Agricultural viability: Mitchell catchment

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

Andrew Ash, Alison Laing, Neil MacLeod, Dean Paini, Jeda Palmer, Perry Poulton, Di Prestwidge, Chris Stokes, Ian Watson, Tony Webster and Stephen Yeates
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CSIRO Northern Australia Water Resource Assessment acknowledgements
This report was prepared for the Department of Infrastructure, Regional Development and Cities. The Northern Australia Water Resource Assessment is an initiative of the Australian Government’s White Paper on Developing Northern Australia and the Agricultural Competitiveness White Paper, the government’s plan for stronger farmers and a stronger economy. Aspects of the Assessment have been undertaken in conjunction with the Northern Territory Government, the Western Australian Government, and the Queensland Government.

The Assessment was guided by three committees:

(i) The Assessment’s Governance Committee: Consolidated Pastoral Company, CSIRO, DAWR, DIIS, DoRDC, 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, DoRDC, Kowanyama Shire, Mareeba Shire, Mitchell Watershed Management Group, Northern Gulf Resource Management Group, NPF Industry Pty Ltd, Office of Northern Australia, Queensland DAFF, Queensland DSD, Queensland DEWS, Queensland DNRME, Queensland DES, Regional Development Australia - Far North Queensland and Torres Strait

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

This report was reviewed by Gareth Jones (Queensland Department of Agriculture and Fisheries), Cuan Petheram, Ian Watson and Chris Chilcott (CSIRO).

This Technical Report would not have been possible without the help, support, encouragement and advice from a large number of people. Supporting information and advice was provided by Greg Mason, Joe Rolfe, Bernie English and Irene Kernot (Queensland Department of Agriculture and Fisheries), David Morrison (Queensland Department of Natural Resources, Mines and Energy) and Clayton Lynch (TGT, Mareeba).

Many CSIRO people, not part of the immediate team, or report authors, provided a range of inputs to the agricultural viability activity. This includes technical advice, project design, project management, financial controls, administration support, contract management, database and query advice, communications, help with document files and input from other activities such as climate and land suitability. The CSIRO people we wish to thank (on no particular order) include: Cuan Petheram, Chris Chilcott, Suzanne Blankley, Seonaid Philip, Peter Stone, Thea Williams and Caroline Bruce.

Photo: Small-scale hay production on a cattle station in the central part of the Mitchell catchment. Source: CSIRO
Director’s foreword

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

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

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

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

Chris Chilcott
Project Director
The Northern Australia Water Resource Assessment Team

Project Director Chris Chilcott
Project Leaders Cuan Petheram, Ian Watson
Project Support Caroline Bruce, Maryam Ahmad, Tony Grice¹, Sally Tetreault Campbell
Knowledge Delivery Jamie Vleeshouwer, Simon Kitson, Lynn Seo, Ramneek Singh
Communications Thea Williams, Siobhan Duffy, Anne Lynch

Activities

Agriculture and aquaculture viability Andrew Ash, Mila Bristow², Greg Coman, Rob Cossart³, Dean Musson, Amar Doshi, Chris Ham³, Simon Irvin, Alison Laing, Neil MacLeod, Alan Niscioli², Dean Paini, Jeda Palmer, Perry Poulton, Di Prestwidge, Chris Stokes, Ian Watson, Tony Webster, Stephen Yeates

Climate Cuan Petheram, Alice Berthet, Greg Browning⁴, Steve Charles, Andrew Dowdy⁴, Paul Feikema⁴, Simon Gallant, Paul Gregory⁴, Prasanth Hapuarachchi⁴, Harry Hendon⁴, Geoff Hodgson, Yrij Kuleshov⁴, Andrew Marshall⁴, Murray Peel⁵, Phil Reid⁴, Li Shi⁴, Todd Smith⁴, Matthew Wheeler⁴

Earth observation Neil Sims, Janet Anstee, Olga Barron, Elizabeth Botha, Eric Lehmann, Lingtao Li, Timothy McVicar, Matt Paget, Catherine Ticehurst, Tom Van Niel, Garth Warren

Ecology Carmel Pollino, Emily Barber, Rik Buckworth, Mathilde Cadiegu, Aijun (Roy) Deng, Brendan Ebner⁶, Rob Kenyon, Adam Liedloff, Linda Merrin, Christian Moeseneder, David Morgan⁷, Daryl Nielsen, Jackie O’Sullivan, Rocin Ponce Reyes, Barbara Robson, Ben Stewart-Koster⁸, Danial Stratford, Mischa Turschwell⁸
Groundwater hydrology

Andrew R. Taylor, Karen Barry, Jordi Batlle-Aguilar9, Kevin Cahill, Steven Clohessy3, Russell Crosbie, Tao Cui, Phil Davies, Warrick Dawes, Rebecca Doble, Peter Dillon10, Dennis Gonzalez, Glenn Harrington9, Graham Herbert11, Anthony Knapton12, Sandie McHugh3, Declan Page, Stan Smith, Nick Smolanko, Axel Suckow, Steven Tickell2, Chris Turnadge, Joanne Vanderzalm, Daniel Wohling9, Des Yin Foo2, Ursula Zaar2

Indigenous values, rights and development objectives

Marcus Barber, Carol Farbotko, Pethie Lyons, Emma Woodward

Land suitability


Socio-economics

Chris Stokes, Jane Addison14, Jim Austin, Caroline Bruce, David Fleming, Andrew Higgins, Nerida Horner, Diane Jarvis14, Judy Jones15, Jacqui Lau, Andrew Macintosh15, Lisa McKellar, Marie Waschka15, Asmi Wood15

Surface water hydrology

Justin Hughes, Dushmanta Dutta, Fazlul Karim, Steve Marvanek, Jorge Peña-Arancibia, Quanxi Shao, Jai Vaze, Bill Wang, Ang Yang

Water storage

Cuan Petheram, Jeff Benjamin16, David Fuller17, John Gallant, Peter Hill18, Klaus Joehnk, Phillip Jordan18, Benson Liu18, Alan Moon1, Andrew Northfield18, Indran Pillay17, Arthur Read, Lee Rogers

Note: All contributors are affiliated with CSIRO unless indicated otherwise. Activity Leaders are underlined.

1Independent Consultant, 2Northern Territory Government, 3Western Australian Government, 4Bureau of Meteorology, 5University of Melbourne, 6CSIRO/James Cook University, 7Murdoch University, 8Griffith University, 9Innovative Groundwater Solutions, 10Wallbridge Gilbert Aztec, 11Queensland Government, 12CloudGMS, 13CSIRO and Western Australian Government, 14CSIRO and James Cook University, 15Australian National University, 16North Australia Water Strategies, 17Entura, 18HARC
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<td>TRaCK</td>
<td>Tropical Rivers and Coastal Knowledge</td>
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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 the three study areas comprising the Assessment area
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**, which 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** for each catchment that 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** for each catchment that provide a summary and narrative for a general public audience in plain English.

- **Factsheets** for each catchment that 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](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. This report is a technical report. The red oval indicates the primary activity (or activities) that contributed to this report.
Executive summary

Agricultural productivity and returns for a range of crops and forage–beef options are considered for the Mitchell catchment, based on the climate and soils of the Assessment area. Agriculture in the Mitchell catchment is currently dominated by extensive beef production, although there are some areas of irrigated agriculture and horticulture in the eastern end of the study area that are part of the Mareeba Dimbulah Water Supply Scheme (MDWSS). Crops grown in the irrigation area include mangoes, bananas, sugarcane, avocados and some small areas of broadacre crops such as maize.

Given the limited experience of optimum growing periods, crop yields, water requirements and farming systems in the majority of the Mitchell catchment, broadacre crop and forage–beef simulation models were employed to estimate potential agricultural productivity and irrigation water requirements. Crop and forage models were parameterised using four climate locations (Mareeba, Chillagoe, Highbury and Dunbar) and three soils with some potential for irrigated agriculture in the study area (Vertosols, Brown Sodosols and Chromosols), noting their limitations for irrigated agriculture in terms of trafficability in the wet, nutrient status and erodibility. The crop yields presented are optimum yields, where the crop was modelled without abiotic stress, and represent the upper limit of yield potential for the Assessment area. Actual crop yields are likely to be lower.

The analysis indicated some potential for dryland cropping with sorghum, mungbean, maize and peanuts producing reasonable crop yields given the relatively reliable wet-season rainfall. This translated into gross margins of between $500 and $1500/ha for these crops. However, these results were predicated on being able to access the country in January and on being able to sow at the optimum time climatically. In many years, it is not likely that soils would be trafficable in January, especially the cracking clays (Vertosols), so realising viable crop yields would be challenging. Delaying sowing until March, after the main part of the wet season, dramatically reduced crop yields.

Irrigation permitted high crop yields to be simulated, with year to year variation in yield greatly reduced compared with dryland cropping. Water required by crops varied enormously depending on crop type and season of growth; a grain sorghum crop planted during the wet season and reliant only on supplementary irrigation in the final stages of growth during the dry season required as little as 2 ML/ha, whilst a perennial sugarcane crop required over 10 ML/ha and a high yielding perennial forage such as Rhodes grass required up to 15 ML/ha.

While crop yields were high for most broadacre crops, the costs of irrigation, fertiliser, herbicides and pests meant that gross margins were generally less than $1500/ha. High gross margins (>2500/ha) were obtained for the industrial crops cotton and sugarcane and for peanuts, all based on the assumption of local processing facilities.

In simulations of future climate scenarios, assuming irrigation supplies are not compromised, broadacre crops generally maintained crop yields or even increased crop yields despite higher temperatures and evaporative demand because of the positive effects of increased carbon dioxide
concentrations. Mungbean had a slightly decreased yield under the drier climate change scenario. However, under a dryland simulation, the yield of sorghum was significantly reduced under a drier future climate scenario.

Commercial crop yields and expert opinion were used to assess horticulture crop production because simulation models are not established for tropical fruit production. Compared with broadacre crops, gross margins of horticultural crops were high, ranging from $2000/ha to $16,000/ha for the main crops of avocados, bananas, melons and mangoes.

Most broadacre crops were not capable of generating returns to meet capital costs of development greater than $10,000/ha. Sugarcane, cotton and peanuts were capable of meeting higher development costs as were the main horticultural crops. Cropping systems, particularly double cropping, were explored to determine whether it was technically feasible to implement more intensive cropping systems capable of generating higher net returns than single crops. For example, a rotation system of cotton and mungbean grown within a year was capable of producing yields similar to individually grown crops and consequently the gross margin for this rotation was $3500/ha/year.

A potential use for irrigation is to grow forages that can be incorporated into existing large-scale extensive beef enterprises. The ability of sown forages (Rhodes grass, forage sorghum, lablab) to boost beef productivity and enterprise profitability was tested using a combination of crop, forage and herd production models. Options included direct grazing of forages using substantial areas of irrigation (200 to 400 ha) to grow animals to reach a marketable weight at a younger age or using much smaller areas (80 to 200 ha) to grow hay crops for feeding calves that are weaned early. Total beef produced could be increase by as much as 50% but net profit increases were less (20 to 40%) because of the high costs of growing irrigated forages.
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Part I Agricultural viability technical report
1 Introduction

1.1 History of agriculture in the Mitchell catchment

The Mitchell catchment (Figure 1-1) has a long history of Indigenous occupation and reliance on country that can be traced back more than 50,000 years. Europeans moved into the study area in the late 1800s with an interest in mining, particularly for gold. While mining persists today the main focus is now base metals.

As areas were opened up for mining, agriculture followed in the form of extensive beef cattle grazing. Grazing remains the dominant land use in the catchment, characterised by large leases, which are operated by a mixture of family enterprises and larger pastoral companies. There is also
significant Indigenous ownership of pastoral holdings and some freehold ownership, which is mostly made up of smaller properties in the eastern part of the study area. Soils are generally infertile and cattle-production productivity is therefore low. Most grazing enterprises run breeding operations, producing young cattle for live export or to be grown out in more productive lands to the south. Cattle prices have improved in the last few years, increasing optimism in the beef sector, but the decade up to 2015 showed cattle properties in the Gulf region of Queensland making regular losses, and a decline in equity (Rolfe et al., 2016).

The population in the study area is sparse (about 6500), and there are no major urban population centres. The largest settlements are the towns of Dimbulah, Kowanyama and Chillagoe, all with populations of less than 1500 people.

The Mitchell River discharges a large amount of water into the Gulf of Carpentaria and this has, over the decades, raised the potential for irrigated agriculture. However, given the relative remoteness of the Mitchell catchment, irrigated agriculture has been largely confined to the very east of the study area in the Upper Walsh River (Mareeba Dimbulah Water Supply Scheme (MDWSS)) and in the upper Mitchell catchment, north of Mareeba in the Julatten area. The MDWSS was originally built largely to support the tobacco industry with water sourced from the Tinaroo Falls Dam, which was completed in 1958. With the demise of the tobacco industry, irrigated agriculture is now dominated by mangoes, bananas, avocados, sugarcane and a range of other tree, field and horticultural crops. About two-thirds of the MDWSS lies in the Mitchell catchment but it represents only about 0.2% of the total area of the study area.

1.2 Current scale of agriculture

Agriculture is the largest contributor to the economy of the Mitchell catchment, with the gross value of agricultural production (GVAP) in the study area approximately $135 million (ABS, 2017; based on 2015 data). This approximation is based on the GVAP in the Tablelands, Carpentaria and Cape York Statistical Areas (SA2 ABS classification; ABS, 2011), which cover over 96% of the Mitchell catchment. Specifically, the Tablelands, Cape York and Carpentaria SA2s cover 51%, 27%, and 18% of the study area, respectively. Cropping accounts for about half of the GVAP ($72 million); this is generated on 15,000 ha of cultivated land of which around 10,000 ha produces fruit, nuts and vegetables, and 5000 ha is broadacre cropping, mostly sugarcane. The other half of GVAP in the study area is from beef cattle enterprises, which account for 95% of land use within the study area. Given the large increase in cattle prices in the last two years, it is likely that gross value of production from beef currently exceeds that from cropping. Across the study area, agriculture accounts for approximately 20% of employment (ABS, 2017; based on 2015 data).

1.3 Assessment of agricultural viability

Assessing agricultural viability requires bringing together information and knowledge on climate, soils, water resources, agronomy, natural resource management, pests and diseases, and farm economics and using analytical tools to provide quantitative outputs for interpretation.

Climate is a significant determinant of the type of crops that can be grown, and the methods by which they are grown. Temperature, rainfall and solar radiation are prime determinants of crop growth and physiological development, not only in the context of individual crop needs but also in
terms of how cropping and forage systems can be managed to make the most effective use of available water. The climate in the Mitchell catchment is detailed in a companion technical report on climate (Charles et al., 2016); the influence of climate on crop and forage production is further investigated in this technical report.

The characteristics of soils determine their suitability for different crop and forage options. Soil type will also influence the type of irrigation system that can be used, and the amount of irrigation water required to grow a crop. The companion technical report on land suitability (Thomas et al., 2018b) details the location of different soil types in the Mitchell catchment and describes those soils, including suitability for different crops and forages. That information is utilised in this technical report.

Water for irrigation can be obtained from surface and groundwater resources; the nature of the water source influences the type of irrigation used. For example, furrow irrigation relies almost exclusively on surface water while overhead spraying and trickle irrigation can be sourced from surface or groundwater. In this technical report, the potential for irrigated crop and forage production is assessed assuming both unlimited water availability as well as scenarios where reliability of water is less than 100%. This is important in environments where inter-annual rainfall and surface water capture in storages are highly variable. More details on surface water modelling and groundwater hydrology can be found in the companion technical report on river model calibration (Hughes et al., 2017), the companion technical report on river model simulation (Hughes et al., 2018), and the companion technical report on hydrogeological assessment (Taylor et al., 2018).

In addition to agricultural interests, Indigenous communities in the Mitchell catchment have a strong attachment to rivers and streams from both a cultural perspective and the economic development opportunities that are consistent with cultural values and aspirations (see companion technical report on Indigenous values, rights and objectives (Lyons and Barber, 2018)). Surface water harvesting for irrigation, either through large dams or on-farm storages, may have some effects on aquatic and marine ecology and these aspects are examined in more detail in the companion technical report on ecology (Pollino et al., 2018).

Existing cropping activities in the MDWSS provide some good insights into crop growing seasons, agronomic management, crop yields, and pests and diseases, especially for horticultural crops and broadacre crops such as sugarcane and maize. Potential new areas for cropping are likely to be further west in the Mitchell catchment, on different soils and with different local climates. Assessing potential crop suitability and production aspects in these new areas has drawn on expert knowledge (farmers, advisers, technical specialists) from within the MDWSS, complemented with crop and forage models that predict yields of broadacre crops and forages using local soils, climate and management. In this Assessment the cropping system model, Agricultural Production System sIMulator (APSIM), (Holzworth et al., 2014) and the forage–beef model NABSA (Ash et al., 2015) were used (as described in the Methods section) to assess potential crop yields and beef production incorporating irrigated forage crops.

As there is limited irrigated cropping experience in the Mitchell catchment outside of the MDWSS, crop agronomic management cannot follow an established ‘recipe’. It is important to recognise that crop yields are highly dependent on not just biophysical factors but also management skill and the speed at which learning can occur in a new environment. Management must account for
multiple decisions in areas including nutrition, watering, sowing time, plant populations, rotations, pests, disease and weed suppression, mitigating climate stresses such as wind and flooding, and supply chain issues all the while working on a financial imperative to return a profit. Management skill grows with experience and, until it reaches a high level, the challenges associated with the relative lack of cropping experience in the Mitchell catchment should not be underestimated. Until that management skill is developed, over several years at best, and is able to anticipate challenges that in the first instance often need to be experienced, actual yields would be expected to be significantly lower than potential yields. The difference between actual and potential yields, often referred to as the ‘yield gap’, generally narrows slowly over time, and this needs to be factored into individual enterprise plans.

Another significant management challenge is developing cropping systems that involve crop rotations and multiple crops per year rather than a single annual crop. Such cropping systems, particularly for broadacre cropping, can be necessary to generate sufficient returns for a farm to be profitable. Their success is highly dependent on being able to integrate a nuanced understanding of climate, soils and water availability with the management skills to plan and execute farm operations that can involve narrow windows of opportunity. Similarly, integrating forage crops into beef enterprises requires management acumen in both crop production and cattle operations.

The crop, forage and beef modelling reported in this technical report assumes optimum management and represents the high end of achievable crop yields. The modelling assumes optimum agronomic management and no direct impact of pests, diseases or abiotic stress. Using risk-based approaches the impacts of pests, extreme weather events or management failures can be assessed once potential productivity has been determined.

Some degree of profitability is necessary for agricultural viability. This requires a good understanding of the key factors driving gross margins, which include not just on-farm factors related to crop yields and input costs, but also markets and supply chain costs. Transport costs can represent a significant proportion of total costs of operating in northern Australia because of the long distance to most markets. Even where returns are positive they need to be sufficient to provide a reasonable return on capital investment. The approach used in this Assessment at the farm scale involved calculating the likely costs of development (land, land preparation, capital costs of irrigation storages (where appropriate) and equipment). From this the gross margins needed to provide an acceptable return on investment were determined, allowing for risks such as failed crops associated with extreme weather events or pests or diseases.

The gross margins then drove an analysis of the type of cropping systems and/or crop–livestock systems capable of delivering the required returns given the constraints of soils, environment, climate, and supply and reliability of irrigation resources. The aim was to not be prescriptive about cropping and forage–beef systems for particular locations but rather to provide insights on the issues and opportunities associated with developing integrated cropping or crop–livestock systems rather than individual crops. In this technical report, costs of development and financial returns are determined at the farm scale while economic implications at scheme-scale developments are considered in the companion technical report on socio-economics (Stokes et al., 2017).

The factors outlined above highlight important aspects that need to be considered in an assessment of agricultural viability: regulatory constraints and approvals need to be addressed;
issues of the time needed to learn in a new environment; the speed at which operations can be
scaled; and risks associated with extreme events including weather, pests and diseases. Together
these factors can significantly influence returns on investment, particularly in the early years of a
new agricultural development. Given their significant economic implications, these issues of
approvals, legal and regulatory requirements, learning, scaling and extreme events are covered in
greater detail in the companion technical report on legal, regulatory and policy (LRP) (Macintosh
et al., 2018) and the companion technical report on socio-economics (Stokes et al., 2017).
2 Methods

2.1 Overview

Rather than commencing with the biophysical drivers (such as climate, soils and environment) from which crop, forage and animal production, and financial analyses are generated, an alternative approach was adopted. This involved examining capital costs of development and the returns required to service these to meet investment imperatives. In parallel, the biophysical data collection, analysis and modelling were undertaken. This approach provided an opportunity to iteratively examine the types of cropping systems and/or crop–livestock systems that were capable of delivering required returns, given the constraints of soils, environment, climate, and supply and reliability of irrigation resources.

The approach required significant individual crop and fodder assessment, using modelling, documented industry best practice and expert knowledge. It was envisaged that the coupling of financial requirements to biophysical analyses at the outset would lead to a more relevant and robust analysis and exploration of different farming system options. The logic behind this approach is shown in Figure 2-1.

![Figure 2-1 Market driven approach to agricultural viability and economic feasibility used in this technical report](image)

As well as desktop analysis and discussion with stakeholders, a small amount of opportunistic field work was undertaken to help validate the crop models. This involved soil characterisation on relevant soil types to provide more reliable estimates of water holding capacity. It also included
collection of data (e.g. crop yields and agronomic factors affecting growth) relevant to production in northern Australia, although these data were not necessarily from trials or production areas within the Mitchell catchment.

2.2 Capital costs of development

Required returns on investment and break-even gross margins are strongly influenced by on-farm capital development costs. Capital costs of development were generated using different irrigation development options (e.g. on-farm surface water storage; groundwater; and different irrigation types such as furrow, pivots, trickle/tape).

Capital costs included land clearing and preparation; earthworks associated with dams, channels, etc.; costs associated with bore development, irrigation pumps and associated application equipment such as overhead pivots, pressurised tape/trickle systems; farm machinery and equipment; specialised sheds such as packing sheds and cold storage; worker accommodation for greenfield developments; and costs associated with acquiring development, environmental and native title approvals. All these costs are highly context specific to the location and nature of the development and so a range of simplified scenarios were generated to provide indicative development costs.

Individual costings were obtained from a range of sources, including the Western Australia Department of Agriculture and Food, which had contracted engineering consultants to provide development costs for a range of groundwater and surface water scenarios for the Pilbara and Kimberley regions of Western Australia, assuming a 5000-ha development. In addition, costings were obtained from a consultant contracted for this Assessment, who used a bottom-up approach based on smaller scale 500 ha developments. These costings were supplemented with additional information obtained through the course of the Assessment and past studies in northern Australia, such as the Flinders and Gilbert Agricultural Resource Assessment (Petheram et al., 2013a; Petheram et al., 2013b) and the Northern Australia Food and Fibre Supply Chain study (Ash et al., 2014).

2.3 Farm- and paddock-scale economies

A key component of determining potential financial viability is gross margin analysis (Malcolm et al., 2005). This involved collation of baseline gross margin estimates (total sales revenue less direct production, marketing and transport costs) for an array of broadacre, horticultural, industrial and tree crops. These gross margin estimates were calculated for a representative farm (i.e. typical of the scale and structure of the local farming system, climate and resources) assumed to be located in the catchment and are presented on a gross margin per hectare basis.

Templates were created for calculating the individual crop gross margins and adapted to meet the particular characteristics of a given crop in each catchment. Information to populate the templates was collected from published data and through interactions with economists and agronomists located in each of the study areas. Recently completed projects such as the Flinders and Gilbert Agricultural Resource Assessment (Petheram et al., 2013a; Petheram et al., 2013b) and the Northern Australia Food and Fibre Supply Chain study (Ash et al., 2014) generated a substantial
‘library’ of crop and forage gross margins, which were valuable inputs used to generate indicative gross margins for this technical report.

Key variables affecting crop gross margins are price and crop yield. Crop yield data were derived from simulation models of crops and forages, or for crops not simulated (mainly horticultural and tree crops), data were obtained from relevant industry production data or from the published literature. Commodity prices and input costs were drawn from market reports, trade publications, technical advice sourced from public and private technical experts, and local agribusiness operations.

Variability in gross margins was explored by using the variability in crop yields and historical variation in crop prices. The resulting distribution of gross margins was used to show the likelihood and severity of good and bad years compared with the median result.

Another key sensitivity in gross margins of cropping operations in northern Australia is the cost of transporting the product to market. The Transport Network Strategic Investment Tool (TraNSIT) (Higgins et al., 2015) was used to create supply chains for major crops to determine the costs per tonne of product handled.

Irrigation development can occur at a larger scale (e.g. construction of a large dam) and this will interact with farm-scale economics. Irrigation scheme-scale economics have been assessed in the companion technical report on socio-economics (Stokes et al., 2017) and the relationship between farm-scale analysis and scheme-scale economic analysis is shown in Table 2-1.

**Table 2-1 Summary of the economic analytical approach applied at different scales (paddock, farm, and irrigation scheme)**

Scheme-scale economic analysis is described in the companion technical report on socio-economics (Stokes et al., 2017).

<table>
<thead>
<tr>
<th>ANALYSIS</th>
<th>WHY</th>
<th>INFORMATION NEEDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise gross margins (paddock-scale) analysis</td>
<td>Asks if there are viable enterprises to accompany irrigation development</td>
<td>List of prospective crops, prices and input costs tailored to geographic context (including transport costs) Modification of gross margin budgets</td>
</tr>
<tr>
<td>Farm-scale profitability analysis</td>
<td>Asks if an on-farm irrigation development is viable after considering all fixed and variable costs of the investment. Variations: • What is the most that could be invested in infrastructure based on known gross margins? • What is the minimum gross margin that would be needed to break even on a known investment cost?</td>
<td>Costs of development (e.g. irrigation and storage infrastructure) Gross margins Review estimates from other projects</td>
</tr>
<tr>
<td>Scheme-scale profitability analysis</td>
<td>Asks if the costs of providing scheme-scale infrastructure can be exceeded by returns from a regional development</td>
<td>Specification of scheme-scale development (e.g. cost of infrastructure, what area is suitable)</td>
</tr>
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A range of other factors will also affect economics of intensive agricultural development. These include the staging of development and how long it takes to reach full scale; a ‘learning period’ to understand the most appropriate crops, forages, farming systems and associated agronomic management to suit new environments; and the impact of extreme events that can cause crop or forage failures such as weather (e.g. cyclones, temperature extremes), pests and diseases. The
interaction of these factors on farm and scheme-scale economics is examined in the companion technical report on socio-economics (Stokes et al., 2017).

2.4 Crop, forage and livestock analyses

2.4.1 LITERATURE REVIEW

A review of relevant literature and technical reports was undertaken to complement the analyses in this technical report.

Two processes were used:

1. Past publications and personal experiences were sought and reviewed, covering cropping and livestock experience (either actual (trial, commercial) or desktop). This included the full hierarchy from single-enterprise biophysical studies to bigger picture agro-economic studies.

2. Available information was interpreted and analysed: for example, optimal climate–crop combinations, soil suitability, available market windows (especially counter-seasonal supply options), infrastructure constraints and opportunities, and human capital issues.

2.4.2 CROP AND FORAGE MODELLING AND ANALYSIS

The range of potential crop and forage options considered for the Mitchell catchment was beyond the scope of highly parameterised simulation models, so a pluralistic approach was adopted, using simulation models, industry data, best practice and expert knowledge. For the crops that could not be assessed using simulation models, expert knowledge and local experience from northern Australia was used to assess production potential and water use. This was particularly relevant for crops that are already grown under irrigation in northern Australia such as mangoes, bananas, melons, Asian vegetables, Indian sandalwood and African mahogany. For some of these crops, day degree models exist that have been designed to estimate harvest date and potential crop yield. These simple models were compared with available data in each study area to determine their utility.

For the Mitchell catchment, the range of crops and forages assessed that are potentially suitable included broadacre crops (cereal crops e.g. maize, sorghum; pulses e.g. mungbean, chickpea); industrial crops (cotton, sugarcane); horticultural crops (tree crops e.g. mangoes, bananas; field crops e.g. melons); tree crops (Indian sandalwood); root crops (peanuts, cassava); and forages (e.g. Rhodes grass, sorghum, lablab). Cattle production dominates land use in the Mitchell catchment, so integration of cropping and/or forages with beef enterprises was an important aspect of the analysis. Crop calendars were developed for each of the crops and forages assessed. This was important for exploring the opportunities for multi-crop rotations within a year or over a series of years.

It should be noted that crop modelling was undertaken with existing varieties. As study areas are developed it will become important to develop varieties adapted to local environments. This will take many years and was outside the scope of this Assessment.
Agricultural Production Systems iMulator (APSIM)

APSIM is a modelling framework that has been developed to simulate biophysical process in farming systems – in particular, where there is interest in the economic and ecological outcomes of management practice in the face of climate risk (Holzworth et al., 2014). APSIM has been used for a broad range of applications, including on-farm decision making, seasonal climate forecasting, risk assessment for government policy making (Keating et al., 2003), and assessment of the impact of changes in cropping systems and agronomic practices on the water balance of dryland regions (Verburg et al., 2003). It has demonstrated value in predicting performance of commercial crops, provided that soil properties are well-characterised (Carberry et al., 2009). Validated crop models have been used in previous assessments of cropping potential for a range of prospective crops in northern Australia (Carberry et al., 1991; Yeates, 2001; Pearson and Langridge, 2008; Webster et al., 2013; Ash et al., 2014).

The APSIM simulation framework comprises several modules:

- biological modules that simulate biophysical farming processes
- management modules that define ‘management rules’ that characterise a simulated scenario (e.g. crop, sowing date, application of irrigation and nitrogen fertiliser)
- environmental modules that command the rate at which biological modules operate (e.g. maximum and minimum temperature, rainfall, solar radiation)
- program management modules to facilitate data flow within the simulations and produce outputs (e.g. grain yield, biomass, crop water requirement, water use efficiency, nitrogen use efficiency)
- a central ‘simulation engine’ that drives the processes and passes messages between independent modules.

The soil remains central to the simulated system. The key inputs required by APSIM are long-term daily climate records, characterised soils describing plant available water capacity, and agronomic practice for managing irrigation and crop agronomy. Crops currently available in APSIM that were simulated in this Assessment are shown in Table 2-2.

Table 2-2 Land use category and crop/forage modules currently available in APSIM that were used in this technical report

<table>
<thead>
<tr>
<th>LAND USE</th>
<th>CROP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereal crop</td>
<td>Maize</td>
</tr>
<tr>
<td></td>
<td>Rice</td>
</tr>
<tr>
<td></td>
<td>Sorghum (grain)</td>
</tr>
<tr>
<td>Pulse</td>
<td>Mungbean</td>
</tr>
<tr>
<td></td>
<td>Soybean</td>
</tr>
<tr>
<td></td>
<td>Chickpea</td>
</tr>
<tr>
<td>Oil seed</td>
<td>Sunflower</td>
</tr>
<tr>
<td>Forage grass, hay, silage</td>
<td>Rhodes grass</td>
</tr>
<tr>
<td></td>
<td>Sorghum (forage)</td>
</tr>
<tr>
<td>Forage legumes</td>
<td>Lablab</td>
</tr>
</tbody>
</table>
Although the focus of this work was on irrigated crop and forage production, some analysis of
dryland farming, for opportunistic wet-season cropping, was undertaken. APSIM analyses were
undertaken at four locations within the Mitchell catchment (Mareeba, Chillagoe, Highbury and
Dunbar) using representative soils for each of those locations.

The North Australian Beef Systems Analyser

The North Australian Beef Systems Analyser (NABSA), a crop–forage–livestock model (Ash et al.,
2015), was used to explore the opportunities for irrigated forages and crops to increase
productivity in the beef sector and to provide different market opportunities beyond live export.
NABSA is a whole-farm-scale dynamic simulation model that mimics the response over time of a
beef cattle enterprise with a specified herd structure of age and sex classes. It integrates livestock,
pasture and forage crop production with labour and land resource requirements and availability;
accounts for component revenue and cost streams; and provides estimates of the expected
environmental consequences (e.g. land condition, soil erosion) of various management options
(Figure 2-2).

The NABSA operates at the scale of a single enterprise and integrates data and output from four
separate simulation models: a native pasture simulation model (GRASP; McKeon et al., 2000); a
crop and forage simulation model (APSIM)(Holzworth et al., 2014); a model for predicting cattle
growth; and a model estimating the economic performance of the crop–livestock enterprise for
which it is calibrated. The NABSA outputs include production, economic and environmental data.

The NABSA allows the user to define the type and size of beef enterprise (e.g. breeding, finishing),
and initial age and sex class structure of the beef herd that are relevant to the biophysical features
of the study area that is being simulated. Other input parameters associated with the herd
operations include labour supply and demand; direct husbandry and marketing costs (e.g. costs of
transport, veterinary, fuel, supplementary feeding); overhead costs; prices per kilogram of
liveweight for different animal turn-off classes; and rules for both the sale of animals and for
feeding and/or disposing of animals when forage becomes limiting. Forage production is imported
at each monthly time step from external sources: the pasture production model GRASP (McKeon
et al., 2000) and the fodder/crop model APSIM (Holzworth et al., 2014).
The NABSA simulates key resource condition outcomes for modelled scenarios, and changes in land condition that influence future forage production. Soil erosion is also simulated.

Total gross margin (revenue from sales minus direct production and marketing costs) and annual net economic profits (total gross margin minus overhead costs) are generated based on livestock sales revenue, and enterprise variable and overhead costs, including labour costs and interest paid on outstanding debts. General capital costs (e.g. depreciation and opportunity costs of capital held in livestock, infrastructure and land) are not included, but the capital cost for specific development scenarios (e.g. establishing a pasture, specialised animal handling infrastructure) can be included.

The NABSA model was run in three locations in the Mitchell catchment, at Chillagoe, Highbury and Dunbar, to represent the geographic and climatic spread of cattle properties in the study area (Figure 1-1). Mareeba was used in the cropping analysis to examine the potential of crops in the MDWSS that fall within the Mitchell catchment, but the Mareeba location was not relevant to the forage–beef analysis. The underpinning GRASP simulations of native forage assumed that soils at Highbury and Dunbar were a low productivity sandy forest type, with significant pockets of Vertosols or Sodosols that could support sown forage crops. At Chillagoe, a more productive duplex type soil was used with Yellow Chromosols available for sown forages. Beef enterprises were simulated using 55 years of climate data, from 1960 to 2015. This period was chosen because the daily climate data from the Bureau of Meteorology that is integral to the GRASP pasture model
Agricultural viability in the Mitchell catchment is most reliable from 1957, which is the starting year for fully digitised and error-checked daily data.

The NABSA also generates key financial outputs. For all scenarios (baseline and forage options) input data included the animal class and age structure of the initial cattle herd, prices for livestock and produce sales, and material and service costs associated with operating the enterprise. These data were derived from a mix of published primary data, market reports, experiential data and local agribusiness sources in the study area.

Farm gate prices and costs for the three forage crops (i.e. Rhodes grass, lablab and forage sorghum) were obtained from several sources including commodity statistics (e.g. ABARES, 2017) and confirmed by local experts. Beef prices were based on recent information (MLA, 2017) for the general categories of stock that were traded within the model.

The costs associated with irrigation development were based on information summarised in Section 4. The fixed costs accounted for capital investment (e.g. land clearing, irrigation infrastructure for water storage and delivery, property redevelopment, equipment, vehicles and assets), which were annualised over the life of the investments, and overhead costs (e.g. wages, power, services, repairs, charges due to irrigation), which are similar across all irrigated crops. The variable costs of irrigation included in a simulation were estimated according to the size of the area irrigated and the crop grown.

Annual net profit was calculated as the difference between gross revenues from livestock and crop sales, and the sum of direct production and marketing expenses and overhead costs including labour.

Given the multi-year nature of irrigation investment, the performance of irrigation investments was assessed over a 15-year period. Net present value (NPV) estimates used a real discount rate of 5% per year. The main economic criterion used to compare several forage options was the net value of forage production, which was defined as the difference between the NPV of net profits of each of the forage scenarios and that of a baseline scenario with no irrigation.

A series of NPVs, calculated using the 15-year investment cycle, was generated using 55-year simulation runs from the NABSA.

Capital items varied in their lifespan (e.g. machinery (15 years), on-farm storages and channels (40 years), land clearing and required approvals (100 years)). To accommodate these differences in a 15-year NPV analysis, the straight-line depreciation method was used to calculate the residual value at the end of each 15-year period for any capital items with a longer lifespan.

**Baseline enterprises**

Three representative properties (at Chillagoe, Highbury and Dunbar) were used to assess the effect of forage crops on production and profit of extensive beef properties. The enterprises at each location are based on breeding herds turning off young animals for live export or fattening elsewhere in Queensland. The characteristics for the three representative properties are shown in Table 2-3, based on inputs to and outputs from the NABSA model run over a 55-year period from 1960 to 2015. The property structure and herd size of the representative properties were derived from Rolfe et al. (2016) with model outputs validated against production data, also presented by Rolfe et al. (2016). The Chillagoe enterprise was assumed to be on better soils and turned off
heavier animals (450 kg at 30 months). In contrast, the Dunbar and Highbury properties were assumed to be in areas where soils and productivity are poorer and animals of 300 kg (or 18 months maximum age) were the target sale item. For baseline and forage scenario simulations it was assumed that the stocking rate used was sufficient to maintain land in good condition: this equated to 20 to 25% utilisation rate of pasture. At all three properties it was assumed that 20% of the property was not available for grazing due to inaccessible areas and/or pasture too far from water to be utilised.

Table 2-3 Characteristics of baseline properties at Chillagoe, Highbury and Dunbar based on the NABSA model

Data for representative has been drawn from Rolfe et al., 2016.

<table>
<thead>
<tr>
<th></th>
<th>CHILLAGOE</th>
<th>HIGHLBURY</th>
<th>DUNBAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property size (ha)</td>
<td>40,000</td>
<td>60,000</td>
<td>60,000</td>
</tr>
<tr>
<td>Herd size (AE)</td>
<td>2891</td>
<td>3677</td>
<td>4054</td>
</tr>
<tr>
<td>Effective stocking rate</td>
<td>11</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Base mortality rate (%)</td>
<td>6</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Annual pasture utilisation rate (%)</td>
<td>23</td>
<td>21</td>
<td>22</td>
</tr>
<tr>
<td>Annual liveweight gain (kg/head)</td>
<td>129</td>
<td>115</td>
<td>110</td>
</tr>
<tr>
<td>Weaning rate (%)</td>
<td>55</td>
<td>55</td>
<td>53</td>
</tr>
<tr>
<td>Methane production (kg CO2-e/ha/day)</td>
<td>0.09</td>
<td>0.08</td>
<td>0.09</td>
</tr>
<tr>
<td>Intensity of methane (kg CO2-e/kg beef turn-off)</td>
<td>4.01</td>
<td>3.97</td>
<td>3.99</td>
</tr>
<tr>
<td>Sale price of main turn-off animal (c/kg)</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Gross margin ($/ha)</td>
<td>17.5</td>
<td>12.9</td>
<td>13.5</td>
</tr>
<tr>
<td>Gross margin ($/AE)</td>
<td>245</td>
<td>211</td>
<td>199</td>
</tr>
<tr>
<td>Net profit per year before interest and tax ($)</td>
<td>477,668</td>
<td>465,603</td>
<td>498,290</td>
</tr>
</tbody>
</table>

Approach to incorporating forages into beef production and their economic assessment

The emphasis of this technical report is to examine how irrigated forages can be incorporated into existing beef production systems in the Mitchell catchment. There may also be the possibility of using dryland forages opportunistically to augment beef production. While the climate is highly variable, particularly in terms of rainfall from year to year, the total amount of wet-season rainfall received in the Mitchell catchment means it may be feasible to utilise dryland forages in some years. Consequently, the following analysis includes a dryland option for sown fodder crops.

The potential options involving irrigation type, forage species, and use of those forages in a beef enterprise are numerous. In this technical report, options are limited to key examples involving either stand-and-graze of the forage or hay production. The three forages used were forage sorghum (*Sorghum* spp. hybrid), Rhodes grass (*Chloris gayana*) and the legume lablab (*Lablab purpureus* (L.) Sweet). Forage sorghum was assumed to be fertilised with moderate levels of nitrogen (250 kg N/ha) while Rhodes grass was heavily fertilised (400 kg N/ha) and well-managed to produce a very high yielding forage with good protein level and energy content. Lablab received no nitrogen fertiliser but did receive moderate levels of phosphorus, potassium and sulfur.

Stand-and-graze options were used to fatten sale animals while the hay option was used in combination with early weaning to boost reproduction rates and for surplus hay to be sold locally.
The integrated forage options for the three representative properties at Chillagoe, Highbury and Dunbar are shown in Table 2-4, Table 2-5, and Table 2-6.
Table 2-4 Forage options integrated into a representative 40,000 ha beef enterprise at Chillagoe
The first scenario is a baseline relying solely on native pasture, the second provides a dryland forage option, and the remaining scenarios are irrigated forage.

<table>
<thead>
<tr>
<th>IRRIGATION TYPE</th>
<th>FORAGE CROP</th>
<th>SOIL TYPE</th>
<th>CROP AREA (HA)</th>
<th>GROWTH PERIOD</th>
<th>INPUTS REQUIRED</th>
<th>ANIMALS FED</th>
<th>SALE TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
<td>N/A</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Trade animals sold at 450 kg or 30 months</td>
</tr>
<tr>
<td>None</td>
<td>Forage sorghum</td>
<td>Chromosol</td>
<td>400</td>
<td>Mar–Oct</td>
<td>Low fertiliser</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 425 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Forage sorghum</td>
<td>Chromosol</td>
<td>200</td>
<td>Mar–Oct</td>
<td>Moderate fertiliser and water use</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 425 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Forage sorghum</td>
<td>Chromosol</td>
<td>100</td>
<td>Mar–Oct</td>
<td>Moderate fertiliser and water use</td>
<td>Hay for early weaned animals (weaned at 4 months and fed in yards for 8 weeks) with surplus hay sold locally</td>
<td>Trade animals sold at 450 kg or 30 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Rhodes grass</td>
<td>Chromosol</td>
<td>125</td>
<td>Perennial</td>
<td>High fertiliser and water use</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Rhodes grass</td>
<td>Chromosol</td>
<td>60</td>
<td>Perennial</td>
<td>High fertiliser and water use</td>
<td>Hay for early weaned animals (weaned at 4 months and fed in yards for 8 weeks) with surplus hay sold locally</td>
<td>Trade animals sold at 450 kg or 30 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Lablab</td>
<td>Chromosol</td>
<td>300</td>
<td>Apr–Aug</td>
<td>Low fertiliser and water use</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Lablab</td>
<td>Chromosol</td>
<td>120</td>
<td>Apr–Aug</td>
<td>Low fertiliser and water use</td>
<td>Hay for early weaned animals (weaned at 4 months and fed in yards for 8 weeks) with surplus hay sold locally</td>
<td>Trade animals sold at 450 kg or 30 months</td>
</tr>
</tbody>
</table>

Table 2-5 Forage options integrated into a representative 60,000 ha beef enterprise at Highbury
The first scenario is a baseline relying solely on native pasture, the second provides a dryland forage option, and the remaining scenarios are irrigated forage.

<table>
<thead>
<tr>
<th>IRRIGATION TYPE</th>
<th>FORAGE CROP</th>
<th>SOIL TYPE</th>
<th>CROP AREA (HA)</th>
<th>GROWTH PERIOD</th>
<th>INPUTS REQUIRED</th>
<th>ANIMALS FED</th>
<th>SALE TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>None</td>
<td>N/A</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Trade animals sold at 300 kg or 18 months</td>
</tr>
<tr>
<td>None</td>
<td>Forage sorghum</td>
<td>Vertosol</td>
<td>350</td>
<td>Mar–Oct</td>
<td>Low fertiliser</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Forage sorghum</td>
<td>Vertosol</td>
<td>250</td>
<td>Mar–Oct</td>
<td>Moderate fertiliser and water use</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Irrigation Type</td>
<td>Forage Crop</td>
<td>Soil Type</td>
<td>Crop Area (Ha)</td>
<td>Growth Period</td>
<td>Inputs Required</td>
<td>Animals Fed</td>
<td>Sale Target</td>
</tr>
<tr>
<td>----------------</td>
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<td>---------------</td>
<td>----------------------------------</td>
<td>----------------------------------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>Surface</td>
<td>Forage sorghum</td>
<td>Vertosol</td>
<td>110</td>
<td>Mar–Oct</td>
<td>Moderate fertiliser and water use</td>
<td>Hay for early weaned animals (weaned at 4 months and fed in yards for 8 weeks) with surplus hay sold locally</td>
<td>Trade/export animals sold at 300 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Rhodes grass</td>
<td>Vertosol</td>
<td>185</td>
<td>Perennial</td>
<td>High fertiliser and water use</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Rhodes grass</td>
<td>Vertosol</td>
<td>80</td>
<td>Perennial</td>
<td>High fertiliser and water use</td>
<td>Hay for early weaned animals (weaned at 4 months and fed in yards for 8 weeks) with surplus hay sold locally</td>
<td>Trade/export animals sold at 300 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Lablab</td>
<td>Vertosol</td>
<td>400</td>
<td>Apr–Aug</td>
<td>Low fertiliser and water use</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Lablab</td>
<td>Vertosol</td>
<td>200</td>
<td>Apr–Aug</td>
<td>Low fertiliser and water use</td>
<td>Hay for early weaned animals (weaned at 4 months and fed in yards for 8 weeks) with surplus hay sold locally</td>
<td>Trade/export animals sold at 300 kg or 18 months</td>
</tr>
</tbody>
</table>

Table 2-6 Forage options integrated into a representative 60,000 ha beef enterprise at Dunbar
The first scenario is a baseline relying solely on native pasture, the second provides a dryland forage option, and the remaining scenarios are irrigated forage

<table>
<thead>
<tr>
<th>Irrigation Type</th>
<th>Forage Crop</th>
<th>Soil Type</th>
<th>Crop Area (Ha)</th>
<th>Growth Period</th>
<th>Inputs Required</th>
<th>Animals Fed</th>
<th>Sale Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
<td>N/A</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>Trade animals sold at 300 kg or 18 months</td>
</tr>
<tr>
<td>None</td>
<td>Forage sorghum</td>
<td>Sodosol</td>
<td>400</td>
<td>Mar–Oct</td>
<td>Low fertiliser</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Forage sorghum</td>
<td>Sodosol</td>
<td>275</td>
<td>Mar–Oct</td>
<td>Moderate fertiliser and water use</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Forage sorghum</td>
<td>Sodosol</td>
<td>110</td>
<td>Mar–Oct</td>
<td>Moderate fertiliser and water use</td>
<td>Hay for early weaned animals (weaned at 4 months and fed in yards for 8 weeks) with surplus hay sold locally</td>
<td>Trade/export animals sold at 300 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Rhodes grass</td>
<td>Sodosol</td>
<td>185</td>
<td>Perennial</td>
<td>High fertiliser and water use</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Rhodes grass</td>
<td>Sodosol</td>
<td>80</td>
<td>Perennial</td>
<td>High fertiliser and water use</td>
<td>Hay for early weaned animals (weaned at 4 months and fed in yards for 8 weeks) with surplus hay sold locally</td>
<td>Trade/export animals sold at 300 kg or 18 months</td>
</tr>
<tr>
<td>Irrigation Type</td>
<td>Forage Crop</td>
<td>Soil Type</td>
<td>Crop Area (HA)</td>
<td>Growth Period</td>
<td>Inputs Required</td>
<td>Animals Fed</td>
<td>Sale Target</td>
</tr>
<tr>
<td>----------------</td>
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<td>----------------</td>
<td>------------------------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>Surface</td>
<td>Lablab</td>
<td>Sodosol</td>
<td>400</td>
<td>Apr–Aug</td>
<td>Low fertiliser and water use</td>
<td>Grazed – weaners, grower males and surplus young females</td>
<td>Trade animals sold at 450 kg or 18 months</td>
</tr>
<tr>
<td>Surface</td>
<td>Lablab</td>
<td>Sodosol</td>
<td>200</td>
<td>Apr–Aug</td>
<td>Low fertiliser and water use</td>
<td>Hay for early weaned animals (weaned at 4 months and fed in yards for 8 weeks) with surplus hay sold locally</td>
<td>Trade/export animals sold at 300 kg or 18 months</td>
</tr>
</tbody>
</table>
Climate change and crop, forage and livestock production

To assess the potential impacts of climate change on crop yields and forages incorporated into beef enterprises, climate change scenarios described by Charles et al. (2016) were used to modify the climate files that underpin APSIM and the NABSA simulations, for the crops most relevant to the Mitchell catchment. Three Global Circulation Models (GCMs) encompassing dry (GFDL-CM3), average (ACCESS1-0) and wet (CCSM4) future climate scenarios were selected for this analysis to represent future climates to 2060 (Scenario C, Charles et al., 2016). To evaluate the potential impact of future climate change on agricultural production, APSIM was specified for the current climate (Scenario A) with an atmospheric CO2 concentration of 400 ppm and for each of the three 2060 rainfall scenarios (dry, average, wet), a projected CO2 concentration for 2060 of 725 ppm, as projected for a future climate under RCP 8.5 (Riahi et al., 2011).

A key driver of climate change is increased atmospheric greenhouse gas concentrations. Apart from the effect on climate (e.g. increased temperature), increased concentrations of atmospheric CO2 affect plant growth and crop yields by increasing photosynthetic and water use efficiencies, which can increase plant growth and may offset negative impacts of decreased rainfall and higher temperatures (Stokes et al., 2005). Elevated CO2 concentrations were incorporated in the APSIM model through changes to radiation and transpiration efficiency (Vanuytrecht and Thorburn, 2017). Simulation results for a range of cropping systems presented in this report are based on APSIM release version 7.7. In this release, baseline CO2 levels for the current suite of crop models was set between 340 and 380 ppm. To compare crop production for current climate (i.e. 2017) with a projected future climate for 2060, the atmospheric CO2 level was set in APSIM to 400 ppm for baseline and 725 ppm for 2060 simulations. The APSIM model was then configured to simulated crop growth, production and water use for current climate (base) and three potential future climate scenarios (dry, mid, wet) for a 2060 CO2 concentration trajectory. Modelled results for crop yield, forage biomass and crop water demand were then compared with baseline data; results are presented in Section 5.1.

2.4.3 INTEGRATED CROPPING SYSTEMS

New agricultural developments that focus on annual field crops may require sequential cropping (more than a single crop in a year) to generate significant revenue to meet development, fixed and variable costs. Annual broadacre crops have been grown sequentially for many decades in tropical Australia (e.g. in the Burdekin, Ord, Atherton Tablelands). The focus here has been to assess potential integrated cropping systems that go beyond a single crop per year assessment. The aim was not to be prescriptive about cropping systems for particular locations, but rather to provide insights on the issues and opportunities associated with developing integrated cropping systems as opposed to establishing individual crops.

The number of different possibilities for cropping systems is very large, given the range of field crops, horticultural crops, forages and rotations that can be grown in northern Australia. The approach focused on examining possible cropping system combinations that could be practically integrated into the climate and environment of the Mitchell catchment. For example, does the pattern of rainfall and soil trafficability permit two crops per year when combined with management resources and capacity to rapidly finish one crop and move into another crop with tightly constrained planting windows?
A warm dry winter (Fig. 3-1) allows summer crops to be grown year-round and this provides some potential for multiple crops in a year on the better agricultural soils where reliable irrigation resources are available to provide supplementary water to the crop. The process for selecting sequential cropping options in the Mitchell catchment was to use individual crop species evaluated in Section 2.4 to identify potential crop combinations that could be feasible based on growing season compatibility, operational feasibility, known biotic risks and market demand.

Two potential cropping scenarios were selected for further analysis:

1. Cotton grown from January to June followed by mungbean, grain sorghum or forage (lablab, sorghum or silage maize) grown between July and October

2. A sugarcane break crop (e.g. mungbean, soybean, maize) rotation.

Soybean–maize was attractive agronomically but limited markets for these crops are likely to prevent large-scale adoption of this rotation. Annual horticulture (e.g. melons) grown before July and followed by mungbean was also considered; however, this option is likely to be feasible in only small areas due to limited markets for horticultural crops in this window.

**Cotton–mungbean–legume rotation**

Scenario 1 assumed a scheme-scale production area consisting of a number of farms that collectively met the following criteria:

- 18,000 to 20,000 ha available land
- 10,000 ha planted to cotton
- 5000 ha sown to mungbean
- 5000 ha sown to forage legume (e.g. lablab).

For example, a farm with 1000 ha of arable land suitable for cultivation was assumed to double crop 1000 ha annually. Crops were planted in rotation: cotton–mungbean and cotton–forage (Figure 2-3). Cotton was sown to 1000 ha in early January and harvested before mid-July. A mungbean crop of 500 ha was sown mid-August following cotton with harvesting completed in the first half of November to minimise weathering loss due to rainfall at maturity. Lablab was sown to 500 ha during August and cut and baled prior to the start of the wet season in late November to December to minimise rainfall-induced harvest losses. While early establishment of lablab maximises biomass production, seedlings are susceptible to rare frost events.

![Figure 2-3 Planting and harvesting windows for a cotton–mungbean–legume rotation](image)

The APSIM model was configured to run both cotton–mungbean and cotton–lablab rotations using climate data for Chillagoe for 1890 to 2015 (see Fig. 3-1 for climate details). The system (i.e. the soil water, soil nitrogen and surface residues) was reset at the end of each rotation on 1 December. Soil water at reset was assumed to be 50% plant available water capacity. APSIM was configured using a Brown Sodosol found in the Chillagoe region with a water holding capacity of 163 mm (cotton, lablab) and 115 mm (mungbean). A soil water deficit of 65% of plant available water capacity in the top 700 mm of soil was used to trigger irrigation. The soil profile was filled 10
days prior to the start of the cotton sowing window in early January. If there was a soil water deficit in the top 600 mm of soil, irrigation was applied at 3 and 20 days after sowing. Subsequent irrigation was applied, if necessary, on a deficit of 65% of plant available water capacity in the top 700 mm (as per initial pre-sowing irrigation). Applied irrigation efficiency was assumed to be 100%.

Sugarcane break crop rotation

Scenario 2 assumed a scheme-scale production area that met the following criteria:

- 30,000 ha available land
- 24,000 ha planted to sugar
- 6000 ha sown to break crops (e.g. mungbean, soybean, sorghum or remain fallow).

The scenario was structured on five paddocks planted to either a cane plant crop, a ratoon crop of 1 to 3 years of age and a break crop (mungbean, soybean, sorghum) or fallow paddock. Each block of five paddocks was repeated six times to represent the six harvesting months from June to November.

The total area consisted of 30 blocks with 24 planted to sugarcane and 6 blocks sown to a break crop or in fallow. For this example, each block was 1000 ha in size. Cane was planted between May and June and harvested after 13 to 16 months in the harvest period June to November. Ratoon crops were harvested after a further 12 months. Phases for a May to June plant crop and a June to November harvest are shown in (Figure 2-4). The staged harvesting provided a potential sugar mill with six months’ production. A break crop of mungbean was sown following harvest of the third ratoon. Mungbean was sown at the end of July and harvested in November before the wet season to minimise rainfall-induced harvest loss. Alternatively, a soybean crop was sown in November and grown over the wet season and harvested in April before the start of the next plant crop of sugar.

Figure 2-4 Planting and harvesting windows for a sugarcane break crop rotation

The APSIM model was configured to run a cane plant crop, three ratoon crops and a mungbean crop in rotation. The simulation assumed five paddocks, each separately managed in one block. The system (i.e. the soil water, soil nitrogen and surface residues) was reset at the end of each rotation. Two blocks were planted early May, two planted at the end of May and two planted in June. Each block was harvested sequentially from June to November. The rotation was run between 1890 and 2015. Nitrogen fertiliser was applied on establishment of a plant crop (200 kg/ha N), and an additional application of 200 kg/ha N applied on 1 July each year of the ratoon crops. Simulation results for both scenarios are presented in Section 5.1.3.
2.5 Off-site impacts

The methods used aimed to quantify the likely losses of key pollutants (nitrogen, phosphorus, total suspended solids, and chemicals such as herbicides, pesticides and fungicides) from potential agricultural development in the Mitchell catchment. This involved two approaches. The first approach was a relative-risk assessment of the crops using potential nutrient surpluses arising from recommended tillage management and herbicide/pesticide/fungicide application rates in these cropping systems as indicators of risk of losses of the key pollutants. The second approach involved a more detailed estimate of pollutant losses for some specific crops for agricultural development based on APSIM simulations of the cropping systems for those crops.

2.5.1 RISK ASSESSMENT

Nutrient surpluses, number of tillage operations, and application rates of herbicides, pesticides and fungicides were collated or calculated to estimate the risk of losses of nitrogen, phosphorus, total suspended solids, and chemicals from a range of crops. Data were taken from the economic assessment of agricultural development (Section 2.3). These data included crop yields, fertiliser application rates, number of tillage operations, and pesticide, herbicide, and fungicide application rates for multiple crops. Incomplete data meant that the risk of nutrient, sediment or herbicide/pesticide/fungicide losses could not be calculated for some crops.

**Nutrient losses**

Nutrient surpluses occur when a greater amount of nutrient is applied to the crop than is removed from the field in harvested product. Nutrient surpluses are an indicator of potential nutrient losses from fields, and have been used to assess risk of nutrient discharges from agricultural areas in other parts of northern Australia (Thorburn and Wilkinson, 2013). The nutrient surplus in terms of nitrogen and phosphorus excess for a given crop was calculated from:

\[ S = Fert - Nu_{HP} \]  

where \( S \) is the nutrient surplus (kg/ha), \( Fert \) is the quantity of nutrient applied to the crop (kg/ha/crop) in the fertiliser, and \( Nu_{HP} \) is the nutrient in harvestable product (kg/ha) that was calculated from:

\[ Nu_{HP} = NuCon_{HP} \times Y_{DM} \]  

where \( NuCon_{HP} \) is the nutrient concentration in harvestable product (kg/kg), and \( Y_{DM} \) is the crop yield dry weight (kg/ha).

Nitrogen and phosphorus applications (kg of nutrient per ha) were calculated from fertiliser application rates based on the analysis data for the fertilisers used (Impact Fertilisers, 2016; Agrichem, n.d.; Campbells, 2017; Sawyer, 2003; Smart Fertilizer Management, 2017). Data for the standard nutrient and moisture content of the harvestable product for the crops of interest were sourced from literature (USDA, n.d.; Self Nutrition Data, 2014). The biological nitrogen fixed for legume crops was estimated based on literature (Pulse Australia, 2017; GRDC, 2017a).
Sediment and herbicide/pesticide/fungicide losses

The risk of herbicide/pesticide/fungicide and sediment losses was assessed from the amount of chemical applied and the number of tillage operations, respectively.

The risk of loss of suspended sediment during the growth of a given crop was estimated from:

\[ \text{RSS}_{\text{loss}} = \sum \text{till} \]  

where \( \text{RSS}_{\text{loss}} \) is the risk of loss of suspended sediment, and \( \text{till} \) is the tillage operations used during the crop growth period. Tillage operations were rated based on severity.

The risk of losses of herbicides, pesticides and fungicides from a given crop was estimated from:

\[ \text{RPS}_{\text{loss}} = \sum \text{PH}_{\text{app}} \]  

where \( \text{RPS}_{\text{loss}} \) is the risk of loss of herbicide/pesticide/fungicide, and \( \text{PH}_{\text{app}} \) is the application rate of the chemical in question.

2.5.2 SIMULATED POLLUTANT LOSSES

Multiple crops were simulated for the Mitchell catchment for two climate stations and on two distinct soils using the current version (7.7) of APSIM (Holzworth et al., 2014). APSIM is a deterministic, daily time step modelling framework that simulates plant, soil, climate and management interactions. APSIM has a proven capacity to simulate loss of nitrate via runoff, loss of nitrate via leaching, and soil loss from tropical farming systems (Thorburn et al., 2011a; Thorburn et al., 2011b; Biggs et al., 2013) and it has been used to predict the effects of crop management on pollutant exports from cropped lands in other parts of northern Australia (Shaw and Silburn, 2016).

The APSIM soil, water, surface organic matter and crop growth modules were parameterised with catchment-relevant data. The erosion module was parameterised based on expert opinion (M Silburn, 2017, pers. comm.). Crops were simulated using optimal management with the crop-specific fertiliser application rates shown in Table 2-7. It should be noted that the fertiliser rates used in simulations are based on best practice management and differ from those shown in Table 5-24, which are more representative of local industry practice. Simulations were run for 125 years from 1890 to 2015. Nitrogen losses via runoff and leaching as well as sediment losses were estimated for each simulation.

Table 2-7 Nitrogen fertiliser application rates for simulated crops or cropping rotations

<table>
<thead>
<tr>
<th>CROP</th>
<th>NITROGEN FERTILISER RATE (KG/HA/CROP OR KG/HA/MULTIPLE CROPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>250</td>
</tr>
<tr>
<td>Forage sorghum</td>
<td>250</td>
</tr>
<tr>
<td>Mungbean</td>
<td>0</td>
</tr>
<tr>
<td>Rice</td>
<td>200</td>
</tr>
<tr>
<td>Soybean</td>
<td>0</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>200</td>
</tr>
<tr>
<td>Cotton/sorghum</td>
<td>350</td>
</tr>
</tbody>
</table>
CROP | NITROGEN FERTILISER RATE (KG/HA/CROP OR KG/HA/MULTIPLE CROPS)
---|---
Cotton/soybean | 250
Cotton/mungbean | 250
Rice/soybean | 200
Rice/sorghum | 300

2.6 Pests and diseases

2.6.1 MODELLING PEST INCURSIONS

From a biosecurity point of view, invasion risk is defined as the product of the likelihood of an invasion by a pest or pathogen and the impact that species will have. With both likelihood and impact there is a great deal of uncertainty and difficulty in making clear predictions.

For the Mitchell catchment, the types of pests and diseases that provide a risk to the various agricultural and aquaculture industries that could establish are many and varied. It is not the aim of this report to identify all the pest and disease risks as such a list would be extensive and of little predictive value. As an alternative, it is possible to identify the pathways that could facilitate the arrival of an invasive species. These can be divided into man-made (human transport networks) or natural (wind and/or ocean currents) vectors.

Man-made pathways include motor vehicles, ships and planes, as well as produce (e.g. animals, plants, machinery) or humans that are transported via motor vehicle, ship and plane networks. Modelling such pathways remains challenging, particularly if a large number of species are within the potential pool of pests and pathogens, although a number of researchers have attempted this at the global scale (e.g. Paini et al., 2016; Early et al., 2016; Chapman et al., 2017).

The Assessment concentrated on wind-borne pests and diseases, while acknowledging the potential negative consequences of other vectors. Wind dispersal has until recently been difficult to model, but CSIRO recently developed TAPPAS (Tool for Assessing Pest and Pathogen Aerial Spread; CSIRO, 2017), which is an online software tool (https://tappas.csiro.au) that enables users to quickly and easily model the dispersal by wind of living organisms. This tool links to a particle dispersion model (HYSPLIT; NOAA, 2017) and historical meteorological data to run sophisticated wind dispersal models from any point on the globe.

TAPPAS was used to run dispersal simulations from locations throughout Southeast Asia, determining the potential source locations and seasonal variation in arrival risk from this region to the Mitchell catchment. Seven simulations were run at a weekly frequency over a year. Each simulation focused on one country or region (Table 2-8) within Southeast Asia and multiple release locations within each geographical region. Maps of the simulation release locations across Southeast Asia are shown in Appendix A.
Table 2-8 Countries and regions within each country from which wind dispersal simulations were run

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>REGION WITHIN COUNTRY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Papua New Guinea</td>
<td>Southern coast</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>Middle and northern coast</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Papua (southern coast)</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Papua (middle and northern coast)</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Java and Bali</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Sumatra</td>
</tr>
<tr>
<td>Timor-Leste</td>
<td>Entire country</td>
</tr>
</tbody>
</table>

To simulate fungal pathogens, the default fungal spore parameters within TAPPAS were used. Gravitational deposition, determined by spore diameter and density, determined the rate at which spores descended. Each simulation was run for seven days, with spores released for the first 24 hours. If at any stage in the simulation deposition was shown to occur in the target region it was recorded.

To simulate insect pests the default insect parameters within TAPPAS were used. The rate of deposition was determined by wind velocity. Each simulation was run for two days, with insects released for the first three hours. If at any stage in the simulation deposition was shown to occur in the target region it was recorded.

For each region listed in Table 2-8, 52 simulation results were generated at weekly intervals.
3 Biophysical factors affecting agricultural viability

3.1 Climate

Climate has a major influence on the long-term sustainability of agricultural and pastoral production systems and irrigation water requirements. It influences the rate and vigour of crop growth, while catastrophic weather events can result in extensive crop losses. Key climate parameters controlling plant growth and crop productivity are discussed in turn below, although it should be noted that they never act in isolation but are interrelated. The climate of the Assessment area is discussed in detail in the companion technical report on climate (Charles et al., 2016).

3.1.1 RAINFALL

At least 97% of the water used by crops regulates plant temperature so that physiological and chemical processes can occur optimally. The remaining water is required for rigidity and expansion of plant organs, as the solvent to transport soil nutrients and metabolites, and as a substrate in essential biochemical processes such as photosynthesis (Mengel et al., 2001).

Evaporative demand (heat and air dryness) drives crop water use. Rainfall largely occurs during the summer months (or wet season) when intra-seasonal variability of rainfall is high, as shown for the Chillagoe example (Figure 3-1) where mean long-term rainfall totals over a 14-day period can vary by over 200 mm. Thus, timely water availability is a key limitation to the growth of crops across northern Australia. Irrigation can supplement rainfall in seasons receiving less than average rainfall and facilitate cropping during the dry season (winter months) where sufficient water is available.

Wet-season rainfall is associated with tropical lows or intense storms, both of which have implications for crop growth and management. The former can reduce crop growth, through warm night temperatures and lower solar radiation (due to prolonged cloud cover) as shown for the wet season (December to March) in the Chillagoe example (Figure 3-2). Intense storm events produce strong winds, which have the potential to damage crops. Excessive rainfall can complicate the management of agricultural land, for example in preventing tail water runoff to storage ponds and loss of soil nitrogen through leaching, runoff and denitrification. Waterlogging can also reduce crop growth on clay soils and reduce machine access to fields on heavier soils.

In the Mitchell catchment, 85% of annual rainfall occurs during summer months between December and March (Figure 3-1). Annual rainfall totals vary across the study area with means of 915 mm and 864 mm for Mareeba and Chillagoe in the east, increasing to 1065 mm and 1268 mm for Dunbar Station and Kowanyama in the west. While wet-season rainfall is strongly correlated with the Australian Monsoon Index, seasonal rainfall variability experienced in the Mitchell catchment is strongly influenced by Indonesian sea surface temperatures and the El Niño–Southern Oscillation indices (Rogers and Beringer, 2017). Year to year variation in the timing and amount of rainfall affects the amount of water available for irrigation due to a reduction instream
flows and reduced opportunities for water harvesting. Cropping options need to be considered in light of the availability of water for supplementary irrigation.

Figure 3-1 Long-term fortnightly climate variation in rainfall, maximum and minimum temperatures under the historical climate (1890 to 2015)
Data sourced from SILO (Jeffrey et al., 2001) website <https://www.longpaddock.qld.gov.au/silo/>. Whiskers on box plots show 10% and 90% exceedance values.
Figure 3-2 Long-term fortnightly climate variation in solar radiation, relative humidity (RH) and vapour pressure deficit (VPD) under the historical climate
Whiskers on box plots show 10% and 90% exceedance values.
3.1.2 EVAPORATION

Evaporation is ‘the rate of liquid water transformation to vapour from open water, bare soil, or vegetation with soil beneath’, while transpiration is ‘that part of the total evaporation that enters the atmosphere from the soil through the plants’ (Shuttleworth, 1993). The rate and amount of water evaporated from the soil surface is influenced by surface shading of the crop canopy or surface residues and available soil water in the top soil layers. Crop transpiration is the product of not only solar radiation but also air temperature, air humidity and wind that affect the vapour pressure gradient between plant leaf stomata and the atmosphere (see Section 3.1.5).

Evaporation losses from water storages (dams and ringtanks) and delivery systems (diversion streams and channels) need to be considered in determining the overall water availability to meet crop water demand: these are discussed further in Section 3.6.1. Potential evaporation in the study area is from 1800 to 2000 mm, with results presented for Chillagoe in Figure 3-3.

![Figure 3-3](image_url)

**Figure 3-3** Historical potential evaporation (PE) in the Mitchell catchment at Chillagoe
(a) Monthly PE at Chillagoe; (b) time series of annual PE at Chillagoe based on the companion technical report on climate (Charles et al., 2016). (A range is the 10th to 90th percentile monthly PE).

3.1.3 RADIATION

Shortwave radiation from sunlight influences plant growth through the photosynthesis process of converting atmospheric carbon dioxide into carbohydrates within the plant. The potential amount of solar radiation intercepted by the crop is determined by latitude, time of year and crop growth stage. Solar radiation during the summer months (December to March) is generally reduced due to increased cloud cover associated with the monsoon trough over northern Australia as shown for the Highbury/Chillagoe example (Figure 3-4). While long-term mean radiation during the wet season is reduced to below 20 MJ/day from mid-January, radiation levels remain high compared to agricultural regions in southern Australia. Figure 3-4 demonstrates the effect of latitude on monthly solar radiation between the Mitchell catchment (latitude 16.5° S) and, for example, Griffith in southern NSW (latitude 34° S). For Highbury/Chillagoe, solar radiation through the winter remains relatively constant (17 to 21 MJ/day) compared with the same period at Griffith, NSW (8 to 12 MJ/day). Farmers in the Mitchell catchment can maximise crop yields by successfully managing time of sowing and growing season length to maximise radiation intercepted by the crop while avoiding temperature extremes.
Temperature influences all plant physiological processes and is a particularly important factor controlling the length of the growing cycle of crops, where the optimal temperature for plant growth and therefore maximising crop productivity varies between crop species. Temperature extremes at sensitive phenological stages can adversely affect crop productivity. Plant species have differing temperature thresholds for optimum growth and differing responses during periods of extreme high or low temperature. High plant canopy temperatures reduce the efficiency of photosynthesis via increased respiration (particularly at night) and photorespiration, the latter affecting C3 crops (e.g. rice, soybean, mungbean, sesame, cotton and forage legumes). For northern Australia, the highest temperatures generally occur during the summer months of October to December as shown for Chillagoe (Figure 3-5), where the long-term mean daily maximum temperature can exceed 35 °C and night temperatures (i.e. minimums) exceed 18 °C. High temperature effects (day or night) on plant photosynthesis are exacerbated by high humidity and low solar radiation.

Figure 3-5 shows that while the amplitude of annual mean temperatures experienced in the Mitchell catchment at Chillagoe and Highbury Stations are smaller than those further south in Griffith, NSW, extremes above optimal thresholds for plant growth can occur as maximums between September and October and as minimums from November to March. High temperatures will generally coincide with periods of lower solar radiation and high humidity during the wetter months (December to March, Figure 3-4).
Figure 3-5 Monthly mean (a) maximum and (b) minimum daily temperatures for Highbury and Chillagoe in the Mitchell catchment compared to Griffith in southern NSW
Data sourced from SILO (Jeffrey et al., 2001).

When high temperatures coincide with little water in the soil, plants are unable to cool their leaves; photosynthesis is reduced and plant tissue damage can occur. Prior to the onset of summer rains, low soil water, higher air temperatures and solar radiation combine to heat soils, particularly those low in vegetative cover. High soil temperatures can negatively affect seedling emergence and crop establishment. For an irrigated crop, higher temperatures induce higher evaporative demand and increase evapotranspiration, resulting in a higher irrigation requirement. For a simulated sorghum crop sown mid-January, transpiration in 50% of years exceeds 430 mm and increases to 520 mm under a future drier, warmer climate scenario of +3.5 °C above current temperatures for 2060 (Figure 3-6a). While a wetter and warmer future scenario (+1.9 °C) with increased cloud and lower radiation reduces evaporation, overall transpiration continues to increase. For these warmer future scenarios sorghum yields are reduced (Figure 3-6b).
3.1.5 VAPOUR PRESSURE DEFICIT

While relative humidity (RH), the amount of water vapour in the air as a proportion of the potential amount of water the air can hold for a given air temperature and altitude, is well-understood, vapour pressure deficit (VPD) is a more accurate measurement of how plants respond to changes in humidity and temperature. VPD is the difference between water vapour at 100% RH and water vapour currently held in the atmosphere. The higher the VPD, the greater the pressure gradient between the plant and the atmosphere and therefore the greater the transpiration loss from the plant (Rashed, 2016). It is the combination of VPD and high air temperature that reduces the ability of plants to transpire and regulate temperature. High temperatures and low VPD (particularly at night) are as detrimental to canopy temperature regulation as high temperatures and high VPD. During periods of high temperature, supplementary irrigation may assist in reducing plant stress but is of limited value during periods of high VPD, which can occur in the lead up to the start of the wet season (September to November). The long-term mean RH for Chillagoe remains between 50% and 75% except for the September to October period where daily values drop below 40% RH (Figure 3-2). This period correlates with both high VPD and increasing air temperature and will require additional irrigation resources to meet higher surface evaporation and transpiration loss.
The occurrence of periods of high humidity also influences the development of many plant diseases. Irrigated crops can be exposed to high levels of humidity that can favour disease infection during the wet season and during cooler nights in the dry season.

### 3.1.6 WINDSPEED

Wind can be both beneficial and harmful to productivity. It can aid the process of pollination and is particularly important in the development of fruit and seed from wind-pollinated flowers. However, strong winds can cause excessive water loss through transpiration and can cause crops and trees to wilt, lodge or topple. Combined with other factors, winds can be particularly harmful; for example, wind-blown sand particles can damage vegetative surfaces. Destructive winds and potential flooding associated with tropical cyclones pose a significant threat, particularly to tree crops.

### 3.1.7 CYCLONES

Cyclones are a significant risk to any above-ground infrastructure (sheds, irrigation pivots etc.) and to long-cycle tree crops and there is a reasonably high risk of cyclones in the Mitchell catchment from November to April (Charles et al., 2016)(Figure 3-7).

![Figure 3-7 Mean annual number of tropical cyclones in the Australian region in (a) El Niño years; (b) La Niña years Adapted by (Petheram and Bristow, 2008) from Bureau of Meteorology cyclone maps <http://www.bom.gov.au/climate/maps/averages/tropical-cyclones/>.

### 3.1.8 FUTURE CLIMATE

Australia’s climate has been progressively warming since the early 1900s (CSIRO and BoM, 2015). Mean overnight minimum temperatures have increased by 1.1 °C and mean daily maximum temperatures by 0.8 °C. Far north Queensland, including the Mitchell catchment, has experienced a mean temperature increase of between 0.5 °C and 1.0 °C since 1910. Temperatures are expected to increase in the future, resulting in an increased number of extremely hot days. While winter rainfall has declined by 19% in the south-west of the country, parts of northern Australia
have experienced above average increases in rainfall since the 1970s. Future climate projections of rainfall for northern Australia do not show a clear trend, with some models suggesting decreases and others projecting increases in rainfall. Across all models the likelihood of a slight decrease in rainfall is greater than an increase, especially for scenarios using the high emission scenario RCP 8.5 (CSIRO and BoM, 2017). While the frequency of tropical cyclones has been stable across northern Australia, future increases in air and sea surface temperatures are expected to increase the variation and intensity of tropical cyclone activity (CSIRO and BoM, 2016).

In addition to changes in temperature, evaporation and rainfall as a consequence of increased greenhouse gas emissions, agricultural production will also be affected directly by elevated atmospheric CO₂ concentrations. Elevated atmospheric CO₂ concentrations and their direct impact on crop physiological processes of photosynthesis and leaf stomatal conductance are well-documented from Free Air CO₂ Enrichment (FACE) experiments (e.g. Hendrey et al., 1993; Tubiello et al., 2007). In the absence of temperature stress, elevated CO₂ improves water use efficiency of C3 crops and grasses by regulating a stomatal closure response in the plant to increased intercellular CO₂ (Parry et al., 2004). One anomaly of projected increases in mean temperature associated with elevated greenhouse gas is temperature-induced acceleration of crop development as a result of an increase in the rate of thermal time accumulation. While overall crop yields may decrease in response to increased daily temperature, the rate of decline is mitigated due to a shortening of the vegetative and grain filling periods, which result in phenological development and maturation occurring earlier and possibly within a more favourable climate period. The timing and use of supplementary irrigation will also have a role in reducing the severity of temperature-induced stress in crops.

3.1.9 SENSITIVITY OF CROP GROWTH TO CLIMATE

Climate, particularly rainfall, varies spatially across the Mitchell catchment. To capture the effects of this variability on crop yield and irrigation water requirements, APSIM was specified for a number of locations for which long-term climate records are available. Climate data at four locations, Mareeba (17.02S 145.42E), Chillagoe (17.15S 144.52E), Dunbar Station (16.04S 142.38E) and Highbury station (16.42S 143.15E), were used to capture the spatial variability in climate across the wider study area using the SILO data drill (Jeffrey et al., 2001).

For annual crops that are broadly suited to the climate of the Mitchell catchment, optimal planting periods were identified prior to running APSIM by reviewing 15-day and monthly median values and their variability for the key climate parameters solar radiation, temperature, VPD and rainfall. Sowing windows were selected to coincide critical growth phases with climate ‘sweet spots’ prioritising crop yield, production quality, and trafficability in wet weather for sowing and harvesting. In summary, the following criteria were used to arrive at optimum sowing times:

- Identify periods of maximum net photosynthesis during key growth phases to optimise crop yield production. For most annual crops this is achieved by selecting periods when solar radiation is greatest and least variable, and that coincide with temperatures near the optimal range during key growth phases for each crop species. The majority of crops have optimal growth when minimum temperatures are between 10 and 20 °C, and maximum temperatures between 25 and 33 °C, although temperature maximums may range below 25 °C and up to 40 °C when irrigation can be used to manipulate canopy temperatures.
Assume irrigation is available to overcome water stress and to manipulate canopy temperatures.

Avoid significant rainfall at sowing and maturity. Consider the impact of soil texture on trafficability, e.g. heavy clays versus well drained loams.

In the Mitchell catchment, photosynthesis was likely to be optimal early (April to May) and later (August to September) in the dry season for most crop species, provided irrigation was available. Crops with greater heat (cotton, sorghum) or cold night (maize, chickpeas) tolerance could extend beyond this range.

3.2 Soil

Land development for cropping in northern Australia is challenging because of the highly variable wet and dry seasons and because many of the soils are poor quality due to their age and strongly weathered status (Reimann et al., 2012). They are typically low in fertility and often affected by salinity and/or sodicity (Webb et al., 1974). These limitations combine to make the soils susceptible to water erosion in areas of even reasonably low slope (Pillans, 1997; Brooks et al., 2009), and much of the arable land is subject to lengthy periods of flooding. There are, however, deposits of younger soils (e.g. Quaternary alluvium) that may be suitable for agricultural development. To identify these areas, it is important to first understand the spatial location and characteristics of the soils, and then assess their suitability with respect to a range of land uses, in this case crop type by management. See the companion technical report on digital soil mapping (Thomas et al., 2018a) and the companion technical report on land suitability (Thomas et al., 2018b), where soils and landscapes suitable for cropping development were identified.

Given the size of the Mitchell catchment, the variability of the soils, and the time and financial resources associated with this Assessment, it was impractical to use traditional methods to map the soils. In any case, soil mapping has evolved in recent years, through a combination of computing advances and statistics, into a new approach called digital soil mapping, which was used in the companion technical report on digital soil mapping Thomas et al., 2018a. Digital soil mapping allows soil properties, such as pH, sampled at specific locations, to be related to an expanding Australian database of national covariates then modelled across the landscape. Covariates, which are GIS-format datasets, are selected because they directly correlate to landscape and soil properties.

Examples of covariates are slope, correlating to soil depth, and various measures of parent material, correlating to clay mineralogy within the soil profile. Unlike traditional soil mapping used to map soil types, digital soil mapping produces data and maps of individual soil properties (e.g. pH or permeability). As a result, the approach is especially suited to land suitability assessment. A particular strength of digital soil mapping methods over traditional mapping methods is that digital soil mapping produces spatial statistical measures of the quality of the mapped parameter and, thus, reliability estimates.

3.2.1 Soil Generic Groups

Digital soil mapping does not produce traditional soil data and maps. It produces a set of attributes that describe the properties of the soil, which can be used to develop land suitability data but
could also be used for hydrological and/or agricultural modelling. However, Soil Generic Groups (SGGs) were derived for the Mitchell catchment as part of the digital soil mapping process and aligned to the Australian Soil Classification (Isbell and National Committee on Soil and Terrain, 2016). This was done principally to provide a communication tool based on ‘soil types’ with broadly similar properties and management considerations (Table 3-1). Their location in the study area and the percentage of the study area comprising each SGG are shown in Figure 3-8 and Table 3-2. SGG descriptions summarised from Thomas et al. (2018a) follow here.
<table>
<thead>
<tr>
<th>SGG</th>
<th>SGG OVERVIEW</th>
<th>GENERAL DESCRIPTION</th>
<th>LANDFORM</th>
<th>MAJOR MANAGEMENT CONSIDERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Sand or loam over relatively friable red clay subsoils</td>
<td>Strong texture contrast between the A and B horizons, A horizons generally not bleached. B horizon not sodic and may be acid or alkaline. Moderately deep to deep well drained red soils</td>
<td>Undulating plains to hilly areas on a wide variety of parent materials</td>
<td>The non-acid soils are widely used for agriculture; the strongly acid soils are generally used for native and improved pastures</td>
</tr>
<tr>
<td>1.2</td>
<td>Sand or loam over relatively friable brown, yellow and grey clay subsoils</td>
<td>As above but moderately well drained to imperfectly drained brown, yellow and grey soils</td>
<td>As above</td>
<td>As above but may be restricted by drainage related issues</td>
</tr>
<tr>
<td>2</td>
<td>Friable non-cracking clay or clay loam soils</td>
<td>Moderate to strongly structured, neutral to strongly acid soils with little or only gradual increase in clay content with depth. Grey to red, moderately deep to very deep soils</td>
<td>Plains, plateaux and undulating plains to hilly areas on a wide variety of parent materials</td>
<td>Generally high agricultural potential because of their good structure, and their moderate to high chemical fertility and water holding capacity. Ferrosols on young basalt and other basic landscapes may be shallow and rocky</td>
</tr>
<tr>
<td>3</td>
<td>Seasonally or permanently wet soils</td>
<td>A wide variety of soils grouped together because of their seasonal or permanent inundation. No discrimination between saline and freshwater</td>
<td>Coastal areas to inland wetlands, swamps and drainage depressions. Mostly unconsolidated sediments, usually alluvium</td>
<td>Require drainage works before development can proceed. Acid sulfate soils and salinity are associated problems in some areas</td>
</tr>
<tr>
<td>4.1</td>
<td>Red loamy soils</td>
<td>Well drained, neutral to acid red soils with little or only gradual increase in clay content at depth. Moderately deep to very deep red soils</td>
<td>Level to gently undulating plains and plateaux, and some unconsolidated sediments, usually alluvium</td>
<td>Moderate to high agricultural potential with spray or trickle irrigation due to their good drainage. Low to moderate water holding capacity, often hard setting surfaces</td>
</tr>
<tr>
<td>4.2</td>
<td>Brown, yellow and grey loamy soils</td>
<td>As above but moderately well drained to imperfectly drained brown, yellow and grey soils</td>
<td>As above</td>
<td>As above but may be restricted by drainage related issues</td>
</tr>
<tr>
<td>5</td>
<td>Peaty soils</td>
<td>Soils high in organic matter</td>
<td>Predominantly swamps</td>
<td>Low agricultural potential due to very poor drainage</td>
</tr>
<tr>
<td>6.1</td>
<td>Red sandy soils</td>
<td>Moderately deep to very deep red sands. May be gravelly</td>
<td>Sandplains and dunes; Aeolian, fluvial and siliceous parent material</td>
<td>Low agricultural potential due to excessive drainage and poor water holding capacity. Potential for irrigated agriculture</td>
</tr>
<tr>
<td>6.2</td>
<td>Brown, yellow and grey sandy soils</td>
<td>Moderately deep to very deep brown, yellow and grey sands. May be gravelly</td>
<td>As above</td>
<td>Low agricultural potential due to poor water holding capacity combined with seasonal drainage restrictions. May have potential for irrigated agriculture</td>
</tr>
<tr>
<td>7</td>
<td>Shallow and/or rocky soils</td>
<td>Very shallow to shallow &lt;0.5 m. Usually sandy or loamy, but may be clayey. Generally weakly developed soils that may contain gravel</td>
<td>Crests and slopes of hilly and dissected plateaux in a wide variety of landscapes</td>
<td>Negligible agricultural potential due to lack of soil depth, poor water holding capacity and presence of rock</td>
</tr>
<tr>
<td>SGG</td>
<td>SGG OVERVIEW</td>
<td>GENERAL DESCRIPTION</td>
<td>LANDFORM</td>
<td>MAJOR MANAGEMENT CONSIDERATIONS</td>
</tr>
<tr>
<td>-----</td>
<td>--------------</td>
<td>---------------------</td>
<td>----------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>8</td>
<td>Sand or loam over sodic clay subsoils</td>
<td>Strong texture contrast between the A and B horizons; A horizons usually bleached. Usually alkaline but occasionally neutral to acid subsoils. Moderately deep to deep</td>
<td>Lower slopes and plains in a wide variety of landscapes</td>
<td>Generally low to moderate agricultural potential due to restricted drainage, poor root penetration and susceptibility to gully and tunnel erosion. Those with thick to very thick A horizons are favoured</td>
</tr>
<tr>
<td>9</td>
<td>Cracking clay soils</td>
<td>Clay soils with shrink–swell properties that cause cracking when dry. Usually alkaline and moderately deep to very deep</td>
<td>Floodplains and other alluvial plains. Level to gently undulating plains and rises (formed on labile sedimentary rock). Minor occurrences in basalt landscapes</td>
<td>Generally moderate to high agricultural potential. The flooding limitation will need to be assessed locally. Many soils are high in salt (particularly those associated with the treeless plains). Gilgai and coarse structured surfaces may occur</td>
</tr>
<tr>
<td>10</td>
<td>Highly calcareous soils</td>
<td>Moderately deep to deep soils that are calcareous throughout the profile</td>
<td>Plains to hilly areas</td>
<td>Generally moderate to low agricultural potential depending on soil depth and presence of rock</td>
</tr>
</tbody>
</table>
Cracking clay soils (SGG 9) occur to a very limited extent in the study area (Figure 3-8 and Table 3-2). They are found on the gently undulating plains and rises at Wrotham Park, upstream of the confluence of the Mitchell and Walsh rivers. These self-mulching Black Vertosols have high soil water holding capacity but may have restricted rooting depth due to high salt levels in the subsoil. These soils require further investigation, especially at local scale, to assess the likelihood of salinity issues developing under irrigated cropping. Cracking clay soils are also found on the alluvial plains of the Mitchell Delta. These clay soils are suited to a variety of grain, forage and pulse crops but are susceptible to seasonal wetness and flooding in many places.

Although often suitable for cropping, the sands or loams over friable clay (SGG 1.1 and 1.2) are found in relatively small areas in the upper study area (Figure 3-8 and Table 3-2). Many areas in which these soils are well-suited to intensive horticulture are found in locations that are highly fragmented by creeks, resulting in few areas suitable for larger scale development. Where found on the alluvial plains, their narrow irregular nature also makes large-scale development difficult. These soils contain Chromosols, which were used as a representative cropping soil in the cropping analysis.

The friable non-cracking clays and clay loam soils (SGG 2) occur to a limited extent in the south-east and east of the upper study area (Figure 3-8 and Table 3-2). In the upper Lynd River catchment, Ferrosols with large boulders on the surface and throughout the profile make agricultural development difficult and expensive. While these Ferrosols and Dermosols are typically suited to irrigated agriculture their narrow, ribbon-like form in many parts of the landscape in which they are found may limit infrastructure layout. Where these soils are found in the upper study area near Mareeba they are used extensively for cropping.
Soils in SGG groups 4.1 and 4.2 are found on narrow levees adjacent to the major rivers and tributaries throughout the study area, on prior streams throughout the delta and as very deep well drained red sands on the sandstone plateaux in the northern parts of the study area. These Kandosols are moderately permeable, deep to very deep soils, but have low to moderate soil water holding capacity. Irrigation is limited to spray or micro and trickle irrigation. These soils are typically nutrient deficient and require high fertiliser inputs when initially developed. The red, yellow and grey loamy soils occur on a variety of geologies and landforms throughout the study area (Figure 3-8 and Table 3-2). Elevated flood-free areas occur on sandplains derived from ‘old’ alluvium generally adjacent to the major river channels. Very deep, well drained red soils are restricted to the upper slopes of landforms in the south-east of the Lynd catchment and tend to be restricted in size to less than 100 ha.

Sand or loam over sodic and intractable clays, or Sodosols (SGG 8) occur extensively throughout the study area (Figure 3-8 and Table 3-2). On all alluvial plains upstream of the confluence of the
Palmer and Mitchell Rivers, the occasionally flooded ‘narrow’ alluvial plains are generally deeply incised by the main channel resulting in relatively narrow usable areas. Below the confluence, the regularly flooded ‘broad’ delta has numerous flood channels, which become more numerous and meandering closer to the coast. Soils are dominated by hard setting clay loam to silty clay loam surfaced brown gradational soils with strongly sodic, dispersive coarse structured clay subsoil at less than 0.15 metres below the surface, supporting open *Eucalyptus* woodland. These slowly permeable moderately well drained to imperfectly drained soils predominantly have moderate soil water holding capacity, they are subject to regular flooding throughout the delta, and are susceptible to erosion on slopes – particularly gully erosion adjacent to stream channels. Agricultural potential is moderate.

The sandy soils (SGG 6.1 and 6.2) predominantly on the sandstone plateaux of the north western part of the study area are highly permeable Tenosols with low soil water holding capacity. These soils have potential for irrigated horticulture (tree and small crops), utilising trickle/drip systems, otherwise their agricultural potential is low.

The upper parts of the study area (Figure 3-8 and Table 3-2) are dominated by shallow sandy and stony soils (SGG 7). These shallow and gravelly soils with abundant rock outcrop have very limited potential for agricultural development due to low soil water holding capacity, predominantly steep slopes subject to erosion, and because they sit within a fragmented landscape have intense drainage patterns.

The seasonally wet or permanently wet soils (SGG 3) occur extensively on a range of level low-lying landscapes. All soils have limited potential for agricultural development, although a certain proportion of these soils dry out sufficiently in most dry-seasons to potentially permit cropping.

### Table 3-2 Area (ha) and percentage area of each of the SGGs in the Mitchell catchment (Thomas et al., 2018a)

<table>
<thead>
<tr>
<th>SGG</th>
<th>SOIL GENERIC GROUP (SGG) DESCRIPTION</th>
<th>AREA (HA)</th>
<th>PERCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Sand or loam over relatively friable red clay subsoils</td>
<td>55,188</td>
<td>0.77</td>
</tr>
<tr>
<td>1.2</td>
<td>Sand or loam over relatively friable brown, yellow and grey clay subsoils</td>
<td>25,028</td>
<td>0.35</td>
</tr>
<tr>
<td>2</td>
<td>Friable non-cracking clay or clay loam soils</td>
<td>483,059</td>
<td>6.76</td>
</tr>
<tr>
<td>3</td>
<td>Seasonally or permanently wet soils</td>
<td>1,228,775</td>
<td>17.19</td>
</tr>
<tr>
<td>4.1</td>
<td>Red loamy soils</td>
<td>562,602</td>
<td>7.87</td>
</tr>
<tr>
<td>4.2</td>
<td>Brown, yellow and grey loamy soils</td>
<td>740,330</td>
<td>10.36</td>
</tr>
<tr>
<td>5</td>
<td>Peaty soils</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>6.1</td>
<td>Red sandy soils</td>
<td>49,250</td>
<td>0.69</td>
</tr>
<tr>
<td>6.2</td>
<td>Brown, yellow and grey sandy soils</td>
<td>428,143</td>
<td>5.99</td>
</tr>
<tr>
<td>7</td>
<td>Shallow and/or rocky soils</td>
<td>2,618,103</td>
<td>36.64</td>
</tr>
<tr>
<td>8</td>
<td>Sand or loam over sodic clay subsoils</td>
<td>850,284</td>
<td>11.90</td>
</tr>
<tr>
<td>9</td>
<td>Cracking clay soils</td>
<td>105,500</td>
<td>1.48</td>
</tr>
<tr>
<td>10</td>
<td>Highly calcareous soils</td>
<td>15</td>
<td>0.00</td>
</tr>
</tbody>
</table>
3.3 Land suitability for target crops and forages

A major question for any agricultural resource assessment is how much soil is suitable for a particular land use and where can that soil be found. Within this Assessment, this was the main output of the land suitability activity and detail can be found in the companion technical report on land suitability (Thomas et al., 2018b).

The suitability of a soil for a particular land use is determined by a number of attributes. These include climate at that location, slope, drainage, permeability, plant available water capacity, pH, soil depth, surface condition and texture. Some attributes, such as plant available water capacity, are considered for different depths within the soil profile in order to help determine suitability for crops of different rooting depths. From these attributes a set of limitations are derived, which are then considered against each potential land use. In this Assessment 126 land use combinations (i.e. crop \( \times \) season \( \times \) irrigation type) were considered within the land suitability framework.

The land suitability framework is based on the land evaluation guidelines of the Food and Agriculture Organization of the United Nations (FAO, 1976). For each land use a score from 1 to 5 is provided for each attribute. A score of 1 reflects that the attribute poses no significant limitation to sustained application of the specified land use, while a score of 5 reflects that the attribute poses such a severe limitation that it precludes the sustained application of the specified use, based on Australian farming conditions. For example, slope greater than 20% precludes the growing of all crop types due to erosion risk while rockiness will preclude the growing of root crops but not some other crop types.

The overall suitability of a soil for a particular land use is calculated by considering the set of relevant attributes at each location and determining the most limiting attribute amongst them. This most limiting attribute then determines the overall land suitability classification. The soil is classed on a scale of 1 to 5 from ‘Highly Suitable’ to ‘Unsuitable’ as shown in Table 3-3. Note that a large proportion of Australia’s soils currently used for agriculture are classified as Class 3.

Table 3-3 Land suitability classification used in the Assessment (Thomas et al., 2018b)

<table>
<thead>
<tr>
<th>CLASS</th>
<th>SUITABILITY</th>
<th>LIMITATIONS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Highly suitable land</td>
<td>Negligible</td>
<td>Highly productive land requiring only simple management practices to maintain economic production.</td>
</tr>
<tr>
<td>2</td>
<td>Suitable land</td>
<td>Minor</td>
<td>Land with limitations that either constrain production, or require more than the simple management practices of Class 1 land to maintain economic production and minimise land degradation.</td>
</tr>
<tr>
<td>3</td>
<td>Moderately suitable land</td>
<td>Considerable</td>
<td>Land with limitations that either further constrain production, or require more than those management practices of Class 2 land to maintain economic production and minimise land degradation.</td>
</tr>
<tr>
<td>4</td>
<td>Currently unsuitable land</td>
<td>Severe</td>
<td>Currently unsuitable land due to severe limitations that preclude successful sustained use of the land for the specified land use. In some circumstances, the limitations may be surmountable with changes to knowledge, economics or technology.</td>
</tr>
<tr>
<td>5</td>
<td>Unsuitable land</td>
<td>Extreme</td>
<td>The limitations are so extreme that the specified land use is precluded. The benefits would not justify the inputs required to maintain production and prevent land degradation in the long term.</td>
</tr>
</tbody>
</table>
For the purposes of this Assessment it should be noted that the land suitability classification does not take into consideration flooding, risk of secondary salinisation, availability of irrigation water or analysis of economic viability.

Two examples of land suitability for prospective land uses in the Mitchell catchment are given here. The suitability of land for wet-season forage sorghum under spray irrigation and the suitability for sugarcane under furrow irrigation is shown in Figure 3-9. For forage sorghum under this management, only 8.5% of the study area is Class 3 or better. For sugarcane under furrow irrigation, 19% of the study area is moderately suitable (Class 3) with no land Class 1 or Class 2. Maps for 126 land uses (crop × season × irrigation type) in the Mitchell catchment are provided in the companion technical report on land suitability (Thomas et al., 2018b).

![Figure 3-9 Land suitability and reliability estimate for (a) wet-season forage sorghum under spray irrigation and (b) sugarcane grown under furrow irrigation (Thomas et al., 2018b)](image)

The maps do not take into consideration flooding, risk of secondary salinisation, availability of water, or analysis of economic viability.

An index of agricultural versatility was also derived for the Mitchell catchment by looking at the full range of crop × season × irrigation type land uses detailed in Thomas et al. (2018b) (Figure 3-10). The index was calculated for each of the three irrigation types examined (furrow, spray and trickle) as well as for natural, rainfed conditions. Clearly, spray and trickle irrigation have the potential to be used on a much greater area in the Mitchell catchment than furrow irrigation.
Figure 3-10 Agricultural versatility for (a) rainfed, (b) furrow irrigation, (c) spray irrigation, and (d) trickle irrigation in the Mitchell catchment (Thomas et al, 2018b)

Higher index values indicate greater versatility for each irrigation option.

Land suitability areas in hectares for a set of 14 land uses, i.e. combinations of crop × season × irrigation type, are provided in Figure 3-11. Depending on land use, the amount of land classified as Class 3 or better ranges from about 200,000 ha to a little over 3 million ha. Almost all of this land is rated as Class 3, although there is some Class 2 land available for Rhodes grass, cotton, bananas and mango under specific management practices.
3.4 Irrigation

3.4.1 NEED FOR IRRIGATION

Irrigated agriculture in the Mitchell catchment will be limited in the amount of irrigation water that can reliably be supplied. The companion technical report on river model calibration (Hughes et al., 2017) and the companion technical report on river model simulation (Hughes et al., 2018) provide an overview of reliable water yields. There are opportunities for dryland cropping in the Mitchell catchment (Section 3.4.3); however, these opportunities are limited, and irrigation will produce more reliable crop yields. The primary determinants of the amount of irrigation water required are the time of year at which the crop is grown, and the amount of in-crop rainfall received. The amount of irrigation required per ha is also determined by the crop and variety grown, the soil type, and crop management factors such as the irrigation system. The climate of the Mitchell catchment exhibits a strong wet season/dry season rainfall pattern (Figure 3-1) and short-duration crops grown over the wet season will require less irrigation water than perennial...
crops or dry-season crops. The amount of irrigation required per ha is also determined by the crop grown, the soil type, and crop management such as irrigation system used.

### 3.4.2 IRRIGATION EFFICIENCY

Water that is captured and stored from rivers must be transported to and applied in the field where it is needed. This transport of water can result in losses from leakage, seepage, evaporation, outfall, unrecorded usage and system filling. Water extracted from groundwater is usually extracted locally, and losses are low for transport, but can still occur during application. Losses occur along the system, and across Australia the mean water conveyance efficiency from the river to the farm gate has been estimated to be 71% (Marsden Jacobs Associates, 2003).

On-farm losses occur between the farm gate and delivery to the field and usually take the form of evaporation and seepage from on-farm storages and delivery systems. Even in irrigation developments where water is delivered to the farm gate via a channel or in groundwater systems, many farms have small on-farm storages. These on-farm storages enable the farmer to have a reliable supply of irrigation water with a higher flow rate than might be possible from channels, and also enable recycling of tailwater. Several studies have been undertaken in southern Australia of on-farm distribution losses. Meyer (2005) estimated an on-farm distribution efficiency of 78% in the Murray and Murrumbidgee regions, while Pratt Water (2004) estimated on-farm efficiency to be 94% and 88% in the Coleambally Irrigation Area and the Murrumbidgee Irrigation Area respectively. In these irrigation areas, measured channel seepage losses in both supply channels and on-farm channels were generally less than 5% (Akbar et al., 2013). Estimates of channel seepage losses in the Burdekin Irrigation Area range from 2 to 22% (Williams, 2009).

Once water is delivered to the field, it needs to be applied to the crop using an irrigation system. The application efficiency of irrigation systems typically varies between 60 and 90%, with more efficient systems being more expensive.

There are three types of irrigation systems that can potentially be applied in the Mitchell catchment: surface irrigation, spray irrigation and micro irrigation (Table 3-4). Irrigation systems need to be tailored to the soil, climate and crops that may be grown, and matched to the availability and source of water for irrigation. System design will also need to consider investment risk in irrigation systems as well as likely returns, degree of automation, labour availability, and maintenance and operation costs, including energy costs. Generally speaking, spray and micro irrigation systems are more suitable for permeable soils and surface systems are more suitable for heavier soils.

<table>
<thead>
<tr>
<th>Irrigation System</th>
<th>Type</th>
<th>Application Efficiency (%)</th>
<th>Capital Cost ($/ha)</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Basin, border and furrow</td>
<td>60 to 85%</td>
<td>$3400</td>
<td>Suitable for most crops; topography and surface levelling costs may be limiting factor</td>
</tr>
<tr>
<td>Spray</td>
<td>Centre pivot</td>
<td>75 to 90%</td>
<td>$2500 to $5500</td>
<td>Not suitable for tree crops; high energy requirements for operation</td>
</tr>
</tbody>
</table>

Table 3-4 Details of irrigation systems applicable for use in the Mitchell catchment
Adapted from Hoffman et al. (2007), Raine and Bakker (1996) and Wood et al. (2007).
### Surface irrigation systems

Surface irrigation encompasses basin, border strip and furrow irrigation, as well as variations such as bankless channel systems. In surface irrigation, water is applied directly to the soil surface with structures used to direct water across a field. These structures are often individual crop rows (furrows) but can be up to tens of metres wide (basins). Gravity is used to propel the water across the paddock, with levelling often required to increase the uniformity and efficiency of application.

Generally, fields are laser levelled to increase the uniformity of applied water and allow adequate surface drainage from the field. The uniformity and efficiency of surface systems are highly dependent on the system design and soil properties, timing of the application of irrigation water, and the skill of the individual irrigator in operating the system. Mismanagement can severely degrade system performance and lead to systems that operate at poor efficiencies.

Surface irrigation can generally be adapted to almost any crop and often has a lower capital cost compared with alternative systems. Surface irrigation systems perform better when soils are of uniform texture because infiltration characteristics of the soil play an important part in the efficiency of these systems. They are not so well-suited to sandy soils due to losses along the furrows. Therefore, surface irrigation systems should be designed into uniform soil management units and layouts (run lengths, basin sizes) tailored to match soil characteristics and water supply volumes. Automation of surface irrigation through control of water inflow is increasingly being applied in Australian agriculture.

High application efficiencies are possible with surface irrigation systems, provided soil characteristic limitations, system layout, water flow volumes are accounted for, and systems are intensively managed. On ideal soil types and with systems capable of high flow rates, efficiencies can be as high as 85%. On poorly designed and managed systems on soil types with high variability, efficiencies may be below 60%.

The major cost in setting up a surface irrigation system is generally land grading and levelling, and construction of structures to enable capture and recycling of runoff water. Costs are directly associated with the volume of soil that must be moved. Typical earthworks volumes are in the order of 800 m³/ha but can exceed 2500 m³/ha. Volumes greater than 1500 m³/ha are generally considered excessive due to costs (Hoffman et al., 2007).

Surface irrigation systems are the dominant form used throughout the world. With surface irrigation, little or no energy is required to distribute water throughout the field and this gravity fed approach reduces energy requirements of these systems (Table 3-5).

Surface irrigation systems generally have lower water use efficiency than spray or micro systems when compared across an industry and offer less control of applied water; however, well-designed

<table>
<thead>
<tr>
<th>IRRIGATION SYSTEM</th>
<th>TYPE</th>
<th>APPLICATION EFFICIENCY (%)</th>
<th>CAPITAL COST ($/ha)</th>
<th>LIMITATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral move</td>
<td>75 to 90%</td>
<td>$2500 to $5000</td>
<td>Not suitable for tree crops; high energy requirements for operation</td>
<td></td>
</tr>
<tr>
<td>Micro Drip</td>
<td>80 to 90%</td>
<td>$6000 to $9000</td>
<td>High energy requirement for operation; high level of skills needed for successful operation</td>
<td></td>
</tr>
</tbody>
</table>
and managed systems can approach efficiencies found with alternative irrigation systems in ideal conditions.

**Table 3-5 Pumping costs by irrigation type**
Adapted from Culpitt (2011), with costs based on assumption of $1.12/L for diesel ($1.50/L less $0.38/L rebate) and $0.18/kWh for electricity.

<table>
<thead>
<tr>
<th></th>
<th>UNITS</th>
<th>FLOOD HARVESTING</th>
<th>SURFACE IRRIGATION</th>
<th>TAILWATER RETURN</th>
<th>Spray</th>
<th>Lateral Moves</th>
<th>Subsurface DRIP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flow rate</strong></td>
<td>ML/day/ha</td>
<td>120</td>
<td>120</td>
<td>50</td>
<td>8.6</td>
<td>24.2</td>
<td>16.6</td>
</tr>
<tr>
<td><strong>Total dynamic head</strong></td>
<td>m</td>
<td>7</td>
<td>6</td>
<td>5.5</td>
<td>50</td>
<td>35</td>
<td>50</td>
</tr>
<tr>
<td><strong>Pumping plant efficiency</strong></td>
<td>%</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
<td>66%</td>
<td>66%</td>
<td>75%</td>
</tr>
<tr>
<td><strong>Power required</strong></td>
<td>kWh/ML</td>
<td>38.9</td>
<td>33.3</td>
<td>30.6</td>
<td>210.4</td>
<td>147.3</td>
<td>185.2</td>
</tr>
<tr>
<td><strong>Specific fuel consumption</strong></td>
<td>L/kWh</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Equivalent diesel requirement</strong></td>
<td>L/ML</td>
<td>9.7</td>
<td>8.3</td>
<td>7.6</td>
<td>52.6</td>
<td>36.8</td>
<td>46.3</td>
</tr>
<tr>
<td><strong>Pumping cost, electricity</strong></td>
<td>$/ML</td>
<td>$7.0</td>
<td>$6.0</td>
<td>$5.5</td>
<td>$37.9</td>
<td>$26.5</td>
<td>$33.4</td>
</tr>
<tr>
<td><strong>Pumping cost, diesel</strong></td>
<td>$/ML</td>
<td>$10.9</td>
<td>$9.3</td>
<td>$8.5</td>
<td>$58.9</td>
<td>$41.2</td>
<td>$51.9</td>
</tr>
</tbody>
</table>

**Spray irrigation systems**

Spray irrigation refers specifically to lateral move and centre pivot irrigation systems. Centre pivot systems consist of multiple sprinklers spaced laterally along a series of irrigation spans, supported by a series of towers. The towers are self-propelled and rotate around a central pivot point, forming an irrigation circle of generally less than 500 m with areas less than 80 ha. Individual sprinkler volume output is dependent on closeness to the centre of the circle, with sprinklers closer to the centre having lower output. The time taken for the pivot to complete a full circle can range from as little as half a day to multiple days depending on crop water demands and application rate of the system. The rotation speed of the centre pivot and sprinklers used determines irrigation application rate.

Lateral or linear move systems are similar to centre pivot systems in construction but rather than moving around a pivot point an entire line of sprinklers moves down the field. Water is supplied by lateral channel or flexible hose running the length of the field. Lateral lengths are generally in the range of 800 to 1000 m. They offer the advantage over surface systems that they can be more easily utilised on rolling topography and generally require less land forming. Further, fertiliser can be applied through fertigation where crop nutrients are injected through the irrigation system rather than applied to the field.

Both centre pivot and lateral move irrigation systems have been extensively used for irrigating a range of annual broadacre crops and are capable of irrigating most field crops. They are generally not suitable for tree crops or vine crops or for saline irrigation water applications in arid environments, which can lead to foliage damage as the water is sprayed from above the crop. Centre pivot and lateral move systems usually have higher capital costs but are capable of very high efficiencies of water application. Generally, application efficiencies for these systems range from 75 to 90% (Table 3-4). A key factor in the suitable use of spray systems is sourcing the energy
needed to operate these systems, which are usually powered by electricity or diesel depending on costs and infrastructure available. Where available, electricity is considerably cheaper than diesel at powering spray systems (Table 3-5). However, with improved efficiency and reduced cost of solar powered systems, they are emerging as a cost-effective alternative to diesel and electricity. Under high groundwater pressure, centre pivots and lateral moves may be propelled using water pressure.

Micro irrigation systems

Under pressurised systems such as micro irrigation systems, water application can be more easily controlled, and potential benefits of the system through fertigation are also available to the irrigator. For high-value crops, such as horticultural crops, where crop yield and quality parameters dictate profitability, micro irrigation systems should be considered suitable across the range of soil types and climate found.

Micro irrigation systems use thin-walled polyethylene pipe to apply water to the root zone via small emitters spaced along the drip tube. These systems are capable of precisely applying water to the plant root zone, thereby maintaining a high level of irrigation control and water use efficiency. Historically, micro irrigation systems have been extensively used in tree, vine and row crops, with limited applications in complete cover crops such as grains and pastures due to the expense of these systems. Micro irrigation is suitable for most soil types and can be practised on steep slopes. Micro irrigation systems are generally of two types: above-ground and below-ground (where the drip tape is buried beneath the soil surface). Below-ground micro irrigation systems offer advantages in reducing evaporative losses and improving trafficability. However, below-ground systems are more expensive and require higher levels of expertise to manage.

Properly designed and operated micro irrigation systems are capable of very high application efficiencies, with field efficiencies of 80 to 90% (Table 3-4). In some situations micro irrigation systems offer water and labour savings and improved crop quality (i.e. more marketable fruit through better water control). Intensive management of micro irrigation systems, however, is critical; to achieve these benefits requires a much greater level of expertise than other traditional systems such as surface irrigation systems. Micro irrigation systems also have high energy requirements, with most systems operating at pressure ranges from 135 to 400 kPa with diesel or electric pumps most often used (Table 3-5).

3.4.3 LIMITED IRRIGATION WATER

Crop yields presented in this technical report have been modelled with unlimited irrigation water. Unlimited irrigation water will not always be available to farm managers, or necessarily be the most economical option. In situations where water availability is limited, the crop will respond by yielding more with more applied irrigation until a yield plateau is reached. Understanding the shape of the crop yield response to increasing irrigation allows better risk and financial management in water limited environments.

Dryland crops grown without any applied irrigation water rely on rainfall (stored in the soil or received during crop growth) for all of their water requirements. The more rainfall that is received, the greater dryland crop yields. Generally, dryland yields are lower than irrigated yields, but in years receiving above average rainfall during the growing season, dryland yields may achieve
irrigated yields with careful management. Short-duration crops such as mungbean and sorghum established early are able to utilise in-crop rainfall during crop development and higher water holding capacity soils to minimise water stress during the later grain filling period. Harvesting occurs at the end of the wet season. To achieve increased dryland yields in seasons with above average in-crop rainfall, additional fertiliser inputs and pest management will be required.

The inter-annual variability of rainfall means that continuous year-on-year dryland cropping is unlikely to be possible in the Mitchell catchment. Opportunistic cropping, pursued when conditions are favourable, particularly in the higher rainfall areas of the Mitchell catchment, is likely to provide the most profitable and sustainable approach to dryland cropping, although flexibility and readiness is required to take full advantage of the opportunities.

3.5 Crop type

3.5.1 BROADACRE

Cereal crops

Dryland and irrigated cereal production are well-established in many regions in Australia. Around 20 Mha of land is devoted to grain (wheat, barley, grain, sorghum, oats, triticale, maize, etc.) production each year, yielding an annual mean of approximately 35 Mt. Significant export markets exist for wheat, barley and grain sorghum, and there are niche export markets for grains such as maize and oats. The domestic market takes all cereals grown.

Amongst the cereals, summer crops such as grain sorghum and maize have the highest potential in the Mitchell catchment. These could be grown opportunistically using dryland production in the wet season or more continuously using irrigation. Winter cereals such as wheat and barley are not well-adapted to the climate of the Mitchell catchment. If grown during the dry season they would require full irrigation.

To grow cereal crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is often a contract operation, and in larger growing regions other activities can also be performed under contract. Birds are a potential problem that need to be managed.

Pulse crops

Pulse production is well-established in Australia. Approximately two million ha of pulse crops are grown annually, producing 2 to 2.5 million tonnes of mainly chickpea, lupin and field pea with a gross value of production of greater than $600 million (ABARES, 2017). Pulses produced in the Mitchell catchment would most likely be exported. There is a pulse seed cleaning and processing facility in Townsville, and exports are channelled through the Port of Townsville.

Pulses, many of which have a short growing season, are often well-suited to opportunistic dryland production or more continuous irrigated production, probably in rotation with cereals or other non-legume crops. Pulses are often advantageous in rotation with other crops because they provide a disease break and, being legumes, often provide nitrogen for subsequent crops. Even where this is not the case, their ability to meet their own nitrogen needs can be beneficial in reducing costs of fertiliser and associated haulage. Pulses are a high-value broadacre crop...
(chickpeas and mungbeans are over $1000/t) yet produce modest yields (e.g. 1 to 3 t/ha), which means freight costs represent a smaller percentage of the value of the crop compared with higher yielding, lower value cereal crops. This becomes of great importance as the distance from processing facilities and ports increases. To grow pulse crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is generally a contract operation, and in larger growing regions other activities can also be performed under contract. The equipment required for pulse crops is the same as that required for cereal crops, so farmers intending a pulse and cereal rotation would not need to purchase extra equipment.

**High-value niche crops**

There is increasing interest in non-leguminous, small-seeded crops such as chia and quinoa, which have high nutritive value. The market size for these niche crops is quite small compared with cereals and pulses and so the scale of production will be modest.

There is a small, established chia industry in the Ord River region, but its production and marketing statistics are largely commercial in confidence. Nearly all Australian production of chia is contracted to The Chia Company of Australia or is exported to China. In Australia, The Chia Company produces whole chia seeds, chia bran, ground chia seed and chia oil for wholesale and retail sale and exports these products to 36 countries.

The growing popularity of quinoa in recent years is attached to its marketing as a super food. It is genetically diverse and has not been the subject of long-term breeding programs. This diversity means it is well-suited to a range of environments, including northern Australia, where its greatest opportunity is as a short-season crop in the dry season under irrigation.

**Oilseed crops**

Summer oilseed crops such as soybean are more suited to the environment of the Mitchell catchment than winter-grown oilseed crops such as canola. Soybean is generally grown for grain in Queensland but is a useful forage crop (cut green or baled) for livestock. Soybean is sensitive to photoperiod (day length) and requires careful consideration in selection of the appropriate variety for a particular sowing window. Australia produces around 2 to 3 million tonnes of oilseed crop annually, about half from canola and the remainder primarily from cottonseed, soybean and sunflowers. Sunflowers are widely grown in central Queensland and in recent years they have been grown in some areas of the Ord Valley.

**Root crops, including peanuts**

Root crops including peanut, sweet potatoes and cassava, are potentially well-suited to the lighter soils found in some alluvial stretches of the Mitchell catchment. Root crops are not suited to growing on heavier clay soils because they need to be pulled from the ground for harvest, and heavy clay soils are not conducive to easy pulling.

The peanut is the most widely grown root crop in Australia and the industry is well-established in Queensland with major growing areas around Kingaroy, Gayndah-Bundaberg and the Atherton Tablelands. There is a peanut processing facility located in Tolga on the Atherton Tablelands.

Peanuts can be planted in the wet or dry season. Peanuts grown in the Mitchell catchment would probably be summer-grown, with supplementary irrigation possibly required towards harvest. The
peanut is a legume crop that requires little or no nitrogen fertiliser and is very well-suited to growing in rotation with cereal crops as it is frequently able to fix atmospheric nitrogen in soil for following crops. However, based on the Peanut Company of Australia’s efforts at expanding operations into the Katherine region, and the agronomic challenges they faced in a climate similar to that in the Mitchell catchment (Jakku et al., 2016), considerable planning would be needed in determining the best season for production, and practical options for crop rotations.

The stubble remaining after peanut harvest can be used as a high-quality supplementary feed for cattle. Most of the equipment suitable for cereal production (planter, fertiliser spreader, sprayer and harvester) can be used for root crop production; however, a specialised digger is required to remove the roots from the ground prior to harvest. Hay-making equipment is also an advantage, as the residue makes good-quality hay that can be sold locally to the cattle industry.

3.5.2 HORTICULTURAL CROPS

Tree crops
Some fruit and tree crops, including mangoes, bananas and cashews, are well-suited to the climate of the Mitchell catchment and are presently cultivated within the study area in the MDWSS. Other crops, such as avocado and lychee, while currently grown in the more benign climate of the MDWSS, may not be as well-adapted to the drier climate and soils further west in the Mitchell catchment. Tree crops are generally not well-suited to cracking clays, which make up 1.5% of the suitable soils for irrigated agriculture in the Mitchell catchment.

Some of the marketing and risk features of fruit production include a short season of supply and volatile prices as a result of inelastic supply and demand. Managing these issues requires a heightened understanding of risks, markets, transport and supply chain issues. Notwithstanding these challenges, fruit and nut tree production has been growing rapidly in Australia and in 2015–16, gross value of production was $4.74 billion out of a total value of $11.3 billion for all horticulture in Australia (Horticulture Innovation Australia, 2017).

The perennial nature of tree crops makes a reliable year-round supply of water essential. Some species, such as mango and cashew, can survive well under mild water stress until flowering (generally August to October for most fruit trees). It is critical for optimum fruit and nut production that trees are not water stressed from flowering through to harvest, approximately from August to between November and February, depending on plant species. Very little rain falls in the Mitchell catchment between August and December, and farmers would need to have a system in place to access irrigation water during this time.

Specialised equipment for fruit and nut tree production is required. The requirement for a timely and significant labour force necessitates a system for attracting, managing and retaining sufficient staff. Tree pruning and packing equipment is highly specialised for the fruit industry. Optimum irrigation is usually via micro spray; this equipment is also able to deliver fertiliser directly to trees.

Intensive horticulture (fruit and vegetables)
Intensive horticulture is an important and widespread Australian industry, occurring in every state, particularly close to capital city markets. It is highly labour intensive and employs approximately
one-third of all people involved in agriculture, and has a farm gate value of approximately $4.84 billion (out of a total of $11.3 billion for all horticulture) (Horticulture Innovation Australia, 2017).

Production is highly seasonal and often involves multiple crops produced on one particular farm. The importance of freshness in many horticultural products means seasonality of supply is important in the market. The Mitchell catchment may have advantages in that it can supply southern markets when they are out of season. As with fruit trees, a good understanding of risks, markets, transport and supply chain issues is required. Intensive horticulture is already widely practised across similar environments in northern Australia, such as Asian vegetable production around Darwin and melon production around Katherine and in the Ord Valley.

Horticulture typically requires specialised equipment and a large labour force. Therefore, a system for attracting, managing and retaining sufficient staff is also required. Harvesting is often by hand, but packing equipment is highly specialised. Irrigation is with micro equipment, but overhead spray is also feasible. Leaf fungal diseases need to be carefully managed when using spray irrigation. Micro spray equipment has the advantage of being able to deliver fertiliser along with irrigation.

3.5.3 PLANTATION TREE CROPS

Of the potential tree crops that could be grown in the Mitchell catchment, African mahogany and Indian sandalwood are likely to be the most economically feasible. Many other plantation species could be grown but returns are much lower than for sandalwood or African mahogany. African mahogany is well-established in plantations near Katherine and Indian sandalwood is grown in the Ord Valley around Katherine and in north Queensland. The first commercial crops of Indian sandalwood grown in Australia are now being harvested and over the 16-year period of their cultivation to date many agronomic challenges have been solved.

The cracking clay soils found in parts of the Mitchell catchment are not well-suited to plantation tree crops due to increased potential for root shearing. However, it is possible to grow perennial crops on cracking clay soils with well-managed irrigation practices. By keeping the soil sufficiently wet, shrink–swell action and subsequent root damage can be minimised. Apart from some sensitivity to soil type, plantation species require greater soil depth than most other crop species.

Plantation tree crops require over 15 years to mature, but once established they can tolerate prolonged dry periods. Irrigation water is critical in the establishment and in the first two years of a plantation. In the case of Indian sandalwood, the provision of water is not just for the trees themselves but the leguminous host plant, which is a semi-parasite.

After harvest trees are prepared for milling or processing, which does not need to occur locally. For example, given its high value, sandalwood is transported from northern Australia to Albany, where the oil is extracted.

3.5.4 INDUSTRIAL CROPS

Industrial crops require post-harvest processing, usually straight after harvest, and usually in a proximate facility. Examples of industrial crops that are grown in the Australian tropics are cotton and sugarcane.
Cotton

Globally, Australia was the fourth largest exporter of cotton in 2015. With Australian cotton production, 97% is irrigated, with the great majority grown in inland areas of NSW and southern Queensland. The area of land devoted to cotton production varies widely from year to year, largely in response to availability of water. A mean of 320,000 ha of cotton is planted each year, varying from 60,000 to almost 600,000 ha over the last 20 years with a general trend of increased area of production. Gross value of production varies greatly, from $2.2 billion in 2016–17 to $2.95 billion in 2011–12 as a consequence of favourable La Niña crop growing conditions and abundant irrigation water in 2011–12 (ABARES, 2017). Mean production in 2015–16 was 10 bales/ha with lint production at 2250 kg lint/ha (ABARES, 2017). Cotton seed is a by-product of cotton processing and is a valuable cattle feed and cooking oil.

Cotton has a chequered history in northern Australia. Production constraints have insufficient scale of investment to support local processing facilities; the crop has shown vulnerability to insect pests (particularly in the mid-1970s in the Ord River region); and GM moratoria by the Western Australia and Northern Territory governments prevented commercial investment early this century (Yeates et al., 2013; Yeates, 2001). Although many of these issue have been resolved, some negative public perceptions remain.

Research and commercial test farming have demonstrated that the biophysical challenges are manageable if cotton growing is tailored to the climate and biotic conditions of northern Australia (Yeates et al., 2013). In recent years irrigated cotton crops achieving more than 10 bales/ha have been grown successfully in the Burdekin River irrigation area and in the Gilbert catchment of north Queensland. New genetically modified cotton varieties that are both pest and herbicide resistant are an important component of successful northern cotton production systems.

Specialised harvesting and baling equipment is required for cotton production. The nearest gin is at Emerald in central Queensland and a minimum viable area of irrigated cotton necessary to support a viable gin is approximately 10,000 ha.

Sugar

Sugar production is well-established along Queensland and northern New South Wales coastal regions. Opportunities to expand the production area to regions west of the Dividing Range exist (Department of Agriculture, Fisheries and Forestry, 2013). Sugarcane was successfully grown in the Ord River Irrigation Area until 2007, which demonstrates the potential for the Australian sugar industry to establish greenfield regions if suitable areas of soil and irrigation water become available in northern Australia. There are approximately 380,000 ha of cane grown annually; crop yields have been steadily increasing, averaging 91 t/ha of cane in 2015–16, and supplying 24 mills that produce approximately 4.9 Mt of sugar (ABARES, 2017). The gross annual value of production is approximately $1.53 billion (ABARES, 2017).

Sugarcane production requires access to specialised harvesting and transport equipment as well as transport to processing facilities. The nearest sugar mill is on the Atherton Tablelands and may be close enough for new sugar production areas in the east of the Mitchell catchment, but it would not be viable to transport cane from further west in the study area.

Sugarcane also requires specialised planting and row formation equipment; however, most farmers use contract harvesting, and many also use contract planters. Sugar production has the
additional benefit of generating renewable energy from cogeneration. The bagasse (biomass of crushed cane) is burnt to produce steam, which is converted into electricity and then utilised within the mill or by co-located industries such as a cotton gin or beef processing plant.

**Other crops**

Crops such as tea and coffee are unlikely to yield well in the Mitchell catchment due to climate constraints. Niche crops, such as guar and hemp, may be feasible but there are only limited verified agronomic and market data available for these crops. Pot trial studies have been undertaken (e.g. Keating and Fisher, 1985) and field research on guar has been conducted in the Northern Territory. Trials are also underway in north Queensland, which could prove future feasibility. While licenced experimental trials on hemp production have been undertaken in Queensland in recent years, hemp has not been considered in this report due to the high capital cost of fibre production and the current legal restrictions on its use in foods and medicinal products in Australia.

### 3.5.5 FORAGE CROPS

Forage, hay and silage are grown for consumption by animals. Forage is consumed in the paddock in which it is grown and is often referred to as ‘stand-and-graze’. Hay is cut, dried, baled and stored before being fed to animals, usually in yards for weaning or when animals are being held for sale. Silage use resembles that for hay, but crops are stored wet, in anaerobic conditions where fermentation occurs to preserve the feed’s nutritional value. Silage is often used as a production feed to grow animals for a specific market.

Dryland and irrigated production of fodder is well-established in Australia, with over 20,000 producers, most of whom are not specialist producers. Fodder is grown on approximately 30% of all commercial Australian farms each year, and 70% of fodder is consumed on the farms on which it was produced. The largest fodder consumers are the horse, dairy and beef feedlot industries. Fodder is also widely used in horticulture for mulches and for erosion control (RIRDC, 2013). There exists a significant fodder trade in support of the northern beef industry, although there is room for expansion as fodder costs comprise less than 5% of beef production costs (Gleeson et al., 2012).

The Mitchell catchment is well-suited for dryland or irrigated production of forage, hay and silage. Potential markets exist in the extensive cattle industry of northern Australia, which may comprise amongst the most promising opportunities for dryland and irrigated agriculture. There is potential for farmers primarily engaged in extensive cattle production to use irrigated forage, hay and silage to increase the value of beef turned off their enterprises.

Forage grasses, both annual and perennial, include sorghum (Sorghum spp.), Rhodes grass (Chloris gayana), maize (Zea mays) and Jarra grass (Digitaria milanjiana ‘Jarra’), with particular cultivars specific for forage. These grass forages require considerable amounts of water and nitrogen as they can be high yielding (20 to 40 tonnes dry matter/ha/year). Given their rapid growth, crude protein levels can drop quickly to less than 7%, reducing their value as a feed. To maintain high nutritive value (10 to 15% crude protein), high levels of nitrogen need to be applied and in the case of hay, the crop needs to be cut every 45 to 60 days.
Forage legumes are desirable because of their high protein content and their ability to fix atmospheric nitrogen in the soil. The nitrogen fixed during a forage legume phase is often in excess of requirements and remains in the soil as additional nitrogen available to subsequent crops. Annual production of legumes tends to be much lower than grasses (10 to 15 tonnes dry matter/ha/year) but their input costs are usually much lower due to reduced fertiliser requirements and, because they are shorter cycle crops, their total water use is often lower. Cavalcade (Centrosema pascuorum) and lablab (Lablab purpureus) are currently grown in parts of northern Australia and would be well-suited to the Mitchell catchment. The high protein content (>15% crude protein) makes them an attractive cattle feed.

Apart from irrigation infrastructure, machinery for planting is required for forage production. Fertilising and spraying equipment may be desirable but not necessary. Cutting crops for hay or silage requires more specialised harvesting, cutting, baling and storage equipment. Silage requires either bunkers or large tarpaulins for covering forage above ground to maintain anaerobic conditions. Grass crops usually make better silage than legume crops because they have higher levels of sugars to aid with fermentation. Forage crops such as maize can be grown until the head just reaches the ‘milk stage’ to provide high levels of digestible energy while the leaves and stems are still green and high in protein.

3.6 Crop and forage management

3.6.1 Irrigation

The irrigated crop and forage production data presented in this technical report are modelled estimates of potential production and assume unlimited water availability. Simulated crop water demand for the 20th, 50th and 80th percent exceedance values on two soil types (a Brown Sodosol with plant available water capacity of 163 mm and a Vertosol with a plant available water capacity of 204 mm) are presented in Table 5-5 and Table 5-6 (Section 5.1.1) with associated estimates of crop yields in Table 5-3 and Table 5-4 (Section 5.1.1). The simulations assume 100% efficiency of water supply in meeting the transpiration demand of the plant. Inefficiencies in delivering water to the crop depend on the source of supply (above or below ground), the irrigation delivery system (open channel or pipe) and the irrigation delivery method (flood, spray or micro irrigation). For Australia, delivery efficiency from the river to the farm gate has been estimated at 71% (Marsden Jacobs Associates, 2003). The largest losses are generally associated with evaporation and seepage loss from the water storage (e.g. farm dam) and the delivery system. The efficiencies of irrigation delivery systems are discussed in detail in Section 3.4 and need to be considered when evaluating crop water demand values in Table 5-5 and Table 5-6 (Section 5.1.1).

Unlimited water for irrigation may not always be available to farmers due to climate, ecological or economic considerations or other competing users. Crops sown during the wet season (November to April) may require little or no supplementary irrigation to achieve profitable production, while those sown during the drier winter months may require full irrigation during the growing period to meet crop transpiration demand. The water holding capacity of a soil and the amount of plant available water at time of sowing will also be factors in determining seasonal irrigation requirements and are discussed in more detail in Section 3.2. Opportunities for dryland cropping
to take advantage of favourable seasonal conditions exist in the Mitchell catchment and are discussed in Section 3.4.

To demonstrate the production response to different amounts of supplementary irrigation, simulated yields for a cotton and a chickpea crop for increments of 100 mm/ha of applied irrigation from dryland (rainfed only) to 400 mm/ha are presented in Figure 3-12. For a cotton crop sown on 15 January, in-season rainfall offsets irrigation demand during early development. However, in low-rainfall seasons production risk increases without access to supplementary irrigation as shown by the lower dryland cotton yield in Figure 3-12. While a chickpea crop sown in early May can achieve a crop yield of 0.94 t/ha on stored soil water, additional supplementary irrigation will be required to maximise production potential as demonstrated by the simulated chickpea yields in Figure 3-12.

![Figure 3-12 Probability of exceedance of yields for (a) a cotton crop (bales/ha) sown on 15 January and (b) a chickpea crop (t/ha) sown on 1 May for irrigation regimes between dryland (rainfed) and full irrigation (400 mm/ha)](image)

3.6.2 SOWING TIME

Time of sowing can have a significant effect on achieving economical crop and forage yields and on the availability and amount of water for irrigation required to meet potential crop growth. Sowing date selection must balance the need for the best growing environment (optimising solar radiation and temperature) with water availability, pest avoidance, trafficability during the season and at harvest, crop rotation, supply chain requirements and infrastructure development costs. Growers manage time of sowing to optimally use stored soil water and in-season rainfall and to avoid rain at maturity. Access to supplementary irrigation provides flexibility in sowing date and in the choice
and timing of crop or forage systems in response to seasonal climate conditions. Depending on the rooting depth of a particular species and the length of growing season, crops established at the end of the wet season may access a full profile of soil water (e.g. 204 mm plant available water capacity for a Vertosol) and require less supplementary irrigation than a crop grown over the wet and dry seasons such as in a double cropping system (e.g. cotton–mungbean) or a perennial cropping system (e.g. sugar, Rhodes grass pasture). It should be noted that double or perennial cropping systems are more likely to return the capital cost of the irrigation development. While timing of sowing to maximise available water can reduce the overall irrigation requirement, it may expose crops to periods of lower solar radiation and supra-optimal temperatures during plant development and flowering.

Cropping calendars identify optimum sowing times and compare the growing seasons of different crops. Prior to this technical report there were no cropping calendars for the Mitchell catchment. The sowing window, during which a crop can be reliably and profitably grown, is identified for each potential crop or forage in the cropping calendar in Figure 3-13. The calendar assumes best agronomic management in establishment, weed and insect control, as well as best nutrient management to minimise stress during crop and grain development. Crops are irrigated when a soil water deficit occurs, with 100% irrigation application efficiency in delivering water to the crop.

Sowing windows vary in both timing and length amongst crops, varieties and regions. While crops may be cultivated outside optimum windows, limited field experience currently exists in the Mitchell catchment for the majority of crops and forages evaluated. These cropping calendars are based on knowledge of these crops derived from past and current agricultural experience in the Ord River Irrigation Area (Western Australia), Katherine and Douglas Daly (Northern Territory) and the Burdekin region (Queensland), and have been combined with an understanding of plant physiology, which enables crop response to differences in local climates to be anticipated. The optimum planting window and growing season for each crop were further refined through local experience and use of the APSIM cropping systems model.
**Figure 3-13 Annual cropping calendar for agricultural options in the Mitchell catchment**

Sugarcane is a special case as one paddock is usually established between May and June and harvested over a six-month window 12 to 17 months later, which is dependent on the operational period of the local processing mill (Figure 3-14). Three ratoon crops of 12 months’ duration each are harvested before the paddock is fallowed or sown to a break crop such as mungbean, cotton,
soybean or maize. Cane yields of ratoon crops decline over time and therefore the duration of ratooning usually varies between three and four years. While long-term mean yields for a plant crop and three ratoons will be higher than a plant crop and four ratoons due to generally lower production in the fourth year, establishment and annual management costs may be reduced when spread over a five-year period. Sugarcane yields presented in Section 5.1.1 are based on a plant cane crop and three ratoon cane crops.

![Sugarcane crop calendar over 22 months showing growth stages in each of five paddocks](image)

**Figure 3-14 Sugarcane crop calendar over 22 months showing growth stages in each of five paddocks**

### 3.6.3 NUTRITION

Adequate crop nutrition is essential for achieving economic yields of crops. Tropical soils are highly weathered and are usually low in the water-soluble nutrients nitrogen (N), phosphorus (P), potassium (K) and sulfur (S) and require their addition as fertiliser. Soil organic carbon is also low. Hence nutrient management systems in the Mitchell catchment will require practices that can maximise organic carbon inputs via cover crops, stubble retention and mulch farming while minimising the loss of water soluble nutrients, particularly during the wet season. Synchronising nutrient availability with crop demand is key to achieving adequate and cost-effective crop nutrition. Managers can mitigate against nutritional risks by conducting thorough soil testing of paddocks. Because soil can be variable over relatively short distances, it may be necessary to sample soil for testing in a number of locations.

### 3.6.4 WEED MANAGEMENT

Weeds can be a major contributor to economic loss in agricultural production systems and may also provide a mechanism for disease transmission. Management of weeds, particularly in irrigated systems, is important for reducing competition of resources (particularly water and nitrogen) and for maximising water and nitrogen use efficiencies in production. The cropping systems modelled in this report assume best practice in managing weed and pest infestation.

### 3.7 Pastures and livestock

#### 3.7.1 BEEF PRODUCTION IN THE MITCHELL CATCHMENT

Beef production is the primary land use in the Mitchell catchment. Approximately 90% of the study area is under various forms of leasehold tenure, with most being pastoral leasehold. There are approximately 185,000 head of cattle in the study area, equating to $62 million in gross value (ABS, 2011). A future irrigation development in the Mitchell catchment could strengthen the northern Australia beef industry by complementing the production of beef cattle, predominantly from extensive dryland grazing, with locally grown irrigated forages.
The dominant beef production system that is employed across most of the Mitchell catchment is centred on cow-calf breeding operations with several variations in the post-weaning management and marketing of male animals produced by the breeding herds. The selection of operation type for any holding is largely determined through the interplay of land resource endowments, local climate and 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 low (1 animal per 10 to 20 ha). Pasture production occurs mostly in the December to April period, where plant growth rates can be very high. Almost no pasture production occurs over the remainder of the year.

The combination of pasture growth occurring over just a few months each year and low soil fertility results in low average forage quality. Forage quality is moderate during the growing season, reaching up to 12% crude protein in the diet (Bray et al., 2015) but falling to around 5% late in the dry season.

Animal production is low as a result of the low carrying capacity and the poor average quality of forage (Table 3-6). Weaning rates in the catchment are typically low (5 to -60%), as are estimated annual liveweight gains, which can range from 70 to 150 kg, with a mean of around 100 kg/animal/year (Rolfe et al., 2016).

Table 3-6 Characteristics of beef operations in the northern Gulf region of Queensland
Based on data drawn from Rolfe et al., 2016.

| Property size (ha) | MEAN | RANGE
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour per business (FTE)</td>
<td>3.1</td>
<td>1.5 to 7.8</td>
</tr>
<tr>
<td>Cattle adult equivalents (AE)</td>
<td>4332</td>
<td>290 to 14,309</td>
</tr>
<tr>
<td>Cattle sales per year (no)</td>
<td>1336</td>
<td>132 to 4190</td>
</tr>
<tr>
<td>Weaning rate (%)</td>
<td>56</td>
<td>42 to 70</td>
</tr>
<tr>
<td>Annual liveweight gain (kg/animal)</td>
<td>101</td>
<td>70 to 150</td>
</tr>
<tr>
<td>Mean gross margin per AE ($)</td>
<td>116</td>
<td>20 to 207</td>
</tr>
</tbody>
</table>

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 weaners (120 to 160 kg) or yearling animals (250 to 350 kg) that are sold to operations in more fertile areas further south in Queensland. Yearling animals are also exported live to Asian markets. In more fertile landscapes and more settled areas further east in the study area, animals can be grown out to a liveweight of around 450 kg by 30 months of age, although this is more the exception than the rule.

To cope with low productivity per animal, holdings are reasonably large, ranging from around 10,000 ha in the more settled areas in the east of the study area to over 500,000 ha in the west of the study area. However, scale does not necessarily equate to profitability (Rolfe et al., 2016) and
until the recent increase in cattle prices many properties in the catchment had been unprofitable over the previous decade (McLean et al., 2014).

Given the intra- and inter-annual variability in rainfall and thus in pasture availability and the generally low quality of the forage, one of the biggest challenges for cattle producers is to achieve an appropriate balance between cattle numbers and forage supply. Strategies to achieve this balance have received considerable attention (e.g. O’Reagain et al., 2014) but in practice it is difficult to achieve for many producers. Consequently, over-utilisation of the native pasture resource base has been a recurring issue, with land degradation prevalent throughout the study area. A land condition assessment carried out over a decade ago (Shaw et al., 2007) recorded a decline in land condition on the majority of land types, and the problem does not appear to be improving (Gobius, 2013).

One option for overcoming some of the productivity constraints is to utilise improved forages to complement the base forage provided by semi-intact native woodlands and grasslands. Improved forages can be dryland or irrigated. Given the severe protein deficiency in native pastures during the dry season (May to November), considerable attention has in the past focused on legumes that augment native pasture (Miller and Stockwell, 1991). This strategy involves oversowing legumes (such as *Stylosanthes*, or stylo) into a native pasture without mechanical intervention, although fire may be used prior to sowing to reduce competition from established native pasture species. Indeed, research undertaken by CSIRO over many years on Wrotham Park Station, in the central part of the Mitchell catchment, tested the establishment, persistence and productivity of *Stylosanthes* legumes (Arnold, 1997). Stylo established well and was scaled out across larger areas of Wrotham Park. Productivity gains of animals grazing native grasses augmented with stylo under natural rainfall conditions are modest at around 20 to 30 kg/animal per year (Coates et al., 1997). While costs of sowing a stylo pasture are low compared with full cultivation and planting, reliability of establishment has resulted in only modest levels of adoption (Peck et al., 2011).

Use of higher input, higher productivity irrigated pastures to improve beef outputs and turn-off has received more attention in recent years. On the back of improving cattle markets over the last two years, the general interest in more intensive irrigated developments has increased. However, there is currently little use of irrigated forage in the Mitchell catchment. Published production data on forages in tropical Australia are mostly from the 1970s to the 1990s, as a consequence of research efforts on improved pastures and forages for the tropics being greatly reduced in the 1990s in favour of efforts on sustainably managing the natural pastures of tropical rangelands.

Irrigated forage options include:

- **Perennial grasses (e.g. Rhodes grass)**
  Perennial grasses are used across northern Australia, with Rhodes grass (*Chloris gayana*) most widely grown, especially in the Pilbara and West Kimberley regions of Western Australia and also in north Queensland and the Douglas Daly region in the Northern Territory. However, the total area of perennial grasses under irrigation is quite small (<2000 ha).
  There are very little production data available on irrigated perennial grasses in tropical Australia. Work conducted for the WA Department of Water (Giovi Ltd, unpublished report) found dry matter production of irrigated Rhodes grass near Derby was in the order of 35 t/ha. Liveweight gain of steers ranged from 0.4 to 0.8 kg/head/day (annual liveweight gains of 146 to 292 kg/head). Fertiliser application rates were high in that study with nitrogen applied at around 400
kg N/ha. Jones (1990) examined the influence of nitrogen application and stocking rate on performance of steers grazing irrigated Pangola (*Digitaria decumbens*), another perennial grass, at Kununurra. At N application rates of 350 kg/ha and stocking rates of 5 to 6 steers/ha, annual liveweight gains of around 250 kg/head were simulated based on grazing studies. With dry matter production levels above 30 t/ha, stocking rates of up to 10 animals/ha may be possible during periods of peak growth.

One of the challenges in irrigated tropical grass systems is to maintain forage quality when dry matter production levels are very high. It is easy for nitrogen to become diluted and forage quality to fall. This is exacerbated if either cutting or grazing regimes are not frequent enough to maintain the pasture in a leafy stage with high levels of metabolisable energy. A cutting frequency of less than 50 days is required to maintain crude protein concentrations above 12% (O’Gara, 2010; Tessema et al., 2010).

- **Annual grasses (e.g. forage sorghum, maize)**
  Annual forage grasses such as forage sorghum (*Sorghum* spp. hybrids) have been widely grown across northern Australia and are recommended by state and territory agencies as suitable forages for the tropics. Production levels of hay are up to 20 to 25 t/ha when well-fertilised and irrigated (O’Gara, 2010). Although forage sorghum is widely used it has mostly been for hay production and there are very little data available on animal production under grazing. Early work at Kununurra (Western Australia) indicated liveweight gains of up to 0.4 kg/day could be obtained when grazed at 5 to 6 steers/ha and with a nitrogen application of 350 kg N/ha (Blunt and Fisher, 1973).

- **Annual legumes (e.g. lablab, cowpea)**
  Given the very low protein content of native tropical grasses over the dry season, legumes offer a means of increasing the protein content of diets of cattle in northern Australia. Cowpea (*Vigna unguiculata*) and lablab (*Lablab purpureus*) are both well-suited to the tropics (Milford and Minson, 1968). Production of irrigated lablab can be 10 to 14 t/ha and cowpea 5 to 8 t/ha (Muldoon, 1985), which is considerably less than the production of tropical grasses. However, protein levels are high with 20 to 25% crude protein in leaves and around 10% protein in stem material (Muldoon, 1985).

Irrigated forages can be used for grazing, hay or silage. In recent years the greatest use of irrigated forages in tropical Australia has been for hay production rather than for grazing. This is because the areas of irrigated forage have been quite small and hay has been produced for special purpose feeding in yards for short periods (e.g. weaning, holding cattle for live export) with any excess sold locally. Irrigation has generally not been on a sufficiently large scale for the forage produced to be used for grazing of whole cohorts of animals in a large pastoral enterprise. The scale required for this type of enterprise option would range from hundreds to thousands of hectares, depending on the size of the pastoral operation. In this Assessment, these larger scale grazing options have been explored, as have smaller scale hay or silage operations.

### 3.8 Off-site impacts

Agriculture can affect the water quality of downstream freshwater, estuarine and marine ecosystems. Principal pollutants from agriculture are nitrogen, phosphorus, total suspended solids, herbicides and pesticides (Lewis et al., 2009; Kroon et al., 2016; Davis et al., 2017). Losses
via runoff or deep drainage are the main pathways by which agricultural pollutants enter water bodies. The climate, location (e.g. soils and topography), land use (e.g. cropping system) and management (e.g. conservation and irrigation practices) influence the type and quantity of pollutants lost from an agricultural system.

The development of agriculture in northern Australia has been associated with declining water quality (Lewis et al., 2009; Mitchell et al., 2009; De’ath et al., 2012; Waterhouse et al., 2012; Thorburn et al., 2013; Kroon et al., 2016). Since the 1850s it has been estimated that pollutant loads in north-eastern Australian rivers (typically those in which agriculture as a land use dominates) have increased considerably for nitrogen (2 to 9 times baseline levels), phosphorus (3 to 9 times), suspended sediment (3 to 6 times), and pesticides (~17,000 kg) (Kroon et al., 2016).

Degraded water quality can cause a loss of aquatic habitat, biodiversity, productivity, and ecosystem services. Increased nitrogen and phosphorus can cause planktonic blooms and weed infestation, increased hypoxia, and result in fish deaths. Suspended sediment can smother habitat and aquatic organisms, reduce light penetration, and reduce dissolved oxygen levels. Pesticides may be toxic to habitats and aquatic organisms (Pearson and Stork, 2009; Brodie et al., 2013; Davis et al., 2017).

Northern Australian river systems are distinctive as they may have highly variable flow regimes, unique species composition, low human population densities and, in some cases, naturally high turbidity (Brodie and Mitchell, 2005). Primary influences on water quality include increased sediment loads associated with land clearing, grazing, agriculture and late dry-season fires, and nutrient pollution from agricultural and pastoral land use (Dixon et al., 2011).

Water quality monitoring has been undertaken in specific areas of the Mitchell catchment. There is evidence that agricultural development within the Mitchell catchment has resulted in reduced quality of the water discharged from the MDWSS: nutrient concentrations have been recorded to be two to ten times higher than the acceptable level in Cattle Creek and Two Mile creek, with ammonia concentrations high enough to be acutely toxic to aquatic animals (Butler et al., 2008). Furthermore, there has been a rapid increase in gully erosion in the last 50 years, resulting in increased suspended sediment loads in aquatic systems (Shellberg et al., 2016).

3.9 Pests and diseases

Identifying potential pest and disease problems that can occur in greenfield agricultural areas can be problematic. The warmer, north Australian environment is more favourable for insects and pathogens to adapt and multiply with the introduction of a new food source (i.e. a crop). However, the environment also favours beneficial organisms that prey on pest species. Production systems that recognise the ecological realities of the natural environment are recommended; the collapse of the cotton industry in the Ord in Western Australia during the 1970s is one example of failure to do this (Chapman et al., 1996). Irrigating a number of crops each year in rotation can provide a year-round food source for pests and carry-over of pathogens between crops.

There have been serious outbreaks of diseases in crops in recent years across northern Australia, including green cucumber mottle mosaic virus on melons in the Katherine region in the Northern Territory; the fungal rice blast affecting rice production in the Ord; Panama disease tropical race 4
Pests are not limited to just insects, with macro-pests such as birds (cockatoo, galah, brolga), macropods (kangaroos and wallabies) and feral pigs a risk to irrigated crops, particularly during the drier winter months when indigenous food sources may be scarce. Locally developed and adaptable integrated pest and pesticide resistance management plans are an essential component of best practice and must be implemented pre-emptively.

Pigs are a major problem in Queensland, and some 75% of their estimated population of four to six million is found in tropical north Queensland. Pigs can cause indirect damage, for example by carrying weed seed such as parthenium (*Parthenium hysterophorus*) from watercourses to open country. They may also cause direct and major physical damage to a wide range of crops and cultivated ground. Pigs have a daily water requirement, which means that during the dry season their range is generally restricted to watercourses and man-made water supplies (McGaw and Mitchell, 1998); precisely the areas where conditions are most favourable for crops. Pig control is expensive (over $25/pig) and is rarely more than 75% effective (Mitchell and Kanowski, 2003). Selection of crops not attractive to pigs (e.g. cotton) is desirable where their numbers are high.

In terms of new pests or diseases from outside Australia, two papers (Early et al., 2016; Chapman et al., 2017) show that the most likely human-facilitated pathways to import invasive species are general trade, and live plant or animal trade. While it is not currently possible to determine the risk to the Mitchell catchment from these forms of human-facilitated trade, it is possible to look at the historical rate of invasions (also referred to as incursions) in Australia.

Caley et al. (2015) examined the incursion rate in Australia for four orders of insects (Coleoptera: beetles, Hemiptera: true bugs, Lepidoptera: moths and butterflies, and Diptera: flies). While there is considerable uncertainty around the actual date in which an incursion occurred, the authors note that approximately 1555 species incursions occurred between 1900 and 2005, which is approximately 15 species/year. The rate of incursions has no doubt varied with time and is likely to be focused in agricultural regions of Australia. The rate of incursion for the Mitchell catchment is unlikely to be as high as 15 species/year given its relative size in comparison to the Australian mainland. However, it is reasonable to assume that growers in northern Australia will be affected by future pest and disease incursions.

Threats to agriculture in the Mitchell catchment are not just from new arrivals from overseas but also from human-mediated dispersal from other areas within Australia. There are many different human-mediated vectors within Australia that have been shown to spread invasive species. These include tourists, livestock, vehicles, machinery, trains and transport containers.

For example, tourists have been shown to have facilitated the introduction of invasive weed species into Kosciusko National Park (Mallen-Cooper, 1990; Bear et al., 2006). The movement of cattle has been shown to spread the prickly acacia weed (ARMCA, 2000). *Parthenium* weed is spread by the movement of vehicles, machinery, livestock and stock feed (PWNSP, 2009). There have even been examples of foxes transported to Tasmania in transport containers (Saunders et al., 2006).
4 Development costs

4.1 Development options examined

A key activity in this technical report has been to quantify the development costs of irrigated agriculture at a farm scale (described in Section 2.2) to help guide the biophysical and economic analysis of a range of crop, forage and beef options.

Cost estimates vary enormously depending on assumptions made. For example, one Northern Territory-based source of information used to derive development costs used prices quoted by local contractors and suppliers and expenses quoted from landholders engaged in on-farm irrigation developments. These financial data did not include contingencies and are more relevant to small-scale operations. In contrast, another source of information produced for the Western Australian Government by an engineering consultancy firm determined costs for a 5000 ha development, assuming fully engineered earthworks and water delivery infrastructure and using large-scale contractors. Professional fees (engineering and irrigation consultants) of 10% and contingency costs of 30% were used, which elevated costs by 40% compared with the bottom-up, small-scale approach. Two instances of where cost estimates varied significantly with enterprise scale were in road costs and laser levelling. Road costs for internal on-farm roads were estimated to be $50,000/km in the Western Australia results and $10,000/km in the Northern Territory. The differences in laser levelling costs were $5000/ha (Western Australia) and $1200/ha (Northern Territory). In this technical report, scenarios were created to compare (i) lower cost, owner-operator developments relying on local contractors but do not include owner-related labour costs and (ii) fully contracted developments using engineering companies who also use a range of subcontractors. To keep scenarios relatively consistent a contingency cost of 10% was used across all scenarios.

There were three additional areas of significant variation in the estimates of costs. One was the costs of approvals, undertaking environmental assessments, native title settlements, etc. These costs vary enormously across jurisdictions and the nature of individual developments. Additional work on approvals, legal and regulatory constraints can be found in a companion technical report on legal, regulatory and policy (LRP) (Macintosh et al., 2018).

The second area of variation relates to the earthworks involved in on-farm storages. Earthworks are the major cost component for irrigation involving on-farm dams or ringtanks and the cost of these varies greatly depending on the landscapes and topography involved. For example, the establishment of a well-sited gully dam requires relatively little earth to be shifted whereas on a flat landscape up to three times more earth may be required to be shifted per ML of water storage constructed.

The third significant variable involves groundwater irrigation development, including the depth to groundwater and ease of locating successful high delivery bores. For example, it may require drilling two or three deep boreholes to deliver one successful bore in a location while reliable water may be accessed at shallow depth in another region at much lower cost.
To accommodate the different assumptions and sources of variation in development cost estimates a range of scenarios were developed that vary from low-cost, on-farm developments carried out by owner/operators with some sub-contracting to highly engineered development operations carried out by commercial engineering companies.

The scenarios examined were (i) on-farm irrigation developments relying on stream diversions that gravity feed on-farm storages, (ii) flood-flow pumping from rivers or streams during the wet season into on-farm storages and (iii) groundwater irrigation. Irrigation methods include furrow irrigation, pivots and tape.

The development areas were at two scales: 500 and 5000 ha. These were assumed to be either a greenfield development or an existing farm. Greenfield developments include additional costs of housing and accommodation for workers, sheds and storage areas, and access roads to the farm.

All scenarios included costs for the basic farm equipment (tractors, ploughs, planters, slashers, etc.) needed for agricultural operations. They did not include specialised equipment (such as peanut diggers or cotton harvesters) for specific crops in broadacre agriculture. The large-scale (5000 ha) operations did include the costs of hay balers, tractors and loaders on the assumption that hay making will be at least a part of all large-scale operations. Horticultural scenarios included the costs of cold stores and packing sheds as well as specialised farm machinery, which made overall capital costs quite high.

For smaller scale (500 ha) developments, approval processes and costs were assumed to be relatively straightforward, whereas for large-scale developments, complex processes and higher approval costs have been used as it is likely that they will cross a threshold of potential environmental impact requiring more stringent assessment and approvals processes.

4.2 Land development and irrigation costs

The development options examined in this technical report are summarised in Table 4-1 along with costs per ha, which have been derived from the costing spreadsheet.

Costs per ha for development ranged from $10,000/ha for owner managed, small-scale, offstream water storages that are gravity fed and furrow irrigated to over $40,000/ha for greenfield horticultural development that included costs of land, deeper groundwater with 75% drilling success, housing, packing sheds, cold storage, farm equipment, fertigation and tape irrigation.

While the capital costs of scenarios based on on-farm water storages from stream diversions can be around $10,000/ha, this cost is very sensitive to the earthworks component of development activities. Moving from efficient gully dam sites to flatter landscapes that require significantly more excavation can result in nearly a doubling in capital costs. If such developments are undertaken using commercial engineering companies then the costs increase to around $24,000/ha. The scenario involving flood-flow pumping across a floodplain to ringtank storage results in total capital costs of approximately $20,000/ha because of the earthworks required for ringtanks and the high capacity pumps and piping that are required to shift large volumes of water within a short period of time.

Where groundwater is shallow and high flow rate bores are easy to locate pivot irrigation, reliant on groundwater and fertigation-enabled, can be developed for around $13,000/ha. If the
groundwater is deeper and requires multiple drill-holes to locate successful bores then development costs increase to over $20,000/ha.

Table 4-1 Characteristics of a range of development opportunities at 500 and 5000 ha scales

<table>
<thead>
<tr>
<th>SCALE (HA)</th>
<th>STORAGE (ML) TOTAL (EFFECTIVE)</th>
<th>GREENFIELD OR EXISTING FARM</th>
<th>IRRIGATION TYPE</th>
<th>EFFICIENCY OF SITING</th>
<th>COSTING BASIS</th>
<th>COSTS (AUD $/HA)</th>
<th>COSTS (AUD $/ML APPLIED)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>6000 (3500)</td>
<td>Greenfield</td>
<td>On-farm stream diversion, gravity fed, furrow</td>
<td>High</td>
<td>Owner + local contractors</td>
<td>14,838</td>
<td>2120</td>
</tr>
<tr>
<td>500</td>
<td>6000 (3500)</td>
<td>Existing</td>
<td>On-farm stream diversion, gravity fed, furrow</td>
<td>High</td>
<td>Owner + local contractors</td>
<td>10,054</td>
<td>1436</td>
</tr>
<tr>
<td>500</td>
<td>6000 (3500)</td>
<td>Existing</td>
<td>On-farm stream diversion, gravity fed, furrow</td>
<td>Moderate</td>
<td>Owner + local contractors</td>
<td>15,334</td>
<td>2191</td>
</tr>
<tr>
<td>500</td>
<td>6000 (3500)</td>
<td>Existing</td>
<td>On-farm stream diversion, pivots for forage</td>
<td>Moderate</td>
<td>Owner + local contractors</td>
<td>21,579</td>
<td>3083</td>
</tr>
<tr>
<td>5,000</td>
<td>60,000 (35,000)</td>
<td>Existing</td>
<td>On-farm stream diversion, largely gravity fed, furrow</td>
<td>High</td>
<td>Owner + local contractors</td>
<td>12,485</td>
<td>1784</td>
</tr>
<tr>
<td>5,000</td>
<td>60,000 (35,000)</td>
<td>Existing</td>
<td>On-farm stream diversion, largely gravity fed, furrow</td>
<td>Low to moderate</td>
<td>Development fully contracted</td>
<td>24,414</td>
<td>3488</td>
</tr>
<tr>
<td>500</td>
<td>6000 (4200)</td>
<td>Existing</td>
<td>Flood-flow pumping 2 km to a ringtank storage</td>
<td>Moderate</td>
<td>Owner + local contractors</td>
<td>18,172</td>
<td>2162</td>
</tr>
<tr>
<td>500</td>
<td>N/A</td>
<td>Existing</td>
<td>Groundwater, pivots and fertigation</td>
<td>High (shallow bores)</td>
<td>Owner + local contractors</td>
<td>12,233</td>
<td>1529</td>
</tr>
<tr>
<td>500</td>
<td>N/A</td>
<td>Greenfield</td>
<td>Groundwater, pivots and fertigation</td>
<td>Moderate depth bores and drilling success rate</td>
<td>Owner + local contractors</td>
<td>20,662</td>
<td>2583</td>
</tr>
<tr>
<td>500</td>
<td>N/A</td>
<td>Greenfield, includes cold stores, packing shed</td>
<td>Groundwater, tape</td>
<td>Moderate depth bores and drilling success rate</td>
<td>Owner + local contractors</td>
<td>40,951</td>
<td>8190</td>
</tr>
</tbody>
</table>
Greenfield developments added between $5000 and $8000/ha to development costs depending on the infrastructure required. For broadacre cropping the additional costs were mainly in new access roads, connection to electricity grids, construction of sheds, and worker accommodation. For horticultural greenfield developments there were also costs associated with packing sheds, cool rooms, etc., and production related costs were pushed higher by the need for specialised equipment such as tape irrigation systems.

This assessment of capital costs aimed to provide a range of values to cover different development options. It is not intended to be exhaustive as capital costs will vary greatly according to specific site circumstances. The range of costs used here was designed to inform what might be required from different cropping and/or forage systems to generate sufficient returns to meet required (previously defined) financial criteria.

### 4.3 Overhead costs

In addition to capital costs, overhead costs need to be considered. The overhead costs for this Assessment were based on those developed by Brennan McKellar et al. (2013) for the Flinders and Gilbert catchments in north Queensland for an indicative 500 ha broadacre farm. Those values have been revised and adjusted for inflation to 2017 prices (Table 4-2).

#### Table 4-2 Assumed overhead costs for a 500 ha broadacre farm

<table>
<thead>
<tr>
<th>OVERHEAD ITEM</th>
<th>ASSUMED ANNUAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>$210,000 per 500 ha farm</td>
</tr>
<tr>
<td>Repair and maintenance</td>
<td>$105/ha + 1% of equipment and structures capital</td>
</tr>
<tr>
<td>Other (including $50/ha land lease)</td>
<td>$37,500 per 500 ha farm</td>
</tr>
</tbody>
</table>

Labour is the largest overhead cost and has been estimated at annual wages of $205,000 for one manager, one permanent staff member and two casuals to run a 500 ha farm. Fixed costs for repairs and maintenance were assumed to be $105/ha/year plus 1% of the capital cost of farm equipment and structures. Other expenses included insurance, professional services, registrations and a lease fee of $50/ha/year to account for the value of land prior to irrigated development, assuming low-intensity prior use. In total these overheads come to $600/ha/year plus 1% of the capital value of farm equipment and structures.

### 4.4 Indicative net returns required on capital investment

Table 4-3 provides equivalent annual costs (EAC) for infrastructure with lifespans of 15 and 40 years (typical of on-farm equipment, structures and developments) for a range of discount rates, assuming annual maintenance costs of 1% of the initial capital cost (as per the overhead costs described above). The bottom of this table provides EACs for developments with an equal mix of 15-year and 40-year assets as an illustration of the annual returns a farm would have to generate to meet the capital costs of irrigation development. On this basis, annual net returns of about $500/ha to $4100/ha are required to cover capital costs of development ranging from $5000/ha to $40,000/ha at a 7% discount rate. Capital costs of development for broadacre agriculture in Table 4-1 mostly fell between $10,000/ha and $20,000/ha, indicating that net returns of between $1000/ha and $2000/ha would be required to meet the EAC of development. Assuming additional
4-1 mostly fell between $10,000/ha and $20,000/ha, indicating that net returns of between $1000/ha and $2000/ha would be required to meet the EAC of development. Assuming additional overhead costs of $600/ha this would require gross margins of between $1600 and $2600/ha for a new farm to break even. Note that EAC costs of development and break-even farm gross margins calculated in this way are directly equivalent to how these values are treated in the more comprehensive discounted cash flow framework in the companion technical report on socio-economics (Stokes et al., 2017) for simple cases where costs and farm performance are constant over time, and the evaluation period matches the lifespan of assets. (The financial analyses in Stokes et al. (2017) are conducted at the scale of a full irrigation scheme and include assessments of variable farm performance, staged development, and integrating a processor into a scheme development.)

Table 4-3 Annual net returns required for a new farm to meet EACs of development for a range of capital costs of irrigation development, discount rates and asset lifespans

<table>
<thead>
<tr>
<th>DISCOUNT RATE</th>
<th>EQUIVALENT ANNUAL COST OF DEVELOPMENT ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capital costs of development costs ($/ha)</td>
</tr>
<tr>
<td></td>
<td>$5000</td>
</tr>
<tr>
<td>15-year lifespan assets</td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td>$469</td>
</tr>
<tr>
<td>7%</td>
<td>$599</td>
</tr>
<tr>
<td>10%</td>
<td>$707</td>
</tr>
<tr>
<td>40-year lifespan assets</td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td>$266</td>
</tr>
<tr>
<td>7%</td>
<td>$425</td>
</tr>
<tr>
<td>10%</td>
<td>$561</td>
</tr>
<tr>
<td>Indicative developments with equal split of 15-year and 40-year assets</td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td>$368</td>
</tr>
<tr>
<td>7%</td>
<td>$512</td>
</tr>
<tr>
<td>10%</td>
<td>$634</td>
</tr>
</tbody>
</table>
5 Results

5.1 Crop–forage–livestock systems

5.1.1 CROP PRODUCTION

Broadacre crops
The APSIM model was configured for best management practice, assuming pests and diseases are well-controlled. Simulation results can be considered as potential maximum yields for current climates and soil types for both irrigated and rainfed (dryland) conditions.

There is limited local knowledge of optimal varieties for the majority of simulated crops in the Mitchell catchment, particularly for recent developments in higher yielding hybrid varieties. Crop models were parameterised using existing knowledge, with some calibration using information on commercial production in northern Australia, where available. For fully irrigated crops a fixed sowing date was specified for each crop based on the cropping calendars discussed in Section 3.6.2 and simulations were run using 125 years of climate data.

Dryland cropping
To evaluate the potential for dryland cropping a number of potential crops suitable for establishing under rainfed conditions (sorghum, cotton, mungbean, maize, peanut and rice) were configured and run in the APSIM. As dryland farming depends on stored soil water and in-crop rainfall, the timing of crop establishment to maximise both production and economic yield is critical.

The annual cropping calendar in Figure 3-13 shows that, for many crops, the sowing window includes the month of January. For relatively short-season crops such as sorghum and mungbean, this coincides with both the sowing time that provides close to maximum crop yield and the time at which the season’s water supply can be most reliably assessed with a high degree of confidence. On average, significant rainfall is expected in January and February (approximately 255 mm (±148 mm) and 187 mm (±128 mm)), respectively, with the mean calculated spatially across the study area), and the likely rainfall in a given year can be assessed using seasonal rainfall outlooks, which have moderate levels of skill in the Mitchell catchment at this time of year.

Historical analysis of forecast accuracy for the Mitchell catchment suggests that rainfall received is consistent with BoM rainfall predictions approximately 60 to 65% of the time (BoM: http://www.bom.gov.au/climate/ahead/verif/).

Table 5-1 shows how soil water content at sowing and subsequent rainfall in the 90 days after each sowing date varies over three different sowing dates. As sowing is delayed from January to March, the amount of stored soil water remains reasonably constant. However, there is a significant decrease in rainfall in the subsequent three months after sowing. Combining the median soil water content at sowing and the median rainfall received in the 90 days following sowing provides totals of 499, 302, and 167 mm for the January, February and March sowing dates, respectively. In ‘wetter than average years’ (20th percentile exceedance) the amount of soil...
water at the end of January combined with the rainfall in the following 90 days (over 670 mm) is sufficient to grow a good short-season crop. For ‘drier than average years’ (80th percentile exceedance), the soil water stored at sowing and the expected rainfall in the ensuing 90 days will result in water stress and comparatively reduced crop yields. Figure 5-1 highlights some of the problems that are likely to be encountered sowing a dryland crop at the end of March where the majority of crop water will come from stored soil water.

Without the certainty provided by irrigation, dryland cropping is opportunistic in nature, relying on favourable conditions in which to establish, grow and harvest a crop. To capture dryland management APSIM was configured for opportunistic sowing (in contrast to a fixed sowing date for irrigated crops) for the crop establishment periods shown in Table 5-1. Sowing was triggered when plant available soil water was 60 mm or more and 20 to 25 mm rainfall had been received within three consecutive days. If these criteria were not met no crop was sown.

### Table 5-1 Soil water content at sowing and rainfall for the 90-day period following sowing for three sowing dates on a Brown Sodosol at Chillagoe

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

<table>
<thead>
<tr>
<th>SOWING DATE</th>
<th>SOIL WATER CONTENT AT SOWING DATE (mm)</th>
<th>RAINFALL IN 90 DAYS FOLLOWING SOWING DATE (mm)</th>
<th>STORED SOIL WATER + RAINFALL IN SUBSEQUENT 90 DAYS (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20th</td>
<td>50th</td>
<td>80th</td>
</tr>
<tr>
<td>31 January</td>
<td>152</td>
<td>145</td>
<td>101</td>
</tr>
<tr>
<td>28 February</td>
<td>146</td>
<td>140</td>
<td>102</td>
</tr>
<tr>
<td>31 March</td>
<td>141</td>
<td>136</td>
<td>98</td>
</tr>
</tbody>
</table>

Figure 5-1 Probability of exceedance graph highlights the difference between rainfall and water lost from the system by evaporation, runoff and drainage on monthly intervals for Dunbar Station

When planted at an appropriate time, quite good yields were simulated for rainfed maize, cotton, sorghum, mungbean and peanuts, especially in the best 20% of years. Given the relatively high rainfall in the wet season in the Mitchell catchment, there is an opportunity for profitable rainfed crops to be grown, notwithstanding some of the operational challenges associated with wet-season access. This is highlighted in Table 5-2, which shows the gross margins for a range of crops that have some prospect of being viable without irrigation. Sorghum, cotton, maize, mungbean
and peanuts were all simulated to produce crop yields capable of generating positive gross margins on both the Sodosol and heavier clay Vertosols. Rice mostly produced negative gross margins.

These gross margins were based on being able to sow when there is most soil water and the highest chance of follow-up rain, which is January. This may not be possible in many years based on the analysis in Figure 5-1. For example, if sowing of maize on a Sodosol is delayed from January until mid-March, crop yields drop from 6.9 t/ha to 3.0 t/ha and gross margins decline from $597/ha to -$347/ha.

Table 5-2 Gross margin analysis for dryland crops in the Mitchell catchment, the mean across four locations for two soil types
These are modelled results from the (APSIM) crop model. The 20th percentile, 50th percentile (median) and 80th percentile exceedance values are reported, for the 125 years between 1890 and 2015. Gross margins for the 20th, 50th and 80th percentile were calculated using the variable costs shown, and the 20th, 50th and 80th percentile yields, respectively. Gross margins for industrial crops (cotton, sugarcane) assume delivery to a (currently non-existent) processing plant.

<table>
<thead>
<tr>
<th>CROP</th>
<th>SOWING DATE</th>
<th>CROP YIELD (t/ha)</th>
<th>PRICE ($/unit)</th>
<th>VARIABLE COST ($/ha)</th>
<th>GROSS MARGIN ($/ha)</th>
<th>BREAK-EVEN CROP YIELD (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20th</td>
<td>50th</td>
<td>80th</td>
<td>50th</td>
<td>20th</td>
<td>50th</td>
</tr>
<tr>
<td>Sodosol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>15 Jan – 20 Mar</td>
<td>7.5</td>
<td>5.8</td>
<td>2.9</td>
<td>$240/t</td>
<td>$892</td>
</tr>
<tr>
<td>Cotton</td>
<td>1 Jan – 28 Feb</td>
<td>4.2</td>
<td>2.8</td>
<td>1.7</td>
<td>$480/bale</td>
<td>$1020</td>
</tr>
<tr>
<td>Mungbean</td>
<td>1 Jan – 15 Feb</td>
<td>2.0</td>
<td>1.8</td>
<td>1.5</td>
<td>$1100/t</td>
<td>$753</td>
</tr>
<tr>
<td>Maize</td>
<td>1 Jan – 15 Feb</td>
<td>8.3</td>
<td>6.9</td>
<td>4.5</td>
<td>$280/t</td>
<td>$1316</td>
</tr>
<tr>
<td>Peanut</td>
<td>1 Jan – 15 Feb</td>
<td>4.5</td>
<td>3.4</td>
<td>2.2</td>
<td>$1000/t</td>
<td>$1854</td>
</tr>
<tr>
<td>Vertosol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>15 Jan – 20 Mar</td>
<td>8.5</td>
<td>7.7</td>
<td>5.0</td>
<td>$240/t</td>
<td>$968</td>
</tr>
<tr>
<td>Cotton</td>
<td>1 Jan – 28 Feb</td>
<td>5.4</td>
<td>4.3</td>
<td>3.2</td>
<td>$480/bale</td>
<td>$1348</td>
</tr>
<tr>
<td>Mungbean</td>
<td>1 Jan – 15 Feb</td>
<td>1.5</td>
<td>1.3</td>
<td>1.1</td>
<td>$1100/t</td>
<td>$713</td>
</tr>
<tr>
<td>Maize</td>
<td>1 Jan – 15 Feb</td>
<td>8.9</td>
<td>7.9</td>
<td>6.3</td>
<td>$280/t</td>
<td>$1368</td>
</tr>
<tr>
<td>Rice</td>
<td>1 Dec – 30 Jan</td>
<td>4.2</td>
<td>2.9</td>
<td>1.4</td>
<td>$400/t</td>
<td>$1259</td>
</tr>
</tbody>
</table>

While good rainfall and stored soil water enable dryland cropping the risks associated with timely opportunities to sow a crop during the wet season (January to March) need considering. For example, analysis of the long-term climate for Chillagoe indicates the mean number of rain days experienced in January are in the order of 17 (±8) days, February 18 (±6) days, March 14 (±6) days and April 7 (±5) days. In some years the number of wet days and associated reduction in trafficability will reduce the number of contiguous sowing days and the area able to be sown. While trafficability following a rainfall event is dependent on rainfall amount, soil type and clay content, management options such as laser levelling, controlled traffic and no-till planters help to facilitate early trafficability on a paddock after rain. Delaying time of sowing increases soil water
but reduces the amount of rainfall likely to be received to finish a crop. For a simulated dryland maize crop sown on a Brown Sodosol at Chillagoe, the probability of exceeding crop yields 6.8 t/ha in 50% of years for a 1 January sowing declines to crop yields of 2.2 t/ha if sowing is delayed until 15 April (Figure 5-2).

Figure 5-2 Probability of exceedance graph of simulated dryland maize yields (t/ha) for fortnightly sowing dates from January to April for a Brown Sodosol

Irrigated cropping

Simulated crop yields presented in Table 5-3 for a Brown Sodosol and Table 5-4 for a Vertosol show wet season (WS), dry season (DS) and perennial (P) yields for the 20th, 50th and 80th percent exceedance values for each of the four evaluated climate locations (Mareeba, Chillagoe, Highbury Station and Dunbar Station). Wet-season crops are sown and grow over the wet season while dry-season crops are planted towards the end of the wet season and are harvested during the dry season. These results are potential yields under irrigation rather than predictions of actual yields. Actual on-farm crop yields would be lower for a range of reasons including the availability and delivery of sufficient supplementary irrigation to meet crop water demand in a particular season, the incidence of pests and diseases, adequate expertise in irrigation and agricultural management in northern environments, and the impact of major weather events such as cyclones.

Crop yields in Table 5-3 and Table 5-4 are expressed in the form of 20th, 50th (median) and 80th percent exceedance values. For example, sorghum yields at Chillagoe (Table 5-3) for the top 20% of years crop yields exceed 9.2 t/ha whereas in 80% of years crop yields are expected to achieve a mean of 8.2 t/ha. Table 5-5 and Table 5-6 show the corresponding simulated amounts of irrigation water required to meet crop transpiration demand. Irrigation efficiency (discussed in Section 3.6.1) was assumed at 100% for all simulated results and does not include delivery or system losses, which can be in the order of 50 to 90% (Howell, 2003; Savenije and Hoekstra, 2009), depending on the application system and time of year.

The simulated yields of irrigated crops were much less variable than those of dryland crops. Irrigation facilitates not only higher, but also more reliable production compared with rainfed crops. Modelled yields are comparable to expected yields for current agricultural regions in Queensland, the Northern Territory and Western Australia, which may be used to guide cropping potential for greenfield sites in the Mitchell catchment. Crop yields of 13 t/ha (maize), 7 to 10 t/ha (sorghum), 2.2 t/ha (mungbean), and 5 t/ha (peanut) have been achieved under irrigation in Queensland (QDAF, 2017; GRDC, 2017b).
In the Mitchell catchment, as elsewhere, it is largely differences in water availability that determine differences in crop yield. The amount of water necessary to fully irrigate a crop varied significantly from year to year and depended on soil type. The ‘applied irrigation water’ values in Table 5-5 and Table 5-6 show that the difference in the volume of water required to fully irrigate a crop can be around twice as much for some crops (e.g. sorghum, chickpea, soybean, sugar) in the 20th percentile years compared with the 80th percentile years. There was less difference between 20th percentile and 80th percentile years on the Vertosol because of the higher water holding capacity of this soil type. The varying demand on irrigation water between years highlights the impact of inter-annual variability of rainfall on irrigation requirements.

The inter-annual variation that can be expected in total irrigation requirement has major implications for the reliability with which crops can be irrigated. Crops sown in the August to November period require most water; however, this time of year is usually dry, streams generally have the least flow, and water storages are also likely to be least full. The area of crop that can be reliably irrigated must be carefully assessed each year, with reference to the available stored soil water, the likelihood of future in-season rainfall, and the volume and availability of stored water (e.g. dam, offstream storage).

### Table 5-3 20th, 50th and 80th percent exceedance values for crop yield (t/ha) at four climate locations in the Mitchell catchment on a Brown Sodosol

<table>
<thead>
<tr>
<th>CLIMATE</th>
<th>MAREEBA</th>
<th>CHILLAGOE</th>
<th>HIGHTBURY STATION</th>
<th>DUNBAR STATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROP</td>
<td>SEASON</td>
<td>20TH</td>
<td>50TH</td>
<td>80TH</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20TH</td>
<td>50TH</td>
<td>80TH</td>
</tr>
<tr>
<td>Maize</td>
<td>DS</td>
<td>15.8</td>
<td>14.7</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14.5</td>
<td>13.7</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.0</td>
<td>11.3</td>
<td>10.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.1</td>
<td>11.3</td>
<td>10.8</td>
</tr>
<tr>
<td>Sorghum</td>
<td>DS</td>
<td>9.1</td>
<td>8.5</td>
<td>7.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.2</td>
<td>8.7</td>
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<td></td>
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<td></td>
<td></td>
<td>9.2</td>
<td>8.8</td>
<td>8.0</td>
</tr>
<tr>
<td>Mungbean</td>
<td>DS</td>
<td>2.9</td>
<td>2.7</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<td>2.0</td>
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</tr>
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<td>WS</td>
<td>4.3</td>
<td>4.0</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>3.6</td>
<td>3.5</td>
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<td></td>
<td></td>
<td>3.8</td>
<td>3.6</td>
<td>3.5</td>
</tr>
<tr>
<td>Chickpea</td>
<td>DS</td>
<td>3.5</td>
<td>3.1</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>2.7</td>
<td>2.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Cotton</td>
<td>DS</td>
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<td>10.0</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
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<td>10.8</td>
<td>10.7</td>
<td>10.6</td>
</tr>
<tr>
<td>Cotton</td>
<td>WS</td>
<td>9.8</td>
<td>9.5</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>10.9</td>
<td>10.1</td>
<td>9.7</td>
</tr>
<tr>
<td>Sugar</td>
<td>P</td>
<td>185.5</td>
<td>119.1</td>
<td>105.3</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>123.4</td>
<td>112.4</td>
</tr>
<tr>
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<td>DS</td>
<td>6.8</td>
<td>6.4</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.5</td>
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<td>5.5</td>
<td>5.3</td>
<td>5.1</td>
</tr>
</tbody>
</table>
Table 5-4 20th, 50th and 80th percent exceedance values for crop yield (t/ha) at four climates locations in the Mitchell catchment on a Vertosol
DS = Dry season; WS = Wet season; P = Perennial

<table>
<thead>
<tr>
<th>CLIMATE</th>
<th>SEASON</th>
<th>MAREEBA</th>
<th>CHILLAGOE</th>
<th>HIGHTBURY STATION</th>
<th>DUNBAR STATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>50th</td>
<td>80th</td>
<td>20th</td>
<td>50th</td>
</tr>
<tr>
<td>Maize</td>
<td>DS</td>
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<td>13.7</td>
<td>13.1</td>
<td>14.5</td>
</tr>
<tr>
<td>Sorghum</td>
<td>DS</td>
<td>8.1</td>
<td>7.6</td>
<td>6.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Rice</td>
<td>DS</td>
<td>9.8</td>
<td>9.7</td>
<td>9.5</td>
<td>10.0</td>
</tr>
<tr>
<td>Rice</td>
<td>WS</td>
<td>6.6</td>
<td>6.0</td>
<td>5.3</td>
<td>6.5</td>
</tr>
<tr>
<td>Mungbean</td>
<td>DS</td>
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<td>2.3</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Soybean</td>
<td>WS</td>
<td>4.5</td>
<td>4.1</td>
<td>3.8</td>
<td>4.4</td>
</tr>
<tr>
<td>Chickpea</td>
<td>DS</td>
<td>3.4</td>
<td>3.1</td>
<td>2.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Cotton</td>
<td>DS</td>
<td>10.1</td>
<td>10.0</td>
<td>9.8</td>
<td>10.1</td>
</tr>
<tr>
<td>Cotton</td>
<td>WS</td>
<td>9.9</td>
<td>9.5</td>
<td>8.7</td>
<td>9.9</td>
</tr>
<tr>
<td>Sugar</td>
<td>P</td>
<td>185.0</td>
<td>116.0</td>
<td>102.1</td>
<td>192.7</td>
</tr>
</tbody>
</table>

Table 5-5 20th, 50th and 80th percent exceedance values for irrigation water required to meet crop transpiration demand (ML/ha) at four climate locations in the Mitchell catchment on a Brown Sodosol
DS = Dry season; WS = Wet season; P = Perennial

<table>
<thead>
<tr>
<th>CLIMATE</th>
<th>SEASON</th>
<th>MAREEBA</th>
<th>CHILLAGOE</th>
<th>HIGHTBURY STATION</th>
<th>DUNBAR STATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20th</td>
<td>50th</td>
<td>80th</td>
<td>20th</td>
<td>50th</td>
</tr>
<tr>
<td>Maize</td>
<td>DS</td>
<td>5.8</td>
<td>5.3</td>
<td>4.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Sorghum</td>
<td>DS</td>
<td>2.5</td>
<td>1.6</td>
<td>0.8</td>
<td>3.0</td>
</tr>
<tr>
<td>Mungbean</td>
<td>DS</td>
<td>3.1</td>
<td>2.8</td>
<td>2.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Soybean</td>
<td>WS</td>
<td>4.6</td>
<td>3.8</td>
<td>2.8</td>
<td>5.1</td>
</tr>
<tr>
<td>Chickpea</td>
<td>DS</td>
<td>2.6</td>
<td>1.9</td>
<td>1.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Cotton</td>
<td>DS</td>
<td>6.2</td>
<td>5.7</td>
<td>5.4</td>
<td>6.1</td>
</tr>
<tr>
<td>Cotton</td>
<td>WS</td>
<td>4.6</td>
<td>4.0</td>
<td>3.4</td>
<td>4.6</td>
</tr>
<tr>
<td>Sugar</td>
<td>P</td>
<td>11.3</td>
<td>8.8</td>
<td>7.4</td>
<td>15.0</td>
</tr>
<tr>
<td>Peanut</td>
<td>DS</td>
<td>6.0</td>
<td>5.3</td>
<td>4.5</td>
<td>5.9</td>
</tr>
</tbody>
</table>
Table 5-6 20th, 50th and 80th percent exceedance values for irrigation water required to meet crop transpiration demand (ML/ha) at four climate locations in the Mitchell catchment on a Vertosol

<table>
<thead>
<tr>
<th>CLIMATE</th>
<th>MAREEBA</th>
<th>CHILLAGOE</th>
<th>HIGHLBURY STATION</th>
<th>DUNBAR STATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROP</td>
<td>SEASON</td>
<td>20th</td>
<td>50th</td>
<td>80th</td>
</tr>
<tr>
<td>Maize</td>
<td>DS</td>
<td>5.3</td>
<td>4.8</td>
<td>4.3</td>
</tr>
<tr>
<td>Sorghum</td>
<td>DS</td>
<td>4.0</td>
<td>2.5</td>
<td>1.9</td>
</tr>
<tr>
<td>Rice</td>
<td>WS</td>
<td>4.0</td>
<td>2.9</td>
<td>2.2</td>
</tr>
<tr>
<td>Mungbean</td>
<td>DS</td>
<td>3.5</td>
<td>3.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Soybean</td>
<td>WS</td>
<td>5.2</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Chickpea</td>
<td>DS</td>
<td>2.4</td>
<td>1.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Cotton</td>
<td>DS</td>
<td>6.0</td>
<td>5.6</td>
<td>5.2</td>
</tr>
<tr>
<td>Cotton</td>
<td>WS</td>
<td>4.3</td>
<td>3.7</td>
<td>3.0</td>
</tr>
<tr>
<td>Sugar</td>
<td>P</td>
<td>10.1</td>
<td>7.8</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Horticultural crops

Yields of horticultural crops for the Mitchell catchment are presented in Table 5-7. These data were devised through expert opinion from local jurisdictions and where possible are based on known crop yields in similar locations (climate by soil). The horticultural yields should be considered as potential yields under irrigation rather than predictions of actual yields. Actual on-farm crop yields may be lower for a range of reasons including the availability and delivery of sufficient supplementary irrigation to meet crop water demand in a particular season, the incidence of pests and diseases, adequate expertise in irrigation and agricultural management in northern environments and the impact of major weather events such as cyclones. Crop yields can vary substantially amongst varieties. For example, Kensington Pride (KP) mangoes typically produce between 5 and 10 t/ha while newer Plant Variety Rights (PVR) types such as Calypso can produce 15 to 20 t/ha. Subsequent gross margin analysis (Section 5.1.2) has determined gross margins in horticultural crops are more sensitive to price received (which can be highly volatile) than the range of expected crop yields.

Estimates of the irrigation water requirements for horticultural crops are presented in Table 5-8. The 20th, 50th and 80th percentile exceedance values were estimated from 125 years of climate data using the method of Brouwer and Heibloem (1986). This crop factor method does not account for soil type, so results are shown for each of the four evaluated climate locations (Mareeba, Chillagoe, Highbury Station and Dunbar Station) only. The values in Table 5-7 do not account for irrigation efficiencies associated with getting water to the crop or application (discussed in Section 3.6.1). Horticultural crops are almost exclusively irrigated using trickle or micro-sprinklers, so generally have application efficiencies greater than 80% (Table 3-4). The range in values of irrigation water requirements for horticultural crops is primarily driven by season length. Horticulture includes short-duration crops such as rockmelons and watermelons, as well as perennial tree crops that require year-round water. Of the perennial crops, the larger tree crops
with bigger root systems (e.g. mango) are able to explore more soil from which to extract water and therefore require less irrigation water than smaller perennial crops (e.g. banana).

Table 5-7 Estimated horticultural crop yield in the Mitchell catchment
Based on industry data and estimated crop yields. DS = Dry season; WS = Wet season; P = Perennial.

<table>
<thead>
<tr>
<th>CROP</th>
<th>SEASON</th>
<th>CROP YIELD</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocado</td>
<td>P</td>
<td>1240</td>
<td>trays/ha</td>
</tr>
<tr>
<td>Banana</td>
<td>P</td>
<td>3400</td>
<td>13 kg cartons/ha</td>
</tr>
<tr>
<td>Capsicum</td>
<td>DS</td>
<td>2970</td>
<td>8 kg cartons/ha</td>
</tr>
<tr>
<td>Cashew</td>
<td>P</td>
<td>2800</td>
<td>kg/ha</td>
</tr>
<tr>
<td>Lime</td>
<td>P</td>
<td>3170</td>
<td>9 kg trays/ha</td>
</tr>
<tr>
<td>Mango (KP)</td>
<td>P</td>
<td>1000</td>
<td>7 kg trays/ha</td>
</tr>
<tr>
<td>Mango (PVR)</td>
<td>P</td>
<td>2500</td>
<td>7 kg trays/ha</td>
</tr>
<tr>
<td>Papaya</td>
<td>P</td>
<td>6600</td>
<td>13 kg cartons/ha</td>
</tr>
<tr>
<td>Rockmelon</td>
<td>DS</td>
<td>24.7</td>
<td>t/ha</td>
</tr>
<tr>
<td>Watermelon</td>
<td>DS</td>
<td>47.5</td>
<td>t/ha</td>
</tr>
</tbody>
</table>

Table 5-8 20th, 50th and 80th percent exceedance values for irrigation water required to meet horticultural crop transpiration demand (ML/ha) at four climate locations in the Mitchell catchment
DS = Dry season; WS = Wet season; P = Perennial

<table>
<thead>
<tr>
<th>CLIMATE</th>
<th>MAREEBA</th>
<th>CHILLAGOE</th>
<th>HIGHTBURY STATION</th>
<th>DUNBAR STATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROP</td>
<td>SEASON</td>
<td>20th</td>
<td>50th</td>
<td>80th</td>
</tr>
<tr>
<td>Avocado</td>
<td>P</td>
<td>7.6</td>
<td>6.7</td>
<td>5.9</td>
</tr>
<tr>
<td>Banana</td>
<td>P</td>
<td>10.9</td>
<td>9.7</td>
<td>8.6</td>
</tr>
<tr>
<td>Capsicum</td>
<td>DS</td>
<td>4.3</td>
<td>4.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Cashew</td>
<td>P</td>
<td>8.9</td>
<td>7.9</td>
<td>6.9</td>
</tr>
<tr>
<td>Lime</td>
<td>P</td>
<td>8.9</td>
<td>7.9</td>
<td>6.9</td>
</tr>
<tr>
<td>Mango (KP)</td>
<td>P</td>
<td>6.4</td>
<td>5.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Mango (PVR)</td>
<td>P</td>
<td>6.4</td>
<td>5.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Papaya</td>
<td>P</td>
<td>8.9</td>
<td>7.9</td>
<td>6.9</td>
</tr>
<tr>
<td>Rockmelon</td>
<td>DS</td>
<td>4.0</td>
<td>3.7</td>
<td>3.2</td>
</tr>
<tr>
<td>Watermelon</td>
<td>DS</td>
<td>4.6</td>
<td>4.2</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Plantation tree crops

Yield of the tree crop sandalwood is presented in Table 5-9. These data were obtained through expert opinion from local jurisdictions and where possible are based on known crop yields in similar locations. The crop yields should be considered as potential yields under irrigation rather than predictions of actual yields. Actual on-farm crop yields may be lower for a range of reasons including the availability and delivery of sufficient supplementary irrigation to meet crop water demand in a particular season, the incidence of pests and diseases, adequate expertise in irrigation and agricultural management in northern environments, and the impact of major weather events such as cyclones.
Estimates of the irrigation water requirements for sandalwood are presented in Table 5-10. The 20th, 50th and 80th percent exceedance values were estimated in the same way as for horticultural crops (Brouwer and Heibloem, 1986). This crop factor method does not account for soil type, so results are shown for each of the four evaluated climate locations (Mareeba, Chillagoe, Highbury Station and Dunbar Station) only. As with horticultural crops, the values in Table 5-10 do not account for irrigation efficiencies associated with getting water to the crop or application (discussed in Section 3.6.1). Sandalwood is mostly irrigated using trickle or micro-sprinklers, so generally have application efficiencies greater than 90%. Sesame would generally be irrigated via surface or spray systems (Table 3-4).

Table 5-9 Potential crop yield of sandalwood in the Mitchell catchment
Potential crop yield estimated using expert opinion and known yields in similar locations (climate and soil).

<table>
<thead>
<tr>
<th>CROP</th>
<th>SEASON</th>
<th>CROP YIELD</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandalwood</td>
<td>P</td>
<td>9500</td>
<td>kg/ha (heartwood)</td>
</tr>
</tbody>
</table>

Table 5-10 20th, 50th and 80th percent exceedance values for applied irrigation water demand (ML/ha) in sandalwood at four climate locations in the Mitchell catchment

<table>
<thead>
<tr>
<th>CLIMATE</th>
<th>MAREEBA</th>
<th>CHILLAGOE</th>
<th>HIGHLBURY STATION</th>
<th>DUNBAR STATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROP</td>
<td>SEASON</td>
<td>20th</td>
<td>50th</td>
<td>80th</td>
</tr>
<tr>
<td>Sandalwood</td>
<td>P</td>
<td>3.9</td>
<td>3.3</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Climate change and crop production

Results of APSIM modelling compare mean grain yield or biomass, evapotranspiration and crop water demand under the base historical climate (Scenario A) and a future climate scenario, broadly representative of a 2060 climate (Scenario C; Charles et al., 2016). APSIM results indicate that CO₂ fertilisation and associated increase in water use efficiency have the potential to mostly mitigate negative impacts on crop yields under future climates. Temperature-induced shortening of the growing period supported by supplementary irrigation is also a contributing factor in minimising crop yield loss (Figure 5-3a to Figure 5-6a). While transpiration (Figure 5-3b to Figure 5-6b) increased above base values under future climates, particularly Scenario C (dry), crop yields remained comparable to yields under Scenario A, provided additional water is available for irrigation (Figure 5-3c to Figure 5-6c) to meet increasing crop water demand. A dryland sorghum crop (Figure 5-7) is included for comparison with irrigated crops under Scenarios A and C. Only under Scenario C (wet) were rainfed crop yields similar to those under Scenario A.
Figure 5-3 Simulated (a) crop yield, (b) evapotranspiration and (c) crop irrigation water demand for an irrigated grain sorghum crop under a current (base) climate and dry, mid and wet future climates centred on 2060. Error bars represent 20th and 80th percentiles.

Figure 5-4 Simulated (a) crop yield, (b) evapotranspiration and (c) crop irrigation water demand for an irrigated sugarcane crop under a current (base) climate and dry, mid and wet future climates centred on 2060. Error bars represent 20th and 80th percentiles.

Figure 5-5 Simulated (a) biomass, (b) evapotranspiration and (c) crop irrigation water demand for an irrigated forage sorghum crop under a current (base) climate and dry, mid and wet future climates centred on 2060. Error bars represent 20th and 80th percentiles.
5.1.2 GROSS MARGINS OF INDIVIDUAL CROPS

Broadacre crops

Estimated gross margins for the irrigated crops considered in the Mitchell catchment are summarised in Table 5-11. The complete set of calculated gross margins are available from the CSIRO Data Access Portal. Crop yields used in the calculation of gross margins are the 20th, 50th and 80th percent exceedance values (with matching water demand values) and the 20th, 50th and 80th percent exceedance values for gross margins reflect these yield differences. Crop yield is used as the main variation in gross margin returns because the prices received for broadacre crops change relatively slowly. This contrasts with horticultural crops where gross margins are strongly affected by price volatility over short time frames (days to weeks). The variable costs shown in Table 5-11 are only for the 50th percentile exceedance value, noting that the 20th and 80th percentile values were used in the calculations of gross margins.

Gross margins were highly variable between crops, with the industrial crops (sugar and cotton) and peanuts returning the highest gross margins. It was assumed in sugar and cotton that processing facilities (sugar mill, cotton gin) were available locally to reduce cartage costs. If these processing facilities were not assumed to be available then the gross margins would have been negative. The gross margins for sugar and cotton are consistent with other regions in Queensland but it is important to note that the crop yields produced by APSIM simulations reflect optimum management and no unexpected pest or disease incursions and so are likely to be optimistic. Sesame and sunflower yields are based on expert opinion and recorded values rather than APSIM simulations. Peanut returns were very high based on high yields (>5 t/ha) and the current good
prices that are received for peanut crops. Maize also provided highly positive gross margins, mostly due to simulated high yields. Sorghum, soybeans and wet-season rice provided the lowest returns. Wet-season rice had low yields, reflecting the low radiation that is experienced over the rainy season.

Table 5-11 Gross margin analysis for irrigated broadacre crops in the Mitchell catchment, the mean across four locations, for two soil types

<table>
<thead>
<tr>
<th>CROP</th>
<th>SOWING DATE</th>
<th>CROP YIELD (t/ha)</th>
<th>PRICE ($/unit)</th>
<th>VARIABLE COST ($/ha)</th>
<th>GROSS MARGIN ($/ha)</th>
<th>BREAK-EVEN CROP YIELD (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20th</td>
<td>50th</td>
<td>80th</td>
<td>50th</td>
<td>20th</td>
<td>50th</td>
</tr>
<tr>
<td>Sodosol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>DS</td>
<td>9.2</td>
<td>8.7</td>
<td>8.0</td>
<td>$240</td>
<td>$1606</td>
</tr>
<tr>
<td>Maize</td>
<td>DS</td>
<td>13.6</td>
<td>12.8</td>
<td>12.0</td>
<td>$280</td>
<td>$1914</td>
</tr>
<tr>
<td>Mungbean</td>
<td>DS</td>
<td>2.4</td>
<td>2.3</td>
<td>2.2</td>
<td>$1100</td>
<td>$1154</td>
</tr>
<tr>
<td>Soybean</td>
<td>WS</td>
<td>4.0</td>
<td>3.8</td>
<td>3.6</td>
<td>$475</td>
<td>$1348</td>
</tr>
<tr>
<td>Chickpea</td>
<td>DS</td>
<td>3.1</td>
<td>2.8</td>
<td>2.6</td>
<td>$900</td>
<td>$1239</td>
</tr>
<tr>
<td>Cotton</td>
<td>DS</td>
<td>10.7</td>
<td>10.5</td>
<td>10.2</td>
<td>$480</td>
<td>$2955</td>
</tr>
<tr>
<td>Cotton</td>
<td>WS</td>
<td>10.3</td>
<td>9.8</td>
<td>9.5</td>
<td>$480</td>
<td>$2936</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>P</td>
<td>195.4</td>
<td>121.9</td>
<td>110.2</td>
<td>$42</td>
<td>$2098</td>
</tr>
<tr>
<td>Peanut</td>
<td>DS</td>
<td>5.9</td>
<td>5.7</td>
<td>5.3</td>
<td>$1000</td>
<td>$2438</td>
</tr>
<tr>
<td>Sunflower</td>
<td></td>
<td>3.0</td>
<td></td>
<td></td>
<td>$700</td>
<td>$1291</td>
</tr>
<tr>
<td>Sesame</td>
<td></td>
<td>2.5</td>
<td></td>
<td></td>
<td>$1300</td>
<td>$1456</td>
</tr>
<tr>
<td>Vertosol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>DS</td>
<td>8.4</td>
<td>7.6</td>
<td>3.7</td>
<td>$240</td>
<td>$1592</td>
</tr>
<tr>
<td>Maize</td>
<td>DS</td>
<td>13.6</td>
<td>12.9</td>
<td>12.1</td>
<td>$280</td>
<td>$1926</td>
</tr>
<tr>
<td>Mungbean</td>
<td>DS</td>
<td>2.2</td>
<td>2.1</td>
<td>2.0</td>
<td>$1100</td>
<td>$1155</td>
</tr>
<tr>
<td>Soybean</td>
<td>WS</td>
<td>4.4</td>
<td>4.1</td>
<td>3.7</td>
<td>$475</td>
<td>$1392</td>
</tr>
<tr>
<td>Chickpea</td>
<td>DS</td>
<td>3.1</td>
<td>2.8</td>
<td>2.6</td>
<td>$900</td>
<td>$1237</td>
</tr>
<tr>
<td>Cotton</td>
<td>DS</td>
<td>10.1</td>
<td>10.0</td>
<td>9.9</td>
<td>$480</td>
<td>$2941</td>
</tr>
<tr>
<td>Cotton</td>
<td>WS</td>
<td>10.2</td>
<td>9.6</td>
<td>9.0</td>
<td>$480</td>
<td>$2925</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>P</td>
<td>193.7</td>
<td>119.3</td>
<td>107.2</td>
<td>$42</td>
<td>$2044</td>
</tr>
<tr>
<td>Rice</td>
<td>DS</td>
<td>10.0</td>
<td>9.9</td>
<td>9.7</td>
<td>$400</td>
<td>$2148</td>
</tr>
<tr>
<td>Rice</td>
<td>WS</td>
<td>6.2</td>
<td>5.5</td>
<td>4.6</td>
<td>$400</td>
<td>$1529</td>
</tr>
</tbody>
</table>

**Horticultural crops**

Estimated gross margins for horticultural crops considered in the Mitchell catchment are summarised in Table 5-12. The complete set of calculated gross margins are available from the CSIRO Data Access Portal. Crop yields used in the calculation of gross margins are the estimated mean yields in the Mitchell catchment, based on existing commercial production and expert growth.
opinion. Variations in price are a major driver of profitability in horticultural crops and gross margins tend to be more sensitive to price than crop yield. Consequently, gross margin values are shown for the estimated mean price as well as for values 25% higher and lower than the mean price. The variable costs shown in Table 5-12 are only for the 50th percentile exceedance value, noting that the 20th and 80th percentile values were used in the calculations of gross margins.

Gross margins were highly variable between the different horticultural crops, with avocado, mango (PVR) and papaya showing the highest gross margins in this analysis. KP mangoes, rockmelon, watermelon and capsicum all returned positive gross margins when mean prices were assumed. Limes and cashews had the lowest gross margins. Gross margins were highly sensitive to price variation, with negative returns common when prices 25% lower than the assumed means were used.

**Table 5-12 Gross margin analysis for irrigated horticultural crops in the Mitchell catchment, the mean across four locations**

<table>
<thead>
<tr>
<th>CROP</th>
<th>SEASON</th>
<th>CROP YIELD</th>
<th>UNIT</th>
<th>PRICE ($/UNIT)</th>
<th>VARIABLE COST ($/ha)</th>
<th>GROSS MARGIN ($/ha)</th>
<th>BREAK-EVEN CROP YIELD (t, carton, tray/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocado</td>
<td>P</td>
<td>1243</td>
<td>carton</td>
<td>35</td>
<td>16,685</td>
<td>24,553</td>
<td>7903</td>
</tr>
<tr>
<td>Banana</td>
<td>P</td>
<td>3400</td>
<td>carton</td>
<td>18</td>
<td>44,398</td>
<td>14,048</td>
<td>-9636</td>
</tr>
<tr>
<td>Capsicum</td>
<td>DS</td>
<td>2969</td>
<td>carton</td>
<td>17.5</td>
<td>33,543</td>
<td>18,593</td>
<td>1,952</td>
</tr>
<tr>
<td>Cashew</td>
<td>P</td>
<td>2800</td>
<td>kg</td>
<td>2.5</td>
<td>4675</td>
<td>1345</td>
<td>2,366</td>
</tr>
<tr>
<td>Lime</td>
<td>P</td>
<td>3166</td>
<td>carton</td>
<td>14</td>
<td>38,659</td>
<td>8198</td>
<td>-10,861</td>
</tr>
<tr>
<td>Mango (KP)</td>
<td>P</td>
<td>1000</td>
<td>tray</td>
<td>22</td>
<td>11,724</td>
<td>9606</td>
<td>542</td>
</tr>
<tr>
<td>Mango (PVR)</td>
<td>P</td>
<td>2500</td>
<td>tray</td>
<td>20</td>
<td>26,014</td>
<td>14,211</td>
<td>1,322</td>
</tr>
<tr>
<td>Papaya</td>
<td>P</td>
<td>6600</td>
<td>carton</td>
<td>17</td>
<td>57,455</td>
<td>82,795</td>
<td>3,000</td>
</tr>
<tr>
<td>Rockmelon</td>
<td>DS</td>
<td>1900</td>
<td>carton</td>
<td>18</td>
<td>23,998</td>
<td>10,839</td>
<td>1,365</td>
</tr>
<tr>
<td>Watermelon</td>
<td>DS</td>
<td>47.5</td>
<td>tonne</td>
<td>900</td>
<td>26,250</td>
<td>14,829</td>
<td>-2634</td>
</tr>
</tbody>
</table>

**Plantation tree crops**

Sandalwood is being commercially grown in northern Australia, including in north Queensland, but most financial information is commercial in confidence. In addition, unlike all the other crops in this Assessment, which are harvested at least annually, sandalwood is tree crop that is harvested every 15 years. Based on information obtained from commercially available reports and experts working in the sandalwood industry, a financial analysis for sandalwood is shown in Table 5-13. Trees are harvested and the heartwood of trunks is extracted on-farm. Heartwood is sent to a distillation plant in Albany, Western Australia where sandalwood oil (3.5% of heartwood) is extracted. The discounted gross margin analysis shows a gross margin per ha of nearly $700,000. If this is annualised this represents a gross margin of around $47,000 per year.
Table 5-13 Net Present Value analysis of sandalwood based on a 15-year crop cycle
Revenue and costs are based on a 5% discount rate over the 15 years.

<table>
<thead>
<tr>
<th>SANDALWOOD</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (t/ha heartwood)</td>
<td>10</td>
</tr>
<tr>
<td>Yield (kg/ha oil)</td>
<td>380</td>
</tr>
<tr>
<td>Price received ($/kg oil)</td>
<td>$4000</td>
</tr>
<tr>
<td>Income ($/ha)</td>
<td>$756,091</td>
</tr>
</tbody>
</table>

Variable costs

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-harvest</td>
<td>$28,351</td>
</tr>
<tr>
<td>Harvesting</td>
<td>$33,851</td>
</tr>
<tr>
<td>Total</td>
<td>$62,203</td>
</tr>
<tr>
<td>Gross margin ($/ha)</td>
<td>$693,887</td>
</tr>
</tbody>
</table>

Ability of individual crops to meet required returns

The gross margins for individual crops were compared against the net returns required for different capital costs of development. The gross margins required are the sum of the discounted net returns, including depreciation of capital items assuming a mixture of 15-year and 40-year lifespans (Table 4-3), plus the overhead costs associated with fixed labour, lease costs, etc. ($600/ha) as described in Section 4.3.

Table 5-4 illustrates for each crop its ability to generate sufficient returns to meet the discounted capital costs of development and overhead costs. Some crops e.g. sorghum, sunflower, soybeans, wet-season rice, cashews and limes did not produce sufficient returns to meet the combined overhead costs and any of the capital costs of development. Other broadacre crops (maize, mungbean and chickpeas) could meet capital costs of $5000/ha but not $10,000/ha. Cotton and sugarcane could meet returns required for capital costs of up to $20,000/ha while for peanuts it was $25,000/ha.

In general, most of the common horticultural crops already grown in north Queensland could meet returns associated with higher capital costs of $30,000 to $40,000/ha. Capital costs for horticulture are high, as demonstrated in Table 4-1, which showed that greenfield horticultural developments requiring specialised equipment, packing sheds and cold storage can be more than $40,000/ha.
Table 5-14 Matrix of individual crops and their ability to generate gross margins sufficient to meet or exceed the sum of overhead costs ($600/ha) and capital costs of development based on net present value analysis employing a 7% discount rate. Assumes a mixture of 15-year and 40-year lifespans of capital in calculating net returns.

<table>
<thead>
<tr>
<th>CROP</th>
<th>CAPITAL COSTS OF DEVELOPMENT ($/HA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$5,000</td>
</tr>
<tr>
<td>Sorghum</td>
<td>X</td>
</tr>
<tr>
<td>Maize</td>
<td>✔</td>
</tr>
<tr>
<td>Rice DS</td>
<td>✔</td>
</tr>
<tr>
<td>Rice WS</td>
<td>X</td>
</tr>
<tr>
<td>Mungbean</td>
<td>X</td>
</tr>
<tr>
<td>Soybean</td>
<td>✔</td>
</tr>
<tr>
<td>Chickpea</td>
<td>✔</td>
</tr>
<tr>
<td>Cotton DS</td>
<td>✔</td>
</tr>
<tr>
<td>Cotton WS</td>
<td>✔</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>✔</td>
</tr>
<tr>
<td>Peanut</td>
<td>✔</td>
</tr>
<tr>
<td>Sunflower</td>
<td>X</td>
</tr>
<tr>
<td>Sesame</td>
<td>✔</td>
</tr>
<tr>
<td>Avocado</td>
<td>✔</td>
</tr>
<tr>
<td>Banana</td>
<td>✔</td>
</tr>
<tr>
<td>Capsicum</td>
<td>✔</td>
</tr>
<tr>
<td>Cashew</td>
<td>X</td>
</tr>
<tr>
<td>Lime</td>
<td>X</td>
</tr>
<tr>
<td>Mango (KP)</td>
<td>✔</td>
</tr>
<tr>
<td>Mango (PVR)</td>
<td>✔</td>
</tr>
<tr>
<td>Papaya</td>
<td>✔</td>
</tr>
<tr>
<td>Rockmelon</td>
<td>✔</td>
</tr>
<tr>
<td>Watermelon</td>
<td>✔</td>
</tr>
</tbody>
</table>

The inability of most broadacre crops to generate adequate returns as a single annual crop raises the challenge of how might gross margins be improved to better align with required returns for investment. Gross margins can be improved by either reducing variable costs or increasing returns. In terms of reducing costs, achieving efficiencies in input costs (water, fertiliser, herbicides and pesticides) is usually an ongoing priority for management. Freight costs make up a significant percentage of variable costs and can represent a significant proportion of gross returns (Table 5-15). Freight costs can represent up to 25% of gross returns for broadacre grain costs and are very sensitive to the distance to market given the relatively low prices received per tonne of product. In contrast, freight costs represent about 10% of gross returns for pulse crops (mungbean, chickpea) even though they need to be transported to cleaning and processing facilities near Townsville. A
combination of high prices per tonne and relatively low crop yields means total tonnage
transported is low compared with coarse grains.

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

High-volume horticultural crops (melons, bananas, papaya) have relatively high transport costs (17
to 25% of gross returns) compared with higher value crops such as avocados and mangoes (5 to
15%). Ash et al. (2017) identified supply chain costs as a significant challenge for agricultural
development in the north. Options for reducing freight costs to market include local processing
facilities or for horticultural products, establishing lower cost export options through the ports of
Townsville or Cairns. Aquaculture is growing in importance in northern Australia and intuitively
there would appear to be potential synergies between crops grown in the catchment and their
ability to provide feed to local aquaculture enterprises. However, in the companion technical
report on aquaculture viability (Irvin et al., 2018), it is highlighted that there are challenges with
cost-effectively providing appropriate feed sources locally.

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

Table 5-15 Freight costs as a percentage of total value of production for a range of crops grown in the Mitchell
catchment

<table>
<thead>
<tr>
<th>CROP TYPE</th>
<th>CROP</th>
<th>MARKET/PROCESSING LOCATION</th>
<th>FREIGHT COST PERCENTAGE OF TOTAL VALUE OF PRODUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse grains</td>
<td>Sorghum, maize, rice</td>
<td>Tablelands, Townsville</td>
<td>5 to 25%</td>
</tr>
<tr>
<td>Pulses</td>
<td>Chickpea, mungbean</td>
<td>Townsville</td>
<td>7 to 11%</td>
</tr>
<tr>
<td>Oilseed</td>
<td>Soybean</td>
<td>Townsville</td>
<td>16 to 21%</td>
</tr>
<tr>
<td>Peanut</td>
<td>Peanut</td>
<td>Tablelands</td>
<td>2 to 6%</td>
</tr>
<tr>
<td>Industrial</td>
<td>Sugarcane, cotton</td>
<td>Mitchell catchment</td>
<td>1 to 5%</td>
</tr>
<tr>
<td>High-volume horticulture</td>
<td>Rockmelon, watermelon, banana, papaya</td>
<td>Brisbane</td>
<td>17 to 25%</td>
</tr>
<tr>
<td>High-value horticulture</td>
<td>Avocado, mango, capiscum</td>
<td>Brisbane</td>
<td>5 to 15%</td>
</tr>
</tbody>
</table>
5.1.3 CROPPING SYSTEM OPPORTUNITIES

Feasible sequential cropping system options

Cotton–mungbean–lablab rotation

Results from the APSIM simulations for the first cropping system scenario for cotton, mungbean and lablab are presented as a series of probability of exceedance graphs in Figure 5-8 to Figure 5-10. Applied irrigation (Figure 5-11) and in-crop rainfall (Figure 5-12) are also shown. Annual production data for each crop and the applied irrigation at both the paddock- and scheme-scales are presented in Table 5-16. The simulated median cotton yield and irrigation requirements are consistent with measured values from experiments in a similar climate and soil texture at the Gilbert River (Queensland) during low to average cloud cover seasons (Yeates, 2013 to 2015, unpublished data). Based on research in the Burdekin, below median cotton yields would be expected to occur with greater frequently in cloudy seasons and above the top 20% yields of seasons in sunny milder seasons than simulated in Figure 5-8. The climate data used in this analysis are based on a gridded climate surface. It may not fully represent the within-season variability because the relatively sparse nature of climate stations can result in variability that is smoothed during the spatial interpolation process to derive climate data at a specific longitude and latitude. In-crop rainfall (Figure 5-12) contributes over 500 mm during the cotton crop, reducing the need for approximately 200 mm of additional irrigation to meet crop water demand.

Figure 5-8 APSIM predicted irrigated cotton production over 125 years with an early-January sowing
Figure 5-9 APSIM predicted irrigated mungbean production over 125 years with a mid-August sowing

Figure 5-10 APSIM predicted irrigated lablab production based on an August sowing

Figure 5-11 Irrigation water applied for cotton, mungbean and forage lablab over 125 years
Figure 5-12 In-crop rainfall for cotton, mungbean and forage lablab over 125 years

Table 5-16 Paddock- and scheme-scale production and irrigation data for cotton–mungbean and cotton–lablab rotations

<table>
<thead>
<tr>
<th></th>
<th>PADDOCK-SCALE (PER HA)</th>
<th>SCHEME-SCALE (20,000 HA)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PRODUCTION</td>
<td>SD</td>
</tr>
<tr>
<td></td>
<td>(Bales or t/ha)</td>
<td>(mm)</td>
</tr>
<tr>
<td>Cotton</td>
<td>9.5</td>
<td>0.47</td>
</tr>
<tr>
<td>Mungbean</td>
<td>2.3</td>
<td>0.12</td>
</tr>
<tr>
<td>Lablab hay</td>
<td>9.2</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Sugarcane break crop rotation

An example for a May plant crop (Figure 5-13) shows three ratoon periods for a plant crop (established May) and a June harvest period. A break crop of mungbean is sown following harvest of the 3rd ratoon at the end of July. Alternatively, a soybean crop is sown in November and grown over the wet season and harvested in April prior to the establishment of the next plant cane crop (Figure 5-13). Figure 5-14 shows annual production of fresh sugarcane for a 24,000-ha scenario. Applied irrigation water (assuming 100% efficiency) is presented in Figure 5-15. Cane availability for a 6-month harvest period is shown in Figure 5-16.

Fresh cane weight increases with crop duration as daily temperature and radiation increase during spring. However, to supply mill production over a 6-month operating period, staged harvesting occurs between July and November. The amount of irrigation required depends on atmospheric demand driven by daily temperature and radiation, and amount of leaf area of the crop (canopy size). A maturing sugarcane crop with a full canopy transpires less water during the cooler winter months. Increasing the growing period from 12 to 17 months before harvest increases fresh cane weight (Figure 5-16) and increases the irrigation demand of the sugarcane crop.

To evaluate the simulated results for relative sensibility the results have been compared with industry values for sugarcane production and irrigation requirements for the Burdekin and
selected sugarcane growing regions in northern Australia. Production values for the Herbert-Burdekin region and the Mitchell catchment scenario from the Assessment are presented in Table 5-17. Applied irrigation amounts for existing northern Australian sugarcane growing regions are presented in Table 5-18 along with simulated estimates of crop water demand to be supplied by irrigation for the Mitchell catchment scenario.

Mungbean yields (t/ha) and crop water demand (ML/ha) supplied by irrigation are presented in Figure 5-17 and assumed 100% efficiency of supply to the crop. Time of sowing will influence potential crop yields as shown in Figure 5-17. Soil water at time of cane harvest in June will be low and require any following break crop to be fully irrigated during the late winter and early spring period. Figure 5-17a shows crop yield decline from delayed sowing and the increase in the demand for additional irrigation when sowing is delayed after June.

![Figure 5-13 Sequence of plant cane, ratoon crops and break crops of soybean/mungbean in a sugarcane crop rotation system](image)

![Figure 5-14 Annual sugarcane production from the 30,000 ha farm modelled between 1898 and 2014](image)

![Figure 5-15 Annual irrigation requirement for a 30,000 ha sugarcane system between 1898 and 2014](image)
Figure 5-16 Fresh sugarcane available for milling during the June to November harvest window. Error bars represent 10th and 90th percentiles.

Figure 5-17 (a) Annual mungbean yield (t/ha) following a June, July and August cane harvest; (b) Crop water requirement (ML/ha) from irrigation for a mungbean crop following a June, July and August cane harvest.

Table 5-17 Observed sugarcane production data for the Herbert-Burdekin compared to simulated data from the Mitchell catchment between 2006 and 2014. Herbert-Burdekin data from the Australian Sugar Milling Council (ASMC, 2017).

<table>
<thead>
<tr>
<th>YEAR</th>
<th>HERBERT-BURDEKIN (OBSERVED)</th>
<th>MITCHELL CATCHMENT (SIMULATED)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cane (t)</td>
<td>Area (ha)</td>
</tr>
<tr>
<td>2006</td>
<td>12,921,548</td>
<td>127,321</td>
</tr>
<tr>
<td>2007</td>
<td>12,511,375</td>
<td>127,005</td>
</tr>
<tr>
<td>2008</td>
<td>12,332,782</td>
<td>120,880</td>
</tr>
<tr>
<td>2009</td>
<td>11,154,318</td>
<td>119,816</td>
</tr>
<tr>
<td>2010</td>
<td>9,752,738</td>
<td>89,398</td>
</tr>
<tr>
<td>2011</td>
<td>12,471,413</td>
<td>132,033</td>
</tr>
<tr>
<td>2012</td>
<td>11,104,867</td>
<td>121,637</td>
</tr>
<tr>
<td>2013</td>
<td>11,291,076</td>
<td>125,419</td>
</tr>
<tr>
<td>2014</td>
<td>12,213,695</td>
<td>126,963</td>
</tr>
</tbody>
</table>
Table 5-18 Applied irrigation amounts before losses for sugarcane growing regions in northern Australia and simulated data for the Mitchell catchment
Observed data from Sugar Research Australia (SRA, 2017).

<table>
<thead>
<tr>
<th>DISTRICT</th>
<th>ANNUAL WATER USE (MM)</th>
<th>EFFECTIVE RAINFALL (MM)</th>
<th>IRRIGATION REQUIREMENT (MM)</th>
<th>LEVEL OF IRRIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ord</td>
<td>1960</td>
<td>550</td>
<td>1410</td>
<td>Total</td>
</tr>
<tr>
<td>Cairns</td>
<td>1630</td>
<td>1360</td>
<td>270</td>
<td>Limited supply</td>
</tr>
<tr>
<td>Mareeba/Dimbulah</td>
<td>1550</td>
<td>405</td>
<td>1145</td>
<td>Total</td>
</tr>
<tr>
<td>Burdekin</td>
<td>1520</td>
<td>450</td>
<td>1070</td>
<td>Total</td>
</tr>
<tr>
<td>Mitchell catchment</td>
<td>No data available</td>
<td>No data available</td>
<td>1165</td>
<td>Total</td>
</tr>
</tbody>
</table>

Productive potential and farming system risks associated with sequential cropping system options

Sequential cropping systems could significantly improve the productive potential of newly developed irrigated land, increasing the likelihood of returning a profit on the capital cost and operation of a development. Experience elsewhere in Australia and internationally has identified the following risks:

- **Operational risks.** Growing crops back to back is dependent on timely transitions between the crops and selecting crops with growing seasons that will reliably fit into the available cropping windows. In the tropics, variable and often intense wet-season rainfall increases operational risk via reduced trafficability and the potential for soil and nutrient loss. Conservation and reduced tillage systems where crop stubbles are retained have been demonstrated to significantly minimise these risks in tropical Australia (Chapman et al., 1996). The Brazilian Cerrado is a recent example of a locally developed zero or reduced tillage system where retained crop stubbles permit successful large-scale sequential cropping during the wet season (e.g. Piaui, 2010; Lopes et al., 2012; Lopes and Guilherme, 2016).

- **Biophysical risks.** These often emerge with time, for example build-up of pests, diseases, weeds and pesticide resistance; changed (increased) watertable depth; or soil chemical and structural decline (e.g. Chauhan et al., 2012, Lopes et al., 2012; Lopes and Guilherme, 2016). Many of these challenges can be anticipated prior to commencement of sequential cropping.

- **Nutrient cycling risks.** Previous crop stubbles and fertilisers must be accounted for and depending on the crop sequence there are positives and negatives.

**Returns from cropping systems**

The two examples outlined above highlight how returns can be increased from crop rotations, especially double cropping. Simply combining the gross margins from cotton and mungbean (Table 5-16) can increase gross margins to around $3500/ha. Returns of that magnitude can easily meet the required returns to service capital costs of up to $25,000/ha. There may also be cost efficiencies associated with double cropping that would further enhance gross margins over and above simply combining individual crop gross margins.
## INTEGRATING FORAGES INTO LIVESTOCK SYSTEMS

Table 5-19 shows the forage production and water used for the three locations in the Mitchell catchment for native pasture, and dryland (forage sorghum only) and irrigated cultivated forages.

### Table 5-19 Forage production and irrigation water used for native pasture and three sown forage crops

<table>
<thead>
<tr>
<th>CROP</th>
<th>IRRIGATION</th>
<th>PROBABILITY</th>
<th>CHILLAGOE</th>
<th>HIGHLURY</th>
<th>DUNBAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yield (t DM/ha)</td>
<td>Water use (ML/ha)</td>
<td>Yield (t DM/ha)</td>
</tr>
<tr>
<td>Pasture</td>
<td>Rainfed</td>
<td>20th percentile</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>1.3</td>
<td>1.2</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80th percentile</td>
<td>1.6</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Sorghum</td>
<td>Rainfed</td>
<td>20th percentile</td>
<td>4.9</td>
<td>9.8</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>5.9</td>
<td>10.8</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80th percentile</td>
<td>7.2</td>
<td>11.6</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>Irrigated</td>
<td>20th percentile</td>
<td>11.3</td>
<td>3.3</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>14.9</td>
<td>4.2</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80th percentile</td>
<td>16.8</td>
<td>4.9</td>
<td>18.5</td>
</tr>
<tr>
<td>Rhodes grass</td>
<td>Irrigated</td>
<td>20th percentile</td>
<td>34.1</td>
<td>12.1</td>
<td>35.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>34.8</td>
<td>13.2</td>
<td>35.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80th percentile</td>
<td>35.5</td>
<td>14.7</td>
<td>36.1</td>
</tr>
<tr>
<td>Lablab</td>
<td>Irrigated</td>
<td>20th percentile</td>
<td>8.9</td>
<td>3.5</td>
<td>13.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>9.0</td>
<td>4.2</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80th percentile</td>
<td>9.1</td>
<td>4.8</td>
<td>14.1</td>
</tr>
</tbody>
</table>

Baseline annual mean native pasture yields were 1.1 to 1.6 t/year across the three locations. This low level of production reflects the relatively low nutrient soils and the moderate land condition in the Mitchell catchment. Rainfed (dryland) forage sorghum production was approximately 6 t/ha at Chillagoe and around 10 t/ha at Highbury and Dunbar. The Vertosols and Sodosols at Highbury and Dunbar can store significant amounts of soil water and this contributed to higher crop yields under rainfed conditions. Temperatures in the middle of the year are considerably lower at Chillagoe than at Highbury and Dunbar and this also contributed to lower yields of forage sorghum, both in dryland and irrigated situations.

Yields of irrigated Rhodes grass were very high (>30 t/ha), with most production occurring from September to May, and a large amount of nitrogen fertiliser applied. Associated with high forage production was a high irrigation demand (12 to 16 ML/ha). In contrast, forage sorghum required
only 3 to 5 ML/ha as it was grown over a 6-month period and during the dry season when evaporative demand was much lower.

Irrigated lablab produced from 9 to 14 t/ha, which is consistent with production data from other catchments (Muldoon, 1985). Water demand was 3.5 to 6.0 ML/ha as, like forage sorghum, it was grown over the dry season.

Both the sown grasses, forage sorghum and Rhodes grass, received high levels of fertiliser, and Rhodes grass in particular received very high rates of nitrogen fertiliser to try to maintain protein concentrations of forage at levels sufficient to sustain high levels of animal production. The legume lablab did not require nitrogen fertiliser, but it was assumed phosphorus, potassium, sulfur and trace elements were deficient; these were applied in the model.

Forage sorghum received less fertiliser than Rhodes grass (250 kg N/ha versus 400 kg N/ha) and protein concentrations of forage sorghum were around 12% in early stages of growth but these fairly rapidly declined to around 7% crude protein. In contrast, the aim of the Rhodes grass scenario was to achieve high levels of protein, especially during the dry season when native pasture protein levels are very low. Consequently, protein concentrations in Rhodes grass were 12 to 14% from April through to November but were lower from December to March as biomass production was very high and nitrogen dilution occurred. Lablab maintained high levels of protein (14 to 18%) throughout its growth.

The enterprise outcomes comparing the baseline with dryland and irrigated forages integrated into fattening (grazed forage) and reproduction (early weaning) are shown in Table 5-20, Table 5-21, and Table 5-22. The data shown in Table 5-19 represent forage production under conditions of full irrigation, i.e. water provided in every year of the historical sequence of years (1960 to 2015) as a measure of potential production under irrigation. However, the variable climate experienced in the Mitchell catchment will result in some years where there is insufficient runoff to fill surface water storages. Irrigation in the Mitchell catchment is almost entirely dependent on surface water storage with limited opportunities for use of groundwater. Based on assessments of runoff (Hughes et al., 2018), it was assumed for this analysis of integration of forages into beef enterprises that reliable irrigation was available in 80% of years. This was implemented by first determining the bottom 20% of years for runoff at each location for the period 1960 to 2015 using the APSIM model. In the subsequent model simulations of the forage–beef model (NABSA), irrigation was not applied in those 20% of low runoff years.

As stocking rate increases, pasture utilisation rate also increases and beef outputs and profitability rise linearly until pasture condition starts to decline in response to over-utilisation. Concurrently pasture productivity, animal performance and profit also begin to decline due to the negative feedback effects of overstocking. Given the sensitivity of financial outcomes in response to pasture utilisation, the model runs were constructed to generate the same utilisation rate across all forage treatments, as illustrated in Table 5-20 to Table 5-22. While utilisation rates are comparable, stock numbers were higher in forage crop scenarios because of the added contribution of sown pastures to forage availability as well as the faster growth rate of cattle, which means faster turnover of cattle.

Use of irrigated forage crops for grazing increased the growth of young cattle considerably, from 110 to 130 kg/head/year in baseline simulations to 186 to 272 kg/head/year (Table 5-20 to Table 5-22). Animal growth rates were highest for the legume (lablab) and least for animals grazing
forage sorghum, which had the lowest protein content. In addition, allowing young females access to forage crops boosted their weights, which had a lifetime benefit in increasing weaning rates by 2 to 3% units. Consequently beef turn-off was as much as 50% higher than the baseline for the scenarios in which animals grazed forage. However, profit increases did not match the production gains because of the higher costs associated with establishing, fertilising and irrigating sown forages. At Chillagoe in particular, where baseline production was higher than the other two locations, increases in net returns from sown forages were relatively low. The costs of forage production per additional kg of beef over baseline beef production were in the order of $2.00 to $3.00 with no clear pattern of variation between locations or forage crop type. This is a useful, practical measure for producers as it gives a measure of the beef prices needed to meet the costs of the forage crop system. Beef prices are currently around $3.00 per kilogram of liveweight.

While dryland forage sorghum did not incur irrigation costs, and fertiliser requirements per ha were half those in irrigation scenarios, the additional area required to produce sufficient forage meant that net returns were either lower (Chillagoe) or modestly higher (Dunbar) than baseline scenarios. The Highbury results were an exception as the deep clay soils hold sufficient water to grow a productive dryland forage sorghum crop, capable of good beef production at relatively low cost. This highlights there may be some niche opportunities for dryland forage crops in areas where there are Vertosols or deep alluvial soils.

An alternative use of forage examined here was growing a small area for hay, which was fed to early weaned calves (weaned at 4 months rather than 7 months), with the aim of reducing lactational demands on breeding females and thereby boosting conception and weaning rates and reducing mortality on the back of improved body condition. Model results suggest that weaning rates can be increased by 7 to 10% through a well-executed early weaning program that has a co-benefit of reducing mortality in breeders. While the same number of young animals were produced as in the baseline scenario, higher weaning rate meant more animals were turned off and the whole beef production enterprise was more efficient. Costs are also low as the area of irrigated forage required for hay production is 35 to 50% of that necessary for grazed forage scenarios. Consequently, net profits are 10 to 20% higher than the baseline and the additional costs per kg of additional beef produced are only around $0.50.

While the grazed and hay scenarios produced similar net profits the capital costs required for the hay scenario are considerably lower because of the lower area of forage crop required.

*Table 5-20 Production and financial outcomes from the different irrigated forage and beef production scenarios for a representative 40,000 ha property at Chillagoe*

<table>
<thead>
<tr>
<th></th>
<th>BASELINE</th>
<th>GRAZED FORAGE FOR STEER FATTENING</th>
<th>EARLY WEANING STRATEGY USING HAY, EXCESS HAY SOLD LOCALLY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forage</td>
<td>None</td>
<td>Dryland forage sorghum</td>
<td>Forage sorghum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rhodes grass</td>
<td>Lablab</td>
</tr>
<tr>
<td>Herd size (AE)</td>
<td>2891</td>
<td>2975</td>
<td>3024</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3056</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3093</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2934</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2938</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2934</td>
</tr>
<tr>
<td>Pasture utilisation (%)</td>
<td>22.9</td>
<td>22.9</td>
<td>22.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>22.7</td>
</tr>
<tr>
<td>Methane (kg CO2-e/ha/day)</td>
<td>4.0</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3.6</td>
</tr>
</tbody>
</table>

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### Table 5-21 Production and financial outcomes from the different irrigated forage and beef production scenarios for a representative 60,000 ha property at Highbury

<table>
<thead>
<tr>
<th>Forage</th>
<th>BASELINE</th>
<th>GRAZED FORAGE FOR STEER FATTENING</th>
<th>EARLY WEANING STRATEGY USING HAY, EXCESS HAY SOLD LOCALLY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forage</td>
<td>None</td>
<td>Dryland forage sorghum</td>
<td>Forage sorghum</td>
</tr>
<tr>
<td>Herd size (AE)</td>
<td>3677</td>
<td>3899</td>
<td>3872</td>
</tr>
<tr>
<td>Pasture utilisation (%)</td>
<td>20.6</td>
<td>20.6</td>
<td>20.3</td>
</tr>
<tr>
<td>Methane (kg CO\textsubscript{2}-e/ha/day)</td>
<td>4.2</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Methane (kg CO\textsubscript{2}-e/kg beef)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Weaning rate (%)</td>
<td>55.0</td>
<td>58.0</td>
<td>58.0</td>
</tr>
<tr>
<td>Annual growth rate (kg/animal)</td>
<td>115</td>
<td>216</td>
<td>211</td>
</tr>
<tr>
<td>Beef produced per year (kg)</td>
<td>405,873</td>
<td>574,105</td>
<td>569,962</td>
</tr>
<tr>
<td>Gross margin ($/ha)</td>
<td>$211</td>
<td>$267</td>
<td>$251</td>
</tr>
<tr>
<td>Gross margin ($/AE)</td>
<td>$13</td>
<td>$17</td>
<td>$16</td>
</tr>
<tr>
<td>Profit (EBIT) ($)</td>
<td>$465,603</td>
<td>$683,572</td>
<td>$612,759</td>
</tr>
<tr>
<td>Marginal cost of beef produced from sown forages (c/kg beef)</td>
<td>170</td>
<td>211</td>
<td>242</td>
</tr>
</tbody>
</table>

Note: The table outlines the production and financial outcomes of different forage and beef production scenarios for a 60,000 ha property at Highbury.
### Table 5-22 Production and financial outcomes from the different irrigated forage and beef production scenarios for a representative 60,000 ha property at Dunbar

<table>
<thead>
<tr>
<th>Forage</th>
<th>BASELINE</th>
<th>GRAZED FORAGE FOR STEER FATTENING</th>
<th>EARLY WEANING STRATEGY USING HAY, EXCESS HAY SOLD LOCALLY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herd size (AE)</td>
<td>4054</td>
<td>4178</td>
<td>4290</td>
</tr>
<tr>
<td>Pasture utilisation (%)</td>
<td>22</td>
<td>21.7</td>
<td>21.7</td>
</tr>
<tr>
<td>Methane (kg CO₂-e/ha/day)</td>
<td>4.5</td>
<td>3.6</td>
<td>3.5</td>
</tr>
<tr>
<td>Methane (kg CO₂-e/kg beef)</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Weaning rate (%)</td>
<td>53.0</td>
<td>54.0</td>
<td>55.0</td>
</tr>
<tr>
<td>Annual growth rate (kg/animal)</td>
<td>110</td>
<td>194</td>
<td>219</td>
</tr>
<tr>
<td>Beef produced per year (kg)</td>
<td>419,262</td>
<td>540,520</td>
<td>575,839</td>
</tr>
<tr>
<td>Gross margin ($/ha)</td>
<td>$199</td>
<td>$218</td>
<td>$224</td>
</tr>
<tr>
<td>Gross margin ($/AE)</td>
<td>$13</td>
<td>$15</td>
<td>$16</td>
</tr>
<tr>
<td>Profit (EBIT) ($)</td>
<td>$498,291</td>
<td>$551,823</td>
<td>$603,291</td>
</tr>
<tr>
<td>Marginal cost of beef produced from sown forages (c/kg beef)</td>
<td>257</td>
<td>233</td>
<td>277</td>
</tr>
</tbody>
</table>

Financial outcomes, in particular profit, are highly sensitive to beef price. Beef prices can change rapidly as highlighted in Figure 5-18 which shows saleyard prices for trade steers the last 10 years, with prices varying from $1.50/kg to $3.80/kg. The results shown in Table 5-20 to Table 5-22 are based on sale beef prices of $3.00/kg for prime animals (slaughter or export trade steers) dropping to $1.80/kg for cows culled in old age. Figure 5-19 shows the profit for the different scenarios at Highbury in response to the price of beef received. This shows that once beef prices drop to $2.00/kg, the grazed forage crop options generate similar or lower net profits (EBIT) than the baseline scenario. However, for the hay scenario net profits remain above the baseline across all prices tested because the marginal costs of production per kg of beef produced are low. As outlined above this is a result of the hay providing a benefit that is much more systematic than its direct value, i.e. it has flow-on benefits to the whole breeding herd.
Figure 5-18 Price of beef (c/kg) from trade steers (330 to 400 kg) at saleyards in eastern Australia, 2007 to 2017

Figure 5-19 Response in net profit (EBIT) to changing beef price for the baseline, irrigated and grazed Rhodes grass and irrigated Rhodes grass hay forage options at Highbury

The net profit figures shown in Table 5-20 to Table 5-22 are based on earnings before interest or tax and do not consider returns on the capital investment required to establish irrigated forage cropping operations. To assess the broader viability of irrigation, including investment costs, an analysis of net present value (NPV) was undertaken. For this analysis two levels of capital development costs were used based on the development costs outlined in Section 4: moderate costs of $12,000/ha and high costs of $20,000/ha. The NPV is sensitive to ongoing returns, with the price of beef being a key driver of returns. Consequently, two beef prices were used: $3.00/kg as per the results in Table 5-20 to Table 5-22, which represents a price towards the higher end.
experience over the last decade (Figure 5-18); and $2.00/kg, which represents the price received 
for beef for much of the period between 2007 and 2014.

Net present values and internal rates of return for irrigated forage development options are 
shown in Table 5-23. Although most of the forage crop interventions produced an increase in net 
profit (Table 5-20 to Table 5-22), when the capital costs of development were considered in a 15-
year NPV analysis, very few of the options produced a positive NPV. At Chillagoe, where it was less 
of an advantage to use introduced forages compared with the baseline, only one option (Rhodes 
grass hay) produced a positive NPV. At Highbury and Dunbar, positive NPVs were evident for a 
number of the hay options. Hay requires a much smaller capital outlay because the area of 
development is smaller and the benefits flow through the whole breeding herd as a result of the 
early weaning strategy. Even with hay, positive NPVs were mostly produced under the scenarios 
with moderate capital costs.

With the exception of dryland sorghum at Highbury, none of the grazed forages produced a 
positive NPV. The area of cropping required for the grazed forage options was considerable and 
this required a high capital cost of development, which could not generate a positive NPV, even 
where annual profit increases were significant.

This highlights the importance of undertaking a full investment analysis to determine the likely 
returns on capital from different forage options. A NPV or a similar return on investment type 
analysis is usually undertaken by large companies while smaller investors, such as individual 
farmers or small to medium companies, may use other criteria for reaching decisions on the value 
of an investment. For example, returning a reasonable net profit, even where there is a negative 
NPV, may suffice for some investors who might rely on medium term increases in the capital value 
of the land to justify their investment.

Table 5-23 Net present values and internal rates of return for irrigated forage development options

<table>
<thead>
<tr>
<th>CROP</th>
<th>CAPITAL COST</th>
<th>BEEF PRICE ($/KG)</th>
<th>NET PRESENT VALUE ($)</th>
<th>Chillagoe</th>
<th>Highbury</th>
<th>Dunbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum – dryland</td>
<td>Moderate</td>
<td>$2.00</td>
<td>-$2,817,126</td>
<td>-$45,771</td>
<td>-$1,556,141</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>$3.00</td>
<td>-$2,086,963</td>
<td>$1,705,844</td>
<td>-$232,670</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$2.00</td>
<td>-$3,410,445</td>
<td>-$490,761</td>
<td>-$2,149,461</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$3.00</td>
<td>-$2,680,282</td>
<td>$1,260,854</td>
<td>-$825,990</td>
<td></td>
</tr>
<tr>
<td>Sorghum – graze</td>
<td>Moderate</td>
<td>$2.00</td>
<td>-$2,890,957</td>
<td>-$2,024,357</td>
<td>-$2,638,408</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>$3.00</td>
<td>-$2,026,509</td>
<td>-$300,825</td>
<td>-$964,241</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$2.00</td>
<td>-$4,077,597</td>
<td>-$3,507,657</td>
<td>-$4,270,037</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$3.00</td>
<td>-$3,213,149</td>
<td>-$1,784,124</td>
<td>-$2,595,870</td>
<td></td>
</tr>
<tr>
<td>Sorghum – hay</td>
<td>Moderate</td>
<td>$2.00</td>
<td>-$848,005</td>
<td>-$182,295</td>
<td>-$92,161</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>$3.00</td>
<td>-$453,563</td>
<td>$551,568</td>
<td>$582,241</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$2.00</td>
<td>-$1,441,325</td>
<td>-$834,947</td>
<td>-$744,812</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$3.00</td>
<td>-$1,046,883</td>
<td>-$101,083</td>
<td>-$70,411</td>
<td></td>
</tr>
<tr>
<td>Rhodes grass – graze</td>
<td>Moderate</td>
<td>$2.00</td>
<td>-$1,931,356</td>
<td>-$1,986,500</td>
<td>-$3,949,320</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>$3.00</td>
<td>-$879,447</td>
<td>-$129,175</td>
<td>-$854,623</td>
<td></td>
</tr>
</tbody>
</table>
### 5.2 Risks of nutrient and pesticide use

#### 5.2.1 RISK ASSESSMENT

Nitrogen (N) use varied considerably for crops assessed in the Mitchell catchment (Table 5-24). The N surplus was high for bananas and relatively high for sugarcane, which have high N inputs and a low quantity of N removed in the harvestable product. Conversely, N surplus was low for a number of crops or even negative in the case of Jarrah grass. A negative N surplus indicates that nitrogen inputs are less than the N in the harvestable product. In these instances, N from mineralisation of soil N would be required to meet crop N demands (Angus, 2001). It should be noted that efficiencies of use will be higher with split applications of N and where crop rotations or cover crops are used as part of the cropping system.

**Table 5-24 Nitrogen use for crops assessed in the Mitchell catchment**

Crop yields are a mixture of simulated potential yields from APSIM, observed yields from neighbouring regions, and documented values.

<table>
<thead>
<tr>
<th>CROP</th>
<th>N APPLIED TO CROP (KG/HA)</th>
<th>N FIXED (KG/HA)</th>
<th>TOTAL NITROGEN INPUTS (KG/HA)</th>
<th>N IN HARVESTABLE PRODUCT (KG/HA)</th>
<th>N SURPLUS (KG/HA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>400</td>
<td>0</td>
<td>400</td>
<td>73</td>
<td>327</td>
</tr>
<tr>
<td>Chickpeas</td>
<td>6</td>
<td>87</td>
<td>93</td>
<td>92</td>
<td>1</td>
</tr>
<tr>
<td>Cotton</td>
<td>180</td>
<td>0</td>
<td>180</td>
<td>110</td>
<td>70</td>
</tr>
<tr>
<td>Jarra grass (hay)</td>
<td>71</td>
<td>0</td>
<td>71</td>
<td>122</td>
<td>-51</td>
</tr>
<tr>
<td>Maize</td>
<td>180</td>
<td>0</td>
<td>180</td>
<td>142</td>
<td>38</td>
</tr>
<tr>
<td>Mungbean</td>
<td>23</td>
<td>65</td>
<td>88</td>
<td>85</td>
<td>3</td>
</tr>
<tr>
<td>Peanut</td>
<td>15</td>
<td>124</td>
<td>139</td>
<td>131</td>
<td>8</td>
</tr>
</tbody>
</table>
Phosphorus (P) use varied substantially for crops assessed in the Mitchell catchment (Table 5-25). The P surplus was very high for crops such as bananas and watermelon that have high P inputs and a low quantity of P in the harvestable product. Conversely, the P surplus was low or even negative for crops such as chickpeas or sesame. A negative P surplus indicates that P inputs are less than the P in the harvestable product. In these instances, P reserves in the soil are being depleted (Stewart and Tiessen, 1987).

Table 5-25 Phosphorus surplus for multiple crops grown in the Mitchell catchment

<table>
<thead>
<tr>
<th>CROP</th>
<th>TOTAL P INPUTS (KG/HA)</th>
<th>P IN HARVESTABLE PRODUCT (KG/HA)</th>
<th>P SURPLUS (KG/HA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana</td>
<td>101</td>
<td>9</td>
<td>92</td>
</tr>
<tr>
<td>Chickpeas</td>
<td>11</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Cotton</td>
<td>22</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td>Jarra grass (hay)</td>
<td>17</td>
<td>18</td>
<td>-1</td>
</tr>
<tr>
<td>Maize</td>
<td>19</td>
<td>27</td>
<td>-8</td>
</tr>
<tr>
<td>Mungbean</td>
<td>25</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>Peanut</td>
<td>33</td>
<td>11</td>
<td>22</td>
</tr>
<tr>
<td>Rice</td>
<td>28</td>
<td>20</td>
<td>8</td>
</tr>
<tr>
<td>Rockmelon</td>
<td>60</td>
<td>9</td>
<td>51</td>
</tr>
<tr>
<td>Sesame</td>
<td>3</td>
<td>18</td>
<td>-15</td>
</tr>
<tr>
<td>Sorghum (grain)</td>
<td>48</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Soybean</td>
<td>22</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>38</td>
<td>16</td>
<td>22</td>
</tr>
<tr>
<td>Sunflower</td>
<td>60</td>
<td>17</td>
<td>43</td>
</tr>
<tr>
<td>Watermelon</td>
<td>60</td>
<td>5</td>
<td>55</td>
</tr>
</tbody>
</table>

The total herbicide, pesticide and fungicide application rates per crop varied substantially for crops grown in the Mitchell catchment (Table 5-26). Some crops, such as bananas, have high pesticide, herbicide and fungicide application rates, while other crops such as rice or mangoes, have much lower application rates. It should be noted that this assessment is quite limited as it is simply
reporting total amounts applied rather than the impact of the active ingredients. Many newer herbicides and pesticides have much lower application rates but their active ingredients are relatively more potent than older chemicals. For example, the pesticide, chlorantraniliprole (Alatacor, Dupont Chemicals), is a recent pesticide that is highly effective against caterpillars in pulse crops and is applied at a rate of just 70 g/ha.

Table 5-26 Herbicide, pesticide and fungicide application rates for multiple crops grown in the Mitchell catchment

<table>
<thead>
<tr>
<th>CROP</th>
<th>TOTAL HERBICIDE APPLICATION (L/HA/CROP)</th>
<th>TOTAL PESTICIDE APPLICATION (L/HA/CROP)</th>
<th>TOTAL FUNGICIDE APPLICATION (L/HA/CROP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorghum (grain)</td>
<td>5.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Avocado</td>
<td>5.5</td>
<td>13.7</td>
<td>13</td>
</tr>
<tr>
<td>Banana</td>
<td>25.3</td>
<td>90</td>
<td>3.7</td>
</tr>
<tr>
<td>Cashew</td>
<td>2</td>
<td>6.4</td>
<td>0</td>
</tr>
<tr>
<td>Chickpeas</td>
<td>8.4</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>Cotton</td>
<td>9.1</td>
<td>2.2</td>
<td>0</td>
</tr>
<tr>
<td>Jarra grass (hay)</td>
<td>6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maize</td>
<td>5.5</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Mango Calypso</td>
<td>3</td>
<td>0.5</td>
<td>3.4</td>
</tr>
<tr>
<td>Mango KP</td>
<td>3</td>
<td>0.5</td>
<td>3.4</td>
</tr>
<tr>
<td>Mungbean</td>
<td>4</td>
<td>3.1</td>
<td>70.1</td>
</tr>
<tr>
<td>Peanut</td>
<td>4.1</td>
<td>0</td>
<td>13.2</td>
</tr>
<tr>
<td>Rice</td>
<td>3.5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Rockmelon</td>
<td>1.5</td>
<td>1.5</td>
<td>4.9</td>
</tr>
<tr>
<td>Sesame</td>
<td>3.8</td>
<td>0.14</td>
<td>0</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>9.1</td>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>Sunflower</td>
<td>NA</td>
<td>0.8</td>
<td>0</td>
</tr>
<tr>
<td>Soybean</td>
<td>2.4</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Watermelon</td>
<td>1.5</td>
<td>1.5</td>
<td>4.9</td>
</tr>
</tbody>
</table>

The number of tillage operations varied substantially across crops grown in the Mitchell catchment. The greater the number of tillage operations, the greater the risk of loss of soil to the environment, which has the potential to end up as suspended sediment in waterways. As well, intensive tillage operations are likely to be more damaging than low-impact tillage operations. Thus, crops such as melons and bananas, which require a high number of both total and intensive tillage operations, pose the greatest risk of soil loss and subsequent environmental degradation. Crops such as rice and maize that have a low number of both total and intense tillage operations pose a lower risk.
5.2.2 SIMULATED POLLUTANT LOSSES

Simulated annual loss of nitrogen (N) via runoff varied depending on crop, climate and soil (Figure 5-20a–d). Mean annual simulated loss of N was 1 kg/ha and the maximum annual loss was 16 kg/ha from a cotton crop on a Brown Sodosol (Figure 5-20c). In general, losses of N via runoff were higher in cotton than in other crops and tended to be higher for the Brown Sodosol than for the Grey Vertosol (Figure 5-20a–d).

Simulated annual losses of leached N were higher than losses via runoff and varied a depending on crop, climate and soil (Figure 5-20e–h). Mean annual simulated N loss was 8 kg/ha and the maximum annual loss was 108 kg/ha from a sugar crop on a Brown Sodosol (Figure 5-20e). In general, losses of leached N were higher in sugar than in other crops and tended to be higher for the Vertosol than for the Brown Sodosol (Figure 5-20e–h).

Simulated annual soil losses also varied according to crop, climate and soil (Figure 5-20i–l). Mean simulated annual loss was 6 t/ha and the maximum annual loss was 42 t/ha from a mungbean crop on a Brown Sodosol (Figure 5-20k). In general, soil loss from cotton, mungbean and sugarcane was higher than for forage sorghum and rice and soil loss tended to be higher for the Brown Sodosol than for the Vertosol.

Pollutant losses vary considerably based on rainfall as N loss via runoff and soil erosion are driven by frequency and intensity of rainfall, while N leaching is driven by water drainage. An example of these differences is a cotton crop simulated at Dunbar Station on a Grey Vertosol: annual rainfall was 559 mm in 2005 and 1440 mm in 2006. Simulated annual N losses through runoff were 0.05 kg/ha in 2005 and 0.9 kg/ha in 2006, while N leaching was 3 kg/ha in 2005 and 39 kg/ha in 2006, respectively, and soil losses were 1.1 t/ha and 5.1 t/h respectively (data not shown). These results are based on a single annual crop and do not include a cover crop or other form of rotational cropping system. Cropping system implications are explored in the next section in the context of reducing pollutant losses.

Climate is also a driver of pollutant losses. Comparison of years with considerably different annual rainfall found N losses via runoff or leaching were greater in years with high rainfall than with low rainfall. Soil texture also plays a role in driving pollutant losses, with sandy soils more prone to N losses via leaching than clay soils (Gaines and Gaines 1994). Future agricultural development could minimise pollutant losses by prioritising development on soils with lower potential for pollutant losses.
Reducing pollutant losses

There is a large body of literature that has investigated approaches to minimise pollutant losses from farming systems in Australia. Refining application rates of fertiliser to better match crop requirements and improving irrigation management are effective ways to minimise N losses (Brodie et al., 2008; Thorburn et al., 2008; Thorburn et al., 2011a; Thorburn et al., 2011c; Webster et al., 2012; Biggs et al., 2013; Thorburn and Wilkinson, 2013). Lower fertiliser application rates has reduced losses of N via leaching from banana crops Armour et al. (2013). The use of ‘best management practices’ including controlled traffic, and banded application of herbicides can substantially reduce the loss of herbicides (Masters et al., 2013; Silburn et al., 2013). Furthermore, crop rotation, particularly the use of a cover crop, can minimise soil loss (Carroll et al., 1997; Dabney et al., 2001). In a simulated example of a cropping rotation that includes a summer cover crop, simulated annual soil loss was reduced from 6.5 t/ha for a single cotton crop, to between 2.2 and 2.4 t/ha for a cotton/sorghum or cotton/soybean rotation (Figure 5-21). Nitrogen losses were little affected by the cropping system rotation but for all scenarios these losses were very low.
Figure 5-21 Simulated annual nitrogen (N) losses via runoff or leaching and soil loss from Chillagoe climate station and a Brown Sodosol for a cotton crop, a cotton/sorghum crop rotation, and a cotton/soybean crop rotation for the Mitchell catchment. Simulation duration was 125 years (1890 to 2015).

5.3 Pest and disease risk

For the Mitchell catchment the risk of arrival of wind-borne fungal pathogens and insect pests directly from Southeast Asia is small and only during a relatively narrow period. The simulations from wind dispersal modelling showed there was no risk from a fungal pathogen or insect pest landing in the Mitchell catchment from Sumatra, Java or Bali (Table 5-27). The greatest risk of a fungal pathogen arriving to this catchment was from Papua, with Papua New Guinea (PNG) and Timor-Leste presenting a lower risk. For insect pests, the only threat is from the coastal area of Papua.

Where risks exist they are only present for part of the year. From mid-April to the beginning of September, the prevailing winds are generally southerlies through to easterlies, i.e. either blowing offshore or back towards Papua New Guinea. As a result, there are no arrivals from any points in Southeast Asia to the Mitchell catchment during this period.

For insects the simulations showed only one week (early February) in which an insect pest could potentially arrive (from Papua) via wind dispersal.
Table 5-27 Proportion of 52 simulations in which a fungal pathogen or an insect pest could have been transported from a location in Southeast Asia to the Mitchell catchment

<table>
<thead>
<tr>
<th>Location</th>
<th>Fungal Pathogen</th>
<th>Insect Pest</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNG (south coast)</td>
<td>0.04</td>
<td>0.00</td>
</tr>
<tr>
<td>PNG (mid- and north coast)</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>Indonesia (Papua – south coast)</td>
<td>0.15</td>
<td>0.02</td>
</tr>
<tr>
<td>Indonesia (Papua – mid- and north coast)</td>
<td>0.08</td>
<td>0.00</td>
</tr>
<tr>
<td>Indonesia (Java and Bali)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Indonesia (Sumatra)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Timor-Leste</td>
<td>0.06</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Biosecurity risk associated with aquaculture in the Mitchell catchment is discussed in the companion technical report on aquaculture viability (Irvin et al., 2018).

5.4 Factoring risk in financial assessment

The analyses undertaken in this technical report that relate to irrigated cropping or forages for integration into beef operations assumed ideal agronomic management. The financial assessments (gross margins in cropping, net profits in integrated beef operations) that utilised these crop outputs therefore provide a picture under optimum management conditions.

There are additional risk factors that need to be considered in a full investment analysis. These include:

- Reliability of water supply. Water will not necessarily be available every year for irrigation, especially for irrigation dependent on surface water storages. Reliability of water from surface storage in the Mitchell catchment is in the order of 80%, which will affect returns on investment. Larger storages improve water reliability but at excessive capital cost. In drier years, water licence conditions will not allow adequate (or any) water capture.

- Learning about the environment. Initiating irrigated cropping in these environments requires a period of learning and experience, which may take several years. During this learning phase, returns are likely to be below longer term expectations and this needs to be factored into financial assessments. Challenges in learning are exacerbated by a high turnover of staff in both the agricultural sector and in government.

- Extreme events. Much of northern Australia is vulnerable to extreme weather events, particularly large wet-season events such as monsoonal troughs and cyclones, and fires in the dry season. In addition, pests and diseases can strike unexpectedly and decimate production over a season or for a number of years. While it is difficult to predict when and where these events will occur, they need to be incorporated as a risk factor in economic assessments.

- Tenure, native title, and approval processes. Developing land for irrigated agriculture usually requires a range of tenure, native title and approval processes to be navigated and negotiated, and this can add considerable cost and time to a development. Unless managed appropriately, these risks can undermine the viability of greenfield agricultural developments.
See the companion technical report on socio-economics (Stokes et al., 2017) and the companion technical report on legal, regulatory and policy (LRP) (Macintosh et al., 2018), which address these aspects in greater detail.
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Appendix A  TAPPAS simulation release locations for Southeast Asia

Apx Figure A-1 TAPPAS simulation release locations for PNG (southern coast)

Apx Figure A-2 TAPPAS simulation release locations for PNG (middle and northern coast)
Apx Figure A-3 TAPPAS simulation release locations for Indonesia (Papua – southern coast)

Apx Figure A-4 TAPPAS simulation release locations for Indonesia (Papua – middle and northern coast)
Apx Figure A-5 TAPPAS simulation release locations for Indonesia (Java and Bali)

Apx Figure A-6 TAPPAS simulation release locations for Indonesia (Sumatra)

Apx Figure A-7 TAPPAS simulation release locations for Timor-Leste
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CONTACT US

FOR FURTHER INFORMATION

Dr Chris Chilcott
 t +61 8 8944 8422
e chris.chilcott@csiro.au
w www.csiro.au/en/research/LWF

Dr Cuan Petheram
 t +61 2 6246 5987
e cuan.petheram@csiro.au
w www.csiro.au/en/research/LWF

Dr Ian Watson
 t +61 7 4753 8606
e ian.watson@csiro.au
w www.csiro.au/en/research/AF

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