale capital and overhead costs associated with a 2000-ha irrigated cropping and forage development. A third category, variable costs associated with irrigated crop production, which form part of the crop gross margin calculation, is captured in Section 3.6.1.
**Capital costs**

The specific costs of on-farm infrastructure development can vary considerably, for example the method for applying water onto individual fields (e.g. spray irrigation, surface irrigation), types of crops and number and depth of groundwater bores. Therefore, the analysis reported in this case study is only for the purpose of providing a framework for on-farm investment analysis and illustrating some drivers of investment performance.

The irrigation development unit costs shown in Table 3-4 are based on the capital costs of a greenfield irrigation development outlined in the companion technical report on agricultural viability (Ash et al., 2018a). It only includes those capital costs associated with developing the land, establishing the property and irrigation systems, and purchasing farm machinery. Costs associated with developing the groundwater resource, for four mean bore yields, are provided separately in Table 3-5 and as a per hectare cost in Table 3-6.

It should be noted that this financial analysis assumes a linear depreciation in assets, which means the results of the net present value (NPV) analysis are not sensitive to the assumption of whether irrigation is undertaken by a landholder with existing grazing infrastructure or whether it is a completely greenfield development.

In Table 3-4 the farm machinery costs are higher than some other agriculture enterprises of a similar scale because a cotton–mungbean–forage rotation requires both cropping and forage machinery.

**Table 3-4 Farm-scale capital and operational costs**

Adjusted to 2017 costs using the consumer price index. Based on a 2000-ha irrigation development.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (y)</th>
<th>COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm-scale costs: capital</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm setup costs</td>
<td>40</td>
<td>3,585,000</td>
<td>1%</td>
<td>Includes internal roads, fences, houses, vehicles, workshops, domestic power supply and sheds.</td>
</tr>
<tr>
<td>Approvals and legal</td>
<td>na</td>
<td>200,000</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>Land preparation</td>
<td>100</td>
<td>1,870,000</td>
<td>1%</td>
<td>Includes survey and design, clearing and raking, internal roads and fences.</td>
</tr>
<tr>
<td>Spray</td>
<td>15</td>
<td>11,680,000</td>
<td>1%</td>
<td>Includes spray, installation of fertigation system and power supply.</td>
</tr>
<tr>
<td>Cropping and forage</td>
<td>15</td>
<td>3,565,000</td>
<td>1%</td>
<td>Includes rippers, boom spray, fertiliser spreader, truck, tractor, mulch lifter and roller, forklift, picking trailers and booms.</td>
</tr>
<tr>
<td>Cropping and forage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Total development cost   | 20,900,000    | $207,000  |                        | Not including costs of water development. |
| 10% contingency          | 2,090,000     | na        |                        |                                                     |
| Total development cost   | 23,000,000    | $207,000  |                        | Equates to a cost of $11,500/ha not including costs of water development. |
A large component of the start-up costs of an irrigation development is associated with the water supply, irrespective of the source. In this case study a range of potential groundwater infrastructure configurations are investigated. Key factors controlling the cost of a groundwater development are:

- yield – this influences the number of bores required
- depth to the target water-bearing geological unit – this controls the drilling depth
- hydraulic head – the depth of groundwater (taking into consideration drawdown from groundwater pumping) influences the cost of pumping.

It should be noted that, based on limited data, mean bore yields in the Grant and Poole sandstone are thought most likely to be between 25 and 50 L/s (Section 3.3.1). Results for 10 and 75 L/s are provided for instructive purposes. Mean bore yields of 75 L/s from the Grant and Poole sandstone are considered unlikely and mean bore yields of only 10 L/s is also unlikely and aside from the high cost it would result in an unwieldy number of bores to operate and maintain.

Table 3-5 Indicative groundwater development capital costs
Costs include groundwater bores and pumps, drilling, diesel tanks, installation and associated costs and 10% contingency. Annual pumping costs of $2/ML per m of head not included.

<table>
<thead>
<tr>
<th>MEAN BORE YIELD (NUMBER OF BORES)</th>
<th>CAPITAL COST ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean bore depth (m)</td>
<td></td>
</tr>
<tr>
<td>10 L/s (300)</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>41,487,600</td>
</tr>
<tr>
<td>50</td>
<td>49,737,600</td>
</tr>
<tr>
<td>100</td>
<td>66,237,600</td>
</tr>
<tr>
<td>150</td>
<td>82,737,600</td>
</tr>
<tr>
<td>200</td>
<td>99,237,600</td>
</tr>
<tr>
<td>300</td>
<td>132,237,600</td>
</tr>
<tr>
<td>400</td>
<td>165,237,600</td>
</tr>
<tr>
<td>25 L/s (120)</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>16,737,600</td>
</tr>
<tr>
<td>50</td>
<td>20,037,600</td>
</tr>
<tr>
<td>100</td>
<td>26,637,600</td>
</tr>
<tr>
<td>150</td>
<td>33,237,600</td>
</tr>
<tr>
<td>200</td>
<td>39,837,600</td>
</tr>
<tr>
<td>300</td>
<td>53,037,600</td>
</tr>
<tr>
<td>400</td>
<td>66,237,600</td>
</tr>
<tr>
<td>50 L/s (60)</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>8,487,600</td>
</tr>
<tr>
<td>50</td>
<td>10,137,600</td>
</tr>
<tr>
<td>100</td>
<td>13,437,600</td>
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<tr>
<td>150</td>
<td>16,737,600</td>
</tr>
<tr>
<td>200</td>
<td>20,037,600</td>
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<td>300</td>
<td>26,637,600</td>
</tr>
<tr>
<td>400</td>
<td>33,237,600</td>
</tr>
<tr>
<td>75 L/s (40)</td>
<td></td>
</tr>
<tr>
<td>25</td>
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<td>50</td>
<td>6,837,600</td>
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<td>11,237,600</td>
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<td>13,437,600</td>
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<td>300</td>
<td>17,837,600</td>
</tr>
<tr>
<td>400</td>
<td>22,237,600</td>
</tr>
</tbody>
</table>

Table 3-6 Indicative groundwater development capital costs per ha
Costs include groundwater bores and pumps, drilling, diesel tanks, installation and associated costs and 10% contingency. Assumes 2000-ha irrigation development. Annual pumping costs of $2/ML per m of head not included.

<table>
<thead>
<tr>
<th>MEAN BORE YIELD (NUMBER OF BORES)</th>
<th>CAPITAL COST ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean bore depth (m)</td>
<td></td>
</tr>
<tr>
<td>10 L/s (300)</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>20,744</td>
</tr>
<tr>
<td>50</td>
<td>24,869</td>
</tr>
<tr>
<td>100</td>
<td>33,119</td>
</tr>
<tr>
<td>150</td>
<td>41,369</td>
</tr>
<tr>
<td>200</td>
<td>49,619</td>
</tr>
<tr>
<td>300</td>
<td>66,119</td>
</tr>
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<td>82,619</td>
</tr>
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<td>25 L/s (120)</td>
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<td>8,369</td>
</tr>
<tr>
<td>50</td>
<td>10,019</td>
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<td>13,319</td>
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<tr>
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<td>16,619</td>
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<tr>
<td>200</td>
<td>19,919</td>
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<tr>
<td>300</td>
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<td>33,119</td>
</tr>
<tr>
<td>50 L/s (60)</td>
<td></td>
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<tr>
<td>25</td>
<td>4,244</td>
</tr>
<tr>
<td>50</td>
<td>5,069</td>
</tr>
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<td>100</td>
<td>6,719</td>
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<td>150</td>
<td>8,369</td>
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<td>200</td>
<td>10,019</td>
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<td>13,319</td>
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<td>400</td>
<td>16,619</td>
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<tr>
<td>75 L/s (40)</td>
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<tr>
<td>50</td>
<td>3,419</td>
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<td>100</td>
<td>4,519</td>
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<td>5,619</td>
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<tr>
<td>200</td>
<td>6,719</td>
</tr>
<tr>
<td>300</td>
<td>8,919</td>
</tr>
<tr>
<td>400</td>
<td>11,119</td>
</tr>
</tbody>
</table>
Table 3-7 Combined farm and water development costs for a 2000-ha irrigation development and 20 GL/year groundwater development

Costs are a combination of per ha costs from Table 3-5 and Table 3-6.

<table>
<thead>
<tr>
<th>MEAN BORE YIELD (NUMBER OF BORES)</th>
<th>CAPITAL COST ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean bore depth (m)</td>
<td>25</td>
</tr>
<tr>
<td>10 L/s (300)</td>
<td>32,244</td>
</tr>
<tr>
<td>25 L/s (120)</td>
<td>19,869</td>
</tr>
<tr>
<td>50 L/s (60)</td>
<td>15,744</td>
</tr>
<tr>
<td>75 L/s (40)</td>
<td>14,369</td>
</tr>
</tbody>
</table>

In Table 3-6, assuming mean bore yields of 25 and 50 L/s the per hectare unit capital costs range from about $15,000/ha to $45,000/ha depending upon the cost of drilling (Table 3-7).

**Cotton gin**

The costs and considerations associated with post-processing infrastructure such as cotton gins and community infrastructure are not discussed in this case study. The companion technical report on socio-economics (Stokes et al., 2017) lists the capital cost of a new 80,000 bale/year cotton gin to be about $30 million, with fixed costs of about $1 million/year and variable costs of $22 to $30/bale. A challenge in establishing a cotton gin at Fitzroy Crossing will be power, currently energy is supplied to Fitzroy Crossing from a dual fuel hybrid gas/diesel power station (Stokes et al., 2017). There is no grid interconnection between towns in the Fitzroy catchment. An alternative location for a cotton gin in the Kimberly would be Kununurra, which does not have the same energy challenges as Fitzroy Crossing and is en route to and closer to ports for export.

### 3.4.2 APPROVAL PROCESSES, COSTS AND TIME

The land on which these developments might occur is currently held as pastoral leasehold land under the *Land Administration Act 1997* (WA) (LAA). Under the Act the primary use of this land is for pastoral purposes (Section 106) although the Act does allow for other purposes under some circumstances (Department of Planning, Lands and Heritage, 2018a). If the lease, or parts of the lease, are to be used for other purposes then a permit is required on approval from the Pastoral Lands Board (Part 7, Division 5).

Permits may be approved under Section 119 for the sowing of non-Indigenous species and under Section 120 for growing crops, fodder, horticultural or other agricultural production if the proposed use is reasonably related to the pastoral use of the land. The issuing of a permit under the Act may lead to a ‘future act process’ if the rights and interests of native title are affected. Legal advice for each individual development is required to determine whether a process under the *Native Title Act 1993* (Cth) is required. The Pastoral Lands Board website (Department of Planning, Lands and Heritage, 2018a) suggests that these processes take two to three years.

Diversification permits are not transferable to a third party and the agricultural activity may only be conducted by the pastoral lessee or their employees. If the pastoral lease is sold, the permit cannot be transferred to the new lessee, although the Board has mechanisms by which the new...
lessee can apply for a new permit for the same activity in which the approval process is streamlined.

For a 2000-ha development at a capital cost of $15,000/ha (at the lower end of the scale shown in Table 3-7) the total cost of the development would be a minimum of $30 million. Given that a favourable candidate crop is cotton it would be difficult to argue that the development was reasonably related to the pastoral use of the land in which case a diversification permit might not be approved.

Under this scenario, the Minister for Lands has several options for granting a lease which would allow for such a development, such as a General Lease (Section 79), a lease for the benefit of aboriginal people (Section 83) or a licence to co-exist with the pastoral lease (Section 91). For the first two of these leases the land would need to be surrendered out of the relevant pastoral lease prior to a Section 79 or Section 83 lease being granted. In the case of the General Lease, National Competition Policy suggests that the land would then need to be made available for competitive release, although the Western Australian Government may enter into a private treaty arrangement in some circumstances (Department of Planning, Lands and Heritage, 2018b).

Ideally, freehold tenure is required for agricultural developments such as those considered in this case study. The Western Australian Government does have a mechanism by which pastoral leasehold land can become freehold land for the purposes of irrigated agriculture development. The mechanism, the Land Tenure Pathway for Irrigated Agriculture (LTPIA), is acknowledged as a complex process, requiring approvals from a number of government departments. While no proponent has been through the LTPIA process yet, the advice provided by the Department of Planning, Lands and Heritage suggests that at least 8 years are required for the complete set of steps. A long-term (e.g. 49-year) Development Lease can also be granted under Section 79 of the LAA under the LTPIA process. All project proposals require Western Australian State Government Cabinet approval.

A number of recent media articles have highlighted the delays, costs and frustrations experienced by proponents of irrigated agriculture in the west Kimberley over the past several years in trying to seek approval for irrigated agriculture developments (e.g. ABC 2017; The West Australian, 2017a, 2017b). A submission to the Senate Select Committee on Red Tape by the Kimberley Pilbara Cattlemen’s Association (KPCA, 2017) details a number of examples from the west Kimberley and the Pilbara where environmental and other approvals have been seen as a hindrance to irrigated agricultural development. The submission states that this has the potential to result in investors committing their resources elsewhere. Typically, the developments being proposed are at a much smaller scale than are being considered here. It is therefore reasonable to consider that developments of the scale of 2000 ha would face considerable regulatory and approval complexity. The costs in dollars and time are difficult to estimate however the $200,000 suggested in Table 3-4 is likely to be an under estimate, with the actual cost estimated to be as high as five to ten times this amount (Richard George 2018, pers. comm.).

Notwithstanding this frustration, there are recent examples of environmental approvals for irrigation development in the Kimberley. For example, the Environmental Protection Authority (EPA) recommended approval for the Shamrock Station Irrigation Project in May 2018 which would provide a disturbance footprint of up to 1200 ha, comprising 650 ha of clearing for pivot irrigation (Environmental Protection Authority, 2018a). In the East Kimberley, the EPA
recommended the implementation of Carlton Plain Stage 1 project, comprising 3055 ha for irrigated agriculture, in March 2018 (Environmental Protection Authority, 2018b).

Additional, but unknown costs will be required in order to address native title. Under the LTPIA the process of developing an Indigenous Land Use Agreement (ILUA) with appropriate Native Title Parties will be proponent-led rather than state-led. Liability for costs, including compensation and the costs of the Native Title Parties will be the responsibility of the proponent. The LTPIA documentation provided by the Western Australian Government suggests that an ILUA takes an average of 18 months to negotiate and its registration up to 6 months.

Greenfield irrigation developments of the scale considered in this case study are not common in northern Australia and there are few examples from which costs, time and complexity can be provided. However, as part of the Western Australian State Government’s development of Ord Stage 2, negotiations between the State, other parties and the Miriuwung Gajerrong Traditional Owners led to the ‘Ord Final Agreement ILUA’ (Office of Native Title, undated). The acquisition of 65,000 ha of land for a range of development purposes and a number of other issues resulted in a compensation package of $57 million. The Ord Final Agreement is too complex to be considered in detail here but there were a number of other negotiated settlements as part of the agreement, including the State handing back 50,000 ha of land to the Miriuwung Gajerrong people and Consolidated Pastoral Company relinquishing almost 200,000 ha of pastoral land, principally for the creation of conservation reserves.

An analysis of the length of environmental assessment and approval processes for water-related developments under the *Environmental Protection Act 1986* (WA) and the *Environmental Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) was done as part of the Assessment and reported in the companion technical report on the legal, regulatory and policy environments (Macintosh et al., 2018). The state-based analysis was confined to the sample of 53 projects from the regional areas north of Perth over the period 2009 to 2018. Projects from a range of sectors were included in order to get sufficient sample size. The sectors included agriculture, aquaculture, mining, transport and several others. The aggregate of the median length of each stage was 603 days, while 23% took under 365 days and 23% took longer than 1000 days. For the EPBC Act (using 116 WA projects from multiple sectors approved over the period 2010 to 2018) the aggregate of the median length of each stage was 337 days. Almost 50% of approvals took less than 365 days while 17% took more than 730 days. The longest was 2662 days.

The approval steps, the time taken for approval and the cost of going through the approval process will be on a case-by-case basis. In many cases this will be privately held information however it is instructive to look at the publicly available documentation surrounding the decision by the EPA in the case of the Shamrock Station Irrigation Project (Environmental Protection Authority, 2018). The EPA’s report was written for the Minister for Environment having decided that the level of Assessment should be set at ‘Assessment on Referral Information’, one of several levels of assessment. The EPA made this decision based on the level of potential impacts to ‘Flora and Vegetation’, ‘Terrestrial Fauna’ and ‘Hydrological Processes and Inland Waters Environmental Quality’. The EPA also identified six decision making authorities that needed to be consulted with, being the Minister for Environment, the Minister for Water, Minister for Lands, Minister for Aboriginal Affairs, the Pastoral Lands Board and the Shire of Broome. A report provided to the EPA by the proponent (Phoenix Environmental Sciences Pty Ltd, 2017) includes appendices detailing a
hydrogeological assessment, a flora and fauna assessment, a subterranean fauna desktop assessment, information concerning fertiliser and chemical application and provisions for a draft Environmental Management Plan. While the various decision making authorities listed above provide advice and recommendations to the EPA process they also have their own processes to make decisions under Acts for which they have carriage. For example, a water licence from the Minister for Water is required under the *Rights in Water and Irrigation Act 1914* and approval to use land under pastoral tenure for irrigated agriculture is required under the *Land Administration Act 1997* from the Pastoral Lands Board, representing the Minister for Lands. Other approvals are required under other Acts, administered by other authorities.

3.5 Project commerciality

To evaluate whether the returns (i.e. gross margins) from an irrigated cropping development are sufficient to pay off the costs of development taking into consideration the time value of money, break-even gross margins required for each of the enterprises listed in Table 3-9 are compared to the median crop gross margins for the cotton–mungbean–forage sorghum rotation.

**Cotton–mungbean–forage sorghum gross margin**

To calculate the effective gross margin of incorporating 1000 ha of forage sorghum into an existing beef enterprise of 23,000 head of cattle, the NABSA model was used to calculate the additional net profit to the beef enterprise. This was found to be an additional $3.1 million (Table 3-8) on Scenario A, which is equivalent to an effective gross margin of $1550/ha when averaged over the 2000-ha development.

**Table 3-8 Potential benefits of incorporating 1000 ha of forage sorghum and 2000 ha of cottonseed into a typical beef enterprise in the Fitzroy catchment**

Assumes 23,000 head of cattle and that capital costs associated with irrigation development are covered by the analysis of cash crops. The only additional costs over Scenario A (i.e. baseline) are additional labour associated with feeding out cottonseed and managing the changed grazing regimes.

<table>
<thead>
<tr>
<th></th>
<th>SCENARIO A</th>
<th>SCENARIO B (SCENARIO A + COTTONSEED + FORAGE SORGHUM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herd size (AE)</td>
<td>23,205</td>
<td>24,107</td>
</tr>
<tr>
<td>Annual live weight gain of 1- to 32-year-old steers (kg/head/y)</td>
<td>131</td>
<td>213</td>
</tr>
<tr>
<td>Weaning rate (%)</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Weaning weight (kg)</td>
<td>129</td>
<td>164</td>
</tr>
<tr>
<td>Net profit ($ million)</td>
<td>2.89</td>
<td>5.99</td>
</tr>
</tbody>
</table>

Assuming the cotton seed was used as a nutritional supplement for cattle the median gross margin for 2000 ha of cotton and 500 ha of mungbeans averaged over the 2000-ha development is -$150/ha, $1030/ha and $1655/ha if the cotton gin is in Emerald, Kununurra and Fitzroy Crossing respectively (Table 3-2).
The cotton – mungbean gross margin combined with the effective gross margin from the irrigated forage is

- $1400/ha for the rotation if unprocessed cotton is transported to the nearest existing cotton gin, which is at Emerald (approximately 3500 km from Fitzroy Crossing).
- $2580/ha for the rotation if unprocessed cotton is transported to a potential cotton gin at Kununurra. Under this scenario some cotton would be grown in the Ord and consequently it would not be necessary to grow 6,000–10,000 ha of cotton in the Fitzroy to support a gin.
- $3205/ha for the rotation if unprocessed cotton is transported to a local gin, for example at Fitzroy Crossing.

**Break-even gross margins required to meet capital costs and operation and maintenance costs of a 2000-ha irrigation enterprise**

This section explores how the break-even gross margins vary with increasing capital cost of development and depth of groundwater pumping (Table 3-9). Break-even gross margins are equal to the equivalent annual cost (EAC) of development, which is the annual cost of owning, operating and maintaining (O&M) an asset over its entire life, plus the annual enterprise overhead costs, at a specified discount rate.

In this case study increasing capital costs of development are due to the requirement for deeper groundwater bores and a larger number of bores due to lower mean bore yields (Table 3-6 and Table 3-7). The profitability of the enterprise can be assessed by comparing the break-even gross margins (Table 3-9) to the three ‘effective’ combined gross margins for the rotation (i.e. $1400/ha, $2580/ha and $3205/ha) presented above. Where the combined gross margin of the rotation exceeds the break-even gross margin, the enterprise is potentially profitable at the specified discount rate and the cell is highlighted in blue in Table 3-9. The three shades of blue in Table 3-9 correspond to the three ‘effective’ combined gross margins, the darkest shade corresponds to $1400/ha (i.e. the conditions under which the enterprise may be profitable with a cotton gin at Emerald) and the lightest shade corresponds to $3205/ha (i.e. the conditions under which the enterprise may be profitable with a local cotton gin).

For example, to achieve a 3% return on investment with a cotton gin at Fitzroy Crossing the cost per hectare needs to be less than about $27,500/ha if the hydraulic head is 30 m below ground level (after accounting for drawdown due to groundwater pumping) (Table 3-9), that is groundwater would need to be pumped 30 m in addition to the 15 to 20 m of head required to operate the overhead irrigation (the head required to operate the overhead irrigation is included as a variable cost in the gross margin calculation). If the mean bore yield for a cluster of bores is 25 L/s, for the capital cost of development to be less than $27,500/ha the depth of drilling (i.e. depth to the target water-bearing geological unit) would need to be less than 144 m (Table 3-7).

A real, pre-tax discount rate of 7% was selected for this analysis on the assumption that this rate reflects what a private sector business may seek from an investment with risk, a number commonly used for public investment decisions. However, it should be noted that returns from agriculture are often less than 7% because agricultural investment decisions are often not based solely on potential returns from production. For this reason, a 3% discount rate was also examined on the basis that some investors may have alternative motivations for undertaking irrigation. For example, investment may involve speculation regarding property prices and water entitlements,
or may include the social and community benefits of irrigation development (Bennan Mckellar et al., 2013), and an investor consequently may be satisfied with lower returns (in this case slightly higher than the longer-term rate of inflation (i.e. 2 to 3%)). In this instance and of relevance to the Fitzroy an investor may be satisfied with a return less than 7% if it means they are able to access a more diverse range of markets for their cattle than live export (the only market for cattle less than 350 kg) and improve reproductive success of their herd.

Using a similar method to the break-even gross margin calculations in Table 3-9 variation in equivalent annual cost based on the depth to the target water-bearing geological unit and depth of hydraulic head are mapped in Figure 3-9 assuming a 3% and 7% discount rate assuming a mean 10 ML/ha applied irrigation over the 2000 ha development. The mapped hydraulic head was adjusted to account for groundwater drawdown that would occur during and following pumping. Due to uncertainty in the spatial distribution of aquifer properties controlling groundwater drawdown the depth to hydraulic head was uniformly increased by 10 m. Due to a lack of spatial information on groundwater yield, break-even gross margins for four groundwater yields (assumed to be an average of a cluster of bores) were calculated. These were 10, 25, 50 and 75 L/s. As discussed in Section 3.4.1 mean bore yields are most likely to be between 25 and 50 L/s. Results for 10 and 75 L/s are provided for instructive purposes and mean bore yields of 75 L/s from the Grant and Poole sandstone are considered unlikely. For comparative purposes results for a single dry-season crop of cotton (irrigation water requirement 8.6 ML/ha) are presented in Figure 3-10. Figure 3-11 shows those parts of the Fitzroy catchment where the gross margin for the rotation (assuming a cotton gin in Kununurra (i.e. $2580/ha)) exceeds the sum of the equivalent annual cost and annual overheads, and the soils are loamy and classified as Class 3 or better.

Table 3-9 Break-even gross margins required to meet capital costs and operation and maintenance costs of a 2000-ha irrigation enterprise for different groundwater resource configurations

Two discount rates are examined, 3% and 7%. Blue shading indicates scenarios where effective combined cotton–mungbean–forage rotation gross margin ($3205/ha corresponds to light blue and $2580/ha to medium blue) exceed break-even gross margins. Assumes linear depreciation in residual value of assets. Break-even gross margin at 100% reliability are equal to the equivalent annual cost (i.e. of capital and includes O&M) plus overheads (and cost of groundwater pumping) at 100% reliability, and assuming infrastructure was split 50:50 between 15-year and 40-year service life (see Table 4-3 in companion technical report on agriculture viability, Ash et al. 2018a), 10 ML/ha applied irrigation and assuming $2/ML per m operational cost for groundwater pumping. $/ha costs can be related to infrastructure in Table 3-7.

<table>
<thead>
<tr>
<th>$/ha</th>
<th>BREAK EVEN GROSS MARGINS REQUIRED FOR A 3% DISCOUNT RATE FOR A GIVEN DEPTH OF GROUNDWATER PUMPING</th>
<th>BREAK EVEN GROSS MARGINS REQUIRED FOR A 7% DISCOUNT RATE FOR A GIVEN DEPTH OF GROUNDWATER PUMPING</th>
</tr>
</thead>
<tbody>
<tr>
<td>0m</td>
<td>10m 20m 30m 50m 80m 10m 20m 30m 50m 80m</td>
<td>10m 20m 30m 50m 80m 10m 20m 30m 50m 80m</td>
</tr>
<tr>
<td>15,000</td>
<td>1703 1903 2103 2303 2703 3303 2136 2336 2536 2736 3136 3736</td>
<td>2136 2336 2536 2736 3136 3736 2136 2336 2536 2736 3136 3736</td>
</tr>
<tr>
<td>17,500</td>
<td>1887 2087 2287 2487 2887 3487 2392 2592 2792 2992 3392 3992</td>
<td>2392 2592 2792 2992 3392 3992 2392 2592 2792 2992 3392 3992</td>
</tr>
<tr>
<td>20,000</td>
<td>2070 2270 2470 2670 3070 3670 2648 2848 3048 3248 3648 4248</td>
<td>2648 2848 3048 3248 3648 4248 2648 2848 3048 3248 3648 4248</td>
</tr>
<tr>
<td>22,500</td>
<td>2254 2454 2654 2854 3254 3854 2904 3104 3304 3504 3904 4504</td>
<td>2904 3104 3304 3504 3904 4504 2904 3104 3304 3504 3904 4504</td>
</tr>
<tr>
<td>25,000</td>
<td>2438 2638 2838 3038 3438 4038 3160 3360 3560 3760 4160 4760</td>
<td>3160 3360 3560 3760 4160 4760 3160 3360 3560 3760 4160 4760</td>
</tr>
<tr>
<td>27,500</td>
<td>2622 2822 3022 3222 3622 4222 3416 3616 3816 4016 4416 5016</td>
<td>3416 3616 3816 4016 4416 5016 3416 3616 3816 4016 4416 5016</td>
</tr>
<tr>
<td>30,000</td>
<td>2805 3005 3205 3405 3805 4405 3672 3872 4072 4272 4672 5272</td>
<td>3672 3872 4072 4272 4672 5272 3672 3872 4072 4272 4672 5272</td>
</tr>
<tr>
<td>35,000</td>
<td>3173 3373 3573 3773 4173 4773 4184 4384 4584 4784 5184 5784</td>
<td>4184 4384 4584 4784 5184 5784 4184 4384 4584 4784 5184 5784</td>
</tr>
<tr>
<td>40,000</td>
<td>3541 3741 3941 4141 4541 5141 4696 4896 5096 5296 5696 6296</td>
<td>4696 4896 5096 5296 5696 6296 4696 4896 5096 5296 5696 6296</td>
</tr>
</tbody>
</table>
Figure 3-9 Sum of equivalent annual cost of development assuming a 3% and 7% discount rate and annual overhead cost for cotton–mungbean–forage sorghum rotation
Assumes mean draw down of 10 m due to groundwater pumping. For a cotton gin at (i) Kununurra and (ii) Fitzroy Crossing, an enterprise may be profitable in those areas shaded (i) light blue and (ii) light blue & yellow respectively. Red shows those areas unlikely to be profitable at the specified discount rates (even with a local cotton gin).
Figure 3-10 Sum of equivalent annual cost of development assuming a 3% and 7% discount rate and annual overhead cost for dry-season cotton
Assumes mean draw down of 10 m due to groundwater pumping. For a cotton gin at (i) Kununurra and (ii) Fitzroy Crossing, an enterprise may be profitable in those areas shaded (i) light blue and (ii) light blue & yellow respectively. Red shows those areas unlikely to be profitable at the specified discount rates (even with a local cotton gin). Assumes lint and seed are sold to gin.
Figure 3-11 Moderately suitable land with considerable limitations or better (i.e. Class 1, 2 or 3) on lighter soils that is potentially profitable at discount rates of 3% and 7% assuming an mean bore yield of 25 L/s and 50 L/s Locations where the combined gross margin of the rotation exceeds the sum of the equivalent annual cost of development and annual overheads, and where there are lighter soils that are Class 3 or better for cotton, mungbeans and forage sorghum. Assumes mean yield of bore clusters is 25 L/s and 50 L/s. Does not take into consideration secondary salinisation. Assumes mean drawdown of 10 m due to groundwater pumping over investment period.
3.6 Project benefits

3.6.1 POTENTIAL PRODUCTION

The gross potential production was calculated by multiplying the mean area under irrigation by the price per hectare of the cotton and mungbeans (assuming full production potential), plus the returns from the beef operation under Scenario B. This comes to a gross potential production of $13,938,000 for each enterprise. Assuming 12,000 ha are developed across the Fitzroy catchment, the total gross value of production is $83,628,000 (Table 3-10).

Table 3-10 Gross value of production
Assumes cotton and mungbeans yield at full production potential.

<table>
<thead>
<tr>
<th>AREA PLANTED</th>
<th>POTENTIAL YIELD</th>
<th>PRICE PER UNIT</th>
<th>GROSS ANNUAL PRODUCTION SINGLE ENTERPRISE ($)</th>
<th>GROSS ANNUAL PRODUCTION ENTIRE CATCHMENT ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton (bales/ha)</td>
<td>2000</td>
<td>10.3</td>
<td>480</td>
<td>9,888,000</td>
</tr>
<tr>
<td>Mungbeans (t/ha)</td>
<td>500</td>
<td>1.9</td>
<td>1000</td>
<td>950,000</td>
</tr>
<tr>
<td>Forage sorghum</td>
<td>1000</td>
<td>na</td>
<td>na</td>
<td>3,100,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>13,938,000</td>
</tr>
</tbody>
</table>

na = data not applicable

3.6.2 REGIONAL ECONOMIC BENEFITS

To estimate the regional economic benefit resulting from a development or developments, regional input-output (I-O) models incorporating total output (Type II) multipliers were used. The analysis focused on the ongoing annual benefits generated from the increased dollar output of the agricultural sectors in each I-O region resulting from the water storage scheme, treating this increased output as an exogenous shock to the economy.

The basis of the approach is that those agricultural businesses directly benefitting from the project will need to increase their purchases of the raw materials, labour and intermediate products utilised by their growing outputs. Should any of these purchases be made within the region, then this provides a stimulus to those businesses that they purchase from, contributing to further economic growth and job creation within the region (the production-induced effect). Furthermore, household incomes increase as a result of those local residents who are employed (as a consequence of either direct or production-induced business stimuli); as a proportion of their additional income is spent in the region, that further stimulates greater economic activity and additional job creation (consumption-induced effects).

The dollar value of the increased total economic activity per year due to the operation of the scheme is estimated by using the exogenous increases in agriculture as an input to the regional I-O models developed from pre-existing I-O tables.

As part of this process, the I-O analysis estimates the total increase to household incomes within the region. By using this value along with the median income within the region, an estimate can be derived of the likely full-time equivalent jobs that would be created (directly, and indirectly through production and consumption effects) as a result of the development.
As outlined in the companion technical report on socio-economics, Stokes et al. (2017) for each dollar of direct annual benefit from new agricultural activity excluding beef it was estimated to generate an additional $0.59 in regional economic activity recurring annually and an additional $0.53 for each additional dollar of beef cattle. For every $100 million in new agricultural activity excluding beef cattle it was estimated to generate an additional 625 full-time equivalent jobs and an additional 439 full-time equivalent jobs for every $100 million in new beef cattle activity.

Based on the gross value of production values presented in Table 3-10, the total increase in regional economic activity is estimated to be about $130 million and would potentially create nearly 500 jobs (Table 3-11).

<table>
<thead>
<tr>
<th>MEAN IRRIGATED AREA (ha)</th>
<th>AGRICULTURAL SECTOR</th>
<th>VALUE OF INCREASED AGRICULTURAL OUTPUT ($ million)</th>
<th>INCREASED REGIONAL ECONOMIC ACTIVITY ($ million)</th>
<th>APPROXIMATE DIRECT AND INDIRECT JOBS CREATED (NUMBER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton–mungbean</td>
<td>Agriculture excluding beef cattle</td>
<td>65.2</td>
<td>103.6</td>
<td>408</td>
</tr>
<tr>
<td>Forage sorghum</td>
<td>Beef cattle</td>
<td>18.6</td>
<td>28.5</td>
<td>82</td>
</tr>
<tr>
<td>Total</td>
<td>na</td>
<td>83.8</td>
<td>131.5</td>
<td>490</td>
</tr>
</tbody>
</table>

na = data not applicable

It should be noted that if the cotton was processed at a local gin then the increase in regional economic activity and the number of direct and indirect jobs created as estimated in Table 3-11 are likely to be an underestimate.

### 3.7 Project impacts of groundwater extraction

Using a groundwater flow model documented in the companion technical report on groundwater flow modelling (Dawes et al., 2018), an evaluation of the potential impacts of 20 GL/year extraction from the Grant Group and Poole Sandstone aquifers at six hypothetical locations (i.e. 120 GL/year in total) in the Fitzroy catchment was undertaken (Figure 3-12). The results indicate that 20 GL/year could potentially be extracted from each of the six locations over the long term (i.e. a 20-year period). The drawdown in groundwater level around the hypothetical pumping sites for each extraction site is mostly concentric, with minimal overlap between sites (Figure 3-12). At the largest extraction rate, 20 GL/year, groundwater drawdown of greater than half a metre – a value that can be considered measurable and distinguishable from natural variations in groundwater level – is modelled to be between 3.8 and 30 km from the pumping centre after 5 years, depending on location of extraction.

After 10 years, groundwater drawdown greater than half a metre extends between 4.5 and 32 km from the pumping centre, and between 5 and 36 km after 20 years (Figure 3-12). The widespread propagation of small drawdown impacts is due to the low storage properties of these confined aquifers.
Figure 3-12 Modelled drawdown in groundwater level in the Grant Group and Poole Sandstone aquifers for a 20 GL/year extraction at six locations after (a) 5 years and (b) 20 years
Drawdown contours relate to drawdown in groundwater level at depth in the aquifer (50 to 300 m) and not in shallow overlying aquifers or the Fitzroy River. Contour interval is 1 m. Outermost contour is −0.5 m.
Field investigations undertaken as part of the Assessment indicate that many reaches of the Fitzroy River have a high likelihood of groundwater discharge that partly support dry-season flows as well as instream pool persistence (Figure 3-12). Nevertheless only three of the seven groundwater sites tested occur in the vicinity of reaches of the Fitzroy River that were characterised by the Assessment to have a medium to high likelihood of groundwater inflow (Taylor et al., 2018). Previous studies have found that some of this groundwater discharge may originate from the Poole Sandstone aquifer, located at significant depth (i.e. several hundreds of metres) below the river, with geological faults providing a preferential pathway for groundwater flow and discharge. For seven locations within the interconnected Grant Group and Poole Sandstone, modelled groundwater level drawdown is reported: three of these locations are beneath the Cunningham Anabranch (see CA 1 to 3 in Figure 3-12) and four beneath the Fitzroy River (see FR 1 to 3 in Figure 3-12). Modelled drawdown at these sites – within the Poole Sandstone aquifer and importantly not the Fitzroy River nor the shallow alluvial aquifer – range from 0.01 to 1.57 m where 20 GL/year is extracted at each of the six locations (Table 3-12).

Table 3-12 Modelled drawdown at seven reporting sites in the Grant Group and Poole Sandstone aquifer system for three extraction scenarios: 5, 10 and 20 GL/year

<table>
<thead>
<tr>
<th>MODEL REPORTING SITE</th>
<th>TIME (y)</th>
<th>DRAWDOWN FOR 5 GL/y (m)</th>
<th>DRAWDOWN FOR 10 GL/y (m)</th>
<th>DRAWDOWN FOR 20 GL/y (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cunningham Anabranch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA#1</td>
<td>5</td>
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Prior to any irrigation being developed, the area of interest would require more intensive assessment of potential ecological impacts based on the specifics of the proposal.

<table>
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<tr>
<th>MODEL REPORTING SITE</th>
<th>TIME (y)</th>
<th>DRAWDOWN FOR 5 GL/y (m)</th>
<th>DRAWDOWN FOR 10 GL/y (m)</th>
<th>DRAWDOWN FOR 20 GL/y (m)</th>
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<td>20</td>
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4 Upper Adelaide River dam and multi-purpose use of water

Darwin is approaching its capacity to securely supply water to urban and industrial users. This case study investigated the potential for a dam on the upper Adelaide River to supply water to meet future urban and industrial demand and supply water to irrigate 6000 ha of dry-season rice (Figure 4-1). To maximise returns rainfed soybeans would be grown over the wet season.

The feasibility of this irrigation development was analysed with respect to:

- the physical capacity to create a water storage and water distribution infrastructure, to supply water to agriculturally suitable soils, and to grow irrigated sugarcane
- the capacity of the scheme to generate positive net revenues
- potential impacts to freshwater aquatic, riparian and near-shore marine species and habitats.

The commerciality of a scheme with two separate investors (water supplier and irrigators) was examined by comparing i) the price the water supplier would have to charge for irrigation water to break even to ii) the price farmers would be able to afford to pay while breaking even. These break

Figure 4-1 Schematic diagram illustrating the components of the case study for a large dam on the Adelaide River, urban water pipeline and irrigation development
even prices are compared across a range of discount rates and ‘values’ for the urban water supply capacity.

In presenting this case study, no consideration is given to legislative issues that may need to be addressed for any development of this scale to proceed. These issues include, but are not limited to, legislation relating to land tenure, planning and infrastructure, cultural heritage, native title, vegetation management, wildlife protection, water resources, fisheries and environmental protection.

4.1 Summary

The case study concludes that the physical conditions at the site would enable the development of a dam to supply irrigation water for a 6000-ha irrigation development of dry-season rice while also being able to provide 30 GL of high security water to Darwin to meet future demands. The case study found:

• A dam capable of storing 298 GL of water can potentially be located on the upper Adelaide River. Due to high inter-annual variability in streamflow its annual water yield would be 153 GL/year (at 85% reliability). The estimated storage cost of $182 million and annual yield of 153 GL results in a unit cost of $1190/ML at the dam wall. Approximately 60% of this water yield at the dam wall would be lost in conveyance and application to the crop.

• Approximately 7000 ha of soils moderately suited to surface-irrigated dry-season rice lie adjacent to the Adelaide River downstream of the dam site and upstream of the confluence of the Margaret River. Rice has well established markets and marketing infrastructure.

• Given adequate irrigation and crop management, these soils are capable of supporting median crop yields of about 9.7 t/ha for irrigated dry-season rice and 3.1 t/ha of rainfed wet-season soybean per year.

• The total capital cost of the dam and urban water transfer infrastructure to the water treatment plant is estimated to cost about $360 million. This is about 20% higher than the order of magnitude cost estimate for the Adelaide River offstream water storage (AROWS) and urban water transfer infrastructure, however, the annual pumping costs from Upper Adelaide River dam is lower.

• The scheme-scale irrigation infrastructure is estimated to cost $86 million. The farm-scale development costs assuming surface irrigation are estimated to be $4.95 million for a 625 ha farm, or $7900/ha. Urban water supply would need to be valued at about $1.25/kL for the whole development (and the separate water supplier and farming investors) to break even at a 7% discount rate for the 6000-ha irrigation development option with 30 GL of high-security urban water.

• Based on the order of magnitude cost estimates for AROWS the equivalent annual cost and overheads (i.e. pumping) are estimated to be between $0.70/kL and $1.10/kL for 30 GL supplied at the water treatment plant.

• The price of domestic and commercial water in Darwin is $1.95/kL delivered to premises.

• Reducing the quantity of water secured for urban and industrial use makes it considerably more challenging to find a set of conditions where both water supplier and irrigator enterprises are
viable. Both need to be commercially profitable at the specified discount rate for the entire
development to be viable.

- The total annual revenue from the agricultural enterprise could be about $33.3 million per year,
  resulting in a total increase in regional economic activity arising from agriculture of about
  $48.6 million. Note no attempt was made to quantify the project regional-scale benefits arising
  from providing high security water to Darwin.

- If reliable markets could be established, water from the dam could be used to irrigate higher
  value crops such as Asian vegetables, rather than dry-season rice. This would substantially
  increase annual revenue and annually recurring regional economic benefits.

- Substantial land in the area is subject to current or future native title claims. Several registered
  and/or recorded sacred and cultural heritage sites are known to exist in the inundation area.
  There is a high likelihood of currently unrecorded sites. Large instream dams are not a favoured
  form of development of Indigenous people in the Darwin catchments.

- The potential Upper Adelaide River dam has potential to have a major localised impact on
  species and their flow habitat immediately downstream of the dam wall. With distance
  downstream from the dam and the point of water extraction, the seasonality of streamflow
  increasingly resembles the natural pattern of streamflow. Below the confluence of the Adelaide
  and Margaret rivers the impact to the flow habitat of these species is minor. At the catchment
  outlet there is minor impact to the flow habitat of crocodiles, barramundi and sawfish and no
  change to the flow habitat to other marine and estuarine species.

- The area would require more intensive assessment of any ecological impacts based on the
  specifics of a proposal prior to irrigation development.

- The strong possibility of different funding and operation models is recognised, but is beyond the
  scope of this case study.

4.2 Storyline for this case study

An additional source of water is required to reliably supply water to Darwin’s urban and industrial
users. Darwin’s urban and industrial demand is approaching the available system yield of Darwin’s
water supply options (42.8 GL), and allowing for a 10% ‘system headroom’ and customer demand
the immediate system yield shortfall has been calculated to be about 5 GL. Future annual water
demand to 2065 is projected to be between about 50 to 60 GL/year depending upon assumptions
regarding population growth and success of demand-management programs (e.g. Living Water
Smart). Furthermore, with approximately 85% of Darwin’s water being supplied from the Darwin
River Dam (265 GL capacity), there are concerns that an unexpected loss of supply from the
Darwin River Dam (e.g. contamination of the reservoir) could greatly affect the Darwin region
(PWC, 2013). The McMinns and Howard East groundwater borefield, which provides the remaining
15% of Darwin’s water supply, has limited capacity for future expansion due to concerns about
some bores in the Howard East borefield running dry towards the end of the dry season.

Several options have been canvassed for increasing the system yield of Darwin’s water supply.
These include:

- **Recommissioning the nearby Manton Dam**
  Manton Dam (13.3 GL capacity) currently serves as a recreational amenity and a pipeline
upgrade and water treatment plant would be required to bring the dam back into commission. Although there is some capacity to increase the height of the dam wall, the additional yield from Manton Dam is modest and commissioning the dam back into service may also require limiting recreational use.

- **A large offstream storage adjacent to the Adelaide River**

An alternative water supply option being investigated by the Northern Territory Power and Water Corporation is a large engineered offstream storage adjacent to the Adelaide River, referred to as the Adelaide River Offstream Water Storage (AROWS). Order of magnitude cost estimates undertaken as part of the Assessment estimate the capital cost of AROWS and pump station and piping infrastructure to be between $250 million and $400 million (for a configuration that yields 31.5 GL in more than 95% of years with pumping commencing at a minimum threshold of 144 m³/s). Based on these broad estimates the sum of the equivalent annual cost and annual overheads is estimated to be between $0.70/kL and $1.10/kL at the water treatment plant. It should be noted that the Northern Territory Power and Water Corporation have confidential detailed feasibility level cost estimates for AROWS and associated infrastructure. Order of magnitude estimates for AROWS are provided in this report solely for contextual reasons.

### 4.2.1 UPPER ADELAIDE RIVER DAM

This case study examined a third option, a major engineered dam on the Adelaide River about 3 km upstream of Adelaide River town. The water storage infrastructure will principally store water for the purpose of ensuring future urban and industrial water security of Darwin and surrounds, with the potential of providing excess storage to support irrigated agriculture on the alluvial soils of the Adelaide and Margaret rivers (Figure 4-2). In this case study it was assumed that water from the Upper Adelaide River dam would be piped about 70 km along the existing road corridor of the Stuart Highway and connected to Darwin’s reticulated system at a water treatment plant to be built at the interception of the Stuart Highway and Cox Peninsula Road, referred to as the Strauss water treatment plant. A water treatment plant at this location would potentially allow for a whole-of-system treatment for the Darwin region water supply in the future, including water from Manton Dam (PWC, 2013).

In this case study water for agriculture would be conveyed down the Adelaide River to a series of reregulating structures downstream of the town of Adelaide River (order of magnitude calculations indicate it would be prohibitively expensive to convey water to the agricultural area using a pipeline).

Two options are explored in this case study:

- **Option 1** provides 30 GL of water for Darwin at high security of supply leaving sufficient water to irrigate about 6000 ha of dry-season rice adjacent to the Adelaide River, with some additional water remaining for environmental releases (i.e. where water is released to mitigate environmental impacts).

- **Option 2** seeks to develop a larger area of irrigation, providing 15 GL of water for Darwin at high security of supply (i.e. ~100% annual time reliability) leaving sufficient water to irrigate about 9000 ha of dry-season rice adjacent to the Adelaide and Margaret rivers and Howley Creek.
Where land is not subject to broad-scale flooding dryland soy beans would be grown over the wet season to maximise returns from the developed area.

This case study assumed that a third-party public or private body or government corporation will construct the Adelaide River dam and major infrastructure required to connect the dam to the Strauss water treatment plant and develop the necessary infrastructure to enable riparian pumping by landholders adjacent to the Adelaide and Margaret rivers and Howley Creek.

This case study assumes that alluvial land adjacent to the Adelaide and Margaret rivers would be acquired and sold in ~700 ha lots, each with river frontage allowing riparian pumping, and that on each lot about 625 ha of land could be developed for irrigated agriculture, leaving sufficient land to maintain existing riparian vegetation and for farm related infrastructure such as roads, channels, pump stations, workshops and housing. Irrigators would be required to purchase and develop the land and the public/private water supplier developing the scheme-related infrastructure would recoup their costs through the sale of water.

The commerciality of a scheme with two separate investors (water supplier and irrigators) was examined by comparing i) the price the water supplier would have to charge for irrigation water to break even to ii) the price irrigators would be able to afford to pay while breaking even. These break even prices are compared across a range of discount rates and ‘values’ for the urban water supply capacity.
Figure 4-2 (a) Satellite image and (b) relief and potential maximum surface water extent
Data used to develop flood map were captured using MODIS satellite imagery. This figure illustrates the maximum percentage of MODIS pixels inundated between 2000 and 2015. Polygon A is indicative of the location of the 6000 ha irrigation development under Option 1. Polygon B is indicative of the location of the additional 3000 ha irrigation development under Option 2.

The water secured for urban and industrial users was assumed to have a ‘value’ of $1/kL, $2/kL and $3/kL delivered to the Strauss water treatment plant. This water is ascribed to have a ‘value’
rather than a price because in practice the ‘value’ might not actually be charged and received as a revenue stream (i.e. in the event that some or all of the water is not required). The actual ‘value’ of the urban and industrial water will depend on a range of factors such as the cost users may be prepared to incur to have a high security of supply even if the water is not required (i.e. in the event of future population growth or water from Darwin River Dam is unavailable). An example of the costs governments and organisations are prepared to incur to ensure the supply of water to large urban and industrial areas are desalination plants. Between 2010 and 2012 four desalination plants were built in Australia to provide security of urban and industrial water supplies at a cost of between $15/kL and $25/kL (excluding ongoing operation (e.g. energy) and maintenance costs) (AWA, 2018). For context the Northern Territory Power and Water Corporation currently has a tariff of $1.95/kL for domestic and commercial users of water in Darwin.

4.3 Case study and study area description

This section discusses the soils and climate in relation to implantation of a rotation of irrigated dry-season rice and dryland soy bean planted over the wet season, on the alluvial clay soils adjacent to the Adelaide River downstream of Adelaide River town. An overview the water and irrigation infrastructure configuration is also provided.

4.3.1 SOIL AND LAND SUITABILITY FOR BROADACRE CROPPING

The Adelaide River alluvial plains in the study area downstream of Adelaide River township to Tortilla Flats is shown in Figure 4-2a while the soils are shown by the soil generic group map in Figure 4-3a and described below. Figure 4-3b shows a land suitability map for dry-season rice under surface irrigation. For more detail on the land suitability analysis in the Darwin catchments see the companion technical report on land suitability, Thomas et al., (2018).

Upstream of the Adelaide River township, the narrow alluvial plains emerge from the steep to rolling hills to form a very broad alluvial plain. The upper slopes of rocky hills that bound the plain are dominated by very shallow, stony soils with no potential for irrigation development. The lower slopes of the hills and gently undulating rises throughout the catchment are dominated by yellow and brown loamy soils suitable for a range of crops, however, the short slopes and large number of drainage lines may restrict the size of usable areas and infrastructure lay-out. Crop, irrigation and land management is also required on sloping lands to control water erosion, particularly during the very high rainfall intensity storm periods over summer when soil cultivation and bare loose soil surface should be avoided.

The potential area of development is the alluvial plains of the Adelaide River (Figure 4-3a) upstream of Tortilla Flats where the plains have a deeply incised main channel, a distinct narrow levee, extensive level alluvial plains subject to occasional to regular flooding, and frequent drainage depressions and swamps.

The duration of flooding increases downstream with all plains below the confluence of the Adelaide and Margaret rivers on the Adelaide River subject to annual flooding for extended periods.
Soils on levees and some prior streams adjacent to the Adelaide River main channel in the upper part are rarely flooded, having very deep (>1.5 m), well-drained, red-coloured massive loamy soils.
with moderately permeable subsoils. The red soils grade to frequently flooded, very deep (>1.5 m) mottled, brown loamy soils and friable loams in the vicinity of Tortilla Flats. These moderately permeable soils are well suited to horticultural crops that can withstand occasional to regular flooding.

Soils on the level alluvial plains in the upper catchments are predominantly imperfectly to poorly drained, slowly permeable, structured gradational soils with hard-setting clay loam to silty clay loam surfaces over sodic, mottled, grey or brown intractable clay subsoils. The plains are subject to occasional to regular flooding and may be subject to surface water ponding for extended periods. In the vicinity of Adelaide River town, the ratio of imperfectly drained to poorly drained soils is estimated to be 60:40. The proportion of poorly drained soils increases downstream where the ratio of imperfect to poorly drained soils at Tortilla Flats (Figure 4-4) above the confluence of the Adelaide and Margaret rivers is estimated at 30:70. Some seasonally wet cracking clay soils and loam over sodic intractable clay subsoils on the upper alluvial plains are suitable for dry-season irrigated cropping, particularly crops tolerant to wetness such as rice, sugarcane and forage crops.

The narrow plains may restrict paddock size and infrastructure lay-out in some areas. These seasonally wet soils require drainage works and surface levelling to improve surface and subsoil drainage. Soils are likely to be suitable for ring tanks.

Figure 4-4 Dryland hay on the Adelaide River alluvium downstream of Adelaide River town
Photo: CSIRO

Below the confluence of the Adelaide and Margaret rivers and in the Margaret River catchment, extensive areas of poorly drained, slowly permeable, poorly drained soils with hard-setting surfaces over mottle sodic intractable grey clay subsoils are subject to annual flooding.

The potential irrigation development outlined in Figure 4-3 predominantly comprises the loam soils on the levees, and the seasonally wet loams over intractable clay and cracking clay soils. The area would require more intensive assessment of usable areas before irrigation development
4.3.2 FARMING SYSTEMS

Rice is a unique crop in many ways, but, most notably, the crop can grow and thrive in waterlogged conditions. Rice is adapted to these conditions via aerenchyma within the rice stems. These are gas spaces that act like snorkels within the rice plant allowing gas exchange between the atmosphere and the rice roots. Plants without similar adaptions will experience severe yield reductions and even die under waterlogged conditions.

This adaption has benefits for rice production in difficult environments. Rice can be grown under normal irrigated conditions (periodic irrigation) or as a ponded crop. When grown as a ponded crop, rice will never experience water stress, so crop yields can be very high with more room for irrigator error relative to periodic irrigation. In terms of soil, plant available water capacity (a measure of how much water the soil can hold under aerated conditions) need not be high or considered at all. The most important soil characteristic is that the soil have low permeability to reduce deep drainage of applied irrigation water. Additionally, ponding can be used to eradicate many weeds from crop rotations. Where conditions at sowing time are likely to be wet, irrigation bays can be filled and rice sown aerially.

If rice is grown in rotation with other crops, it can be grown on permanent beds that can be flooded, or irrigation layouts that allows rapid drainage and irrigation, such as bankless channel designs. These designs allow for better drainage of crops when grown in rotation with rice. Rice will produce a thick mat of roots in the top 10 cm of the soil. This can stabilise soils and assist in improvement of soil structure and water penetration for rotation crops.

In this case study, rainfed soybeans are grown over the wet season to increase revenue. However, under Option 2, wet-season rainfed soybeans would not be grown adjacent to the Margaret River as a result of broad-scale flood risk to cropping over this period.

Approximately 130 ha of rice is currently being grown at Tortilla Flats on the Adelaide River alluvial plain in the case study area (Figure 4-5). The rice is irrigated with water from a ~4GL gully dam.

Water requirement

The water requirement for dry-season rice in the area for 20%, 50% and 80% exceedance values are 8.5, 8.1 and 7.5 ML/ha, respectively, with 60% of the water required in the August and September period (Ash et al., 2018b). Allowing for a requirement of 8.1 ML/ha and a field application efficiency of 80%, then 6.075 ML/ha would be required to be delivered in August and September (i.e. at a rate of nearly 0.1 ML/day). One of the advantages of having a major dam is that in years where the onset of the monsoon is late the land could be irrigated (i.e. 0.5 ML/ha) prior to planting the dryland soybean crop, thereby reducing the climate risk associated with dryland cropping.
Farm gross margin

A crop gross margin is the difference between the gross income and variable costs of growing a crop. It does not include overhead or capital costs; these must be met regardless of whether or not a crop is grown.

Variable costs (also known as direct costs) vary in proportion to farm activity. They include irrigation pumping costs along with other crop inputs such as costs of fertiliser, chemicals and harvesting.

Water charges are also a variable cost when charged on a $/ML basis but are omitted from the gross margin calculations presented in Table 4-1 because the break-even water cost is calculated as part of this analysis. Instead, as part of this financial analysis, farmers’ capacity to pay a water charge is determined. The crop gross margin is calculated using simulated crop yield and water use. For details on crop gross margin calculations, see the companion technical report on agricultural viability in the Darwin catchments, Ash et al. (2018b).

Table 4-1 Crop production parameters for dry-season rice and rainfed wet-season soybean

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<th>CROP</th>
<th>MEDIAN APPLIED IRRIGATION WATER</th>
<th>CROP YIELD</th>
<th>PRICE</th>
<th>VARIABLE COST</th>
<th>GROSS MARGIN</th>
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<td>(t/ha)</td>
<td>($/ha)</td>
<td>($/ha)</td>
<td>($/ha)</td>
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<tr>
<td>Rice (irrigated, dry season)</td>
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<td>9.7</td>
<td>$420</td>
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<td>$1755</td>
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<tr>
<td>Soybean (rainfed, wet season)</td>
<td>na</td>
<td>3.1</td>
<td>$475</td>
<td>$1247</td>
<td>$148</td>
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</tbody>
</table>

Values are taken as 50th percentile APSIM estimates for Vertosols companion. Variable costs of water paid by farmers to the water supplier are not included these gross margins, but are covered separately in financial analyses below.
4.3.3 CONFIGURATION OF WATER SUPPLY AND IRRIGATION

This section describes the configuration of the:

- dam
- reregulating structure and pump station
- irrigation development
- additional hard infrastructure requirements.

**Upper Adelaide River dam**

The potential Upper Adelaide River dam, as featured in Figure 4-6, is a roller compacted concrete dam, with a spillway 23 m above the river bed. The site is perhaps the most topographically favourable location for a dam in the Darwin catchments. The dam site is located on the Adelaide River 199.2 km from the mouth of the Adelaide River and about 3 km upstream of the Adelaide River town.

![Figure 4-6 Upper Adelaide River dam on the Adelaide River looking upstream](image)

In the Darwin catchments the Upper Adelaide River dam is second to the Mount Bennett dam site in terms of lowest cost per ML released from the dam wall. However, it is the most promising site when proximity to soils and quality of water flowing into the potential reservoir are also considered. The full supply level (FSL) or spillway height of the dam for this case study is assumed to 23 m (Table 4-2). This was calculated to be the optimal height for minimising the cost per ML released from the dam wall (Petheram et al., 2017). The Upper Adelaide River dam is likely to cost between $164 million and $237 million. With the town of Adelaide River immediately downstream, the dam was designed to accommodate a flood surge equivalent to the modelled probable maximum flood (Jordan et al., 2017).
Table 4-2 Upper Adelaide River dam parameters

<table>
<thead>
<tr>
<th>NAME</th>
<th>DAM TYPE *</th>
<th>SPILLWAY HEIGHT ABOVE BED (M)**</th>
<th>CAPACITY AT FSL (GL)</th>
<th>CATCHMENT AREA (KM²)</th>
<th>ANNUAL WATER YIELD (GL)***</th>
<th>CAPITAL COST# ($ MILLION)</th>
<th>UNIT COST## ($/ML)</th>
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<tr>
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<td>RCC</td>
<td>23</td>
<td>298</td>
<td>616</td>
<td>153</td>
<td>182</td>
<td>1190</td>
<td>88</td>
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</table>

* 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’. 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.
### Assuming a 7% real discount rate and a dam service life of 100 years. Includes operation and maintenance costs, assuming operation and maintenance costs are 0.4% of the total capital cost.

Configuration of water supply for Upper Adelaide River dam irrigation development

Option 1

Under this nominal conceptual configuration, water would be released down the Adelaide River from the Upper Adelaide River dam to two 3-m high stepped steel sheet piling weirs, one near the upstream limit of the irrigation area adjacent to the Adelaide River and the other near the downstream limit. The purpose of the sheet piling weirs is to limit transmission losses. Private pumps would divert water onto irrigation areas. The area of land within 2.5 km of the Adelaide River that is suitable for irrigated dry-season rice is about 6250 ha. A 7.5 km diversion pipeline from the second sheet piling weir on the Adelaide River would convey water to a terminal storage of 80 ML capacity (elevation 32 m) in the Coomalie Creek area, where there is about 1000 ha of land suitable for irrigated dry-season rice. Under Option 1, 6000 ha of land would be irrigated. Estimated conveyance and field efficiency values are provided in Table 4-3.

Option 2

This option encapsulates Option 1, however, the irrigation development is expanded across into the Margaret River catchment. Under this option water would be pumped from the weir pool behind the first weir on the Adelaide River via a 3-km rising main through a saddle into a 7.2-km long open channel, which discharges into Howley Creek in the Margaret River catchment. Several drop structures would be required in the first 2 km of the open channel. Water would then be allowed to run down Howley Creek and into the Margaret River to another 3-m high stepped steel sheet piling weir near the downstream limit of the irrigation area adjacent to the Margaret River. The area of land within 2.5 km of Howley Creek and the Margaret River that is suitable for irrigated dry-season rice is 8000 ha. However, this land is subject to broad-scale flooding during the wet season which would limit wet-season cropping (Figure 4-2). Under Option 2, 9000 ha of land would be development, 6000 ha adjacent to the Adelaide River and Coomalie Creek and 3000 ha adjacent to Howley Creek and the Margaret River. Estimated conveyance and field efficiency values are provided in Table 4-3.
Crop water use for dry-season rice is assumed to be 8.1 ML/ha before losses. Land use in Adelaide River and Coomalie Creek is dry-season rice and dryland soybean rotation. Land use in Margaret River catchment is dry-season rice only. Efficiency values are rounded.

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>OPTION 1 &amp; 2 ADELAIDE RIVER</th>
<th>OPTION 1 &amp; 2 COOMALIE CREEK</th>
<th>OPTION 2 HOWLEY CREEK AND MARGARET RIVERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adelaide River conveyance efficiency (%)</td>
<td>75</td>
<td>75</td>
<td>85</td>
</tr>
<tr>
<td>Channel and Margaret River distribution efficiency (%)</td>
<td>NA</td>
<td>NA</td>
<td>80</td>
</tr>
<tr>
<td>Field application efficiency (surface) (%)</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Overall efficiency (%)</td>
<td>60</td>
<td>60</td>
<td>55</td>
</tr>
<tr>
<td>Area of irrigation (ha)</td>
<td>5000</td>
<td>1000</td>
<td>3000</td>
</tr>
<tr>
<td>Crop water use before losses (ML/ha)</td>
<td>8.1</td>
<td>8.1</td>
<td>8.1</td>
</tr>
<tr>
<td>Annual volume of water required to be released from Upper Adelaide River dam (GL/y)</td>
<td>67.5</td>
<td>13.5</td>
<td>44.2</td>
</tr>
</tbody>
</table>

4.4 Project costs

4.4.1 IRRIGATION DEVELOPMENT AND FARM-SCALE COSTS

Irrigation development involves a wide range of capital, operation and maintenance costs. These are incurred at both the level of individual farms and the broader supporting infrastructure across the rest of the scheme.

- Off-farm scheme costs can be considered as being comprised of external costs and internal costs, and under this case study are incurred by the private/public water supplier.
  - External costs are associated with major infrastructure (e.g. dams, main roads), approvals (e.g. environmental impact statements) and delivery of water (e.g. main channel, regulating structures, pump stations) and electricity/energy (e.g. diesel generators or substations and transmission lines) to the irrigation development.
  - Internal costs are the subsidiary channels, drains, internal roads, structures, hillside drains, electricity. These costs are often reported as a representative cost per hectare basis as calculating these costs for a specific site requires detailed site data, typically undertaken as part of a feasibility analysis.

- On-farm capital, operation and maintenance costs are associated with developing farmland, irrigation systems and farm infrastructure and machinery. In this case study these are incurred by the irrigator.

Indicative capital, operation and maintenance costs associated with the construction of the Upper Adelaide River dam and associated irrigation infrastructure to enable riparian pumping along the Adelaide and Margaret rivers and Howley Creek are provided in Table 4-4. Costs of infrastructure are listed as a fixed price. These costs were obtained from information presented in Chapter 4 and
One of the advantages of the Upper Adelaide River dam for securing Darwin’s future urban and industrial water supply over many other potential dam options in the Darwin catchments is that by purchasing parts of two properties within the Upper Adelaide River dam’s catchment, Tipperary Station (88 km²) and Silkwood Downs (265 km²), it would be possible to close the catchment to the public, a desirable attribute for a water supply catchment. The remainder of the potential dam’s catchment is within Litchfield National Park, and this case study assumed that it would be possible to negotiate with the park’s managers to keep these parts of the park inaccessible to the general public.

Table 4-4 Pre-feasibility capital and operation and maintenance costs associated with Upper Adelaide River dam

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (Y)</th>
<th>CAPITAL COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam and catchment</td>
<td>Upper Adelaide River dam</td>
<td>100</td>
<td>182,000,000</td>
<td>0.4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Based on FSL of 23 m above river bed. See Petheram et al. (2017) for more details.</td>
</tr>
<tr>
<td>Additional land purchase to close catchment to public</td>
<td>na</td>
<td>16,400,000</td>
<td></td>
<td>Assuming land is purchased at $500/ha and that an additional 328 km² would need to be purchased (this excludes Litchfield National Park).</td>
</tr>
</tbody>
</table>

Table 4-5 provides a summary of the capital costs required to connect the Upper Adelaide River dam to the Strauss water treatment plant. It does not include the cost of the potential treatment plant, which would be required irrespective of any of the options being explored.

Table 4-5 Order of magnitude capital and operation and maintenance costs of conveying water from the potential Upper Adelaide River dam to the potential Strauss water treatment plant

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (Y)</th>
<th>OPTION 1 COST ($)</th>
<th>OPTION 2 COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital costs</td>
<td>Pipeline, pump station and power supply</td>
<td>40</td>
<td>$180,000,000</td>
<td>$159,000,000</td>
<td>1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Approximately 70 km of pipeline. 3 km easement from dam to highway. The majority of the pipeline can be laid along the Stuart Highway road corridor.</td>
</tr>
<tr>
<td>Operational costs</td>
<td>Pumping</td>
<td>na</td>
<td>$1,100,000/y</td>
<td>$526,000/y</td>
<td>na</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Estimated annual cost of pumping to proposed Strauss treatment plant, assuming annual power cost 30c/ kWhr</td>
</tr>
</tbody>
</table>

Table 4-6 provides an estimate of the capital and operation and maintenance costs associated with the development of the irrigation scheme infrastructure for the two options explored in this case study. As described in Section 4.2 Option 1 involves a 6000 ha development adjacent to the
Adelaide River and Option 2 includes an additional 3000 ha adjacent to Howley Creek and Margaret River.

Table 4-6 Estimated capital costs and operation and maintenance costs associated with the 6000 ha (Option 1) and 9000 ha (Option 2) irrigation areas

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (Y)</th>
<th>OPTION 1 CAPITAL COST ($)</th>
<th>OPTION 2 CAPITAL COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total direct construction (TDC) costs</td>
<td>Weirs and terminal storage</td>
<td>40</td>
<td>22,200,000</td>
<td>33,300,000</td>
<td>2%</td>
</tr>
<tr>
<td>Access roads and bridges</td>
<td>40</td>
<td>5,170,000</td>
<td>10,700,000</td>
<td>2%</td>
<td>Upgrade access roads.</td>
</tr>
<tr>
<td>Power supply</td>
<td>40</td>
<td>10,600,000</td>
<td>18,000,000</td>
<td>1%</td>
<td>Supply to and within farm areas and pump station, includes grid connection, substation/switchboards. Annual scheme-scale electricity usage is estimated to be $1.18 million assuming tariff is 30 c/kWhr for large scale business users.</td>
</tr>
<tr>
<td>Communications</td>
<td>40</td>
<td>300,000</td>
<td>500,000</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Pump stations</td>
<td>40</td>
<td>1,330,000</td>
<td>2,700,000</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Rising mains and cooling pipes</td>
<td>40</td>
<td>5,660,000</td>
<td>6,550,000</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Open channel to Howley Creek</td>
<td>40</td>
<td>na</td>
<td>3,300,000</td>
<td>1%</td>
<td>Includes fencing, control gates and road access bridges over channels.</td>
</tr>
<tr>
<td>On-site overheads (OSO)</td>
<td>On-site overheads</td>
<td>na</td>
<td>5,745,000</td>
<td>9,285,000</td>
<td>NA</td>
</tr>
<tr>
<td>Profit and off-site overheads</td>
<td>na</td>
<td>5,215,000</td>
<td>8,490,000</td>
<td>NA</td>
<td>10% of TDC and OSO</td>
</tr>
<tr>
<td>Owner costs</td>
<td>Investigation and design</td>
<td>na</td>
<td>2,320,000</td>
<td>3,780,000</td>
<td>NA</td>
</tr>
<tr>
<td>Acquisition and approvals</td>
<td>na</td>
<td>6,470,000</td>
<td>7,520,000</td>
<td>NA</td>
<td>Includes land environmental assessment and approvals, cultural heritage, native title, land acquisition, survey and legal.</td>
</tr>
<tr>
<td>Total project costs</td>
<td>Total project costs</td>
<td>na</td>
<td>$65,000,000</td>
<td>$105,670,000</td>
<td>$1,000,000 $2,400,000</td>
</tr>
<tr>
<td>Risk adjustment</td>
<td>na</td>
<td>$21,450,000</td>
<td>$34,540,000</td>
<td>NA</td>
<td>33% of total project costs</td>
</tr>
</tbody>
</table>
### Table 4-7 Farm-scale capital and operational costs

Costs as of 2017. Based on a 625 ha farm-scale irrigation development. Assumes all water, clearing, fauna, flora and native title approvals are captured in the scheme-scale approval costs and that scheme-scale costs include providing power to farm. Costs are rounded.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (Y)</th>
<th>COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Farm-scale costs: capital</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm setup costs</td>
<td>40</td>
<td>$1,300,000</td>
<td>1%</td>
<td>Includes internal roads, fences, houses, vehicles, workshops, domestic power supply, sheds.</td>
</tr>
<tr>
<td>Riparian pump and associated housing infrastructure</td>
<td>15</td>
<td>$350,000</td>
<td>2%</td>
<td>500 mm diameter axial flow pump with 150 kw electric pump and housing infrastructure.</td>
</tr>
<tr>
<td>Land preparation</td>
<td>100</td>
<td>$535,000</td>
<td>1%</td>
<td>Includes, survey and design, clearing and raking, internal roads, fences.</td>
</tr>
<tr>
<td>Irrigation system (surface)</td>
<td>15</td>
<td>$1,660,000</td>
<td>1%</td>
<td>Includes laser levelling, diversion structures, within farm channels and tail drains, recycling pit and associated pumps and pipes.</td>
</tr>
<tr>
<td>Cropping equipment</td>
<td>15</td>
<td>$640,00</td>
<td>1%</td>
<td>Includes tractors, rippers, boom spray, slasher, baler, zero till planter, mulcher, ploughs, fertiliser spreader.</td>
</tr>
<tr>
<td><strong>Total development cost</strong></td>
<td></td>
<td>$4,490,000</td>
<td>$114,000/y</td>
<td>Assumes annual O&amp;M costs are $48,000 and cost of electricity usage for riparian pumping $66,000, assuming tariff is 30 c/kWhr for large scale business users.</td>
</tr>
<tr>
<td><strong>10% contingency</strong></td>
<td></td>
<td>$450,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total development cost plus 10% contingency</strong></td>
<td>~$4,950,000</td>
<td>$114,000/y</td>
<td></td>
<td>Assumes annual O&amp;M costs are $44,000 and cost of electricity usage for riparian pumping $66,000.</td>
</tr>
<tr>
<td><strong>Farm-scale costs: operational</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overheads</td>
<td>na</td>
<td>$375,000/y</td>
<td></td>
<td>Overheads are $625/ha. This includes employee costs, general maintenance, lease fee and additional business overhead.</td>
</tr>
</tbody>
</table>
4.5 Project benefits

This section estimates the potential production benefits and regional economic benefits arising from the agriculture component of the scheme. Quantifying the project benefits arising from providing high security water for Darwin would require considerable additional case study specific analysis beyond the scope of the Assessment. Instead, the approach taken for urban water is to calculate the value of the urban water supply that would be required for the scheme to be commercially viable (and this could be compared against cost of alternative options for providing the same supply capacity of urban water: see Section 4.6).

4.5.1 POTENTIAL PRODUCTION

Gross benefits

The gross potential agricultural production was calculated by multiplying the mean area under irrigation and rainfed wet-season cropping by their respective crop yields and prices (Table 4-8).

Table 4-8 Summary of regional economic benefits of agriculture (recurring) arising from the irrigation development

<table>
<thead>
<tr>
<th>OPTION</th>
<th>DRY-SEASON IRRIGATED RICE</th>
<th>WET-SEASON RAINFED SOYBEAN</th>
<th>TOTAL ANNUAL REVENUE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (ha)</td>
<td>Revenue ($m/y)</td>
<td>Area (ha)</td>
</tr>
<tr>
<td>Option 1</td>
<td>6000</td>
<td>$24.4</td>
<td>6000</td>
</tr>
<tr>
<td>Option 2</td>
<td>9000</td>
<td>$36.7</td>
<td>6000</td>
</tr>
</tbody>
</table>

4.5.2 REGIONAL ECONOMIC BENEFITS

The overall regional economic benefit of the scheme, including the indirect and induced effects flowing from the initial construction phase and ongoing production from the scheme, were estimated using regional input-output (I-O) models. These estimates were based on the approach described in detail in the companion technical report on socio-economics (Stokes et al., 2017) and focused on the ongoing annual benefits generated from the increased dollar value of all outputs generated by the scheme, treating this increased output as an exogenous shock to the economy. This section also estimates the overall regional economic benefit of the one-off short-term stimulus from the initial capital investment in the construction phase of the scheme.

The basis of the approach is that businesses directly benefitting from the project will need to increase their purchases of the raw materials, labour and intermediate products used by their growing outputs. Should any of these purchases be made within the region, then this provides a stimulus to the businesses they purchase from, contributing to further economic growth and job creation within the region (the production-induced effect). Furthermore, household incomes increase as local residents are employed (as a consequence of either direct or production-induced business stimuli); a proportion of their additional income is spent in the region, which further stimulates greater economic activity and additional job creation (consumption-induced effects).

The dollar value of the increased total economic activity per year due to the operation of the scheme is estimated by using the exogenous increases in scheme gross revenue as an input to the regional I-O models developed from pre-existing I-O tables.
As outlined in the companion technical report on socio-economics (Stokes et al., 2017) each dollar of direct annual benefit from new agriculture (excluding beef) is estimated to generate an additional $0.46 in regional economic activity recurring annually and an additional one-off benefit of $1.06 for each dollar spent within the region during the construction phase of the scheme (after accounting for leakage, see Stokes et al. (2017)).

Based on the total scheme agricultural revenue presented in Table 4-8, the increase in regional economic activity arising from 6000 ha (Option 1) and 9000 ha (Option 2) of irrigated rice and rainfed soybeans is estimated to be about $48.6 million and $66.4 million, respectively. Note no attempt was made to quantify the project regional-scale benefits arising from providing high security water to Darwin.

According to the analysis presented in the companion technical report on socio-economics (Stokes et al., 2017) the number of additional direct and indirect jobs created by 6000 and 9000 ha of dryland rice and soybean is calculated to be 52 and 72. However, it should be noted that for the Darwin catchments these job numbers are likely to be an underestimate. This is because at the time of the creation of the I-O tables it is likely that a high proportion of the jobs on small mango and Asian vegetable farms were undertaken by backpacker and family labour, neither of which would have been picked up in household income statistics that underpin these employment estimates. There has since been substantial consolidation of horticulture in the region.

In addition to recurring annual benefits arising from annual revenue from the enterprise, there will be one-time benefits arising during the construction phase of the dam, water transfer infrastructure, irrigation area (both scheme-scale and farm-scale). The total construction costs are estimated to be about $510 million and $570 million for the 6000 ha (Option 1) and 9000 ha (Option 2) developments respectively. The one-time local regional benefits are summarised in Table 4-9 assuming half of the total construction cost is spent within the region. The companion technical report on socio-economics (Stokes et al., 2017) discusses a range of further cautions involved in the regional I-O analyses, so the estimates provided here should be used only as a broad indicator of the total regional benefits.

Table 4-9 Summary of regional economic benefits of the construction phase for a case study of a large dam on the Adelaide River, water transfer infrastructure and scheme-scale and farm-scale irrigation development

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNITS</th>
<th>OPTION 1</th>
<th>OPTION 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>$ million</td>
<td>525</td>
<td>585</td>
</tr>
<tr>
<td>Base -20%</td>
<td>$ million</td>
<td>420</td>
<td>470</td>
</tr>
<tr>
<td>Base +20%</td>
<td>$ million</td>
<td>630</td>
<td>705</td>
</tr>
</tbody>
</table>

4.6 Project commerciality

The financial analyses assumed that the overall scheme was divided into two separate groups of investors, the water supplier and the irrigators. The commerciality of supplying water from Upper Adelaide River dam for irrigated agriculture outlined in this case study was examined by
comparing i) the price a water supplier may need to charge for farm water to break even to ii) the price irrigators can afford to pay for irrigation water while breaking even.

The analyses assume that the water supplier pays all capital, operating and maintenance costs for the dam, conveyance and off-farm infrastructure (as itemised and summarised in Table 4-4, Table 4-5, and Table 4-6). The break-even price for irrigation water was calculated as the price the water supplier would have to charge farmers in order for the net present value (NPV) of the water supplier business to be zero, after accounting for the value of the urban water supply capacity. Break-even calculations used discount rates of 3%, 7%, and 10%. As discussed in Section 4.2 water supply capacity secured for urban and industrial users was assumed to have a ‘value’ of $1/kL, $2/kL and $3/kL delivered to the Strauss water treatment plant. In addition, the ‘value’ of urban water supply was also calculated for the whole scheme to break even (where the water supplier and farmers both break even at the specified discount rate). These values for urban water could be compared against alternate options for providing equivalent supply capacity and security.

The farmers capacity to pay for irrigation water considers the collective NPV of all farms accounting for all farm capital, maintenance and fixed costs (Table 4-7), farm gross margins (Table 4-1), and the price the water supplier charges for irrigation water. The price farmers could afford to pay for irrigation water was calculated as the water charge for the farm to break even (NPV = 0). The same ranges of discount rates and urban water ‘values’ were used as for the water supplier break-even pricing above. Where the price farmers can afford to pay exceeds the farm water price for the water supplier to break even, the overall scheme is deemed to be profitable at the specified discount rate and urban water value. The essential question asked here is, “what is the capacity of farmers to pay a charge for irrigation water such that water supplier business, and hence the whole development, is also viable?”. The possibility of different funding and operation models is recognised, but is beyond the scope of this case study. The results for Option 1 and Option 2 are presented in Table 4-10 and Table 4-11, respectively.

All financial analyses in this section are reported assuming a 30-year investment time frame (see the companion technical report on socio-economics, Stokes et al., 2017). A straight-line depreciation approach was used to calculate the residual value of infrastructure at the end of the 30-year period.
Table 4-10 Scheme financial performance (IRR) and farm water pricing for different combinations of discount rate and values for urban water supply for a case study of 30 GL of high security water for Darwin and 6000 ha dry-season irrigated rice and wet-season rainfed soybeans

The results for three discount rates and three values for urban water are presented. The urban water is ‘valued’ because this might not actually be charged and received as a revenue stream in practice. Farm water pricing is on the basis of what would be required for the scheme investor to break even (i.e. where the scheme NPV = 0) after accounting for the value of the urban water supply. This is compared against the price farmers can afford to pay (for farm NPV = 0). The break-even urban water price is the value for urban water where both the supplier and farmers would break even. Options where the scheme is profitable from urban water revenue alone are indicated by a farm water price of $0.00.

<table>
<thead>
<tr>
<th>INDICATOR</th>
<th>UNIT</th>
<th>URBAN WATER VALUE ($/kL)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Break even</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3% Discount rate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban water value</td>
<td>$/kL</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
<td></td>
<td>0.66</td>
</tr>
<tr>
<td>Farm water price for scheme to break even</td>
<td>$/ML</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td>67.30</td>
</tr>
<tr>
<td>Price farmers can afford to pay</td>
<td>$/ML</td>
<td>67.30</td>
<td>67.30</td>
<td>67.30</td>
<td>67.30</td>
<td>67.30</td>
</tr>
<tr>
<td>IRR</td>
<td>%</td>
<td>5.4</td>
<td>11.9</td>
<td>18.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td><strong>7% Discount rate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban water value</td>
<td>$/kL</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
<td></td>
<td>1.23</td>
</tr>
<tr>
<td>Farm water price for scheme to break even</td>
<td>$/ML</td>
<td>151.46</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td>46.29</td>
</tr>
<tr>
<td>Price farmers can afford to pay</td>
<td>$/ML</td>
<td>46.29</td>
<td>46.29</td>
<td>46.29</td>
<td>46.29</td>
<td>46.29</td>
</tr>
<tr>
<td>IRR</td>
<td>%</td>
<td>5.4</td>
<td>11.9</td>
<td>18.0</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td><strong>10% Discount rate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban water value</td>
<td>$/kL</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
<td></td>
<td>1.69</td>
</tr>
<tr>
<td>Farm water price for scheme to break even</td>
<td>$/ML</td>
<td>345.56</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td>29.00</td>
</tr>
<tr>
<td>Price farmers can afford to pay</td>
<td>$/ML</td>
<td>29.00</td>
<td>29.00</td>
<td>29.00</td>
<td>29.00</td>
<td>29.00</td>
</tr>
<tr>
<td>IRR</td>
<td>%</td>
<td>5.4</td>
<td>11.9</td>
<td>18.0</td>
<td>10.0</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-10 shows that under Option 1, for a 7% discount rate and an urban water value of $1/kL farmers can afford to pay $46.29/ML and the water supplier would need to charge $151.46/ML to break even on capital and operation and maintenance costs. Hence the development is unlikely to be viable without third party assistance. However, if the urban water value increased to $2/kL the farmers could still afford to pay $46.29/ML, but the scheme operator would not need to charge irrigators for the water (i.e. farm water price for scheme to break even is $0/ML) for the scheme to be profitable at a 7% discount rate because the value of 30 GL of water ‘secured’ annually for urban water would cover the entire capital and O&M costs of supplying all water for urban, industrial and farm users.
Table 4-11 Scheme financial performance (IRR) and farm water pricing for different combinations of discount rate and values for urban water supply for a case study of 15 GL of high security water for Darwin and 9000 ha dry-season irrigated rice and 6000 ha of wet-season rainfed soybeans

The results for three discount rates and three values for urban water are presented. The urban water is ‘valued’ because this might not actually be charged and received as a revenue stream in practice. Farm water pricing is on the basis of what would be required for the scheme investor to break even (i.e. where the scheme NPV = 0) after accounting for the value of the urban water supply. This is compared against the price farmers can afford to pay (for farm NPV = 0). The break-even urban water price is the value for urban water where both the supplier and farmers would break even. Options where the scheme is profitable from urban water revenue alone are indicated by a farm water price of $0.00.

<table>
<thead>
<tr>
<th>INDICATOR</th>
<th>UNIT</th>
<th>URBAN WATER VALUE ($/kL)</th>
<th>Break even</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>3% Discount rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban water value</td>
<td>$/kL</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Farm water price for scheme to break even</td>
<td>$/ML</td>
<td>121.75</td>
<td>0.00</td>
</tr>
<tr>
<td>Price farmers can afford to pay</td>
<td>$/ML</td>
<td>60.86</td>
<td>60.86</td>
</tr>
<tr>
<td>IRR</td>
<td>%</td>
<td>1.7</td>
<td>5.0</td>
</tr>
<tr>
<td>7% Discount rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban water value</td>
<td>$/kL</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Farm water price for scheme to break even</td>
<td>$/ML</td>
<td>306.51</td>
<td>142.87</td>
</tr>
<tr>
<td>Price farmers can afford to pay</td>
<td>$/ML</td>
<td>38.30</td>
<td>38.30</td>
</tr>
<tr>
<td>IRR</td>
<td>%</td>
<td>1.7</td>
<td>5.0</td>
</tr>
<tr>
<td>10% Discount rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban water value</td>
<td>$/kL</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Farm water price for scheme to break even</td>
<td>$/ML</td>
<td>455.34</td>
<td>291.71</td>
</tr>
<tr>
<td>Price farmers can afford to pay</td>
<td>$/ML</td>
<td>19.75</td>
<td>19.75</td>
</tr>
<tr>
<td>IRR</td>
<td>%</td>
<td>1.7</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Under Option 2, for a 7% discount rate and an urban water value of $2/kL, the capacity of farmers to pay a water charge is lower ($38.30/ML) because rainfed soybean cannot be grown during the wet season on the additional 3000 ha of land due to flood risk, thereby reducing the overall crop revenue per hectare. Furthermore the farm water price for the water supplier to break even is higher (i.e. $142.87/ML under Option 2 versus $0/ML under Option 1) primarily because the total value of water secured for urban use under Option 1 (30 GL) is twice the total value of water secured for urban use under Option 2 (15 GL).

Under Option 1 the break-even value of urban water for the scheme to be viable (i.e. where irrigators could afford to pay the farm water price required for the water supplier to also break even) are $0.66/kL, $1.23/kL and $1.69/kL for 3%, 7% and 10% discount rates respectively. Under Option 2 the break-even values of urban water are considerably higher $1.37/kL, $2.64/kL and $3.66/kL for 3%, 7% and 10% discount rates respectively.
It should be noted, under this model of operation the financial analysis assumes that water made available by the water supplier will be immediately purchased by irrigators. In reality there will be a time lag between the completion of the scheme-scale infrastructure and full uptake of the available water (i.e. this model operates on the assumption that if you build they will come).

4.7 Project impacts

This section provides an overview of aquatic, riparian and near-shore marine assets in the Darwin catchments (Section 4.7.1) and how they may be impacted by water resource development (Section 4.7.2). A summary of other potential impacts is provided in Table 4-12.

The area would require more intensive assessment of any ecological impacts based on the specifics of a proposal prior to irrigation development.

4.7.1 SUMMARY OF ASSETS

The Adelaide catchment contains the Adelaide River coastal floodplain, which is a large seasonally inundated floodplain. The floodplain has tidal and seasonal wetlands habitats, fringed by open woodlands and pockets of the monsoon vine forest. It is part of a broad floodplain complex, which supports a variety of landscapes and ecosystems, with large populations of some of northern Australia’s most iconic wildlife species, such as saltwater crocodiles, magpie geese and barramundi. The floodplain supports a large number of waterbirds. The Adelaide River also provides habitat to the freshwater sawfish, the northern river shark and the speartooth shark.

Ecological assets in the Darwin catchments are described in detail in the companion technical report on asset descriptions, Pollino et al., (2018a).

4.7.2 POTENTIAL AQUATIC, RIPARIAN AND NEAR-SHORE MARINE IMPACTS OF UPPER ADELAIDE RIVER DAM AND IRRIGATION AREA

Major instream dams are efficient at capturing water. However, they can dramatically change the flow patterns immediately downstream of the dam wall. The companion technical report on ecological asset analysis, Pollino et al., (2018b) provides a detailed description of the method of assessment and potential ecological impacts arising from perturbations to streamflow.

The potential Upper Adelaide River dam has potential to have a major localised impact on species and their flow habitat immediately downstream of the dam wall. The river reach between the dam wall and the two regulating structures on the Adelaide River will have permanent water and streamflow during the dry season (i.e. growing season of rice) will be higher than without development, and will be lower during the wet season than without development. This is likely to have a major impact on the flow habitat of several species and has the potential to exacerbate weeds, such as hymenachnem, mimosa and para grass. Furthermore the potential Upper Adelaide River dam and downstream reregulating structure present barriers to the movement of sediment, food and diadromous fish.

With distance downstream from the dam and the point of water extraction, the seasonality of streamflow increasingly resembles the natural pattern of streamflow. Immediately below the second regulating weir on the Adelaide River (81700050, Figure 4-7) there is a moderate impact to
the flow habitat of migratory fish, sawfish, stable flow spawners and waterholes. However, several kilometres downstream (Figure 4-8), below the confluence of the Adelaide and Margaret rivers the impact to the flow habitat of these species is minor. At the catchment outlet (i.e. end-of-system, Figure 4-9) there is minor impact to the flow habitat of crocodiles, barramundi and sawfish. There is no change to the flow habitat to other marine and estuarine species.

Under Option 2 modifications to streamflow will also occur in Howley Creek and the Margaret River upstream of the confluence with the Adelaide River (changes to flow habitat not shown here). Furthermore, the reregulating structure on the Margaret River may impede the movement of aquatic species in the Margaret River system, depending upon the efficiency of the fish ladder.

![Figure 4-7](image_url)

**Figure 4-7 Assessment of change in flow metrics for assets at assessed location 81700050 in the Adelaide catchment**

Assessment location shown on Figure 1-3.
Figure 4-8 Assessment of change in flow metrics for assets at assessed location 81700200 in the Adelaide catchment. Assessment location shown on Figure 1-3.
4.7.3 OTHER POTENTIAL IMPACTS

This section provides a high-level overview of some of the potential on-site and off-site impacts that may result from the 6,000-ha irrigation and dam development outlined in this case study.

Table 4-12 Summary of other selected considerations impacted by the 6000 ha irrigation and dam development

<table>
<thead>
<tr>
<th>ECOLOGICAL AND SOCIAL CONSIDERATIONS</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment infill of reservoir</td>
<td>Modelling predicts that about 0.6% (range of between 0.1 and 0.9%) of the storage volume of Upper Adelaide River dam reservoir will infill with sediment after 30 years, and 1.9% of the storage volume will infill with sediment after 100 years (Petheram et al., 2017).</td>
</tr>
<tr>
<td>Storage impacts on property and infrastructure</td>
<td>A storage at the Upper Adelaide River dam site would inundate sections of the Litchfield Park area, which is managed by the Northern Territory Conservation Land Corporation. The balance of the storage would inundate part of the Silkwood Downs, a pastoral lease with few existing improvements.</td>
</tr>
<tr>
<td>Terrestrial ecology</td>
<td>At the Upper Adelaide River dam site, three endangered species are listed under the Northern Territory Parks and Wildlife Conservation Act, the critically endangered northern quoll (Dasyurus hallucatus), the vulnerable red goshawk (Erythnornis radiatus) and partridge pigeon (Geophaps smithii). Each could be impacted by loss of habitat as a result of inundation by the reservoir. Cane toads are listed as a key threatening process for the northern quoll. Creation of new sources of water may increase breeding opportunity for cane toads.</td>
</tr>
</tbody>
</table>
### ECOLOGICAL AND SOCIAL CONSIDERATIONS

<table>
<thead>
<tr>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sediment, nutrient and pesticide loads from irrigation development</strong></td>
</tr>
<tr>
<td>Increased input of nutrients can boost primary production. Irrigation development that increases the input of sediment into rivers can impact aquatic habitat structure and increased turbidity can shift aquatic community types. Large dams may retain colloidal sedimentary material washed in during rain and flow events, in suspension for some time (e.g. Burdekin Falls Dam – see Burrows (1999)). If trapped sediment remains suspended well into the dry season, there is potential for released water to elevate the turbidity of downstream receiving environments – the ecology of these waters is particularly susceptible to impacts from even small increases in turbidity.</td>
</tr>
<tr>
<td><strong>Secondary salinity</strong></td>
</tr>
<tr>
<td>Due to the absence of a source of salt in the landscape and because water sources are typically fresh, the risk of irrigation-induced salinisation in the Darwin catchments was deemed to be low and consequently no further assessment of salinity risk was undertaken.</td>
</tr>
<tr>
<td><strong>Bio-security, weeds and pests</strong></td>
</tr>
<tr>
<td>Irrigated agriculture in the Darwin catchments will be exposed to existing and new pests and diseases. Although a tropical environment is conducive to a wide range of pests and diseases, the long dry season and the loss of green vegetation that characterises the Darwin catchments provide an unfavourable environment for many pests and diseases 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. Identifying potential pest and disease problems that can occur in greenfield agricultural areas can be problematic. The warmer, north Australian environment provides a more favourable environment in which insects and pathogens can 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 risk of arrival of fungal pathogens and insect pests directly from South-East Asia into the Darwin catchments is small and only during a relatively narrow period. Wind dispersal modelling work undertaken in the Assessment shows that there is no risk from a fungal pathogen or insect pest landing in the Darwin catchments from Sumatra or the middle and northern coast of Papua. The greatest risk of a fungal pathogen arriving to this region is from the southern coasts of Papua New Guinea and Timor-Leste. For insect pests, the only threat is from Indonesia and Timor-Leste. Where risks exist they are only present for part of the year. From late April to late September, the prevailing winds are generally southerlies through to easterlies, i.e. blowing offshore.</td>
</tr>
<tr>
<td><strong>Indigenous land tenure, native title and cultural heritage considerations</strong></td>
</tr>
<tr>
<td>Substantial land in the area is subject to current or future native title claims. A number of registered and/or recorded sacred and cultural heritage sites are known to exist in the inundation area. There is a high likelihood of currently unrecorded sites. Large instream dams were not a favoured form of development of Indigenous people in the Darwin catchments. See companion technical report on Indigenous water values, rights, interests, and development objectives for more information, Barber (2018).</td>
</tr>
</tbody>
</table>
5 Groundwater in the Wildman catchment and irrigated horticulture

In this case study the potential for an irrigation enterprise involving a groundwater development and 500 ha of irrigated bananas was investigated in the Wildman catchment, 200 km east of Darwin (Figure 5-1). The enterprise would provide bananas to the Australian domestic market and look to capitalise on any sudden drop in production from the Australian banana industry, which is currently heavily concentrated on the north-east coast of Queensland between Tully and Cairns.

Figure 5-1 Schematic diagram illustrating the components of the case study envisaging groundwater development for 500 ha of irrigated bananas at Wildman Station

The feasibility of this irrigation development is analysed with respect to:

- the physical capacity for the underlying groundwater system to supply water to soils suitable for banana production
- the capacity of the development to generate positive net revenues
- potential impacts on several nearby groundwater-dependent monsoon vine forests.

The financial analysis for this case study investigates whether the projected revenue from the sale of bananas is sufficient to cover the costs of irrigation development and banana production. The case studies are indicative only.
In presenting this case study, no consideration is given to legislative issues that need to be addressed for any development of this scale to proceed. This includes, but is not limited to, legislation relating to land tenure, planning and infrastructure, cultural heritage, native title, vegetation management, wildlife protection, water resources, and environmental protection.

In undertaking this analysis the case study drew on material from the companion technical reports on hydrogeological characterisation (Turnadge et al., 2018a) and groundwater flow modelling (Turnadge et al., 2018b) in the Mary–Wildman rivers area, and the companion technical reports on climate (Charles et al., 2016), agricultural viability (Ash et al., 2018b) and socio-economics (Stokes et al., 2017).

5.1 Summary

The case study concludes that the physical conditions exist to enable a groundwater development for irrigated banana production.

• The interconnected sand and dolostone aquifers in the Wildman catchment are physically capable of supplying a total of 5 to 10 GL of good quality groundwater from several small-scale localised developments, each of 1 to 3 GL. Extracting 6 GL of groundwater from these systems would require about 12 bores, which would cost approximately $2.2 million to install and fit with pumps, which is a capital cost of about $365/ML.

• The delivery of water to the crop would be highly efficient (greater than 85%), predominantly due to the coincidence of groundwater and suitable soils and the use of expensive but efficient modern drip-tape capable of applying sufficient irrigation water during periods of peak demand.

• More than 25,000 ha of soils Class 3 (moderately suited with considerable limitations) or better for trickle irrigated banana production were identified north of the Arnhem Land Highway between the Mary River floodplain and Kakadu National Park. Under adequate irrigation, the sandy soils of the case study area (i.e. Red Kandasols) could support mean banana yields of about 3400 cartons/ha at full production potential.

• The total capital cost of 500 ha irrigation development and groundwater infrastructure is estimated to be $14.85 million, or $29,700/ha.

• Assuming 3400 cartons of bananas are produced per hectare over the 500 ha development, this is an annual production of about 1.7 million cartons of bananas. This is approximately equal to the number of bananas sold to the Adelaide market.

• Under the conditions examined in this case study and assuming a weighted mean wholesale price of $19.90/carton in Adelaide (assuming 40% of saleable bananas were seconds), the groundwater and irrigation developments are shown to be capable of achieving a gross margin of $5661/ha, which can generate an internal rate of return (IRR) of greater than 20% over a 15-year investment period. At a price of $17.75/carton (~10% reduction in weighted mean price) the IRR is 7%.

• Bananas, like most horticultural crops, have very high input costs as well as high gross incomes, and consequently the gross margins are highly sensitive to yield and particularly wholesale price. For example, a 15% reduction in yield and price results in the gross margins reducing to $2923/ha and –$885/ha respectively. This highlights that to be profitable the enterprise needs to be a carefully and skilfully managed operation, and although bananas are considered
relatively price inelastic, even just a small reduction in wholesale price of bananas in Adelaide (i.e. resulting from an oversupply of bananas) can considerably impact the profitability of the enterprise.

- Bananas are also sensitive to transport cost. The additional cost of transporting bananas to Melbourne combined with lower wholesale prices in Melbourne (~75% of Adelaide price) results in a negative gross margin for bananas produced in the Darwin catchments. These results serve to highlight the importance of understanding horticultural and niche crop markets.

- With 90% of the Australian banana industry being located on the north-east Queensland coast and imports of bananas to Australia being subject to quarantine restrictions, banana prices increased seven-fold following cyclone Larry (2006) and Yasi (2011). Although these short periods can be highly profitable, over a 15-year investment period their frequency is such that they make viable enterprises more profitable rather than making unviable enterprises profitable.

- Approximately 24 distinct groundwater-dependent monsoon rainforest patches have been mapped as occurring within a 10-km radius of the potential development. Soil vegetation atmosphere transfer modelling indicated that an increase in the depth to groundwater of 2 m beneath these rainforest patches would result in a 2% and 10% reduction in leaf area index and transpiration, respectively. These values are within the range of natural variation and are likely to have minor impacts on the composition and function of these patches over the long term. Reductions in leaf area index of about 7% and 14% and reductions in stand transpiration of 22% and 36% occur when groundwater levels fall by 5 and 10 m, respectively. Consequently, a reduction in groundwater levels of 5 m and 10 m are likely to result in a moderate and major change, respectively, in composition and function over the long term.

- Under the configuration of bore infrastructure examined in this scenario, and extracting 9 GL/year of water, approximately half of the monsoon rainforest patches were modelled as experiencing some drawdown in groundwater levels as a result of the development. Of these, however, only one patch experienced a drawdown of more than 2 m. At this patch, a groundwater drawdown of about 10 m occurred.

5.2 Storyline for this case study

This case study investigates the viability of a 500-ha banana plantation in the Wildman catchment, 200 km east of Darwin. The development is based on groundwater sourced from interconnected sand and dolostone aquifers that underlay parts of the area. The bananas would be supplied locally to Darwin and transported to southern markets, taking advantage of seasonal backloading opportunities from Darwin.

Over the last 10 years the banana industry in the Northern Territory has experienced severe reduction in production due to banana freckle fungal disease and soil-borne Panama Tropical Race 4 (TR4) disease. While the Northern Territory industry is recovering and the Northern Territory Government is trialling TR4 resistant varieties the location of the Wildman catchment is a good distance (~200 km) from where TR4 outbreaks occurred.

Currently more than 90% of Australia’s bananas are grown on a 150-km section of the north-east coast of Queensland between Tully and Cairns. In recent years this coast, and the banana industry,
has been badly affected by large, severe tropical cyclones, notably Larry and Yasi. On both occasions the price of bananas increased substantially over the 12-month period subsequent to the cyclones, with southern market prices peaking at seven times the default or mean price. The case study investigates the potential for a geographically remote location to capitalise on the availability of reliable water supply and good soils, as well as the occurrence of brief periods of major loss of production in the highly geographically concentrated banana industry.

In the northerly Darwin catchments, the high annual rainfall totals and high seasonality of rainfall means that during the course of the wet season, in many areas, groundwater levels rise to the surface and no further recharge may occur, with all excess water (i.e. non-transpired water) becoming overland flow. Current Northern Territory Government policy is to legislate a maximum of 20% of groundwater recharge or instantaneous flow to be allocated for consumptive use (in the absence of science showing negative impacts). However, groundwater-dependent monsoon vine forests and springs exist relatively close to the case study area. Consequently the case study will simultaneously examine the potential impacts of groundwater drawn down, particularly towards the end of the dry season, on the monsoon vine forests.

5.3 Case study and study area description

The Wildman River case study area is located approximately 100 km east of Darwin and 110 km west of Jabiru. The case study area shown in Figure 5-2 is the area is bounded in the west by the Mary River and in the east by Kakadu National Park. The area is bounded to the south by a geological basement high.

The area is sparsely populated, with land use mostly limited to cattle grazing and conservation. Four cattle stations currently manage the majority of the case study area:

- Opium Creek Station (NT Land Portion 2707), which includes areas located both west and east of the Point Stuart Road
- the area informally known as the cashew farm (NT Land Portion 5088), which is currently managed in combination with NT Land portions 2623, 2624, and 3611 (the latter known informally as Periscope Block)
- Melaleuca Station (NT Land Portion 2708)
- Carmor Plains Station (NT Land Portion 2710).
Data used to develop the flood map were captured using Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery. This figure illustrates the maximum percentage of MODIS pixel inundated between 2000 and 2015.
The remainder of the case study area is encompassed by two conservation areas: Mary River National Park (NT Land Portion 2622) in the south-west, and Kakadu National Park (NT Land Portion 4061) in the east. Mary River National Park includes a number of ephemeral creeks that discharge to the Mary River in the west. The cashew farm area is the site of an old commercial cashew tree plantation that was developed during the 1980s and 1990s. This area also contains the Twin Sisters Lagoons, which are the largest persistent surface water features present in the case study area.

5.3.1 SOIL AND LAND SUITABILITY FOR SMALL-SCALE IRRIGATION

The Wildman River case study area (Figure 5-2) is comprised largely of low relief, deeply weathered Tertiary plateaus and plains and sloping margins above wet alluvial plains and swamps between the Mary River and Kakadu national parks, north of the Arnhem Highway. The elevation of the plains increases gradually towards the south to form low plateaus then drop away at the plateau margin to expose the underlying mainly metamorphic geologies comprising rocky low hills and rises. The soils of the area are shown by the soil generic group (SGG) map in Figure 5-4a and described below. Figure 5-4b shows a land suitability map for bananas under trickle irrigation.

The poorly drained texture contrast soils, sandy soils and other wet soils on frequently flooded alluvial plains and swamps that dissect the case study area are unsuitable for bananas. The low hills and rises to the south and south-east are dominated by shallow gravelly soils with rock outcrop on upper slopes with no potential for irrigated bananas. Some areas of imperfectly drained to moderately drained deeper soils on lower slopes may be suitable for irrigated bananas but short slopes and frequent creeks generally result in small usable areas that would restrict field size and infrastructure layout.

Soils of the low relief plains and plateaus are predominantly well-drained, moderately permeable, red, massive, gradational loams. Soil depth here varies considerably, with very deep (>1.5 m) well-drained soils occurring on the plains and plateaus while shallow to moderately deep (0.25–1.0 m) well-drained to moderately well-drained soils with abundant iron nodules and iron pans frequently occurring on the margins of the plains, plateaus and rises and on mid to lower slopes. Exposed laterite is common. Imperfectly drained, moderately permeable, mottled brown loamy soils and poorly drained, seasonally wet sands occur on lower slopes.

The deep to very deep (>1 m), gently sloping (<3%), well-drained red soils with few to moderate amounts (<20%) of iron nodules in the profile are suitable for irrigated bananas. The moderately deep (0.5–1 m) well-drained to moderately well-drained soils that contain abundant (>20%) iron nodules are generally suitable for bananas using trickle irrigation, while these soils are generally marginal to unsuitable for spray-irrigated bananas due to very low plant available soil water capacity. The depth to ferruginous pans and weathered rock restricts crop rooting depth, irrigation layout and machinery use in some areas, particularly on the plateau margins and areas grading to the drainage lines. The shallow to very shallow soils (<0.5 m) and the imperfectly drained to poorly drained soils on lower slopes are generally unsuitable for banana development.
All well-drained to moderately well-drained loamy soils are typically strongly acid and nutrient deficient, and hence irrigated cropping requires very high fertiliser inputs, especially on newly developed areas. After the initial high application, fertiliser rates follow recommended annual crop requirements. Irrigation potential is limited to spray- and trickle-irrigated bananas on the moderately deep to deep soils with low to moderate soil water storage (50 to 100 mm) and fewer iron nodules. Erosion control management is required on sloping lands. The potential irrigation development outlined in Figure 5-4 predominantly comprises the deep to very deep red loamy soils.

It is estimated there are 2,300 ha of Class 2 land and 24,400 ha of Class 3 land overlying the Koolpinyah dolostone and Basal sand units in the vicinity of the cashew farm in the Wildman catchment.

*Figure 5-3 Well-drained deep loamy red soils at the Cashew farm, Wildman catchment*  
*Photo: CSIRO*
Figure 5-4 (a) Soil generic group and (b) land suitability for bananas under trickle irrigation
The land suitability map does not take into consideration flood risk, secondary salinity or water availability.
5.3.2 BANANAS

In the Mary–Wildman rivers area, bananas would be established under trickle or micro irrigation, taking advantage of favourable red loamy soils and local groundwater systems that experience high recharge and favourable bore yields. Although supplying sufficient water to meet peak evaporative demand using trickle irrigation may have once been challenging, it is not an issue for modern well-designed trickle systems, though the per hectare costs are higher than sub-optimal systems. Bananas are planted vegetatively, usually from tissue cultured material. Subsequent to harvest of the first bunch, next crops are cultivated from selected sword suckers from the parent plant, each producing a bunch of bananas in turn. These are termed ‘ratoon’ crops and typically three to four of these would be used before a short (~3 months) fallow and replanting. The development of bunches from suckers is faster than the parent crop, and beyond the parent crop harvest becomes increasingly asynchronous. This means harvest becomes increasingly constant in time, assisting with continuity of labour demand and income.

Climate suitability

Bananas are commonly grown in tropical regions of the world at latitudes less than 20°. Temperature variations are smaller in these regions, particularly close to the coastline. Bananas are sensitive to both low and high temperatures as well as very dry air. Furthermore, bananas are susceptible to wind damage. For this reason, production is more favourable close to the equator where tropical cyclones are less prevalent.

Where water and nutrients are not limiting, banana growth and yield is largely limited by temperature. Using mean daily temperature, leaf emergence is limited below 16 °C and little growth is expected below 14 °C (Turner and Lahav, 1983). The overall mean temperature considered optimum for banana growth and leaf emergence ranges between 22 and 31 °C (Robinson and Sauco, 2010). It can be seen from Figure 5-5 that the temperature regime in the area is very well suited to banana production. Figure 5-6 and Figure 5-7 illustrate key climate parameters at Wildman Station.
Water use

Bananas have a high demand for water. Water use of 25 mm/week is considered a minimum for satisfactory growth, and an annual rainfall above 2000 mm evenly distributed throughout the year is considered satisfactory for rainfed (i.e. non-irrigated) bananas. Irrigation would be required for most of the year in the Mary–Wildman rivers area since rainfall is highly seasonal (Figure 5-6). During periods of peak evaporative demand (i.e. 3-day average) it may be necessary to be able to supply 10 mm per day assuming a system capacity of 0.85 (i.e. that the groundwater pumps and irrigation system will be in operation 20 hours in a 24-hour period). Properly designed modern trickle irrigation systems are easily capable of supplying sufficient water during periods of peak evaporative demand in northern Australia.

An advantage of the cashew farm area is its proximity to the Twin Sisters Lagoon for which there is a 4 GL surface water allocation. Pumping water from the lagoon to complement groundwater during periods of peak evaporative demand could mean groundwater pumping infrastructure would not need to be designed to meet the relatively short periods of peak evaporative demand (i.e. reducing capital costs). If surface water was only sourced from the lagoon to help meet peak evaporative demands the volume of water extracted from the lagoon would be modest.

Susceptibility to wind damage

Bananas are susceptible to wind damage largely because of their morphology, in particular the trunk-like pseudo-stem that is actually a rolled leaf. The pseudo-stem supports the weight of the developing fruit and often needs to be ‘propped’ with wooden supports to prevent collapse of the stem prior to harvest. This is particularly the case for taller varieties. Cyclones have caused large-
scale destruction to banana plantations in the Innisfail–Tully region of north-east Queensland. Because of the asynchronous nature of production the shorter, developing daughter or follower suckers are usually damaged to a lesser degree, allowing reasonably fast recovery from wind damage. This is not the case, however, for very high wind speeds experienced in severe tropical cyclones where parent and all follower pseudo-stems may be snapped. In some cases the entire rhizome of the banana plant may be uprooted, necessitating replanting. Analysis of cyclone data in the Assessment area indicates that the Darwin catchments experience a tropical cyclone frequency of 0.57 cyclones per year (Charles et al., 2016). Over the same period of investigation, the Mitchell catchment experiences 1.02 cyclones per year. Assuming that the Mitchell catchment is reasonably representative of the Tully–Innisfail banana growing area, the region around the Darwin catchments have around half the incidence of cyclones. The incidence of severe cyclones is 0.09 per year in the Darwin catchments while the Mitchell catchment experiences 0.28 severe cyclones per year (Charles et al., 2016).

**Applied irrigation water and crop yield**

Mean applied irrigation water requirement for bananas under trickle irrigation after losses, calculated using the FAO56 method (Allen et al., 1998), was estimated to be 11.7 ML/ha (assuming irrigation efficiency of 90%). Using the same analysis (run over 125 years), 80% exceedance annual irrigation requirement was estimated at about 10.5 ML/ha, while 20% exceedance annual irrigation requirement was 12.8 ML/ha. Such a narrow range of irrigation largely reflects the consistently low rainfall totals during the dry season. Assuming an annual allocation of 6000 ML of groundwater, the maximum area that could be irrigated is about 500 ha. Yields at potential production is estimated to be 3400 cartons/ha assuming four ratoons. Full irrigation and optimal management of disease and nutrition is assumed. Micro irrigation is utilised, allowing high water use efficiency, and other management advantages including fertigation. Additionally, micro irrigation may have yield benefits of up to 30% over sprinkler systems (Robinson and Alberts, 1987), though this is not assumed in this case study.

Assuming 3400 cartons of bananas are produced per hectare over the 500-ha development, this is an annual production of about 1.7 million cartons of bananas. This is approximately equal to the number of bananas sold to the Adelaide market (assuming the per capita banana consumption in Adelaide is similar to the Australian average).
Figure 5-6 Long-term fortnightly climate variation in rainfall, maximum and minimum temperatures under the historical climate (1890 to 2015)
Data sourced from SILO. Whiskers on box plots show 10% and 90% exceedance values.
Crop gross margins

Bananas are a high-yielding, high-input commodity and profitability is, therefore, very sensitive to wholesale prices. This case study assumes that all bananas will be supplied to the Adelaide market where mean wholesale prices for Cavendish bananas was $22.70/carton over the 2012–2018 period. Cavendish seconds were $15.60/carton across the same period. Assuming that 40% of
saleable bananas were seconds, the weighted mean price was $19.90/carton. Assuming a yield of 3400 cartons/ha, gross income for bananas is $60,894/ha.

Cartage costs are a major consideration for horticulture crops. Backloading rates may be available at around $200/pallet (70 cartons/pallet) to Adelaide, while standard cartage is $326/pallet (a pallet weights about 910 kg). However, backloading relies on the availability of refrigerated trailers, which are in high demand across the summer months (November to May). Thus, it is assumed that backloading rates are only available in the June to October period, and as a result the weighted mean cartage cost to Adelaide is $273/pallet. High gross income is largely balanced by cartage costs, levies, commission, storage plus variable inputs including labour, and packaging of $55,233/ha. Because of the high input cost and high gross income, gross margin is particularly sensitive to yield and even more so to commodity price. For example, a 15% reduction in yield from potential production of 3400 cartons/ha reduces the gross margin from $5661/ha to $2923/ha. Assuming no change in yield, a 15% reduction in price reduces the gross margin from $5661/ha to –$885/ha.

Very large spikes in domestic banana prices have been experienced as a result of large, severe cyclones in Australia’s main banana growing region in the Tully–Innisfail area of north Queensland (Figure 5-8). Most notable of these cyclones were Larry and Yasi in 2006 and 2011, respectively. The scale of destruction of these cyclones severely reduced banana supply, resulting in large price spikes in the months following these events. It should be noted here that, at present, importation of bananas to Australia is banned due to biosecurity concerns. Should these quarantine restrictions be removed the spikes in price following severe tropical cyclones along the Tully–Innisfail coastline would be considerably dampened, and furthermore it is likely the baseline prices and patterns would be different.

This case study assumes that all bananas can be supplied into the Adelaide market at historical Adelaide prices. However, it is likely that the volume of bananas produced by a 500-ha development at Wildman will result in an over-supply of bananas in the Adelaide market. Although bananas are considered relatively price inelastic, as shown above, even a reduction in price by as little as 15% can reduce gross margins from $5661/ha to –$885/ha.
Transporting some or all of the bananas to the larger market of Melbourne rather than Adelaide results in negative gross margins because wholesale prices in Melbourne market are on average 75% of the Adelaide market (Figure 5-9) across the 2012–2018 period and the cost of transport increases from $273 to $357/pallet.

Figure 5-9 Distribution of wholesale Cavendish banana price in Melbourne and Adelaide markets in the 2012–2018 period
Boxes indicate the 25 to 75 percentile range. Data sourced from Ausmarket Consultants.

5.3.3 GROUNDWATER SYSTEMS IN THE WILDMAN CATCHMENT

The Wildman River case study area is completely underlain by the Paleoproterozoic age Pine Creek Basin. In most of the case study area, these Paleoproterozoic basement rocks are overlain by poorly consolidated clay and sand sediments of the much younger Money Shoal Basin.

The basement geology is mainly composed of three stratigraphic units: the Wildman Siltstone, the Koolpinyah Dolostone and the Mundogie Sandstone (Figure 5-10). In limited areas these rocks are underlain by the Cahill Formation. Outcrops of the Wildman Siltstone are common in areas where Money Shoal Basin sediments are absent. Outcrops of the Mundogie Sandstone are limited to the south-east and north-east of the case study area. Outcrops of the Koolpinyah Dolostone are rare and have been observed at only two locations: Moon Billabong and on Rock Hole Road near Soda Creek (Tickell and Zaar, 2017). No major faults have been mapped in the Wildman River case study area.

The hydrogeology of the Wildman River case study area was first investigated in the 1980s. Preliminary investigations identified the presence of good quality groundwater (i.e. <140 mg/L total dissolved salts (TDS)) and the potential for large-scale groundwater development (i.e. bore yields >50 L/s). Most recently, the hydrogeology of the area was described by Tickell and Zaar (2017). The following description of the hydrogeology of the Mary–Wildman rivers area summarises the findings of Tickell and Zaar (2017).
Aquifers

Two key aquifers were identified: (i) a semi-confined aquifer located in the basal sand unit of the surficial Mesozoic–Cenozoic sequence of unconsolidated sediments, and (ii) the confined Koolpinyah Dolostone aquifer that underlies the Mesozoic–Cenozoic sediments in parts of the area. Minor fractured rock aquifers are hosted in the Wildman Siltstone, Mundowie Sandstone and Cahill Formation in limited parts of the Wildman Rivers catchment (Figure 5-11).

The surficial sequence of Mesozoic–Cenozoic sediments was described as being composed of poorly consolidated sand, clayey sand, clay and sandy clay. The spatial occurrence of these sediments was used to infer the existence of two separate northeast-striking palaeovalleys. The largest palaeovalley was estimated to extend from Point Stuart Road to the north-east corner of the cashew farm and into Kakadu National Park. A second palaeovalley was estimated to occur in the western part of the study area, extending from Mistake Creek towards Swim Creek. The thickness of the Mesozoic–Cenozoic sediments was estimated to range from less than 25 m away from the palaeovalleys up to 100 m within the palaeovalleys. It was also estimated that, at many bores, sand sediments and sandstone rocks represented one-third of the total thickness of sediments present.

The Koolpinyah Dolostone aquifer was observed in outcrop at two locations: at Moon Billabong and on Rock Hole Road near Soda Spring. Very few bores constructed in the Wildman River case study area have intersected the Koolpinyah Dolostone aquifer. For this reason, the spatial extent and occurrence of this aquifer was inferred by mapping the locations of surface depression features (i.e. dolines). It was estimated that, in contrast to the Darwin Rural Water Control District and other areas located east of Darwin, the Koolpinyah Dolostone aquifer is not laterally...
continuous in the case study area. Instead, the Koolpinyah Dolostone occurs in narrow (i.e. <6-km wide) curvilinear strips in parts of the case study area, reflecting the folding pattern of underlying basement rocks.

Figure 5-11 Local aquifers targeted for groundwater-based irrigation development in the Wildman River case study area

Hydraulic connectivity between aquifers
Tickell and Zaar (2017) hypothesised that the semi-confined sand aquifer and the underlying confined karstic dolostone aquifer are hydraulically connected. A clayey saprolitic layer up to 40 m thick commonly exists between these two aquifers. However, hydrochemical observations indicated that mixing occurs between these two aquifers, suggesting that the saprolite layers present are not sufficiently laterally continuous and/or thick to provide a barrier to vertical flow. Both Graham (1985) and Tickell and Zaar (2017) hypothesised that vertical preferential flow paths may provide mechanisms for connections between these two aquifers. Specifically, the collapse of cavernous features (caves) at depth in the Koolpinyah Dolostone may lead to the creation of vertical fractures in intervening clay material, as well as in overlying clay sediments. Tickell and
Zaar (2017) proposed that such features may facilitate mixing between sand aquifers and (indirectly) underlying Koolpinyah Dolostone aquifers.

Using a range of methods, annual recharge of the aquifers in the area was estimated to be 50 to 150 mm/year (Turnadge et al., 2018a). Taking the aquifer extent to be $20 \times 20 \text{ km}$, this equates to 45 to 60 GL/year of recharge. These results agree with the previous investigation of Tickle and Zaar (2017), who estimated recharge to be in the range 30 to 45 GL/year.

5.4 Case study costs

5.4.1 FARM-SCALE COSTS

This section concerns farm-scale capital and overhead costs associated with irrigated cropping developments. A third category, variable costs associated with irrigated crop production, which form part of the crop gross margin calculation, is captured in Section 5.3.2.

**Capital costs**

The specific costs of on-farm infrastructure development can vary considerably, for example the method for applying water onto individual fields (e.g. overhead irrigation or surface irrigation) or the types of crops to be grown, and hence machinery and additional infrastructure (e.g. packing sheds) requirements. Therefore, the analysis reported in this case study is only for the purpose of providing a framework for on-farm investment analysis and illustrating some drivers of investment performance.

The irrigation development unit costs shown in Table 3-4 are based on the costs of a greenfield 500-ha irrigation development outlined in the companion technical report on agricultural viability, Ash et al. (2018b). In addition to the irrigation infrastructure summarised in Chapter 4 (water storage infrastructure, irrigation systems), horticulture such as bananas requires capital items such as vehicles like tractors, forklifts and spraying equipment as well as buildings such as workshops and packing sheds. These unit costs were used to calculate the total scenario development capital costs provided in Table 3-4.

A large component of start-up costs is associated with development of the groundwater resource for the supply of water for irrigation. Assuming 12 groundwater bores to a depth of not less than 50 m, total bore drilling costs are about $900,000. Additionally, 12 pumps would cost about $1.2 million. This development assumes that micro irrigation is used. Drip-tape/line and associated costs (e.g. power supply, diesel tanks, fertigation system) are a major expense at about $10,000/ha (not including land preparation), which over 500 ha is $5 million, a major capital outlay.

The costs in Table 3-4 equate to a total capital cost of $14.85 million for the 500-ha development or a cost of $29,700/ha.
Table 5-1 Farm-scale capital and operational costs
Adjusted to 2017 costs using the consumer price index. Based on a 500-ha irrigation development (total farm size of 600 ha).

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (y)</th>
<th>COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS OR TOTAL $)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm-scale costs: capital</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm setup costs</td>
<td>40</td>
<td>3,860,000</td>
<td>1%</td>
<td>Includes internal roads, fences, houses, vehicles, workshops, domestic power supply and sheds.</td>
</tr>
<tr>
<td>Approvals and legal</td>
<td>na</td>
<td>100,000</td>
<td>Na</td>
<td>Includes survey and design, clearing and raking, internal roads and fences.</td>
</tr>
<tr>
<td>Land preparation</td>
<td>100</td>
<td>770,000</td>
<td>1%</td>
<td>Includes survey and design, clearing and raking, internal roads and fences.</td>
</tr>
<tr>
<td>Drilling and groundwater bore and pumps</td>
<td>40</td>
<td>2,190,000</td>
<td>1%</td>
<td>12 groundwater bores and pumps, drilling, installation and associated costs.</td>
</tr>
<tr>
<td>Irrigation system (tape)</td>
<td>15</td>
<td>5,345,000</td>
<td>1%</td>
<td>Includes tape, diesel tanks, installation of fertigation system and power supply.</td>
</tr>
<tr>
<td>Cropping equipment</td>
<td>15</td>
<td>1,235,000</td>
<td>1%</td>
<td>Includes rippers, boom spray, fertiliser spreader, truck, tractor, mulch lifter and roller, forklift, picking trailers and booms.</td>
</tr>
<tr>
<td>Total development cost</td>
<td></td>
<td>13,500,000</td>
<td>$134,000</td>
<td>Annual cost of pumping groundwater is captured in crop gross margins.</td>
</tr>
<tr>
<td>10% contingency</td>
<td></td>
<td>1,350,000</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>Total development cost plus 10% contingency</td>
<td></td>
<td>14,850,000</td>
<td>$134,000</td>
<td></td>
</tr>
<tr>
<td>Farm-scale costs: operational</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overheads</td>
<td>na</td>
<td>300,000/y</td>
<td>na</td>
<td>Overheads are $600/ha. This includes employee overhead costs, general maintenance, lease fee and additional business overhead. Harvest labour are a variable cost and are captured in gross margins.</td>
</tr>
</tbody>
</table>

na = data not applicable

5.5 Project commerciality

The internal rate of return (IRR) was used to assess the profitability of the groundwater development and irrigated banana enterprise at Wildman Station. The IRR is the discount rate that causes the net present value (NPV) to become zero. A project’s IRR needs to be above the desired discount rate for the project to be considered viable.

As new capital projects requiring equipment and infrastructure investment, irrigation developments are analysed over their lifetime costs and benefits. Costs and benefits occurring at different time periods are set on a comparable basis – that is they are expressed in present value terms. When a cost stream has been subtracted from the benefit stream to give a net benefit
stream, a discount rate is applied to yield an NPV for the project. The NPV is used to facilitate comparisons between options. The option with the largest NPV will be preferred. Costs and benefits are also expressed in real terms. In other words, they are expressed in constant dollars. Increases in prices due to the general rate of inflation are not included in the values placed on future costs and benefits.

The farm-scale economic analyses calculated the change in profitability attributable to adopting irrigated enterprises in the Darwin catchments. A generic analytical framework was developed to account for the capital and ongoing operating costs associated with the development of grazing land to irrigated cropping land at the scale of a single farm business in the Darwin catchments.

• Initially the gross margins for bananas, assuming mean historical price for bananas at Adelaide, were used in the analysis to calculate the IRR at which the NPV became zero.
  – The impact of cyclones on the north-east coast of Queensland and in the Darwin catchments was investigated using a stochastic analysis based on the probability of their occurrence (assuming occurrence of cyclones in the Darwin catchments was independent of occurrence of cyclones on the north-east coast of Queensland).

• The price in Adelaide at which the discount rate is equal to 7% over a 15-year investment window was calculated.

Internal rate of return under historical prices at Adelaide incorporating cyclone frequency

This analysis considered the variability of Adelaide wholesale prices, and the probability of a large cyclone in the Tully area was assumed to be 8 years in 100. Similarly, the possibility of disease-based crop wipe-out (e.g. banana freckle disease) in the study area and price variability at the Adelaide market were considered in the stochastic analysis.

Although capital and development costs for a banana plantation are high, banana gross margins are also high compared to broadacre and even industrial crops like cotton. Figure 5-12 shows the percent exceedance plot of 10,000 stochastically generated runs where the gross margins were modified based on the likelihood of large destructive cyclones occurring on the north-east coast of Queensland and the Darwin catchments.

The results in Figure 5-12 indicate that this investment at this scale is viable. The IRR ranges between 6.9% and 143%, with more than 99% of the 10,000 15-year investment periods achieving an IRR of greater than 7%. These results are highly dependent upon the assumption that all bananas can be accepted by the Adelaide market at recent prices. Using the assumption that 25% of bananas need to be transported to the Melbourne market, gross margin and IRR fall dramatically. For the latter scenario the mean IRR was −1%, with less than 2% of all possible cyclone/disease/price combinations able to achieve an IRR greater than 7%.
Price in Adelaide required to achieve a 7% internal rate of return

Assuming that all bananas were transported to Adelaide only, a minimum price of $17.75/carton (~10% lower than the weighted mean price between 2012 and 2018) ensures a minimum rate of return on investment (capital and operational costs) of 7%. More thorough economic analysis is required to estimate the effects of increased supply to the Adelaide market from the Darwin area. Potentially the price will fall to some degree, however, Darwin bananas will likely have an advantage due to lower transport costs than those on the north-east coast of Queensland.

5.6 Project benefits

5.6.1 POTENTIAL PRODUCTION

The gross potential production was calculated by multiplying the mean area under irrigation by the value of produce per hectare of an indicative crop that could be grown at the location.

Assuming a mean yield of 3400 cartons/ha and a mean price of $19.90/carton, the gross income for bananas is $60,894/ha. Across the entire 500-ha property this is a mean gross potential production of $30.5 million.

5.6.2 REGIONAL ECONOMIC BENEFITS

To estimate the regional economic benefit, regional input-output (I-O) models incorporating total output (Type II) multipliers were used (see companion technical report on socio-economics (Stokes et al., 2017)). The analysis focused on the ongoing annual benefits generated from the increased monetary output of the agricultural sectors in each I-O region resulting from the water storage scheme, treating this increased output as an exogenous shock to the economy.

The basis of the approach is that those agricultural businesses directly benefitting from the project will need to increase their purchases of the raw materials, labour and intermediate products utilised by their growing outputs. Should any of these purchases be made within the region, then this provides a stimulus to those businesses that they purchase from, contributing to further economic growth and job creation within the region (the production-induced effect). Furthermore, household incomes increase as a result of those local residents who are employed (as a consequence of either direct or production-induced business stimuli); as a proportion of their
additional income is spent in the region, that further stimulates greater economic activity and additional job creation (consumption-induced effects).

The dollar value of the increased total economic activity per year due to the operation of the scheme is estimated by using the exogenous increases in agriculture as an input to the regional I-O models developed from pre-existing I-O tables.

As part of this process, the I-O analysis estimates the total increase to household incomes within the region. By using this value along with the median income within the region, an estimate can be derived of the likely full-time equivalent jobs that would be created (directly, and indirectly through production and consumption effects) as a result of the project.

As outlined in Stokes et al. (2017), each dollar of direct annual benefit from new agricultural activity was estimated to generate an additional $0.46 in regional economic activity, recurring annually. Based on these estimates a 500-ha banana plantation at Wildman Station could increase the regional economic activity of the Darwin catchments by about $44.7 million and generate an additional 48 full-time equivalent jobs (Table 3-11).

Table 5-2 Estimated increase in agricultural output per year resulting from a 500-ha banana plantation at Wildman Station

<table>
<thead>
<tr>
<th>MEAN IRRIGATED AREA (ha)</th>
<th>AGRICULTURAL CROP</th>
<th>AGRICULTURAL SECTOR</th>
<th>WATER EXTRACTION (GL)</th>
<th>VALUE OF INCREASED AGRICULTURAL OUTPUT ($ million)</th>
<th>INCREASED REGIONAL ECONOMIC ACTIVITY ($ million)</th>
<th>APPROXIMATE JOBS CREATED (NUMBER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>Bananas</td>
<td>Agriculture excluding beef</td>
<td>6</td>
<td>30.5</td>
<td>44.7</td>
<td>48</td>
</tr>
</tbody>
</table>

5.7 Project impacts

A 6-GL/year groundwater extraction scenario was simulated using a distributed groundwater model to check for effects such as groundwater drawdown at various distances from bores (see companion technical report on groundwater flow modelling (Turnadge et al., 2018b)). The scenario assumes three nests of bores as shown in Figure 5-13, with groundwater extracted from the dolostone and sand aquifers represented in Figure 5-11.

A 6-GL/year extraction from the two southernmost development locations (Figure 5-13) was modelled to reduce groundwater levels by up to and possibly beyond 12 m, although this latter drawdown would be restricted to a radius of approximately 2 km from the point of extraction. Nearby monsoon rainforest patches, which are groundwater-dependent ecosystems, are likely to be affected by drawdown in groundwater outside of the range of natural fluctuations. The effects of groundwater drawdown on forest leaf area and transpiration rate were simulated using the WAVES (Water vegetation energy and solute) model (see Turnadge et al., 2018a). These results are summarised in Figure 5-14 for different levels of drawdown.
In Figure 5-13 it can be seen that one monsoon rainforest patch, located close to the hypothetical development points, is likely to be located in an area that may experience a drawdown of about 10 m. This equates to a modelled reduction in leaf area of greater than 12%. Similarly, transpiration rates for this patch of forest will be reduced by greater than 30%. Elsewhere in this area the modelling results indicate that patches of monsoon rainfall forests will be largely unaffected.

Groundwater drawdown beneath the Twin Sisters Lagoon may be about 8 m. The response of the lagoons to groundwater drawdown is related to the nature of their hydraulic connection to the underlying aquifers. The formation of these lagoons is thought to be related to the dissolution of dolostone at depth, followed by collapse causing subsidence at the surface. Inflow of surface water into the surface depression gradually builds a fine sediment layer on the lagoon bed that is less permeable, allowing the lagoon water to be ‘perched’. Despite this, there is evidence that groundwater flows into and out of these lagoons laterally. However, these concepts remain a hypothesis, and are yet to be fully confirmed by observations. There is currently insufficient information to establish the likely impact of groundwater drawn on water levels in Twin Sisters Lagoon.
Figure 5-14 Change in monsoon rainforest patch transpiration rate and leaf area index with change in groundwater elevation (relative to no drawdown scenario)
This case study investigated water harvesting along the Palmer, Mitchell, Walsh and Lynd rivers in the Mitchell catchment (Figure 6-1 and Figure 6-2). The analysis focused on the gross margins required for investment in an irrigation development to be viable, rather than examining profitability with respect to one particular crop.

The case study considers the feasibility of a water harvesting and irrigation development in the Mitchell catchment with respect to:

- the availability of soils suitable for agriculture close to rivers
- the reliability with which water can be pumped from a river and stored for irrigation
- the capacity of the farm to generate positive net revenues at different levels of reliability.

In presenting this case study, no consideration is given to legislative issues that may need to be addressed for any development of this scale to proceed. These issues include, but are not limited to, legislation relating to land tenure, planning and infrastructure, cultural heritage, native title, vegetation management, wildlife protection, water resources, fisheries, and environmental protection.
Commonly used terms in this case study are defined as follows:

- A ‘total system volume’ is an additional annual volume of water made available for consumptive use across the entire catchment (i.e. total new allocation of entitlement).
- ‘Irrigators’ are new water users who have a share in the additional total system volume.
- ‘Water harvesting’ refers to a practice where water is extracted during moderate-to-high flow events and either applied directly to a crop, or more commonly, held in an offstream storage on a property for use later, during the dry season. Water harvesting licences allow water users access to unregulated events and this access may be constrained by ‘commence to take thresholds’ and ‘annual take volumes’.

It should be noted that water planning and the allocation of water is a legislative responsibility of the Western Australian, Northern Territory and Queensland governments. Any reference to the allocation of water in this case study is hypothetical.

6.1 Summary

This case study concluded that:

- The Mitchell catchment contains more than 500,000 ha of land moderately suitable or better (i.e. Class 1, 2 or 3) for irrigated cropping within 5 km from a large river.
- A 400-ha development under furrow irrigation and a favourably sited 4000-ML offstream storage would cost about $5.59 million or $15,100/ha. Although the per hectare cost of this development is relatively low the annual operation and maintenance cost (including farm overheads and water pumping) of $374,000 is high relative to other options (Petheram et al., 2017).
- Based on a medium-season length crop under furrow irrigation, such as irrigated cotton or peanuts, a crop gross margin of about $2375/ha would be required either every year (i.e. 100% reliability) or as an average, in real terms, for the investment to be viable at a discount rate of 7%. Under more water efficient but expensive spray irrigation a break-even crop gross margin of $2592/ha would be required.
- At an annual water reliability of 80% and 60%, break-even crop gross margins under furrow irrigation increase to $2760/ha and $3296/ha, respectively, at the specified discount rate (7%). Compared to the break-even crop gross margin at 100% annual reliability, this is an increase of about 16% and 39%, respectively.
- Cotton and peanuts planted on Sodosols (sodic soils) and cotton planted on Vertosols (cracking clay soils) (peanuts cannot be grown on Vertosols) have median gross margins of $2912/ha, $3172/ha and $2647/ha, respectively. For cotton, these gross margins assume the existence of a local cotton gin (see Chapter 3 and 7 for discussions on processing facilities).
- At a total system volume of about 2000 GL (Scenario B2000) the reliability with which most new irrigators can extract their individual entitlements is about 85% with a low pump start threshold of 200 ML/day, though the reliability varies with location in the catchment. Increasing the pump start threshold to 1800 ML/day decreases the total system volume that can be extracted in 85% of years to about 1250 GL.
• Assuming a median crop gross margin of $3000/ha, which could potentially be achieved by irrigating cotton and peanuts on Sodosols, a 4000-ML offstream storage, 400-ha irrigation development and a 7% discount rate, the investment is potentially viable with 2000 GL of water allocated across the catchment, provided all ringtank locations are similar to the costs presented in this case study. In reality at larger scales of development less favourable sites (i.e. further from the river) will have to be developed and costs will increase.

• Based on these numbers, it is feasible that existing property owners in the Mitchell catchment could achieve a viable investment for an irrigated cotton (assuming a local gin) development or a peanut development. However, irrigators would need to be able to extract their full entitlement in about 75% and 85% of years for irrigation based on furrow and spray respectively to be viable. The viability of a greenfield irrigation development becomes less likely with subsequent increases in water release across the catchment, due to reduced reliability.

• The gross margins for short-season crops are insufficient to cover the cost of both water storage and land development at 100% annual water reliability. A reduction in the reliability of water supply makes an unprofitable enterprise even less profitable.

• Although a rotation system of cotton and mungbeans grown within a year is capable of producing yields similar to the sum of the individually grown crops, the large water losses to evaporation and seepage over the course of a year means insufficient land could be irrigated to achieve the returns necessary to pay off the water storage infrastructure and cost of pumping the water, at either a 3% or 7% discount rate and at 100% annual reliability of water extraction.

• This analysis highlights that while double cropping is a good strategy for achieving the returns required to pay off the capital of infrastructure in some instances, it is poorly suited to water harvesting enterprises that use large farm-scale ringtanks because the investor has to pay to store and pump large volumes of water than they are not able to apply to the crops due to evaporation and seepage losses.

6.2 Storyline for this case study

This case study investigates small-scale water harvesting to supply water for irrigation development (each 150 to 1100 ha) on individual properties scattered throughout the Mitchell catchment (i.e. mosaics of irrigation).

Typically, offstream storages used for water harvesting take the form of large farm-scale ringtanks, that are usually fully enclosed earthfill-embankment structures close to major watercourses/rivers 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. Where flood waters are slow moving, simply maintaining good grass cover 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 high, riprap protection to above the peak flood elevation may be required (see companion technical report on large farm-scale dams (Benjamin, 2018)).

In this case study, stored water is used to irrigate a cash crop as a means of diversifying an existing enterprise. The concept of developing smaller-scale on-farm irrigation enterprises opens a plethora of opportunities and combinations that will be determined by local topography of
drainage lines, suitable ringtank sites, distance and suitability of soils for irrigation, and prospects for various crops or stock feeding options. Rather than an analysis of one particular crop, a general analysis of reliability of water extraction is undertaken; this is then related to an analysis of the gross margins required for the investment to be profitable if crops of different growing length are used and water is to be stored for different lengths of time.

The outline of this case study is as follows.

- Section 6.3 describes the case study area, including the soils, the reliability with which water can be extracted by irrigators at different levels of entitlement and key factors that may influence the reliability
- Section 6.4 describes the case study costs, including the capital, and operation and maintenance costs for water harvesting operations
- Section 6.5 assesses the case study commerciality and provides results of a general financial analysis
- Section 6.6 describes the case study benefits in terms of potential production and regional economic benefits, based on crops that were deemed to be potentially profitable in Section 6.5
- Section 6.7 describes a selection of potential on-site and off-site impacts associated with several scales of potential development.

The case study example area is the Mitchell catchment, as shown in Figure 6-2.
Figure 6-2 (a) Relief and potential maximum surface water extent and (b) ringtank suitability
Data used to develop flood map were captured using MODIS satellite imagery. This figure illustrates the maximum percentage of MODIS pixels inundated between 2000 and 2015. Ringtank suitability analysis does not take into consideration water availability and is based on soil information to a depth of 1.5 m (see Petheram et al., 2017).
6.3 Case study area and description

This section provides an overview of the cropping opportunities in the Mitchell catchment with respect to soils and water, and potential water harvesting infrastructure configurations.

6.3.1 CROPPING OPPORTUNITIES IN THE MITCHELL CATCHMENT

The climate and soils of the Mitchell catchment are suited to agricultural production (Ash et al., 2018c) and water is the primary biophysical limitation.

Soil and land suitability along the Palmer, Mitchell, Walsh and Lynd rivers

This section provides a broad description of the soils in close proximity to the major rivers of the Mitchell catchment (Figure 6-3, Figure 6-4). The soils are described from the furthest upstream to the lowest reaches of the Mitchell River. These descriptions are likely to be broadly representative of other major drainage lines in the Mitchell catchment. Table 6-1 provides estimates of area of land that is potentially suitable for selected river reaches.

The Mitchell River water harvesting case study area (Figure 6-5) comprises level Quaternary unconsolidated sediments on the alluvial plains and delta of the Mitchell River and its major tributaries (Walsh, Lynd and Palmer rivers). Landform elements include alluvial plains, prior streams, levees, channel benches and floodplains. Above the confluence of the Mitchell and Walsh rivers, the alluvial plains are confined between ‘hard rock’ geologies resulting in a deeply incised main channel with relatively narrow plains, levees and minor channel benches. Below the confluence of the Mitchell, Walsh and Lynd rivers, the broad delta comprises floodplains and swamps with numerous flood channels and prior streams with narrow levees. The soils of the case study area are shown by the soil generic group map in Figure 6-5a and are described below. Figure 6-5b shows an agricultural versatility land map for various crops under flood and spray irrigation. This map was produced to provide an aggregated summary of the land suitability products (Thomas et al., 2018). Versatile agricultural land was calculated by identifying where the highest number of the 14 selected land use options (Figure 6-5b) were mapped as being suitable (i.e. suitability classes 1 to 3). High index values denote land that is likely to be suitable for a large proportion of the 14 selected land use options. Note that Figure 6-5b does not take into consideration flooding, risk of secondary salinisation, landscape contiguity or availability of water.

The narrow levees, prior streams and channel benches throughout the alluvial plains and delta have sandy and loamy surfaced, well-drained to moderately well-drained, moderately permeable, very deep red, brown and yellow massive soils (Kandosols), friable loamy soils (Dermosols) and minor sand or loam over friable clays (Chromosols). Flood channels and prior streams become more common in the lower delta resulting in a complex soil distribution of contrasting soils over short distances.

Loam over friable clays (Dermosols) and texture contrast soils with sodic intractable clay subsoils (Sodosols) occur extensively throughout the alluvial plains of the Mitchell, Lynd, Palmer and Walsh rivers, and throughout the delta area (Figure 6-3, Figure 6-4). Soils are dominated by hard-setting clay loam to silty clay loam surfaced gradational soils (Dermosols) and texture contrast soils (Sodosols) with structured brown clay subsoils at less than 0.15 m over strongly sodic, dispersive clay subsoils at depth. These slowly permeable, moderately well-drained to imperfectly drained
soils predominantly have moderate soil water storage (75 to 100 mm in top 1 m), and are subject to erosion on slopes, particularly gully erosion adjacent to stream channels.

Figure 6-3 Hard-setting Sodosol landscape occurring extensively on the alluvial plains and delta of the Mitchell River and its major tributaries
Photo: CSIRO

Hard-setting, imperfectly drained, slowly permeable, mottled, grey and brown cracking clay soils (Vertosols) with coarse surface structure occur extensively throughout the delta (Figure 6-4), particularly around Dunbar. These clay soils grade to poorly drained to very poorly drained swamps in the lower delta.

The narrow levees, prior streams and channel benches are suitable for a range of spray-irrigated grain and forage crops and micro-irrigated horticultural crops, but the generally long thin units restrict irrigation layout and machinery use in most areas. Cropping on the channel benches is unlikely due to regular (almost annual) high velocity flooding. Soils are unlikely to be suitable for ringtanks.

The loam over brown gradational and texture contrast soils with sodic intractable clays subsoils (Sodosols) are suitable for sugarcane, dry-season cotton, dry-season grain and pulse crops under furrow irrigation. The main limitations are 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 addition of soil conditioners to improve surface structure and infiltration would be beneficial. Lands are subject to regular flooding in the delta area. Landscape complexity is an issue due to the intricate distribution of flood channels and prior streams, resulting in ‘small’ and/or ‘narrow’ areas that limit paddock size and irrigation infrastructure layout. Soils are suitable for ringtanks but erosion of the tank walls during floods (especially with wave action during windy weather) requires special construction techniques, topdressing with non-dispersible topsoil, and regular maintenance.
The hard-setting cracking clays are suitable for sugarcane, dry-season cotton, dry-season grain and pulse crops. The main limitations are inundation on the floodplains during the wet season, coarse surface texture 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. Soils are suitable for ringtanks.

All poorly drained swamps are unsuitable for development.

Figure 6-4 Grasslands on hard-setting Vertosols (cracking clays) of the Mitchell River delta
Photo: CSIRO.
Figure 6-5 (a) Soil generic group and (b) agricultural versatility index map
Agricultural versatility index map does not consider flood risk, secondary salinity or water availability. High index values denote land that is likely to be suitable for more of the 14 selected land use options.
Table 6-1 Area of land with Class 1, 2, or 3 soils within 5 km of river reach
River reaches shown in Figure 6-2 and Figure 6-5. Season length is indicative of the growing season of the crop, which is correlated to the crop water use and water losses from the ringtank. ‘No flooding’ indicates the area of land with Class 1, 2, or 3 soil that is not impacted by broad-scale flooding as shown in Figure 6-2a. Sorghum is forage sorghum.

<table>
<thead>
<tr>
<th>LAND USE</th>
<th>SEASON</th>
<th>REACH A</th>
<th>REACH B</th>
<th>REACH C</th>
<th>REACH D</th>
<th>REACH E</th>
<th>REACH F</th>
<th>REACH G</th>
<th>REACH H</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chickpea dry season furrow</td>
<td>Short</td>
<td>38,700</td>
<td>27,904</td>
<td>57,981</td>
<td>54,799</td>
<td>11,907</td>
<td>27,086</td>
<td>21,195</td>
<td>107,761</td>
<td>347,332</td>
</tr>
<tr>
<td>Chickpea dry season spray</td>
<td>Short</td>
<td>104,972</td>
<td>35,625</td>
<td>71,687</td>
<td>93,456</td>
<td>39,207</td>
<td>60,862</td>
<td>63,405</td>
<td>127,236</td>
<td>596,449</td>
</tr>
<tr>
<td>Mungbean dry season furrow</td>
<td>Short</td>
<td>41,115</td>
<td>28,535</td>
<td>57,981</td>
<td>56,863</td>
<td>11,908</td>
<td>27,074</td>
<td>21,828</td>
<td>107,916</td>
<td>353,220</td>
</tr>
<tr>
<td>Mungbean dry season spray</td>
<td>Short</td>
<td>104,972</td>
<td>35,625</td>
<td>71,687</td>
<td>93,456</td>
<td>39,207</td>
<td>60,862</td>
<td>63,405</td>
<td>127,236</td>
<td>596,449</td>
</tr>
<tr>
<td>Cotton dry season furrow</td>
<td>Medium</td>
<td>38,568</td>
<td>32,974</td>
<td>76,150</td>
<td>93,470</td>
<td>39,196</td>
<td>60,860</td>
<td>63,396</td>
<td>138,362</td>
<td>615,048</td>
</tr>
<tr>
<td>Cotton dry season spray</td>
<td>Medium</td>
<td>9,981</td>
<td>2,252</td>
<td>9,211</td>
<td>6,697</td>
<td>7,880</td>
<td>17,517</td>
<td>10,867</td>
<td>4,716</td>
<td>69,121</td>
</tr>
<tr>
<td>Cotton wet season furrow</td>
<td>Medium</td>
<td>38,176</td>
<td>5,698</td>
<td>11,865</td>
<td>16,142</td>
<td>17,188</td>
<td>29,357</td>
<td>8,029</td>
<td>154,418</td>
<td></td>
</tr>
<tr>
<td>Cotton wet season spray</td>
<td>No flooding</td>
<td>7,702</td>
<td>1,977</td>
<td>5,288</td>
<td>7,282</td>
<td>7,765</td>
<td>17,634</td>
<td>10,897</td>
<td>5,906</td>
<td>64,451</td>
</tr>
<tr>
<td>Peanut dry season furrow</td>
<td>Medium</td>
<td>68,695</td>
<td>8,509</td>
<td>11,008</td>
<td>36,164</td>
<td>34,348</td>
<td>50,551</td>
<td>51,241</td>
<td>18,577</td>
<td>279,092</td>
</tr>
<tr>
<td>Peanut dry season spray</td>
<td>Medium</td>
<td>40,803</td>
<td>30,028</td>
<td>62,267</td>
<td>56,838</td>
<td>11,915</td>
<td>27,163</td>
<td>21,833</td>
<td>117,233</td>
<td>368,082</td>
</tr>
<tr>
<td>Sorghum dry season furrow</td>
<td>Medium</td>
<td>62,210</td>
<td>33,054</td>
<td>64,920</td>
<td>65,800</td>
<td>21,324</td>
<td>63,645</td>
<td>38,733</td>
<td>122,621</td>
<td>445,308</td>
</tr>
<tr>
<td>Sorghum dry season spray</td>
<td>Long</td>
<td>41,190</td>
<td>32,939</td>
<td>54,724</td>
<td>57,275</td>
<td>11,908</td>
<td>27,075</td>
<td>21,828</td>
<td>108,346</td>
<td>355,286</td>
</tr>
<tr>
<td>Sugarcane wet season furrow</td>
<td>Long</td>
<td>105,051</td>
<td>40,298</td>
<td>68,915</td>
<td>93,889</td>
<td>39,207</td>
<td>60,865</td>
<td>63,406</td>
<td>128,715</td>
<td>600,347</td>
</tr>
<tr>
<td>Rhodes grass furrow</td>
<td>Long</td>
<td>30,794</td>
<td>19,343</td>
<td>60,224</td>
<td>48,351</td>
<td>11,828</td>
<td>26,108</td>
<td>18,002</td>
<td>105,341</td>
<td>319,992</td>
</tr>
<tr>
<td>Rhodes grass spray</td>
<td>Long</td>
<td>122,449</td>
<td>41,429</td>
<td>75,584</td>
<td>98,528</td>
<td>51,645</td>
<td>70,693</td>
<td>67,128</td>
<td>133,390</td>
<td>660,845</td>
</tr>
</tbody>
</table>

In many cases it will be necessary to pipe water directly from the river to the ringtanks, in which case optimally the ringtank would be within 100 m of the pump station to minimise the cost of pipe infrastructure. Where the topography is suitable for gravity-fed channels or natural watercourses draining away from the river, these can be utilised to convey water further distances. Nevertheless, it is likely that the majority of irrigation developments associated with water harvesting will be developed within 5 km of a major river. For this reason the descriptions and calculations are assumed to be within 5 km of major rivers.

**Crop water use**

Once water is extracted from the river the area that can be grown is a function of the crop water requirement and the volume of water lost from the ringtank due to evaporation and seepage. Both of these factors are related to the length of the crop growing season.

Evaporative demand (heat and air dryness) drives crop water use. Under full canopy cover, water use is similar between crops and consequently the total water used by a crop is strongly related to the length of its growing period (Ash et al., 2018c). This is examined in Section 6.3.4.
Table 6-2 presents crop water requirement (i.e. before losses) for representative short, medium, and long-season crops in the Mitchell catchment on Sodosols. Note there are small differences in crop water requirement between soil types, depending on when crops are sown. The crops presented in Table 6-2 were selected because, excluding niche crops which could only be grown over small areas, they have the highest gross margin of crops in the Mitchell catchment with well-established markets and marketing infrastructure. See companion technical report on agriculture viability (Ash et al., 2018c) for the complete table of crop gross margins in the Mitchell catchment. Ash et al., (2018c) also examines the profitability of incorporating an irrigated fodder crop into an existing beef enterprise.

**Crop gross margin**

A crop gross margin is the difference between gross income and variable costs of producing a crop. It does not include overhead or capital costs; these must be met regardless of whether a crop is grown. Capital and overhead costs are discussed in Section 6.4.

Variable costs (also known as direct costs) vary directly in proportion to the output of a crop enterprise. They include irrigation operating costs (e.g. pumping costs) that vary in proportion to the volume of water used on-farm, as well as other crop inputs (e.g. costs of fertiliser, chemicals, harvesting).

The crop gross margin is calculated using simulated crop yield and water use. For details on crop gross margin calculations, see the companion technical report on agriculture viability (Ash et al., 2018c).

Table 6-2 provides examples of median gross margin for five high-value crops that could be planted during the dry season in the Mitchell catchment. These gross margins provide context for the analysis undertaken in sections 6.6 and 6.5.

<table>
<thead>
<tr>
<th>CROP</th>
<th>CROPPING SEASON</th>
<th>MEDIAN CROP YIELD</th>
<th>MEDIAN APPLIED IRRIGATION WATER (ML/ha)</th>
<th>PRICE ($/UNIT)</th>
<th>VARIABLE COST ($/ha)</th>
<th>MEDIAN GROSS MARGIN ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-season</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chickpeas</td>
<td>Dry season</td>
<td>2.8 t/ha</td>
<td>2.3</td>
<td>900</td>
<td>1239</td>
<td>1233</td>
</tr>
<tr>
<td>Mungbeans</td>
<td>Dry season</td>
<td>2.3 t/ha</td>
<td>3.2</td>
<td>1100</td>
<td>1154</td>
<td>1025</td>
</tr>
<tr>
<td>Medium-season</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peanut</td>
<td>Dry season</td>
<td>5.7 t/ha</td>
<td>5.4</td>
<td>1000</td>
<td>2438</td>
<td>3172</td>
</tr>
<tr>
<td>Cotton</td>
<td>Dry season</td>
<td>10.5 bales/ha</td>
<td>5.5</td>
<td>480</td>
<td>2955</td>
<td>2912</td>
</tr>
<tr>
<td>Long-season</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugarcane</td>
<td>Perennial</td>
<td>122 t/ha</td>
<td>11.9</td>
<td>42</td>
<td>2098</td>
<td>3020</td>
</tr>
</tbody>
</table>

A rotation of cotton and mungbeans grown within a single year is potentially suited to the Mitchell catchment and is capable of producing yields approaching the sum of the crops grown individually
at their most optimal times. Cotton would need to be planted during the wet season and harvested in June in order to harvest the mungbean crop prior to the commencement of the next wet season rains. The analysis presented in the companion technical report on agriculture viability (Ash et al., 2018c) indicates that a cotton and mungbean rotation in the Mitchell catchment could potentially achieve a gross margin of about $3500/ha.

It should be noted, however, that there may be challenges in implementing this rotation on the heavier soils (i.e. soils with a heavier clay content) in the Mitchell catchment due to trafficability limitations when planting cotton during the wet season. This aspect of this rotation is not explored in this case study, since double cropping based on water harvesting is not a viable option (as shown in Section 6.5.1). A more detailed description of the benefits and challenges of double cropping in northern Australia is provided in the case study on groundwater and a cotton–mungbean–forage sorghum for a (Chapter 3).

6.3.2 CONFIGURATION OF WATER SUPPLY AND IRRIGATION DEVELOPMENT

In this case study it is assumed that ringtanks are 4 GL capacity and circular in design, since circular ringtanks require the least earthworks per unit of ponded area of any shape. With ringtanks it is common to surround quite large areas with a low embankment to achieve very high surface area to excavation ratios. Although higher dam walls may result in a lower proportion of water lost to evaporation, the low batters used on the embankments of ringtanks (i.e. 3 horizontal to 1 vertical) means that doubling the height of the dam wall requires considerably more earthfill than doubling the length of the dam wall. In this case study an embankment height of 4.25 m above ground surface and a mean water depth of 3.5 m were selected as a compromise between minimising the proportion of water lost to evaporation and seepage and the cost of construction. Table 6-3 describes the assumed ringtank dimensions. For more information on ringtank costs see companion technical report on large farm-scale dams (Benjamin, 2018).

It was also assumed that each ringtank is serviced by a diesel-driven pump station comprising three 600 mm diameter axial-flow pump units each with a 90 kW diesel engine. Collectively these pump units could provide a flow rate of 160 ML/day (~2 m³/second), sufficient to fill a 4 GL ringtank in approximately 25 days. It is assumed that the ringtank is situated within 100 m of the pump station situated atop the river bank, and water would be conveyed between the pump station and ringtank via pipeline. The actual cost of the pump station will vary from one site to another depending upon local conditions. The costs presented in Section 6.4 are likely to be for more favourable siting conditions.
Table 6-3 Assumed dimensions for circular 4 GL ringtank
From companion technical report on large farm-scale dams (Benjamin, 2018).

<table>
<thead>
<tr>
<th>EMBANKMENT DESCRIPTION</th>
<th>DIMENSION</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>4.25</td>
<td></td>
</tr>
<tr>
<td>Diameter (m)</td>
<td>1180</td>
<td>At embankment centre line</td>
</tr>
<tr>
<td>Crest width (m)</td>
<td>3.1</td>
<td></td>
</tr>
<tr>
<td>Embankment length (m)</td>
<td>3707</td>
<td>At centre line</td>
</tr>
<tr>
<td>Batter slopes</td>
<td>3.0:1</td>
<td>Both sides</td>
</tr>
<tr>
<td>Water depth (m)</td>
<td>3.5</td>
<td>Above natural surface</td>
</tr>
<tr>
<td>Foundation depth (m)</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

6.3.3 WATER HARVESTING: FACTORS AFFECTING RELIABILITY OF EXTRACTION

Methods and model configuration

Assessing the reliability with which water can be harvested is challenging because of the wide range of variables that can influence the results. Factors affecting the volume of water an irrigator can potentially extract include:

- **Streamflow characteristics** – covers the volume and variability across a range of spatial scales including daily (i.e. rate of rise and fall of water levels), monthly (seasonality of flow) and inter-annual and inter-decadal variability. These streamflow characteristics vary across a catchment.

- **Irrigator’s entitlement and location and total system volume** – the volume of water extracted by an irrigator and the volume and timing of water being extracted upstream impacts on the reliability of the irrigator extracting their full entitlement.

- **Pump/division rates** – can be considered representative of either a physical capacity to pump/divert water (i.e. based on pump capacity) or a licence condition.

- **Pump start threshold** – can be considered representative of either a physical threshold below which there is insufficient water to pump (highly site-specific depending on the presence and size of pumping pool/local river morphology) or a licence condition imposed to mitigate potential environmental impacts or ensure the reliability of existing water users is not compromised.

- **Lowermost gauge flow requirements** – are licence conditions that seek to mitigate the impact of extractions on existing industries, downstream users and/or the environment by requiring a certain volume of water pass the most-downstream gauge each wet season before extraction can commence. There are many strategies that could potentially be implemented to mitigate environmental impacts; lowermost gauge flow requirement was examined here because it is one of the least complex environmental flow provisions to regulate and police in remote areas such as the Mitchell catchment.

These factors are interrelated and consequently the only way to isolate one factor from another is within a numerical modelling framework. Each of these factors is examined in turn below.

To analyse the reliability with which water can be extracted under water harvesting operations in the Mitchell catchment, seven extraction locations (referred to as ‘hypothetical irrigators’) were situated on reaches of the Palmer, Mitchell, Walsh and Lynd rivers, where each hypothetical
irrigator may represent either one or multiple users on a particular river reach. The volume of water assigned to each hypothetical irrigator is referred to as a reach entitlement, and changes in proportion to the total system volume. For example, the entitlement assigned to each irrigator (not including existing entitlement holders) is twice as large under the 2000-GL water release as under the 1000-GL water release. The water release volumes are distributed among the seven hypothetical irrigators using the set proportions outlined in the companion technical report on river model simulation (Hughes et al., 2018).

In distributing the new entitlements, consideration was given to the following factors:

- land suitability, in terms of:
  - water storage (Figure 6-2b)
  - irrigated cropping (Figure 6-5b)
- streamflow (Table 6-4)
- providing a realistic spatial distribution of irrigators across the catchment (i.e. not all irrigators will be located at the downstream end of the catchment or at the top of the catchment) so that a range of river reaches can be assessed under different levels of stress (i.e. incrementally larger extractions)
- flood risk (Figure 6-2a).

As existing entitlements in the Mitchell catchment are low (i.e. < 5 GL), the proximity to existing entitlements was not a consideration in distributing the new entitlements as per Petheram et al. (2016). Details on the proportion of total system volume assigned to each hypothetical user is described in the companion technical report on river model simulation (Hughes et al., 2018).

In this modelling exercise, the reliability with which each hypothetical irrigator could extract their ‘reach entitlement’ of water was explored, and the way potential licence conditions may impact on the reliability of water extraction at different locations in the catchment, different combinations of total system volumes, pump/diversion rates, pump start thresholds and lowermost gauge flow requirement (919009) were simulated.

**Streamflow**

The volume reliability of extractions is dependent on both natural streamflow characteristics (e.g. how quickly and slowly the river rises and falls) and the extent of upstream extractions.

Streamflow in the Mitchell catchment is highly seasonal, with high variability between years. Table 6-4 reports different streamflow metrics for the inflows to the river reaches containing six of the hypothetical irrigators upstream of gauged locations (see Figure 6-6 for location of irrigators). A 50% exceedance of flow means that the streamflow will exceed the value shown in Table 6-4 in half the years.
Table 6-4 Streamflow metrics at selected gauging stations in the Mitchell catchment
Annual streamflow data are calculated under Scenario A. The terms 20th, 50th and 80th refer to the 20%, 50% and 80% exceedances, respectively. Map ID refers to Figure 6-6 to Figure 6-10.

<table>
<thead>
<tr>
<th>STATION ID</th>
<th>MAP ID</th>
<th>STATION NAME</th>
<th>CATCHMENT AREA (km²)</th>
<th>ANNUAL STREAMFLOW (GL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maximum</td>
</tr>
<tr>
<td>919009</td>
<td>g</td>
<td>Mitchell River at Dunbar</td>
<td>45543</td>
<td>33365</td>
</tr>
<tr>
<td>919011</td>
<td>f</td>
<td>Mitchell River at Gamboola</td>
<td>20317</td>
<td>15358</td>
</tr>
<tr>
<td>919014</td>
<td>a</td>
<td>Mitchell River at Cooktown Crossing</td>
<td>2514</td>
<td>5217</td>
</tr>
<tr>
<td>919203</td>
<td>b</td>
<td>Palmer River at Strathleven</td>
<td>7062</td>
<td>4243</td>
</tr>
<tr>
<td>919204</td>
<td>c</td>
<td>Palmer River at Drumduff</td>
<td>7732</td>
<td>5119</td>
</tr>
<tr>
<td>919309</td>
<td>e</td>
<td>Walsh River at Trimbles Crossing</td>
<td>8649</td>
<td>6886</td>
</tr>
</tbody>
</table>

Results

In this section a selection of results are presented on how the reliability of extracting water in different parts of the Mitchell catchment is affected by:

- system/reach entitlement volume
- pump/diversion capacity
- pump start threshold
- lowermost gauge flow requirement.

The influence of these factors is demonstrated in the extraction reliability figures (shown in Figure 6-6 to Figure 6-10) and Table 6-5. The full range of results is presented in the companion technical report on river model simulation (Hughes et al., 2018).

Explanation of extraction reliability figures

Figure 6-6 to Figure 6-8 each contain seven plots (a) to (g), each of which corresponds to a hypothetical irrigator (i.e. one or more irrigators in a reach). On each of these plots the left-side vertical axis (i.e. y1 axis) of these figures is the total system volume (axis title reads ‘system allocation’), which is the total volume of water entitlements across the entire Mitchell catchment. On the right-side vertical axis (i.e. y2 axis) is the reach entitlement (axis title reads ‘reach allocation’), which is the volume of water hypothetically allocated to the hypothetical irrigator in that reach, which may be representative of one or more irrigators in that reach. The bottom horizontal axis (i.e. x axis) is the number of days to pump/divert the full entitlement (a measure of pump/diversion capacity). Days to pump entitlement is inversely proportional to the size of the pump/division where smaller pumps take longer to pump the full entitlement. The colours in the plots indicate the proportion of years (over the historical climate 1890 to 2015) that the full reach entitlement can be extracted.
Impact of entitlement volume on reliability of extraction

As the reach and total system volumes increase, the reliability at which each water harvester can extract their proportion of the total system volume decreases. For example, in Figure 6-6 the reliability of irrigators extracting their proportion of a total system volume of 1000 GL of water is higher than 95% for a pump start threshold of 200 ML/day. However, for a total system volume of 3000 GL, water harvesters can only extract their proportion of the 3000 GL/year in 70 to 85% of years, depending on their location. The largest reduction in reliability occurs in the most downstream reach (Figure 6-6, Figure 6-7), which is most impacted by upstream extractions.

Impact of pump capacity on reliability of extraction

The impact of pump/diversion capacity can be explored in all figures. Figure 6-6 shows that as the number of days to pump a hypothetical irrigator’s full entitlement increases, the reliability of extraction decreases. The reduction in reliability with an increase in number of days to pump entitlement (i.e. reduction in pump capacity) becomes more pronounced at higher values of number of days to pump full entitlement and with increasing pump start threshold (Figure 6-7).

Impact of pump start threshold on reliability of extraction

As the pump start threshold increases, the reliability of a hypothetical irrigator extracting their full entitlement decreases (Figure 6-7). The reduction in reliability with increasing pump start threshold is because the number of days over which pumping is permitted decreases, and highlights the importance of having higher pump capacities (i.e. to ensure full entitlement can be extracted) with increasing large pump start thresholds.

Impact of lowermost gauge flow requirement on reliability of extraction

Increasing the lowermost gauge flow requirement before pumping/diversion can commence decreases the reliability a hypothetical irrigator can extract their full entitlement (Figure 6-8). 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 total system volume of 1500 GL/year can be extracted decreases from between 85 to 95% (Figure 6-6) to between 75 and 85% (Figure 6-8).

Table 6-5 Indicative reliability of hypothetical irrigators extracting full entitlement for selected pump start thresholds

<table>
<thead>
<tr>
<th>TOTAL SYSTEM VOLUME (GL/YEAR)</th>
<th>PUMP START THRESHOLD (ML/DAY)</th>
<th>RELIABILITY OF EXTRACTING FULL ENTITLEMENT (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>200</td>
<td>85%</td>
</tr>
<tr>
<td>1750</td>
<td>600</td>
<td>85%</td>
</tr>
<tr>
<td>1250</td>
<td>1800</td>
<td>85%</td>
</tr>
<tr>
<td>750</td>
<td>1800</td>
<td>95%</td>
</tr>
<tr>
<td>1500</td>
<td>1800</td>
<td>80%</td>
</tr>
<tr>
<td>3500</td>
<td>1800</td>
<td>60%</td>
</tr>
</tbody>
</table>

Table 6-5 Indicative reliability of hypothetical irrigators extracting full entitlement for selected pump start thresholds

Assumes no end of system flow requirement and a days to pump entitlement of 25. See companion technical report on river model simulation, Hughes et al., 2018, for figures with pump start thresholds of 1800 ML/day. Actual numbers will vary depending upon combination of location of extractions and licence conditions.
Figure 6-6 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. (a) to (g) on the map inset shows the most downstream location of each reach.
Figure 6-7 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
(a) to (g) on the map inset shows the most downstream location of each reach.
Figure 6-8 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 end-of-system flow requirement of 1000 GL/year (a) to (g) on the map inset shows the most downstream location of each reach.
6.3.4  FACTORS REDUCING THE VOLUME OF WATER DELIVERED FROM THE RINGTANK TO CROP

Some water extracted or diverted for irrigation is lost to evaporation and seepage during storage, conveyance to the field, and during application to the crop (see Petheram et al., 2017).

**Evaporation and seepage losses**

Losses of water from large farm-scale dams can 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. The longer the crop growing season the longer the period of time that water needs to be stored, and consequently the larger the losses to evaporation and seepage (Table 6-6).

Given the potential for high evaporative and seepage losses from ringtanks, and that during mid- to late wet season (i.e. February and March) the soil profile is full or close to being full of water, planting during this period reduces the total volume of irrigation water required. However, during the mid- to late wet season access may be limited by trafficability. Furthermore, those areas to the west of Chillagoe are currently inaccessible by road during the wet season until the early dry season. Hence for the purposes of this case study, with the exception of the cotton–mungbean rotation it was assumed that crops were planted in April to minimise evaporative and seepage losses, make use of stored soil water and ensure access. Nevertheless, at many locations it is likely that the operation of pumps to fill ringtanks with water would require helicopter access to pumping and ringtank infrastructure.

A cotton–mungbean rotation would require a January/early-February planting of cotton, which is only likely to occur if road access was considerably improved.

**Table 6-6 Effective volume after net evaporation and seepage for ringtanks of mean water depth 3.5 m 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 storage capacity is 4000 ML. For storages of 4000 ML capacity and mean water depth of 3.5 m, the reservoir surface area is 110 ha. S:E ratio is the storage capacity to excavation ratio. For more details see the companion technical report on surface water storage (Petheram et al., 2017).

<table>
<thead>
<tr>
<th>MEAN WATER DEPTH (m)</th>
<th>S:E RATIO</th>
<th>SEEPAGE LOSS (mm/day)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY (%)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY (%)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 months  (April to July)</td>
<td>6 months (April to September)</td>
<td>9 months (April to December)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>14:1</td>
<td>1</td>
<td>3422</td>
<td>86%</td>
<td>3051</td>
<td>76%</td>
<td>2553</td>
<td>64%</td>
</tr>
<tr>
<td></td>
<td>14:1</td>
<td>2</td>
<td>3288</td>
<td>82%</td>
<td>2851</td>
<td>71%</td>
<td>2252</td>
<td>56%</td>
</tr>
<tr>
<td></td>
<td>14:1</td>
<td>5</td>
<td>2888</td>
<td>72%</td>
<td>2250</td>
<td>56%</td>
<td>1350</td>
<td>34%</td>
</tr>
</tbody>
</table>

**On-farm storage, conveyance and field application efficiency**

In addition to evaporative and seepage losses that occur from a ringtank during storage, losses occur in conveying water from the ringtank to the field and then in applying water to the crop. These losses should be considered when planning irrigation systems and developing likely irrigated
areas. In Table 6-7 the overall efficiency is calculated as the product of the water storage efficiency, on-farm distribution efficiency and field application efficiency.

**Table 6-7 Efficiency assumptions for overhead irrigation development associated with water harvesting in the Mitchell catchment**
Water storage efficiency assuming 2 mm/day seepage loss from Table 6-6. Field application efficiency assumes water is applied to the crop using spray irrigation.

<table>
<thead>
<tr>
<th>SEASON LENGTH</th>
<th>WATER STORAGE EFFICIENCY (%)</th>
<th>ON-FARM DISTRIBUTION EFFICIENCY (%)</th>
<th>FIELD APPLICATION EFFICIENCY (%)</th>
<th>OVERALL EFFICIENCY (%)</th>
<th>POTENTIAL AREA THAT COULD BE IRRIGATED (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short (4 months)</td>
<td>82%</td>
<td>90%</td>
<td>85%</td>
<td>63%</td>
<td>1100</td>
</tr>
<tr>
<td>Medium (6 months)</td>
<td>71%</td>
<td>90%</td>
<td>85%</td>
<td>54%</td>
<td>400</td>
</tr>
<tr>
<td>Long (9+ months)</td>
<td>56%</td>
<td>90%</td>
<td>85%</td>
<td>43%</td>
<td>150</td>
</tr>
</tbody>
</table>

Based on the overall efficiency (Table 6-7 and Table 6-8) and water requirements of the representative short- (mungbeans/chickpea), medium- (cotton/peanuts) and long- (sugarcane/cotton-mungbeans) season crops, the area of land that could be irrigated using water from a 4-GL ringtank and a 4-GL entitlement is about 1100 ha of chickpeas/mungbeans, 400 ha of cotton/peanuts and 150 ha of sugarcane/cotton–mungbean rotation under overhead irrigation (Table 6-7) and about 1060 ha of chickpeas/mungbeans, 370 ha of cotton/peanuts and 135 ha of sugarcane/cotton-mungbean rotation under furrow irrigation. In both cases the higher water use of the longer-season crop is compounded by the larger losses to evaporation and seepage.

At less suitable sites for constructing ringtanks (i.e. sandy soils) under conditions where seepage loss is 5 mm/day, the area of land that could be irrigated using water from a 4-GL ringtank and a 4-GL entitlement would be about 950 ha of chickpea, 300 ha of cotton and 90 ha of sugarcane under overhead irrigation.
6.4 Project costs

6.4.1 FARM-SCALE COSTS

This section concerns farm-scale capital and overhead costs associated with irrigated-cropping developments. A third category of costs is variable costs associated with irrigated-crop production, which forms part of the crop gross margin calculation and is captured in Section 6.3.1.

Capital costs

The specific costs of on-farm infrastructure development can vary considerably depending on the storage and conveyance system used by the landholder. The way in which water is accessed will determine costs – for example, whether water is accessed directly from a river and delivered through open channels or piped systems to the crop and how far, or pumped via an offstream water storage (e.g. ringtank). Costs will also depend on the method for applying water onto individual fields (e.g. spray irrigation, furrow irrigation). Therefore, the analysis reported in this case study is only for the purpose of providing a framework for on-farm investment analysis and illustrating some drivers of investment performance.

The costs presented in this case study are likely to be indicative of the more favourable locations for pumping. At less favourable sites it may be necessary to site the ringtank further from the top of the river bank, transport material for a clay core from elsewhere or require riprap for flood protection.

Water storage

Construction costs of a ringtank may vary considerably depending on tank 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 earlier, 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 6-9 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 O&M 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 6-9 by between 10 to 20%, depending upon volume of rock required and proximity to a quarry with suitable rock (Benjamin et al. 2018).
Table 6-9 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, ~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. O&M is operation and maintenance. For more detail on costs see companion technical report on large farm-scale dams (Benjamin, 2018).

<table>
<thead>
<tr>
<th>SITE DESCRIPTION/CONFIGURATION</th>
<th>EARTHWORKS ($)</th>
<th>GOVERNMENT PERMITS AND FEES ($)</th>
<th>INVESTIGATION AND DESIGN FEES ($)</th>
<th>PUMP STATION ($)</th>
<th>TOTAL CAPITAL COST ($)</th>
<th>O&amp;M OF RINGTANK ($/y)</th>
<th>O&amp;M OF PUMP STATION ($/y)</th>
<th>TOTAL O&amp;M ($/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000-ML ringtank</td>
<td>1,602,500</td>
<td>35,500</td>
<td>76,000</td>
<td>500,000</td>
<td>2,214,000</td>
<td>17,000</td>
<td>84,000</td>
<td>101,000</td>
</tr>
</tbody>
</table>

In some instances 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. This can considerably reduce the cost of construction and consequently the enterprise would be more profitable for a specified discount rate than the analysis reported in this case study based on fully enclosed earthfill-embankment structures.

Irrigation development
The irrigation development costs shown in Table 6-10 outline indicative costs for water storage, land development, irrigation infrastructure as well as farm infrastructure (e.g. workshops, fences, power) and farm machinery (i.e. items such as tractors and vehicles; cultivation, planting and spraying equipment). These costs were used to calculate the total development capital costs for the options provided in Table 6-11 and Table 6-12.

Table 6-10 Base costs for water harvesting irrigation development for 4000-ML ringtank and 500-ha development under spray irrigation

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFESPAN (y)</th>
<th>COST ($/y)</th>
<th>O&amp;M (% CAPITAL COST)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm infrastructure</td>
<td>40</td>
<td>$1,275,000</td>
<td>1%</td>
<td>Roads, fences, housing, vehicles, workshops, power, packing sheds etc. Only for greenfield development</td>
</tr>
<tr>
<td>Approvals</td>
<td>NA</td>
<td>$100,000</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Water storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ringtank</td>
<td>40</td>
<td>$1,700,000</td>
<td>1%</td>
<td>Assumes ringtank sited in location with no flooding or slow-moving flood waters</td>
</tr>
<tr>
<td>Pump infrastructure</td>
<td>15</td>
<td>$500,000</td>
<td>1%</td>
<td>Includes pump station housing, pipework and associated costs. O&amp;M costs for housing and piping and associated infrastructure</td>
</tr>
<tr>
<td>Overhead/spray</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land preparation</td>
<td>40</td>
<td>$850/ha</td>
<td>1%</td>
<td>Clearing, raking, internal roads, fences</td>
</tr>
<tr>
<td>Irrigation system (overhead/spray)</td>
<td>15</td>
<td>$5725/ha</td>
<td>1%</td>
<td>Includes spray, diesel tanks, main lines, installation of fertigation system and power supply</td>
</tr>
<tr>
<td>Furrow</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land preparation</td>
<td>40</td>
<td>$850/ha</td>
<td>1%</td>
<td>Clearing, raking, internal roads, fences</td>
</tr>
</tbody>
</table>

148 | Case studies for the Northern Australia Water Resource Assessment
Based on the costs outlined, Table 6-11 and Table 6-12 show indicative costs of three irrigated-cropping options. These options were based on three crop season lengths:

- short-season crops required water to be stored for about 3 to 4 months and applied irrigation water was typically between 2 and 4 ML/ha before losses
- medium-season crops required water to be stored between 4 to 6 months and applied irrigation water was typically between 4 and 7 ML/ha before losses
- long-season crops were either a perennial or rotation crop and required water to be stored for 9 or more months and applied irrigation water was typically 10 to 12 ML/ha before losses.

The longer the crop or fodder growing period, the higher the plant water use and the higher the evaporative and seepage losses because water must be stored for longer periods of time.
Of the three scales of development examined (1100/1060 ha (spray/furrow), 400/370 ha and 150/135 ha, under overhead/furrow irrigation), the 150/135-ha development had the lowest cost because many of the development costs in Table 6-10 are proportional to the size of the area irrigated. However, on a per hectare basis the costs of an existing 1100/1060-ha development are lowest. For example, under furrow irrigation the total capital cost of the 1060 ha development is about $7,480/ha, while the 135-ha development is the highest at about $35,470/ha, because the cost of the water storage infrastructure becomes an increasing larger proportion of the total cost. For long-season crops the per hectare cost of the development is similar under overhead and furrow irrigation because the capital cost is dominated by the water storage.

6.5 Project commerciality

To evaluate whether the returns (i.e. gross margins) from an irrigated-cropping development are sufficient to pay off the costs of development taking into consideration the time value of money, break-even gross margins required for each of the enterprises listed in Table 6-11 are compared to the median crop gross margins for the higher value broadacre short, medium and long-season crops listed in Table 6-2.

Break-even gross margins are equal to the equivalent annual cost of development, which is the annual cost of owning, operating and maintaining an asset over its entire life, plus the annual enterprise overhead costs, at a specified discount rate.

To account for ‘failed’ years due to insufficient water, the break-even gross margin values calculated at 100% reliability are inflated by multipliers provided in the companion technical report on socio-economics (Stokes et al., 2017). Although these multipliers are used in this context to account for years of insufficient water, in reality they could also be used to adjust the break-even gross margin values for other issues impacting on potential production (e.g. pests, poor management).

This analysis used a discount rate of 7% on the basis that this rate reflects what a private-sector business would seek from an investment with risk, and is often the value for which public investments are evaluated. However, it should be noted that returns from agriculture are often less than 7%, and hence agricultural investment decisions are often not based solely on achieving a high return on a capital investment. For this reason a 3% discount rate was also examined on the basis that some investors may have alternative motivations for undertaking irrigation and that a discount rate of between 3% and 7% may be acceptable. For example, investment may involve speculation regarding property prices and water licences, or may include the social and community benefits of irrigation development (McKellar et al., 2015).

Table 6-13 provides break-even gross margin values at 100%, 80% and 60% reliability for discount rates of 3% and 7%. The blue shading indicates those combinations of crop season length and annual reliability where the crop gross margins could be capable of meeting the capital costs of development and operation and maintenance costs (including pumping).
Table 6-13 Break-even gross margins required to meet capital cost and operation and maintenance costs of irrigation enterprise

Two discount rates are examined, 3% and 7%. Blue shading indicates scenarios where potential crop gross margins exceed break-even gross margins. Break-even gross margin at 100% reliability calculated using equivalent annual cost (i.e. of capital and includes O&M) plus overheads at 100% reliability, and assuming infrastructure was split 50:50 between 15-year and 40-year service life (see Table 4-3 in companion technical report on agriculture viability (Ash et al., 2018c)). Risk adjustment multipliers for annual reliability values of 80% and 60% are 1.18 and 1.43, respectively, and were applied to the break-even gross margin at 100% reliability. Risk adjustment multipliers are sourced from Table 6-8 in Stokes et al. (2017), assuming mean water extraction in ‘failed’ years is 25% of full entitlement. Break-even gross margins take into consideration the lower cost of pumping water in ‘failed’ years by applying multipliers to the annual cost of diesel of 0.85 and 0.7 for an 80% and 60% annual reliability.

<table>
<thead>
<tr>
<th>Annual reliability</th>
<th>3% DISCOUNT RATE ($/ha)</th>
<th>7% DISCOUNT RATE ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100%</td>
<td>80%</td>
</tr>
<tr>
<td>Overhead irrigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1100-ha short-season cropping</td>
<td>1349</td>
<td>1578</td>
</tr>
<tr>
<td>400-ha medium-season cropping</td>
<td>2089</td>
<td>2428</td>
</tr>
<tr>
<td>150-ha long-season cropping</td>
<td>3765</td>
<td>4344</td>
</tr>
<tr>
<td>Furrow irrigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1060 ha short-season cropping</td>
<td>1129</td>
<td>1318</td>
</tr>
<tr>
<td>370 ha medium season cropping</td>
<td>1937</td>
<td>2246</td>
</tr>
<tr>
<td>135 ha long-season cropping</td>
<td>3830</td>
<td>4409</td>
</tr>
</tbody>
</table>

6.5.1 THE IMPACT OF GROWING-SEASON LENGTH AND RELIABILITY OF WATER EXTRACTION ON PROFITABILITY OF WATER HARVESTING

This section discusses the impact of growing-season length and reliability of water extraction on the profitability of water harvesting. Typically, crops with a longer growing season achieve higher gross margins. However, the trade-off is that these crops also require more water and the water has to be stored for a longer period of time, resulting in higher evaporation and seepage losses.

The two best-performing short-season crops on Sodosols in the Mitchell catchment are mungbeans and chickpeas, which have median gross margins of $1025/ha and $1233/ha, respectively (Ash et al., 2018c). Table 6-13 indicates that it is only possible for an investor to undertake a profitable water harvesting enterprise growing short-season crops such as chickpeas under furrow irrigation at close to 100% reliability of water supply (i.e. no ‘failed’ years) at a low discount rate of 3%. At a discount rate of 7% an investor intending to grow short-season crops would need to achieve median gross margins of $1653/ha or $1345/ha under overhead and furrow irrigation, respectively. These break-even gross margins are greater than potential returns from chickpeas, the short-season crop with the highest median gross margin (Table 6-2).

The medium-season length crops with the highest median gross margins are cotton and peanuts on Sodosols and cotton on Vertosols (peanuts cannot be grown on Vertosols). These have a median gross margin of $2912/ha, $3172/ha and $2647/ha, respectively. In the case of cotton, the gross margins listed in Table 6-2 assume local processing facilities (i.e. a cotton gin) are available. At these gross margins it is possible for an investor to grow irrigated peanuts on Sodosols and achieve a 7% return on investment with a reliability of annual water supply of 80% but not 60%.
For cotton planted on Sodosols, it would be possible to achieve a 7% return on investment at annual reliabilities of about 85%, under spray irrigation and about 75% under furrow irrigation. Cotton planted on Vertosols could achieve a 7% return on investment at 100% annual reliability or a 3% return on investment for annual reliabilities of 70% or better. At 60% annual reliability, peanuts could still achieve a 3% return on investment on Sodosols under spray or furrow irrigation. To achieve a 7% return on investment with a reliability of only 60% an investor would need to grow peanuts on Sodosols with a high price of peanuts (preferably at the start of the investment period) for several years of the 15-year investment period under furrow irrigation. It should be noted, however, that the break-even gross margins are calculated based on the favourable costing configuration presented in this case study. At larger total system volumes and developed area, less favourable ringtank locations would need to be developed, which would require higher break-even gross margins in order to pay off the capital and operation and maintenance costs.

Without a local cotton gin, cotton would have to be transported to the nearest gin in Emerald, which is more than 1250 km, depending upon the exact location in the Mitchell catchment. As a consequence of the large costs involved in transporting unprocessed cotton (of which only about 40% is lint), gross margins would fall below the break-even gross margin required.

Of the long-season crops, sugarcane is the perennial crop with the highest median gross margin of nearly $3000/ha, though this requires a sugar mill in close proximity. Consequently it is poorly suited to water harvesting and irrigation mosaic enterprises, which are typically dispersed throughout the landscape. Nevertheless, even at 100% annual reliability and a 3% discount rate the median gross margins required by sugarcane fall considerably short of the break-even gross margins.

As discussed in Section 6.3.1 a rotation of wet-season cotton and dry-season mungbeans grown within a single year is potentially suited to the Mitchell catchment and is capable of producing yields approaching the sum of the crops grown individually at their most optimal times, with a gross margin of about $3500/ha possible (Ash et al., 2018c). However, at default prices for cotton and mungbeans this still falls short of the break-even gross margin required, even at 100% annual reliability of water supply and a 3% discount rate. This highlights that while rotation cropping may be a good strategy for achieving the returns required to pay off the capital of infrastructure in some instances, it is poorly suited to water harvesting enterprises using large farm-scale ringtanks because the investor has to pay to store and pump considerably more water than they are able to apply to the field compared to short- or medium-season crops. A reduction in the reliability of water supply for a long-season crop only makes an unprofitable enterprise even more unprofitable.

6.6 Project benefits

6.6.1 POTENTIAL PRODUCTION

The gross potential production was calculated by multiplying the mean area under irrigation by the value of produce per hectare of an indicative crop that could be grown at the location.
The total area for irrigated-crop development was calculated taking into consideration the more limiting of (i) land suitable for irrigated agriculture and (ii) the volume of water that can be physically extracted considering transmission and field application losses. As shown in Section 6.3.3, the larger the volume of water extracted the lower the reliability of extracting the full entitlement of water. The lower the reliability of extracting a full entitlement of water the less likely a cropping enterprise will be profitable (Section 6.5).

Based on the analysis in Section 6.5, of cropping enterprises that are potentially commercially profitable at a discount rate of 7%, cotton and peanuts could be grown at annual reliabilities as low as about 85%, depending upon the type of soils. Based on the analysis in Section 6.3.3, it is physically possible to extract a little more than 2000 GL of water across the Mitchell catchment at an annual reliability of 80%. With an overall efficiency (i.e. storage, conveyance and field application) of about 54% and a crop water use of about 5.5 ML/ha before losses, approximately 200,000 ha of cotton and peanuts could potentially be irrigated. This would be equivalent to about 500 developments of 400 ha, each with a 4000-ML ringtank. This would require a minimum of 1000 km of river frontage along the major rivers in the Mitchell catchment if these developments were placed end to end.

The gross benefit of developing 200,000 ha of land, half under dry-season cotton and half under dry-season peanuts, would be about $1.06 billion per year (after adjusting for the value of land prior to development, assuming this was under low intensity use valued at $55 per ha per year).

6.6.2 REGIONAL ECONOMIC BENEFITS

To estimate the regional economic benefit resulting from a development or developments, Regional Input-Output (I-O) models incorporating total output (Type II) multipliers were used. The analysis focused on the ongoing annual benefits generated from the increased dollar output of the agricultural sectors in each region resulting from the water storage scheme, treating this increased output as an exogenous shock to the economy.

The basis of the approach is that those agricultural businesses directly benefitting from the project will need to increase their purchases of the raw materials, labour and intermediate products utilised by their growing outputs. Should any of these purchases be made within the region, then this provides a stimulus to those businesses that they purchase from, contributing to further economic growth and job creation within the region (the production-induced effect). Furthermore, household incomes increase as a result of those local residents who are employed (as a consequence of either the direct or production-induced business stimuli); and, as a proportion of their additional income is spent in the region, that further stimulates greater economic activity and additional job creation (consumption-induced effects).

The dollar value of the increased total economic activity per year due to the operation of the scheme is estimated by using the exogenous increases in agriculture as an input to the Regional I-O models developed from pre-existing I-O tables.

As part of this process, the I-O analysis estimates the total increase to household incomes within the region. By using this value along with the median income within the region an estimate can be derived of the likely full-time equivalent jobs that would be created (directly, and indirectly through production and consumption effects) as a result of the project.
As outlined in Stokes et al. (2017), for each dollar of direct annual benefit from new agricultural activity it was estimated to generate an additional $1.09 in regional economic activity recurring annually. For every $100 million in new agricultural activity it was estimated to create an additional 1073 full-time equivalent jobs. Impacts of development on the I-O region are presented for three scales of increase in gross economic output (20,000, 50,000 and 200,000 ha) for the categories ‘Agriculture excluding beef cattle’ (Table 3-11). Note that all results scale linearly as the economic output of each type of agricultural activity increases.

Based on the proceeding analysis it is physically possible to irrigate 200,000 ha of land. As shown in Table 6-14, 200,000 ha of irrigated cotton and peanuts could have a gross value of production of $1.06 billion and create an additional regional economic activity of $1.16 billion (or $2.22 billion total increase in regional economic activity) and potentially create over 10,000 new full-time equivalent direct and indirect jobs. It should be reiterated, however, that this assumes unconstrained development.

Table 6-14 Estimated increase in agricultural output per year resulting from three physically plausible scales of irrigation development based on water harvesting and ringtanks

<table>
<thead>
<tr>
<th>MEAN IRRIGATED AREA (ha)</th>
<th>AGRICULTURAL CROP</th>
<th>AGRICULTURAL SECTOR</th>
<th>WATER EXTRACTION (GL)</th>
<th>VALUE OF INCREASED AGRICULTURAL OUTPUT ($ MILLION)</th>
<th>INCREASED REGIONAL ECONOMIC ACTIVITY ($ MILLION)</th>
<th>APPROXIMATE JOBS CREATED (NUMBER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20,000</td>
<td>Dry-season cotton &amp; dry-season peanuts</td>
<td>Agriculture excluding beef</td>
<td>200</td>
<td>$106 million</td>
<td>$222 million</td>
<td>1,073</td>
</tr>
<tr>
<td>50,000</td>
<td>Dry-season cotton &amp; dry-season peanuts</td>
<td>Agriculture excluding beef</td>
<td>500</td>
<td>$265 million</td>
<td>$555 million</td>
<td>2,682</td>
</tr>
<tr>
<td>200,000</td>
<td>Dry-season cotton &amp; dry-season peanuts</td>
<td>Agriculture excluding beef</td>
<td>2,000</td>
<td>$1,060 million</td>
<td>$2,221 million</td>
<td>10,727</td>
</tr>
</tbody>
</table>

6.7 Project impacts

6.7.1 SUMMARY OF ASSETS

The Mitchell catchment is largely intact in terms of the continuity of its plant and animal communities and the ecological processes that underpin them. The Mitchell River, unlike its major tributaries is a large perennial river, and although there are rivers in northern Australia with this characteristic, they are a minority. The flow in the river is highly seasonal, underpins river–floodplain productivity and provides critical habitats for species, including freshwater sawfish, a barramundi fishery and the extensive Northern Prawn Fishery, one of Australia’s most valuable fisheries.

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. See companion technical report on ecological asset descriptions (Pollino et al., 2018a) for more information on ecological assets in the Mitchell catchment.

6.7.2 CHANGES IN FLOW ARISING FROM DIFFERENT LEVELS OF WATER EXTRACTION

Figure 6-9 and Figure 6-10 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), for a total system volume of 1500 GL/year and 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 6-9). However, at the same location and same total system volume of 1500 GL/year, the 80% annual exceedance streamflow is about 40% of the 80% annual flow under Scenario A (Figure 6-10). 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 (Figure 6-10).

These results illustrate how water harvesting/extractions have greater impact in 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 6-9 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 6-10 80% annual exceedance 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
6.7.3 POTENTIAL ECOLOGICAL CHANGE ARISING FROM CHANGES IN STREAMFLOW

The highly seasonal flows of the Mitchell catchment underpin river–floodplain productivity and provide critical habitats for species including freshwater sawfish, as well as a barramundi fishery and the extensive Northern Prawn Fishery, one of Australia’s most valuable fisheries. The catchment supports a large number of offstream wetland habitats where it discharges into the Gulf of Carpentaria.

Relative to dams, water harvesting generally has lower impacts on aquatic systems (see companion technical report on ecological analysis (Pollino et al., 2018b)). Water harvesting can result in changes to streamflow, with pumping taking the ‘top’ off flow events. Changes in flow are sensitive to lower pumping extraction thresholds.

These impacts are greatest in the early wet seasons. Without mitigation strategies pumping during this period can delay or limit the refreshing of waterholes and estuaries, and lead to increased periods of off-river wetlands being disconnected from river channels. Barramundi typically move inland on the cue of small flows at the beginning of the wet season, and delays could prevent the success of recruitment of juvenile barramundi.

In dry years, when streamflow is low, pumping from the river has a greater potential for impact. Depending upon extraction licence conditions (i.e. flow past last gauge and pump start thresholds) pumping in dry years can result in reduced dry season ‘life’ of waterholes, with the potential for waterholes that are usually permanent to dry out. The thermal conditions in waterholes can also be exacerbated by extended dry periods. Pumping events in a dry period can also reduce the connection time of off-river wetlands, as well as the number of wetlands being connected, which can reduce natural aquatic productivity.

If the pattern of drying persists across years, localised changes in the ecology are likely. This could lead to the loss of off-river wetlands. There is also the potential for reduction in connectivity and persistence of waterholes, increasing the vulnerability of fish species such as sawfish, bull sharks and barramundi.

The companion technical report on ecological analysis, Pollino et al., (2018b), details changes in flow habitat that may arise from different quantities and patterns of water extraction.

6.7.4 OTHER CONSIDERATIONS

Table 6-15 summaries a selection of potential non-flow-related ecological, social and cultural considerations with respect to water harvesting irrigation developments.
Table 6-15 General discussion of potential non-flow-related ecological, social and cultural considerations with respect to small-scale water harvesting irrigation developments

<table>
<thead>
<tr>
<th>ECOLOGICAL AND SOCIAL CONSIDERATIONS</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation at reservoir and irrigation development</td>
<td>As the exact locations of water harvesting schemes are not defined, the vegetation communities likely to be affected cannot be defined. Vegetation communities along watercourses and adjacent alluvial soils generally have higher ecological value or conservation status than those more distant from the watercourse.</td>
</tr>
<tr>
<td>Sediment, nutrient and pesticide loads</td>
<td>Changes in sediment, nutrient and pesticide loads cannot be estimated without a specific crop designated. However, minor increases commensurate with the level of agricultural development can be expected.</td>
</tr>
<tr>
<td>Fish passage</td>
<td>The absence of major instream structures such as weirs, under water harvesting options, eliminates fish passage issues, except where diversion structures are used. However, other infrastructure that may accompany development such as road crossings may also reduce the ability of some species to move along a river.</td>
</tr>
<tr>
<td>Freshwater and coastal aquatic ecology in response to flow alteration</td>
<td>First flushing flows are ecologically important to waterholes where water quality and thus ecological health has deteriorated during the dry season. Last flow gauge requirements may help ensure the integrity of first flush events.</td>
</tr>
<tr>
<td>Terrestrial ecology</td>
<td>Ringtanks or other storages may provide a water source for terrestrial animals.</td>
</tr>
<tr>
<td>Impoundment ecology</td>
<td>Although artificial, ringtanks that store water can provide some habitat values, especially to mobile or dispersive fauna such as birds and aquatic insects. The poorer quality of the stored water (i.e. stormflow water – see above), seasonal drawdown and lack of connection to natural watercourses limit the habitat values of the storages. Artificial on-farm water storages have often been the starting point of weed and pest fish invasions in many catchments.</td>
</tr>
<tr>
<td>Human ecology</td>
<td>Large ringtanks may provide minor recreational opportunities.</td>
</tr>
</tbody>
</table>
In this case study, a potential irrigation development upstream of the confluence of the Mitchell and Walsh rivers was investigated (see Figure 7-1). The development is based on a rotation of sugarcane and mungbeans, with a new sugar mill located on-site. Irrigation water would be supplied from a dam constructed on the Mitchell River and irrigation water would be delivered to the crops via overhead sprinkler systems.

The feasibility of this irrigation development is analysed with respect to:

- the physical capacity to create a water storage and water distribution infrastructure, to supply water to agriculturally suitable soils, and to grow irrigated sugarcane
- the capacity of the scheme to generate positive net revenues, based on a vertically integrated development that includes a new mill and is developed and operated by a single investor
- potential impacts to freshwater aquatic, riparian and near-shore marine species and habitats.

The financial analysis for this case study investigates whether the projected revenues from the processed products from the mill (sugar and energy) and the sale of mungbeans are sufficient to cover the costs of irrigation development. The perspective of a tightly integrated scheme
developed and operated by a single investor is appropriate for a new sugarcane development where the farming and processing would need to be planned and developed together.

The analysis of the irrigation development is presented at the enterprise scale, using results under two scenarios. Both scenarios use the same 125-year historical climate data (from 1890 to 2015). Scenario A uses historical climate and current development, whereas Scenario B uses historical climate and future irrigation development (i.e. an irrigation development based on water supplied by a large dam). All results in the Assessment are reported over the ‘water year’, defined as the period 1 September to 31 August. This allows each 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).

In presenting this case study, no consideration is given to legislative issues that may need to be addressed for any development of this scale to proceed. These issues include, but are not limited to, legislation relating to land tenure, planning and infrastructure, cultural heritage, native title, vegetation management, wildlife protection, water resources, fisheries and environmental protection.

7.1 Summary

The case study concludes that the physical conditions at the site would enable the development of a dam to supply irrigation water for a 70,000-ha irrigation development of sugarcane and mungbeans. The case study found:

- A dam capable of storing 2316 GL of water can potentially be located adjacent to the Pinnacles Range on the Mitchell River. Because of high inter-annual variability in streamflow and evaporative losses its annual water yield would be 1248 GL/year (at 85% reliability). The estimated storage cost of $755 million and annual yield of 1248 GL results in a unit cost of $605/ML at the dam wall, with an equivalent annual unit cost of $45/year per ML/year. Approximately 45% of this water yield at the dam wall would be lost in conveyance and application to the crop.

- Approximately 100,000 ha of soils moderately suited to spray-irrigated sugarcane and mungbean production lie downstream of the dam site and upstream of the confluence of the Mitchell and Walsh rivers. Given adequate irrigation and crop management, these soils are capable of supporting median crop yields of about 120 t/ha for sugarcane and 2 t/ha of mungbeans per year. Large areas of land suitable for irrigated agriculture are also located downstream of the confluence of the Mitchell and Walsh rivers.

- Previous analyses have highlighted that without a local sugar mill, large dam-based irrigation sugarcane developments are unlikely to achieve a positive internal rate of return. Mills are, however, capital intensive and for the mill (and therefore the overall development) to be viable, economies of scale are required, with a secure supply of sufficient sugarcane – at least 20,000 to 30,000 ha of farmland growing sugarcane. Producing sugarcane at scale also creates secondary opportunities: cogen (cogeneration of electricity from bagasse, the moist sugarcane fibre that remains after crushing) and sale of molasses as a feed supplement for local cattle producers.

- The total capital cost of the dam, sugarcane farming and sugar mill enterprise outlined in this case study would be about $3.26 billion without cogeneration and $3.66 billion with
cogeneration. The total annual operating cost of the enterprise (i.e. dam to port) would be about $241 million and $245 million with and without a cogeneration plant, respectively.

- The total annual revenue from the enterprise would be about $492 million (i.e. sale of processed sugar and mungbeans) without cogen and $534 million and $570 million with cogen assuming a wholesale electricity price of $90/MW hr and a higher price of $165/MW hr (i.e. representing a wholesale electricity price that may include renewable energy incentives) respectively.

- Without cogen the enterprise internal rate of return (IRR) (to port) is 3.5%. With cogen the IRR is 4.1% and 5.3% assuming a wholesale price of electricity of $90/MW hr and $165/MW hr, respectively, highlighting the sensitivity of the entire development to changes in energy policy and pricing.

- The total increase in potential regional economic activity as a result of the enterprise is estimated to be $1.033 billion/year and it would generate at least 2865 direct and indirect jobs. The one-time potential regional economic benefit during the construction phase is estimated to be $3.6 billion and $4.1 billion with and without cogen.

- To support the labour force working on a 70,000 ha irrigation development and sugar mill and their families, considerable additional costs in community (e.g. schools, hospitals, housing, sewerage) and soft infrastructure (e.g. law enforcement services) would be incurred. Although under the assumptions of this case study the costs of some community infrastructure such as access roads, electricity and water supply would largely be incurred by the developer.

- The reach immediately below the potential Pinnacles dam would show dramatic changes in streamflow habitats (not shown) for most assets, with a reduction in peak events and low-flow events and an increase in sustained low-to-moderate flows.

- With distance downstream of the dam and the point of irrigation extraction, the changes in flow would be moderated by joining tributaries such that the seasonality of streamflow increasingly resembles the natural pattern and the degree of regulation decreases. As a consequence of this at the end-of-system, flow habitat for all near-shore marine and estuarine species, including barramundi, crocodiles, grunter, mullet, sawfish and snubfin dolphin would experience minor change with the potential Pinnacles dam and irrigation development. The flow habitats of major tributaries (i.e. Palmer, Walsh and Lynd) to the Mitchell River would remain unaffected by the Pinnacles River dam and irrigation development.

- Under the cracking clay soils (SGG 9), approximately half of the potential irrigation area, there are considerable levels of salt, which have the potential to mobilise and cause secondary salinity if a watertable rises close to the surface. If this were to eventuate it has the potential to cause a loss in production and for the salt to become an environmental problem. With the application of good quality water and careful management, such as the use of highly efficient overhead irrigation, it is likely that these soils can be successfully irrigated. Further site-specific investigations would be required to further ascertain the risk, and it may be necessary to develop some land further downstream.

- Substantial land in the area is subject to current or future native title claims. Several registered and/or recorded sacred and cultural heritage sites are known to exist in the inundation area. There is a high likelihood of currently unrecorded sites. Large instream dams are not a favoured form of development of Indigenous people interviewed in the Mitchell catchment.
7.2 Storyline for this case study

This case study assesses the viability of a new sugarcane growing district located above the confluence of the Mitchell and Walsh rivers in the vicinity of Wrotham Park Station, where more than 100,000 ha of land moderately suitable for irrigated agriculture and not subject to broad-scale flooding have been identified. Water for the sugarcane district would be supplied from a large dam on the Mitchell River at a location called the Pinnacles (Figure 7-2). Sugarcane was selected because sugar is a well-established industry in north Queensland, with considerable existing infrastructure and bulk-handling facilities at the Port of Mourilyan, Port of Cairns and Port of Townsville. Sugar is also a high-value export commodity, with well-established export markets and marketing infrastructure.

In the Wrotham Park area, sugarcane would be planted after the wet-season rains have ceased, generally from about April, and the planting season would continue until June. Sugarcane is a perennial crop, harvested the year after it is planted. The harvesting season would extend from June to about November, although there may be benefits in starting the harvest in May. After harvesting the plant crop, the crop regrows (called ratooning) and the first ratoon crop grows for a further year before being harvested. The crop will continue to ratoon after each harvest, but yields tend to decline with subsequent ratoons. Most farmers only harvest three or four ratooned crops before killing the crop. After the final ratooned crop is killed there is a fallow period of approximately six months which is generally used to grow a ‘break’ crop, usually a legume (which can supply nitrogen for the subsequent crops). For this case study we considered the option of a farming system that involved a plant crop of sugarcane followed by three ratoon crops and growing mungbeans during the fallow period. The consequence of the fallow is that for one in every five years of the production cycle of each field there would be no sugarcane harvest. However, the plant crop tends to be higher yielding, in part because it has a longer growing season. In practice, sugarcane farms have a mix of different-aged crops, so farms with a three-ratoons cycle have 20% of their farms assigned to each crop age (including the fallow), and only harvest 80% of their area from sugarcane on average in any given year.

The nearest sugar mill to the Wrotham Park area is near Mareeba, about 230 km away by road. Unprocessed sugarcane is mainly water (70%) and expensive to transport, so carting sugarcane to a mill so far away would cost more than the value of the sugarcane and would not be economic (see Poulton et al., 2013). Raw sugar is only about 15% of the mass of the unprocessed sugarcane, so local processing reduces the mass of transported product by about 85%. Sugarcane growing and milling are very tightly coupled and interdependent operations: sugarcane has to be crushed within 24 hours of it being harvested, so growing, harvesting, transporting sugarcane to the mill, and crushing all have to be scheduled together, particularly if the expensive mill capital is to be fully and efficiently utilised. Any new sugarcane development would therefore have to plan and develop farming and processing together.

Sugar mills are capital intensive and for the mill (and therefore the overall development) to be viable, economies of scale are required, with a secure supply of sufficient sugarcane (at least 20,000 to 30,000 ha of farmland growing sugarcane). Producing sugarcane at scale creates secondary opportunities: cogen (cogeneration of electricity from bagasse, the moist sugarcane fibre that remains after crushing) and sale of molasses as a feed supplement for local cattle producers.
For this reason, this case study investigates the viability of a new irrigated sugarcane district in the Mitchell catchment as a vertically integrated development that includes a new local mill. It is assumed here this would be a tightly integrated scheme, developed and operated by a single investor. Three cases are considered in the financial analysis:

1. a mill without cogen
2. a mill with cogen, using a lower bound wholesale price for generated of electricity of $90/MW hr
3. a mill with cogen using a higher price of $165/MW hr that includes renewable electricity incentives.

The companion technical report on socio-economics (Stokes et al., 2017), discusses the uncertainty about future wholesale prices for electricity and explains the basis for choosing this range of prices for sensitivity testing.

The outline of this case study is as follows:

- Section 4.3 describes the case study and case study area including the soils, farming system and configuration of water supply and irrigation development
- Section 7.4 describes the case study costs
- Section 7.5 describes the case study benefits in terms of potential production and regional economic benefits
- Section 7.6 assesses the case study commerciality and describes two financial analyses
- Section 7.7 describes a selection of potential on-site and off-site impacts associated with the scheme area selected in Section 4.3.

The case study area is shown in Figure 7-2. To provide a sense of scale and an indicative sense of place, a potential irrigation development of 70,000 ha is delineated above the junction of the Mitchell and Walsh rivers. Before irrigation development, the area would require a more intensive assessment of usable areas, risks and trade-offs.
Figure 7-2 (a) Satellite image and (b) relief and potential maximum surface water extent upstream of the confluence of the Mitchell and Walsh rivers
Data used to develop flood map were captured using MODIS satellite imagery. This figure illustrates the maximum percentage of MODIS pixels inundated between 2000 and 2015.
7.3 Case study and study area description

This section describes:

- the soils of the Pinnacles irrigation developments and their suitability for irrigated agriculture
- a potential sugarcane–mungbean rotation and its suitability to the Mitchell catchment
- a nominal configuration of the water supply and irrigation development.

7.3.1 SOIL AND LAND SUITABILITY ABOVE THE CONFLUENCE OF THE MITCHELL AND WALSH RIVERS

The potential irrigation development is on the gently undulating to undulating rises and plains (slopes predominantly <5%) on Cretaceous sedimentary rocks of the Great Artesian Basin at Wrotham Park, upstream of the confluence of the Mitchell and Walsh Rivers (Figure 7-3). The soils of the case study area are shown by the soil generic group map in Figure 7-5a and described below. Figure 7-5b shows a land suitability map for sugarcane under spray irrigation.

Approximately 55,000 ha of land moderately suitable with considerable limitations (i.e Class 3) or better for sugarcane under overhead irrigation is found within the bounds of the Mitchell and Walsh rivers and Elizabeth Creek. Immediately south of Elizabeth Creek on the right bank of the Walsh River is an additional 15,000 ha of Class 3 or better land. An additional 10,000 ha of Class 3 land or better is located on the right bank of the Mitchell River immediately below the potential Pinnacles dam. Below the confluence of the Mitchell and Walsh rivers and upstream of the confluence of the Lynd River an additional 25,000 ha of Class 3 land or better lies on the right bank of the Mitchell River. Further downstream of the confluence of the Mitchell and Lynd rivers are many 100,000s ha of land Class 3 or better for sugarcane under overhead irrigation on both banks of the river, however, the land is further from the potential Pinnacles dam. Below the confluence of the Mitchell and Palmer rivers the land becomes increasingly susceptible to flooding, though small to moderate floods will be mitigated to some extent by the Pinnacles dam.

The case study area adjoins the alluvial plains of the Mitchell and Walsh rivers to the north-west and south respectively, deep sands derived from Jurassic quarts sandstones to the east, and a range of Tertiary and Tertiary–Quaternary alluvial deposits to the north.

Slowly permeable, moderately deep to very deep (>0.5 m), moderately well drained, black cracking clays with a soft self-mulching surface dominate the plains and rises (Figure 7-4). Soils have high water holding capacity (100 to 125 mm/m) but may have a restricted rooting depth on lower slopes due to very high salt levels at greater than 1.0 m in the subsoil.

Soils may be suitable for irrigated sugarcane, grain/forage crops and pulse crops. The naturally high salt levels in the subsoil may result in saline seepage on lower slopes and further investigations are required to assess the likelihood of salinity issues from rising water tables under irrigated cropping. Minor rill and gully erosion are evident on steeper slopes (>3%). Soils are likely to be suitable or possibly suitable for ringtanks depending on soil depth and slope.
Figure 7-3 Gently undulating cracking clay plain upstream of the confluence of the Mitchell and Walsh Rivers
Photo: CSIRO

Figure 7-4 Deep friable moderately well-drained cracking clay soil (SGG 9 vertosol) exposed in a gully in the mid-section of the Mitchell catchment
Photo: CSIRO
Minor gravelly deep sands and loamy soils derived from Tertiary sediments overlying the Cretaceous sedimentary rocks occur on the crests of rises and low hills in the centre of the case study area. These soils may be suitable for trickle irrigated horticultural crops but further investigations are required to assess the likelihood of salinity issues from rising watertables developing under irrigated cropping on the lower slopes of the clay soils.

The potential irrigation development outlined in Figure 7-2 and Figure 7-5 predominantly comprises the cracking clay soils. Before irrigation development, the area would require more intensive assessment of usable areas.

7.3.2 FARMING SYSTEMS

This section examines the climate in relation to a sugarcane–mungbean rotation in the Wrotham Park area. It then examines the relationship between applied irrigation water and crop yield at production potential.

Climate suitability for sugarcane and mungbeans

Rainfall in the Mitchell catchment is highly variable among years and highly seasonal (Figure 7-6). Although potential evaporation is also seasonal, driven largely by temperature (Figure 7-6), there is very little year-to-year variation in evaporative demand. In most years the daily fortnightly averaged maximum temperature remains above 30 °C year-round, with greater seasonal variation in the average minimum temperature (Figure 7-6). Consequently, with sufficient water, a tropical perennial grass crop such as sugarcane could produce high biomass yields. Like the Burdekin region, the dry winter months would allow withholding of irrigation to allow the soil to dry down, reduce growth and potentially increase sucrose content before harvest. However, there is some evidence from the Ord district that in that environment, the sugarcane crop does not respond in a similar way to the established regions in Queensland (Leslie and Byth, 2000; Bonnett et al., 2006). Therefore, caution is needed in translating results based on these other regions to new regions. The lack of rain during May to October also provides an ideal break for harvesting sugarcane.
Figure 7-5 (a) Soil generic group and (b) land suitability for spray-irrigated sugarcane upstream of the confluence of the Mitchell and Walsh rivers
The land suitability map does not take into consideration flood risk, secondary salinity or water availability. Broad-scale flooding is shown in Figure 7-2b.
Figure 7-6 Long-term fortnightly climate variation in rainfall, maximum and minimum temperatures under the historical climate (1890 to 2015)
Data sourced from SILO. Whiskers on box plots show 10% and 90% exceedence values.
Figure 7-7 Long-term fortnightly climate variation in solar radiation, relative humidity (RH) and vapour pressure deficit (VPD) under the historical climate (1890 to 2015)
Data sourced from SILO. Whiskers on box plots show 10% and 90% exceedence values.
**Applied irrigation water and crop yield**

Applied irrigation water and crop yield data for sugarcane were simulated using the sugarcane module of the Agricultural Production Systems Simulator (APSIM) crop model, and soils representative of the case study area.

Crop water use and yield values are based on APSIM modelling of a rotation specific to this analysis, and may vary slightly from values in the companion technical report on agriculture viability (Ash et al., 2018c). However, it should be noted that preliminary estimates of crop water use (Table 4-1) could be made using the mean of 50th percentile crop water use values on Vertosols and Sodosols for dry-season mungbeans and sugarcane presented in Ash et al. (2018c). On average across the scheme and across years, the sugarcane parameters would apply to 80% of the new farmland and the mungbean parameters to other 20%. For example, this would give an average irrigation water demand of 9.3 ML/ha (80% x 10.7ML/ha + 20% x 3.7 ML/ha) before losses. The sugarcane parameters are the mean of the plant crop and the three ratoons.

**Table 7-1 Crop production parameters for sugarcane and a mungbean fallow used in financial analysis**

Crop water use values are taken as a mean of 50th percentile APSIM estimates for Vertosols and Sodosols. Yield is average of plant crop and three ratoons with mungbean planted in fallow. No price is provided for sugarcane because it is processed within an integrated scheme and sold as value-added products. Values may vary slightly from technical report on agriculture viability due to difference in times of planting.

<table>
<thead>
<tr>
<th>CROP</th>
<th>IRRIGATION WATER DEMAND</th>
<th>CROP YIELD</th>
<th>PRICE</th>
<th>VARIABLE COST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(ML/ha)</td>
<td>(t/ha)</td>
<td>($/unit)</td>
<td>($/ha)</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>10.7</td>
<td>119.3</td>
<td>na</td>
<td>2044</td>
</tr>
<tr>
<td>Mungbean (dry season fallow)</td>
<td>3.7</td>
<td>2.1</td>
<td>1100</td>
<td>1155</td>
</tr>
</tbody>
</table>

### 7.3.3 CONFIGURATION OF WATER SUPPLY AND IRRIGATION DEVELOPMENT

This section provides a description of the configuration of the:

- Pinnacles dam
- regulating structure and pump station
- configuration of the irrigation development
- additional hard infrastructure requirements.

#### Pinnacles dam

The potential Pinnacles dam, as featured in Figure 7-8, is a roller compacted concrete (RCC) dam, with a spillway 58 m above the river bed and a major saddle dam on the right bank. The Pinnacles dam is located on the Mitchell River adjacent to the Pinnacles range and 423.9 km from the mouth of the Mitchell River. Modelled streamflow characteristics at gauging station 919003A at OK Bridge at the potential dam site is given in Table 7-2. For a given mean annual streamflow, the larger the variability in annual streamflow, the smaller the water yield from the dam. The streamflow in the Mitchell River is about two to three times more variable than rivers of the rest of the world of the same climate type (Petheram et al., 2008).
The Pinnacles dam is one of the potential dam sites in the Mitchell catchment with the lowest cost per ML released from the dam wall. The full supply level (FSL) or spillway height of the dam for this case study is assumed to be 58 m. This was deemed to be the optimal height without excessively large saddle dam requirements. The Pinnacles RCC dam is likely to cost between $680 million and $980 million. The main dam wall and saddle dam were designed to accommodate flood surges of events 1 in 10,000 annual exceedance probability (AEP) and 1 in 50,000 AEP, respectively. Key parameters for the dam are summarised in Table 7-3. For more detail, see companion technical report on surface water storage (Petheram et al., 2017).
Table 7-3 Pinnacles dam parameters

<table>
<thead>
<tr>
<th>NAME</th>
<th>DAM TYPE *</th>
<th>SPILLWAY HEIGHT ABOVE BED (M)**</th>
<th>CAPACITY AT FSL (GL)</th>
<th>CATCHMENT AREA (KM²)</th>
<th>ANNUAL WATER YIELD (GL)***</th>
<th>CAPITAL COST#</th>
<th>UNIT COST##</th>
<th>EQUIVALENT ANNUAL UNIT COST###</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinnacles dam site on the Mitchell River</td>
<td>RCC</td>
<td>58</td>
<td>2316</td>
<td>7728</td>
<td>1248</td>
<td>755</td>
<td>605</td>
<td>45</td>
</tr>
</tbody>
</table>

* 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”. 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.
### Assuming a 7% real discount rate and a dam service life of 100 years. Includes operation and maintenance costs, assuming operation and maintenance costs are 0.4% of the total capital cost.

Re-regulating structure and pump station

Under this nominal conceptual configuration, water would be released from the Pinnacles dam to a concrete gravity weir (re-regulating structure) approximately 45 km downstream of the potential dam. The weir allows for more efficient releases of water from the dam at key times required by the irrigation development, thereby reducing the transmission losses normally involved in supplemented river systems. Based on aerial photography it is assumed a rock foundation for the weir would be present. It is assumed that the weir would be 400-m wide and 6-m high and would cost approximately $12.7 million.

Water would be pumped from behind the concrete gravity weir to a 400 ML balancing storage on the left bank with a FSL 186 m via eight concrete volume pump units housed in two 4-unit structures and two steel rising mains each of 2.4 km in length. The balancing storage (natural surface level 80 to 182 mAHD) would help improve the efficiency with which water can be supplied from the weir to the farm gate.

The potential balancing storage is situated 3 km from the river (Figure 7-5b), although this land is potentially also suitable for irrigated agriculture. By pumping water up to a balancing storage, this enables water to be gravity fed via supply channels across the scheme and for a 3-km wide riparian zone to be maintained between the irrigation development and the Walsh River.

Irrigation scheme configuration

Under this nominal configuration 55,000 ha of Class 3 or better land for sugarcane under overhead irrigation bounded by the Mitchell and Walsh rivers and Elizabeth Creek and the 15,000 ha of Class 3 land immediately south of Elizabeth Creek would be developed. An advantage of these two areas is that they are not susceptible to flooding reducing construction costs (e.g. relative to more flood prone areas such as the Lower Burdekin, which would require additional drainage infrastructure), their proximity to Mareeba and that a bridge would not need to be constructed across the Mitchell River. It should be noted, however, that more detailed analysis and on-ground investigations may indicate that alternative locations and scheme configurations may have lower or higher infrastructure costs, result in lower offsite risks or offer other advantages.
For the nominal irrigation scheme configuration in this case study a 6-km long trapezoidal earth main trunk channel would carry water from the balancing storage to a 25-km north-south main truck channel. From this north-south channel distribution channels would supply water to each farm. Water would need to be siphoned under or conveyed across Elizabeth Creek. An alternative to developing land to the south of Elizabeth Creek would be to develop land on the right bank of the Mitchell River, supplying water via riparian pumping.

It is assumed all farm offtakes are from the distributor channels. Once at the field, water is applied using modern spray irrigation systems capable of delivering peak water requirements to the sugarcane crop at periods of high-evaporative demand. Overhead sprinklers are used to optimise irrigation water efficiency and minimise accessions to groundwater, which have the potential to cause watertable levels to rise and increase salinity risk. Well-managed spray irrigation generates very little tailwater runoff (i.e. water leaving the field following an irrigation event), except during large rainfall events that may occur immediately after irrigation on full soil profiles.

Table 7-4 lists the conveyance efficiency assumptions used in this analysis. In total, the conveyance and application efficiency from the storage to the crop is about 55%. These values are likely to be representative of best practice.

Table 7-4: Conveyance efficiency assumptions for the irrigation development associated with the Pinnacles dam

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>EFFICIENCY (%)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>River conveyance efficiency</td>
<td>80</td>
<td>Representative of transmission loss and delivery inefficiencies from the dam to the weir and evaporative losses from weir. Distance between dam and concrete gravity weir is about 45 km. River is already perennial along these reaches.</td>
</tr>
<tr>
<td>Channel distribution efficiency</td>
<td>90</td>
<td>Representative of evaporation loss from balancing storage structure and channel loss between balancing storage and farm gate.</td>
</tr>
<tr>
<td>On-farm distribution efficiency</td>
<td>90</td>
<td>Representative of on-farm evaporation and seepage loss from farm gate to edge of field.</td>
</tr>
<tr>
<td>Field application efficiency (spray)</td>
<td>85</td>
<td>Representative of indicative loss under spray irrigation. Assumes majority of loss goes to deep drainage.</td>
</tr>
<tr>
<td>Overall efficiency</td>
<td>55</td>
<td></td>
</tr>
</tbody>
</table>

*Poorly constructed channels will have lower conveyance efficiency than those values listed in this table.

Additional hard infrastructure requirements

Key additional hard infrastructure that would be required to support an irrigation scheme associated with the Pinnacles dam are all weather access roads, power and a local sugar mill to process the sugarcane to raw sugar to reduce transportation costs and add value.

Access roads

The Burke Development Road, a Rank 2 unsealed road, passes through the potential Wrotham Park irrigation development. This road would require a major upgrade involving widening and considerable flood proofing to ensure all year access. The upgraded road would need to be designed to accommodate a very large increase in large vehicle traffic (it is estimated that approximately 7 × 35 tonne trucks per hour would be required to transport the processed sugar to port over the 6-month milling period).
molasses, and further crystallisation occurs on the A molasses, leaving B molasses. Eventually it is uneconomic to extract sugar further (usually from C molasses) and this is sold as a cattle feed. Molasses (and fibre) can be further processed to produce ethanol. Throughput rates at different stages of processing depend on the quality of the sugarcane, and hence affect the optimal configuration of mill components.

Mills are capital intensive facilities, so they need be utilised at full capacity to make efficient use of the investment. This requires mills to operate 24 hours a day, 7 days a week (with the exception of outages and weekly maintenance) with farming operations matched to keep the mill operating at full capacity as sugarcane is harvested. It also requires designing the size and components of the mill to suit the quantity, quality and timing of sugarcane that is grown and supplied to the mill.

### 7.4 Project costs

Project costs can be broadly broken up into hard infrastructure costs directly associated with the irrigation development and community and soft infrastructure costs, which may be required to support the increase in population arising from the development. Hard infrastructure costs are entirely or partially met by the developer, where in some cases third parties (e.g. local, state or federal government) may contribute funding, particularly if there is broader benefit to the regional economy or community (e.g. improved road access). Historically community and soft infrastructure costs have been largely borne by government.

#### 7.4.1 HARD INFRASTRUCTURE COSTS

Irrigation development involves a wide range of capital, operation and maintenance costs. These are incurred at both the scheme and farm scale. There may also be costs associated with post-processing infrastructure.

- Scheme-scale costs can be considered as being comprised of external costs and internal costs.
  - **External costs** are those associated with major infrastructure (e.g. dams, main access roads), approvals (e.g. environmental impact statements) and delivery of water (e.g. main channel, regulating structures, pump stations) and electricity/energy (e.g. diesel generators or substations and transmission lines) to the irrigation development.
  - **Internal costs** are the subsidiary channels, drains, internal roads, structures, hillside drains, and electricity to farm). These costs are simply reported as a representative cost per hectare basis as calculating these costs for a specific site requires detailed site data, typically undertaken as part of a feasibility analysis.
- Farm-scale capital, operation and maintenance costs are those associated with irrigation systems and farm equipment.
- Post-process infrastructure costs are those costs associated with constructing and operating post-processing infrastructure required by the enterprise.

Indicative capital, operation and maintenance costs associated with the potential Pinnacles dam on the Mitchell River and upgrading the Burke Development Road from Dimbulah to the Wrotham Park irrigation development are provided in Table 7-5 and Table 7-6 respectively. A detailed breakdown of scheme-scale costs (external and internal) are provided in Table 7-7. Table 7-8
outlines the farm-scale costs. These costs were obtained from information presented the companion technical reports on surface water storage (Petheram et al., 2017), socio-economics (Stokes et al., 2017) and agriculture viability in the Mitchell catchment (Ash et al., 2018c). Capital costs and operation and maintenance costs associated with the sugar mill are presented in Table 7-9. Mill costs were estimated for a mill designed to match the sugarcane outputs of the associated farming operations based on information provided in the companion technical report on socio-economics (Stokes et al., 2017).

**Table 7-5 Capital costs and operation and maintenance costs associated with Pinnacles dam on the Mitchell River**

Capital cost has been rounded. See companion technical report on surface water storage for detailed cost break down (Petheram et al., 2017).

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (Y)</th>
<th>CAPITAL COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dam</td>
<td>Pinnacles dam</td>
<td>100</td>
<td>755,000,000</td>
<td>0.4%</td>
</tr>
</tbody>
</table>

**Table 7-6 Order of magnitude capital costs and operation and maintenance costs associated with upgrading the Burke Development Road from Dimbulah to the Wrotham Park irrigation development**

Capital costs are order of magnitude and have been rounded. Costs based on information from companion technical report on socio-economics (Stokes et al. 2017).

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (Y)</th>
<th>CAPITAL COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major road upgrade</td>
<td>All-weather road from Dimbulah to irrigation area</td>
<td>40</td>
<td>200,000,000</td>
<td>1</td>
</tr>
<tr>
<td>Major bridge</td>
<td>Bridge crossing of Walsh River</td>
<td>40</td>
<td>60,000,000</td>
<td>1</td>
</tr>
<tr>
<td>Total cost to enterprise</td>
<td>40</td>
<td>130,000,000</td>
<td>1</td>
<td>Assumes 50% contribution to capital cost of road and operation and maintenance cost.</td>
</tr>
</tbody>
</table>

**Table 7-7 Irrigation scheme development capital costs and operation and maintenance costs associated with Pinnacles dam**

Capital costs are order of magnitude and have been rounded.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (Y)</th>
<th>CAPITAL COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total direct construction (TDC) costs</td>
<td>Weir</td>
<td>40</td>
<td>13,725,000</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Additional access roads and bridges</td>
<td>40</td>
<td>9,400,000</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Power supply</td>
<td>40</td>
<td>82,700,000</td>
<td>1%</td>
</tr>
<tr>
<td>ITEM</td>
<td>LIFE SPAN (Y)</td>
<td>CAPITAL COST ($)</td>
<td>O&amp;M (% CAPITAL COSTS)</td>
<td>COMMENT</td>
</tr>
<tr>
<td>------</td>
<td>---------------</td>
<td>------------------</td>
<td>-----------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Communications</td>
<td>40</td>
<td>500,000</td>
<td>1%</td>
<td>Two, four-unit stations</td>
</tr>
<tr>
<td>Pump stations</td>
<td>40</td>
<td>12,750,000</td>
<td>2%</td>
<td>Twin rising mains from pump station to balancing storage</td>
</tr>
<tr>
<td>Rising mains and cooling pipes</td>
<td>40</td>
<td>84,600,000</td>
<td>1%</td>
<td>400 ML storage including rising main inlet structures, pipe work under embankment and control gates.</td>
</tr>
<tr>
<td>Balancing storage</td>
<td>40</td>
<td>6,500,000</td>
<td>1%</td>
<td>38 km of main trunk channels, including fencing, control gates and road access bridges over channels.</td>
</tr>
<tr>
<td>Main trunk channels</td>
<td>40</td>
<td>26,500,000</td>
<td>1%</td>
<td>~180 km of main distribution channels including fencing, control gates and road access bridges over channels, siphon across Elizabeth Creek. ~100 km of main distributor roads and transmission lines.</td>
</tr>
<tr>
<td>Main distributor channels, roads and transmission lines within scheme</td>
<td>40</td>
<td>136,700,000</td>
<td>1%</td>
<td>Assuming 70,000 ha irrigation development at $3000/ha includes clearing, raking, earthworks, structures (e.g. siphons, regulators), minor within farm roads and drains, within farm power. Assumes only localised flood drainage required.</td>
</tr>
<tr>
<td>Land and scheme development</td>
<td>40</td>
<td>210,000,000</td>
<td>1%</td>
<td>Includes project and field staff, camp operations, staff recruitment and training, site communications, IT expenses and insurances and public liability.</td>
</tr>
<tr>
<td>On site overheads (OSO)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On site overheads</td>
<td>Na</td>
<td>68,330,000</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Profit and off-site overheads</td>
<td>Nat</td>
<td>63,170,000</td>
<td>NA</td>
<td>10% of TDC and OSO</td>
</tr>
<tr>
<td>Owner costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investigation and design</td>
<td>Na</td>
<td>28,170,000</td>
<td>NA</td>
<td>Preliminary design, geotechnical and materials, detailed design and documentation.</td>
</tr>
<tr>
<td>Acquisition and approvals</td>
<td>Na</td>
<td>32,780,000</td>
<td>NA</td>
<td>Includes environmental assessment and approvals, cultural heritage, native title, land acquisition, survey and legal.</td>
</tr>
<tr>
<td>Total project costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total project costs</td>
<td>na</td>
<td>775,825,000</td>
<td>$8,000,000</td>
<td>Operating and maintenance includes $2 million/y electricity usage.</td>
</tr>
<tr>
<td>Risk adjustment to capital</td>
<td>na</td>
<td>230,000,000</td>
<td>NA</td>
<td>30% of total project costs.</td>
</tr>
<tr>
<td>Total capital cost</td>
<td>na</td>
<td>$1,005,825,000</td>
<td>$8,000,000</td>
<td>Total project costs plus risk adjustment. Operating and maintenance includes $2 million/y electricity usage.</td>
</tr>
</tbody>
</table>
Table 7-8 Farm-scale capital and operational costs for 70,000 ha of farmland growing sugarcane
Capital costs have been rounded. Costs based on companion technical report on agriculture viability in the Mitchell catchment (Ash et al., 2018c).

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFE SPAN (Y)</th>
<th>CAPITAL COST ($)</th>
<th>O&amp;M (% CAPITAL COSTS)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm-scale costs: capital</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildings and facilities</td>
<td>40</td>
<td>105,000,000</td>
<td>1</td>
<td>Includes housing, sheds, workshops, vehicles.</td>
</tr>
<tr>
<td>Farm equipment</td>
<td>15</td>
<td>56,000,000</td>
<td>1</td>
<td>Includes machinery for planting and harvesting mungbeans.</td>
</tr>
<tr>
<td>Irrigation system (spray)</td>
<td>15</td>
<td>315,000,000</td>
<td>1</td>
<td>Includes high quality equipment and pumps.</td>
</tr>
<tr>
<td>Farm-scale costs: operating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual overheads</td>
<td>na</td>
<td>47,229,000</td>
<td>na</td>
<td>Includes maintenance costs, employee costs, land lease and other additional business overheads.</td>
</tr>
<tr>
<td>Annual variable costs</td>
<td></td>
<td>114,464,000</td>
<td>na</td>
<td>Variable costs involved in growing and harvesting sugarcane</td>
</tr>
</tbody>
</table>

Table 7-9 Indicative capital and operating costs for a mill configured to suit the supply of sugarcane from the development
Assumes sugarcane has a CCS of 15% and fibre content of 15%, and that the mill operates at 90% reliability over a 6-month crushing season crushing 1690 t sugarcane/hr (6,680,800 t sugarcane/year). Detailed underpinning assumptions for mill operations and costs are provided in the companion technical report on socio-economics (Stokes et al., 2017). The capital costs of the mill without cogen would be about $400,000 cheaper (i.e. the approximate $300,000 cost of the cogen assets plus 33% contingency), but the mill would require an alternate source of energy or sufficient boiler capacity to power the mill and would incur additional costs in disposing of bagasse (costs that are not included here).

<table>
<thead>
<tr>
<th>ITEM</th>
<th>LIFESPAN (Y)</th>
<th>COST ($)</th>
<th>O&amp;M (% CAPITAL COST)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic mill costs: capital</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Front end (crushers)</td>
<td>40</td>
<td>166,563,661</td>
<td>0.5</td>
<td>Extract juice from sugarcane</td>
</tr>
<tr>
<td>Evaporation</td>
<td>40</td>
<td>154,986,177</td>
<td>0.5</td>
<td>Boil off water from extracted juice</td>
</tr>
<tr>
<td>Back end (pans/centrifugals)</td>
<td>40</td>
<td>94,242,412</td>
<td>0.5</td>
<td>Purify and crystallise sugar</td>
</tr>
<tr>
<td>Other</td>
<td>40</td>
<td>253,521,554</td>
<td>0.5</td>
<td>Utilities and balance of plant</td>
</tr>
<tr>
<td>Subtotal (main sugar capital)</td>
<td>40</td>
<td>669,313,805</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Cogen costs: capital</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiler</td>
<td>40</td>
<td>249,941,830</td>
<td>0.5</td>
<td>Produce steam energy</td>
</tr>
<tr>
<td>Generation</td>
<td>40</td>
<td>37,267,668</td>
<td>0.5</td>
<td>Convert steam to electricity</td>
</tr>
<tr>
<td>Bagasse storage</td>
<td>40</td>
<td>12,025,440</td>
<td>0.5</td>
<td>Generating electricity beyond the crushing season would require larger storage but less boiler and generator capacity</td>
</tr>
<tr>
<td>Grid connection</td>
<td>na</td>
<td>0</td>
<td>na</td>
<td>Grid connection already covered in scheme costs</td>
</tr>
<tr>
<td>Subtotal (cogen capital)</td>
<td>40</td>
<td>299,234,938</td>
<td>0.5</td>
<td></td>
</tr>
</tbody>
</table>
7.4.2 COMMUNITY INFRASTRUCTURE

The availability of community services and facilities in remote areas can play an important role in attracting or deterring people from living in those areas. In the absence of hard infrastructure (such as roads and energy supplies) and community infrastructure (such as schools and housing) required to support large irrigation developments and the people who work there, investment in infrastructure will need to be made.

The distance between the centre of the irrigation development and Chillagoe (~90 km) means that it is likely that a new town would be required for the people working on the development and their families. This would include infrastructure such as schools, hospitals, housing, water treatment, sewerage treatment plants, community centres as well as services such as law enforcement. Historically many of these costs have been incurred by government. Costs associated with the provision of freshwater and electricity are largely already incurred as part of the development. Even if the population was based in Chillagoe and commuted to the irrigation development and mill large costs would still be incurred to provide the necessary supporting community infrastructure. Table 7-10 summarises additional infrastructure in the Chillagoe area required to support a significant increase in population.

Table 7-10 Community infrastructure requirements to support a 70,000 ha irrigation development near Chillagoe

<table>
<thead>
<tr>
<th>ITEM</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community infrastructure</td>
<td>General The main town serving the irrigation developments is Chillagoe, which currently has fewer than 250 permanent residents.</td>
</tr>
<tr>
<td>Schools</td>
<td>A primary school in Chillagoe currently has 21 enrolments and hard infrastructure (classrooms) can be added if needed. Additional staffing needs, if any, would be expected to depend on the number and composition of new enrolments. Indicative costs are $25,000 to $33,000 per student.</td>
</tr>
<tr>
<td></td>
<td>Dimbulah State School had 161 enrolments in 2016 offering schooling through to year 10. Mareeba and Atherton have numerous primary and secondary schools.</td>
</tr>
<tr>
<td>Hospital</td>
<td>Chillagoe does not have a hospital. It has a primary health care centre, and the area is serviced by a flying doctor and nurse. Facilities could require expansion under population growth. The cost of expanding the hospital may range from $200,000 to $500,000 per bed with higher end costs including major operating theatre and large area of hospital per bed.</td>
</tr>
<tr>
<td>Housinng</td>
<td>Recent census data showed that approximately 12% of private dwellings in the Mitchell catchment were unoccupied. Although this is a larger proportion than the state and national average it is not likely to be sufficient to absorb a large increase in population that could arise from the potential dam and irrigation development outlined in this case study.</td>
</tr>
<tr>
<td>Water</td>
<td>Mareeba Shire Council provides water sourced from Lake Tinaroo to Chillagoe. There is no sewerage treatment plant in Chillagoe – a septic system is used. If there was a large increase in population, a sewerage treatment plant would be needed.</td>
</tr>
</tbody>
</table>
7.5 Project benefits

This section and the next section provide a financial analysis of the scheme as an integrated development assuming that the whole scheme is funded and operated by a single developer who incurs all of the direct costs and receives all of the direct benefits of development. This section documents the products and revenue streams generated by the scheme. The following section then addresses the question as to whether the total revenue generated would provide an acceptable rate of return to an investor based on the assumptions about scheme design, costs, and prices used in this case study and summarised in Table 7-11. The strong possibility of different funding and operation models is recognised, but is beyond the scope of this case study.

Table 7-11 Summary of assumptions on costs, prices and operations used for a case study of an integrated 70,000 ha sugar production scheme in the Mitchell catchment

Three cases were explored, a mill without cogen and two prices for wholesale electricity from a mill with cogen. Costs summarised from Table 4-4 to Table 7-9.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNITS</th>
<th>NO COGEN</th>
<th>COGEN, $90/MW hr</th>
<th>COGEN, $165/MW hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheme size</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scheme area</td>
<td>ha</td>
<td>70,000</td>
<td>70,000</td>
<td>70,000</td>
</tr>
<tr>
<td>Total capital costs of water and farm development</td>
<td>$ million</td>
<td>2,843</td>
<td>2,843</td>
<td>2,843</td>
</tr>
<tr>
<td>Total capital costs per ha (excluding sugar mill)</td>
<td>$/ha</td>
<td>33,812</td>
<td>33,812</td>
<td>33,812</td>
</tr>
<tr>
<td>Cropping</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average area under sugarcane (1 in 5-year fallow)</td>
<td>%</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Crop irrigation water use (before application losses)</td>
<td>ML/ha</td>
<td>9.3</td>
<td>9.3</td>
<td>9.3</td>
</tr>
<tr>
<td>Sugarcane yield (excluding fallow years)</td>
<td>t sugarcane/ha</td>
<td>119</td>
<td>119</td>
<td>119</td>
</tr>
<tr>
<td>Sugarcane CCS (raw sugar mill can extract from sugarcane)</td>
<td>%</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Sugarcane fibre content (affects rate mill crushes sugarcane)</td>
<td>%</td>
<td>15.0</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Farm variable costs</td>
<td>$/ha</td>
<td>2,044</td>
<td>2,044</td>
<td>2,044</td>
</tr>
<tr>
<td>Processing (sugar mill)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of crushing season</td>
<td>mo</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Mill capital cost</td>
<td>$ million</td>
<td>890</td>
<td>1,288</td>
<td>1,288</td>
</tr>
<tr>
<td>Mill throughput rate</td>
<td>t/h</td>
<td>1,690</td>
<td>1,690</td>
<td>1,690</td>
</tr>
<tr>
<td>Mill reliability (% time operational)</td>
<td>%</td>
<td>90</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Sugarcane transport costs (farm to mill)</td>
<td>$/t</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
### 7.5.1 POTENTIAL PRODUCTION

**Gross benefits**

Based on APSIM estimates (Table 4-1) the case study assumed average farm production of 119.3 t sugarcane/ha/year from 80% of the 70,000 ha farmland and 2.1 t/ha of mungbean from the 20% of farmland in the fallow part of the crop cycle. The total sugarcane harvested each year would therefore average 6,680,800 t (= 119.3 t sugarcane/ha/year x 70,000 ha x 80%). After processing at the mill the sugarcane is converted to three products: raw sugar, molasses and exported baseload renewable electricity. Table 7-12 summarises the total outputs, including mungbean, produced by the scheme each year, and the projected revenue streams they would generate.

**Table 7-12 Summary of outputs and revenue for a case study of an integrated 70,000 ha sugar production scheme in the Mitchell catchment**

Three cases were explored, a mill without cogen and two prices for wholesale electricity from a mill with cogen.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNITS</th>
<th>NO COGEN</th>
<th>COGEN, $90/MW hr</th>
<th>COGEN, $165/MW hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw sugar production</td>
<td>t/y</td>
<td>1,002,120</td>
<td>1,002,120</td>
<td>1,002,120</td>
</tr>
<tr>
<td>Molasses production</td>
<td>t/y</td>
<td>167,020</td>
<td>167,020</td>
<td>167,020</td>
</tr>
<tr>
<td>Electricity production</td>
<td>MW hr/y</td>
<td>0</td>
<td>476,007</td>
<td>476,007</td>
</tr>
<tr>
<td>Mungbean production</td>
<td>t/y</td>
<td>29,400</td>
<td>29,400</td>
<td>29,400</td>
</tr>
</tbody>
</table>

**Scheme revenue**

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNITS</th>
<th>NO COGEN</th>
<th>COGEN, $90/MW hr</th>
<th>COGEN, $165/MW hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue from raw sugar</td>
<td>$ million/y</td>
<td>451</td>
<td>451</td>
<td>451</td>
</tr>
<tr>
<td>Revenue from molasses</td>
<td>$ million/y</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Revenue from electricity (to node, after losses)</td>
<td>$ million/y</td>
<td>0</td>
<td>43</td>
<td>79</td>
</tr>
<tr>
<td>Revenue from mungbean</td>
<td>$ million/y</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Total scheme revenue</td>
<td>$ million/y</td>
<td>492</td>
<td>534</td>
<td>570</td>
</tr>
</tbody>
</table>

### 7.5.2 REGIONAL ECONOMIC BENEFITS

The overall regional economic benefit of the scheme, including the indirect and induced effects flowing from the initial construction phase and ongoing production from the scheme, were estimated using regional input-output (I-O) models. These estimates were based on the approach...
described in detail in the companion technical report on socio-economics (Stokes et al., 2017) and focused on the ongoing annual benefits generated from the increased dollar value of all outputs generated by the scheme, treating this increased output as an exogenous shock to the economy. This section also estimates the overall regional economic benefit of the one-off short-term stimulus from the initial capital investment in the construction phase of the scheme.

The basis of the approach is that those businesses directly benefitting from the project will need to increase their purchases of the raw materials, labour and intermediate products utilised by their growing outputs. Should any of these purchases be made within the region, then this provides a stimulus to those businesses from whom they purchase, contributing to further economic growth and job creation within the region (the production-induced effect). Furthermore, household incomes increase as a result of those local residents who are employed (as a consequence of either direct or production-induced business stimuli); as a proportion of their additional income is spent in the region, that further stimulates greater economic activity and additional job creation (consumption-induced effects).

The dollar value of the increased total economic activity per year due to the operation of the scheme is estimated by using the exogenous increases in scheme gross revenue as an input to the regional I-O models developed from pre-existing I-O tables.

As part of this process, the I-O analysis estimates the total increase to household incomes within the region. By using this value along with the median income within the region, an estimate can be derived of the likely full-time equivalent jobs that would be created (directly, and indirectly through production and consumption effects) as a result of the project.

Based on the method outlined in the companion technical report on socio-economics (Stokes et al., 2017), using the annual revenue from the mill without cogen (Table 7-14) of $492 million and the more conservative ‘agriculture excluding beef’ multiplier of 1.1 additional regional economic activity (rather than the alternative, higher multiplier of 1.83 for ‘food, beverage and tobacco production manufacturing’), the total regional economic benefit is calculated to be $1.033 billion recurring annually.

No multipliers were developed as part of the Assessment for calculating jobs based on annual revenue generated from processing infrastructure such as sugar mills. However, a conservative estimate of the number of direct and indirect jobs can be calculated by applying the ‘agriculture excluding beef’ jobs multiplier (Stokes et al., 2017) to the annual revenue that would be generated from the agricultural production. Over the 70,000 ha scheme assuming 56,000 ha is planted to sugarcane and 14,000 ha to mungbeans at any one time, and both crops are grown at their production potential (i.e. 119.3 t/ha and 2.1 t/ha respectively) and receive a price equivalent to their long term mean (i.e. $42/t and $1100/t respectively) (Ash et al., 2018c) the total annual agricultural revenue would be $283.1 million. Based on the ‘agriculture excluding beef’ multiplier of 1012 jobs for every $100 million in agricultural revenue, at least 2865 additional direct and indirect jobs would be created. This does not include those direct and indirect jobs that would be created due to the additional regional economic activity arising from the sugar mill.

In addition to recurring annual benefits arising from annual revenue from the enterprise, there will be one-time benefits arising during the construction phase of the dam, irrigation area and sugar mill. These are summarised in Table 4-9.
The companion technical report on socio-economics (Stokes et al., 2017) discusses a range of further cautions involved in the regional I-O analyses, so the estimates provided here should be used only as a broad indicator of the total regional benefits.

Table 7-13 Summary of regional economic benefits of the construction phase for a case study of an integrated 70,000 ha sugar production scheme in the Mitchell catchment

Three options were explored, a mill without cogen and two prices for wholesale electricity from a mill with cogen. Assumes 50% leakage from the region. Given the uncertainty in the size of the base economic stimulus, results are also provided for situations where the base stimulus during the construction and operating phases of the development were 20% higher or lower.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNITS</th>
<th>NO COGEN</th>
<th>COGEN, $90/MW hr</th>
<th>COGEN, $165/MW hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional economic benefit, construction phase (one-time benefit)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>$ million</td>
<td>3609</td>
<td>4050</td>
<td>4050</td>
</tr>
<tr>
<td>Base -20%</td>
<td>$ million</td>
<td>2887</td>
<td>3240</td>
<td>3240</td>
</tr>
<tr>
<td>Base +20%</td>
<td>$ million</td>
<td>4331</td>
<td>4860</td>
<td>4860</td>
</tr>
</tbody>
</table>

7.6 Project commerciality

The financial analysis of the commerciality of the scheme follows the discounted cash flow framework described in the companion technical report on socio-economics (Stokes et al., 2017), which uses a 30-year evaluation period and straight-line depreciation to account for the residual value of assets at the end of the 30 years. As a fully integrated scheme, the analyses considered the streams of all costs and benefits from the development and operation of the dam, farms and mill to revenues generated from the processed products from the mill (and allowance made for the additional net revenue from the mungbean fallow crop).

Based on the assumptions used here the internal rates of return (IRR) for the scheme ranged from 3.5% to 5.3%, with the configuration option of a mill without cogen generating the lowest returns and the configuring with cogeneration at an electricity price of $165/MW hr performing the best (Table 7-14). The entire development is sensitive to changes in energy policy and its influence on wholesale electricity prices (particularly incentive for renewable energy generation), as indicated by the reduced return (IRR of 4.1%) for the mill with cogen at an electricity price of $90/MW hr (representing the wholesale electricity price without renewable energy incentives). None of the development options reached a 7% IRR, the typical benchmark that is used in assessing public investment in infrastructure. It would be up to an investor to decide whether the returns were acceptable and compensated for the risk of investing in such a large and complex scheme (including risks of changes in electricity and product prices). However, a return in the 4% to 5% range from a simple case study such as this (using generic information with associated high uncertainties) may indicate sufficient potential to warrant more thorough investigation. It is possible that with location-specific analysis and fully integrating farm-to-mill operations to reduce costs that a viable development might be configured.
Table 7-14 Summary of scheme financial performance (IRR) for a case study of an integrated 70,000 ha sugar production scheme in the Mitchell catchment

Three options were explored, a mill without cogen and two prices for wholesale electricity from a mill with cogen.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNITS</th>
<th>NO COGEN</th>
<th>COGEN, $90/MW h</th>
<th>COGEN, $165/MW h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total capital cost of development</td>
<td>$ million</td>
<td>3257</td>
<td>3655</td>
<td>3655</td>
</tr>
<tr>
<td>Total scheme annual operating costs (dam to port)</td>
<td>$ million</td>
<td>241</td>
<td>245</td>
<td>245</td>
</tr>
<tr>
<td>Total scheme annual revenue</td>
<td>$ million</td>
<td>492</td>
<td>534</td>
<td>570</td>
</tr>
<tr>
<td>Scheme IRR (to port)</td>
<td>%</td>
<td>3.5</td>
<td>4.1</td>
<td>5.3</td>
</tr>
</tbody>
</table>

7.7 Project impacts

This section provides an overview of aquatic, riparian and near-shore marine assets in the Mitchell catchment (Section 6.7.1) and how they may be impacted by water resource development (Section 4.7.2). A brief summary of other potential impacts is provided in Table 4-12.

Prior to irrigation development, the area would require more intensive assessment of any ecological impacts based on the specifics of a proposal.

7.7.1 SUMMARY OF ASSETS

The Mitchell catchment is largely intact in terms of the continuity of its plant and animal communities and the ecological processes that underpin them. The Mitchell River, unlike its major tributaries is a perennial river, and although there are rivers in northern Australia with this characteristic, they are a minority. The flow in the river is highly seasonal, underpins river–floodplain productivity and provides critical habitats for species, including freshwater sawfish, a barramundi fishery and the extensive Northern Prawn Fishery, one of Australia’s most valuable fisheries.

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. See companion technical report on ecological asset descriptions (Pollino et al., 2018a) for more information on ecological assets in the Mitchell catchment.
7.7.2 POTENTIAL AQUATIC, RIPARIAN AND NEAR-SHORE MARINE IMPACTS OF PINNACLES DAM AND IRRIGATION AREA

Instream dams have the greatest impact on aquatic species and habitats immediately downstream of the storage. The reach immediately below the potential Pinnacles dam shows dramatic changes in streamflow habitats (not shown), with a reduction in peak events and low-flow events and an increase in sustained low-to-moderate flows. The potential Pinnacles dam and downstream re-regulating structure present barriers to the movement of sediment, food and diadromous fish, potentially including freshwater longtom, sooty grunter and Hyrtyl’s tandan. Fish ladders may mitigate the impacts of the dam and weir structures on the movement of diadromous fish, though operational fish ladders for sawfish are likely to be challenging. The establishment of a lake habitat behind the dam could have an influence on the community structure of fish, and the changed habitat may promote the establishment of invasive fish, for example through illegal stocking.

The impoundment offers to provide new, albeit unnatural, aquatic habitat in an otherwise relatively dry catchment.

The reach downstream of the potential Pinnacles dam re-regulating weir (adjacent to the irrigation development) shows a shift in the characteristics of streamflow, where the Mitchell River exhibits the characteristics of an ephemeral river rather than the original perennial river. Immediately below the re-regulating weir adjacent to the irrigation development (node 9190111) major change occurs to the flow habitat of barramundi, migratory fish, sawfish and persistent water holes and a moderate and minor change occurs to the flow habitat of riparian vegetation and stable flow spawners, respectively. Although the flow habitat of stable flow spawners experiences minor change, a loss of habitat and consequently a reduction or loss of species such as bullsharks and sawfish could locally change the foodweb and structure of fish communities, including stable flow spawners. Major changes to persistent waterholes would dramatically reduce connectivity and waterholes potential to act as refugia habitat, as would removal of adjacent riparian vegetation. Moderate changes in riparian structure may also promote establishment of invasive plants, such as rubber vine and hymenachne. Declines in riparian zones can also have an impact on terrestrial fauna, such as birds, which use riparian zones as refugia.
With distance downstream of the dam and the point of irrigation extraction, the changes in flow are moderated by joining tributaries such that the seasonality of streamflow increasingly resembles the natural pattern and the degree of regulation decreases. At the next assessment location, 9190090 on the Mitchell River slightly downstream of the apex of the Mitchell fan aggregation, the flow habitat of barramundi, migratory fish, riparian vegetation, sawfish, turtles and wetland experience minor change. Persistent waterholes were modelled to experience moderate change.

At the end-of-system, flow habitat for all near-shore marine and estuarine species, including barramundi, crocodiles, grunter, mullet, sawfish and snubfin dolphin, experienced minor change with the potential Pinnacles dam and irrigation development. The flow habitats of major tributaries (i.e. Palmer, Walsh and Lynd) to the Mitchell River remain unaffected by the Pinnacles River dam and irrigation development.
Figure 7-10 Assessment of change in flow metrics for assets at assessed location 9190090
Assessment locations shown in Figure 1-5.

Figure 7-11 Assessment of change in flow metrics for assets at assessed location 9190000
Assessment locations shown in Figure 1-5.
See companion technical report on ecological assets (Pollino et al., 2018b) for more information on ecological asset analysis.

### 7.7.3 OTHER POTENTIAL IMPACTS

This section provides a high-level overview of some of the potential on-site and off-site impacts that may result from the 70,000-ha irrigation and dam development outlined in this case study.

#### Table 7-15 Summary of other selected considerations impacted by the 70,000 ha irrigation and dam development

<table>
<thead>
<tr>
<th>ECOLOGICAL AND SOCIAL CONSIDERATIONS</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment infill of reservoir</td>
<td>It is modelled that about 0.6% (range of between 0.1 and 1%) of the storage volume of Pinnacles reservoir will infill with sediment after 30 years, and 2% of the storage volume will infill with sediment after 100 years (Petheram et al., 2017).</td>
</tr>
<tr>
<td>Storage impacts on property and infrastructure</td>
<td>A storage at the Pinnacles site would inundate an area of 27,220 ha and would have a major impact on the Groganville lease holding SP 254826 on the right bank (inundating 19,400 ha) and on the Woolburra lease holding PH 822 on the left bank. Further upstream, the storage would impact a small 274 ha freehold block and then lease holding SP108034. A surveyed road section within the Groganville holding known as Karma Waters Road, which crosses the St Georges River, a right bank tributary, would be inundated. A relocated road crossing the St Georges River upstream of the dam storage would involve some 12 km of new road.</td>
</tr>
<tr>
<td>Terrestrial ecology</td>
<td>Of the eight potential dam sites examined by Petheram et al. (2017) 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 (<em>Calidris tenuirostris</em>) and curlew sandpiper (<em>Calidris ferruginea</em>). There are 6 frog species found near this site, 2 of which are critically endangered. Approximately 25% of the potential inundated area at FSL is covered by a regional ecosystem ‘Of concern’ (3641 ha). No regional ecosystems classified as ‘Endangered’ are recorded in the inundation or irrigation development area. Nevertheless the irrigation development is centred on the largest contiguous unit of cracking clay soil (SGG 9) in the Mitchell catchment so understanding what ecological communities this soil types supports and their relative importance would be necessary to developing a robust understanding of the potential terrestrial impacts. It should be noted that cracking clay soils are found extensively in the Flinders catchment. The effect on terrestrial ecology requires site-based assessment, including examination of existing terrestrial flora and fauna databases.</td>
</tr>
<tr>
<td>Sediment, nutrient and pesticide loads from irrigation development</td>
<td>Increased input of nutrients boosts primary production. These nutrients, particularly nitrogen, can move into water when they are not managed well. Irrigation development that increases the input of sediment into rivers can impact aquatic habitat structure and increased turbidity can shift aquatic community types. Large dams may retain colloidal sedimentary material washed in during rain and flow events, in suspension for some time (e.g. Burdekin Falls Dam – see Burrows, 1999). If trapped sediment remains suspended well into the dry season, there is potential for released water to elevate the turbidity of downstream receiving environments – the ecology of these waters is particularly susceptible to impacts from even small increases in turbidity.</td>
</tr>
<tr>
<td>Secondary salinity</td>
<td>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.</td>
</tr>
</tbody>
</table>
| Bio-security, weeds and pests                                             | 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 and wallabies. Sugarcane and mungbeans are currently grown commercially within 250 km of this proposed development, so the likelihood of new pathogens currently unknown to these industries is low.

<table>
<thead>
<tr>
<th>ECOLOGICAL AND SOCIAL CONSIDERATIONS</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indigenous land tenure, native title and cultural heritage considerations</td>
<td>Substantial land in the inundation and irrigation development area is subject to current and/or future native title claims. There are no currently recorded cultural heritage sites in the potential development 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 and irrigation development area. See companion technical report on Indigenous water values, rights, interests, and development objectives, Lyons and Barber (2018), for more information.</td>
</tr>
<tr>
<td>Increased human activity</td>
<td>Increased access to aquatic species used for recreational purposes potentially resulting in overfishing and potential damage to on and offstream aquatic habitats through increased human activity and new road infrastructure enabling increased access</td>
</tr>
</tbody>
</table>
References


Benjamin (2018)


Graham B (1985) Surface Water Resources in the Northeastern Corner of Wildman River Station (Final report for Water Resources Division project number 2026). Water Resources Division, Darwin, NT.


Kimberley Pilbara Cattlemen’s Association (2017) Submission #10. Submission from the KPCA to Red Tape Committee. Senate Select Committee on Red Tape, specific area of ‘Environmental assessment and approvals’.  


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