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Agricultural resource assessment for the Gilbert catchment

A report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy

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Important disclaimer

Flinders and Gilbert Agricultural Resource Assessment acknowledgments

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The Strategy was guided by two committees:

(i) the **Program Governance Committee**, which included the individuals David Crombie (GRM International), Scott Spencer (SunWater, during the first part of the Strategy) and Paul Woodhouse (Regional Development Australia) as well as representatives from the following organisations: Australian Government Department of Infrastructure and Regional Development; CSIRO; and the Queensland Department of Agriculture, Fisheries and Forestry.

(ii) the **Program Steering Committee**, which included the individual Jack Lake (Independent Expert) as well as representatives from the following organisations: Australian Government Department of Infrastructure and Regional Development; CSIRO; the Etheridge, Flinders and McKinlay shire councils; Gulf Savannah Development; Mount Isa to Townsville Economic Development Zone; and the Queensland Government.

Chapters 1 to 7 of this report were reviewed by Dr Graham Bonnett (CSIRO Plant Industry) and Dr Glen Walker (CSIRO Land and Water). Dr Brian Keating (Sustainable Agriculture Flagship) and Dr Peter Wallbrink (Water for a Healthy Country Flagship) reviewed the entire report. The following people reviewed all or part of one or more case studies (chapters 8 to 10): Dr Andrew Ash (CSIRO Ecosystem Sciences) and Dr Brad Pusey (River Research Pty Ltd).

For further acknowledgements, see page vi.

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Director's foreword

Northern Australia comprises approximately 20% of Australia's land mass but remains relatively undeveloped. It contributes about 2% to the nation's gross domestic product (GDP) and accommodates around 1% of the total Australian population.

Recent focus on the shortage of water and on climate-based threats to food and fibre production in the nation's south have re-directed attention towards the possible use of northern water resources and the development of the agricultural potential in northern Australia. Broad analyses of northern Australia as a whole have indicated that it is capable of supporting significant additional agricultural and pastoral production, based on more intensive use of its land and water resources.

The same analyses also identified that land and water resources across northern Australia were already being used to support a wide range of highly valued cultural, environmental and economic activities. As a consequence, pursuit of new agricultural development opportunities would inevitably affect existing uses and users of land and water resources.

The Flinders and Gilbert catchments in north Queensland have been identified as potential areas for further agricultural development. The Flinders and Gilbert Agricultural Resource Assessment (the Assessment), of which this report is a part, provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of agricultural development in these two catchments as part of the North Queensland Irrigated Agricultural Strategy. The Assessment seeks to:

- identify and evaluate water capture and storage options
- identify and test the commercial viability of irrigated agricultural opportunities
- assess potential environmental, social and economic impacts and risks.

By this means it seeks to support deliberation and decisions concerning sustainable regional development.

The Assessment differs from previous assessments of agricultural development or resources in two main ways:

- It has sought to 'join the dots'. Where previous assessments have focused on single development activities or assets – without analysing the interactions between them – this Assessment considers the opportunities presented by the simultaneous pursuit of multiple development activities and assets. By this means, the Assessment uses a whole-of-region (rather than an asset-by-asset) approach to consider development.
- The novel methods developed for the Assessment provide a blueprint for rapidly assessing future land and water developments in northern Australia.

Importantly, the Assessment has been designed to lower the barriers to investment in regional development by:

- explicitly addressing local needs and aspirations
- meeting the needs of governments as they regulate the sustainable and equitable management of public resources with due consideration of environmental and cultural issues
- meeting the due diligence requirements of private investors, by addressing questions of profitability and income reliability at a broad scale.

Most importantly, the Assessment does not recommend one development over another. It provides the reader with a range of possibilities and the information to interpret them, consistent with the reader's values and their aspirations for themselves and the region.

Peter Stone

Dr Peter Stone, Deputy Director, CSIRO Sustainable Agriculture Flagship

Key findings

North Queensland's Gilbert catchment, comprising an area of approximately 46,000 km^2, drains into the southern Gulf of Carpentaria. Its population of approximately 1200 people is engaged mainly in pastoralism, but tourism, mining and commercial fishing make important contributions to the economy. Dryland and irrigated cropping currently occupy less than 0.02% of the landscape.

This report on the Gilbert catchment seeks to:

- identify and evaluate water capture and storage options
- identify and test the commercial viability of irrigated agricultural opportunities
- assess potential environmental, social and economic impacts and risks.

The Assessment acknowledges that locals have insights, skills and aspirations to contribute to development plans for the benefit of their region, community and environment. Scientific knowledge of the type produced by this Assessment should complement rather than compete with local knowledge.

Water capture and storage options

Two prospective instream water storages (dams) of significant scale have been identified (Green Hills and Dagworth dams). When combined, these two dams are capable of delivering to crops approximately 250 gigalitres (GL) of water in 85% of years. The next four most prospective instream dams add relatively small volumes of water at relatively high cost.

There is more soil suited to irrigation in the Gilbert catchment than there is water to irrigate it. If the most prospective six instream storages were to exist, it would be possible to irrigate approximately 0.6% of the catchment's irrigable soils.

On-farm dams are considered less prospective because of the catchment's often sandy soils, though there are locations suited to on-farm water storage.

Agricultural opportunities

Based on the identified water storage and the large areas of potentially irrigable agricultural soils (approximately 2 million ha), there is the potential for an irrigation development of 20,000 to 30,000 ha supporting year-round mixed irrigated and dryland cropping. The precise area under irrigation will, in any year, vary depending on factors such as irrigation efficiency, water availability, crop choice and risk appetite. A development of this scale is larger than the existing Ord River Irrigation Area, and may be sufficient to sustain local processing facilities such as a cotton gin or a sugarcane mill. If crops were grown to their full potential, the regional gross margin of crop production could exceed $60 million/year.

Dryland production is sensitive to the very high year-to-year variability of rainfall in the Gilbert catchment. Break-even yields of most crops can be achieved only two to three years in ten, which precludes commercial returns on development costs such as land clearing. If these costs are 'sunk', commercial returns from dryland cropping require that crops approach their full yield potential and that they are grown only in years when cropping opportunity is high. This can be clearly distinguished at sowing time using seasonal rainfall outlooks and information about water stored in dams and in soil. Despite these challenges, dryland cropping is likely to be a component of irrigation development.

Environmental impacts and risks

Irrigated agricultural development has a wide range of potential benefits and risks.

The two most prospective dams would, in the downstream environment, amplify the environmental and other challenges associated with dry years. Critical environmental processes (such as wetland inundation) would not be greatly affected by water extraction in 'average' or wet years, largely because the dams would be located in the middle reaches of the catchment and would intercept a mean 14% and median 20% of flow to the Gulf of Carpentaria. Impacts of reduced river discharges to the Gulf on commercial and recreational fishing catches are possible but have not been quantified in this study. Large-scale change of land and water use is likely to require a wide range of regulatory, social and cultural responses, including consideration of native title implications.

Under the development scenarios examined, the high capital costs of dams and water delivery infrastructure (approximately $1 billion) precludes economic returns on combined investment in water assets and irrigated farming. Where third-party investment in water storage and delivery was examined, it was found that commercial returns on irrigated agriculture are possible when crops approached their full yield potential – a condition that becomes more probable with experience.

Key deliverables

This report is one of two catchment reports within a suite of products provided by the Assessment to fulfil its contractual obligations:

- Technical reports present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work.
- Each of the two catchment reports (i.e. this report and another for the Flinders catchment) synthesises key material from the technical reports, providing well-informed but non-scientific readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture.
- Two overview reports – one for each catchment – are provided for a general public audience.
- A factsheet provides key findings for both the Flinders and Gilbert catchments for a general public audience.

All these products are listed in full in Appendix A.

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

The communities of the Flinders and Gilbert catchments enthusiastically embraced the Assessment team. They provided: (i) hospitality, (ii) historical and contextual information, (iii) access to land and help in finding waterholes, bores, promising dam sites and other features, (iv) unpublished reports, and (v) answers to a bewildering array of questions from the Assessment team. Importantly, they also gave us 'the time of day', showing us around the catchment and their landholdings and providing the local context that is so important for work of this kind. In particular, we thank the members of FRAP, the Flinders River Agricultural Precinct. Brendan McNamara as Chair was welcoming from the beginning. Corbett Tritton, Chair of the Flinders River Agricultural Precinct Growers Group and a local grazier and irrigator was generous with his time, expertise and insights into agricultural development as well as providing access to his crops for the Assessment team to collect data. Ninian Stewart-Moore, Brian Hughes, Ardie Lord, Darren Beeton, Alistair McClymont, Edward McIntosh, Scott Harris, Campbell Keough, David and Kenneth Coleman, Colin Blacklock, Ray Theme, Jacqueline and Robert Curley as well as many other landholders helped the Assessment team. Brad Bowen and Ken and Brendan Fry took us through their existing irrigated enterprises. Grant Randell contributed both his expertise and his land and water to help us understand the opportunities for a range of crops. Landholders also contributed their time to formal surveys of their attitudes to agricultural development in the two catchments. Julie Harrison, the FRAP Project Officer, provided an enormous amount of assistance to the Assessment team. If Julie didn't know the answer to a question, she put us in touch with someone who did. She helped organise our contacts with the local community and, importantly, Julie was such an enthusiastic supporter and advocate of the Assessment team that she provided the credibility that we needed for others to contribute their thoughts, expertise and information.

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The North Queensland Irrigated Agriculture Strategy's steering committee and governance committee provided us with wise counsel, good advice and the confidence that the Assessment was progressing well. The Stakeholder Engagement and Communication Strategy working group, especially Bec Jennings and Vern Rudwick, was instrumental in ensuring cross-agency co-ordination and provided communication products to stakeholders.

Our client, the Office of Northern Australia, provided us with the challenge of attempting such a complex multi- and inter-disciplinary project in a very short time. Andrew Dickson, Lee Chaney and Peter Mellor were critical to ensuring the Assessment proceeded smoothly.

A long list of expert reviewers provided advice that improved the quality of our methods report, the various technical reports and the two catchment reports.

Colleagues in CSIRO and elsewhere provided freely of their time and expertise to help with the Assessment. This was often at short notice and of sufficient scale that managing their commitment to other projects became challenging. The list is long, but we'd particularly like to thank Andrew Ash, Chris Stokes, Andrew Johnson, Liz Stower, Mike Grundy, Peter L Wilson, Robyn Cowley, Cam McDonald, Lindsay Bell, Jizelle Khoury, Peter Wallbrink, David Lemon, Brett Baker and Aaron Hawdon. CSIRO administrative, financial and legal staff provided great support, especially Sharyn Butts, Ali Wood, Fiona Johnstone, John Nappo, Jacqui Watt, Nicole Smith, Kristina Roberts, Ken Currie and Cie Rogers. Many other people, including Wayne Lillyman and Bernie Cornfoot provided costings or technical expertise to allow us to produce accurate modelling of development opportunities.

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

Contents

Part I Introduction

Chapters 1 and 2 provide background and context for the Assessment and outline the methods adopted to undertake the work:

- Chapter 1 covers the background and context of the Assessment.
- Chapter 2 provides a high-level outline of the methods used by the Assessment. This information is designed to assist in understanding the limitations to – and uncertainty associated with – the information provided by the Assessment.

Readers will find these chapters provide the context for and critical foundational information about the Assessment with key concepts introduced and explained.

For a synthesis of the key findings from the Assessment, see page ii.

1 Preamble

Authors: Cuan Petheram, Ian Watson, Frances Marston, Heinz Buettikofer and Peter Stone

1.1 Context: development in northern Australia

Sustainable regional development is a priority for the Australian, Western Australian, Northern Territory and Queensland governments. Together, they are implementing a comprehensive plan for the sustainable development of northern Australia through the *Northern Australia Sustainable Futures* program managed by the (then) Australian Government's Northern Australia Ministerial Forum. A key component of the program is the North Queensland Irrigated Agriculture Strategy (NQIAS), a suite of projects investigating the potential for development of water resources in north Queensland that seeks to unlock opportunities for new and existing agricultural production. The Flinders and Gilbert Agricultural Resource Assessment forms part of the NQIAS.

The Northern Australia Ministerial Forum and subsequent *Northern Australia Sustainable Futures* program arose directly from the recommendations of the Northern Australia Land and Water Taskforce which reported to the Australian Government in late 2009 (NALWT, 2009). The Taskforce foresaw a significant increase in the gross value of agricultural production in northern Australia. The Taskforce recognised that a number of improvements could help this growth:

- improved transport infrastructure
- harmonisation of regulatory frameworks across jurisdictions
- changed agricultural systems
- governance arrangements
- land tenure reform
- infrastructure upgrades
- intensification of the pastoral industry
- carbon markets
- increases in the total irrigated land (either through mosaic irrigation or larger precincts)
- investment in Indigenous pastoral businesses.

The Taskforce recognised that risk attended the opportunity for increased agricultural production. Environmental, cultural and community risks needed to be thoroughly considered in any analysis of the opportunity. The Taskforce also recognised that there are critical gaps in our knowledge and data sources and that addressing these would improve the prospects for sustainable development (NALWT 2009).

Growth in agricultural production is needed in order to meet the growing demand for food globally. Between 2000 and 2050, the world's population is projected to grow from six to nine billion people (UNESCO, 2009). The majority of this growth is projected to occur in the tropics, particularly sub-Saharan Africa and South-East Asia. With two-thirds of the world's food insecurity in Asia, sharp upward price movements in food have been identified as potentially resulting in political and social unrest (PMC, 2012). At the same time, it is projected that Asia will become home to the majority of the world's middle class, which will result in an increasing demand for high-quality food produce from this region (PMC, 2012). Australia's National Food Plan recognises this and the Australian Government has explicitly developed a number of activities that aim to help Australia develop its food-producing potential, including in northern Australia (DAFF, 2013).

Irrigated crop-based agriculture, which currently occupies less than 1% of Australia's farmed land, generates over half of the net value of the nation's agricultural exports (NLWRA, 2002), but in doing so uses nearly 70% of all water used for human needs nation-wide (Prosser, 2011). Of Australia's irrigated land, 95% lies south of the Tropic of Capricorn and 65% is located within the Murray–Darling Basin (MDB)

(NLWRA, 2000) (Figure 1.1). Overallocation of water resources in many areas of southern Australia, memories of the recent millennium drought, future projections of reduced rainfall across southern Australia (CSIRO, 2009; CSIRO, 2012) and perceptions of an abundant amount of water in northern Australia have domestic irrigation investors increasingly looking north for agricultural opportunities (ABC, 2013). In fact, some foreign companies have already invested heavily in irrigation in northern Australia (AAP, 2012). With studies in the southern MDB showing that irrigation production generates a level of economic and community activity that is three to five times higher than would be supported from rainfed (dryland) production (Meyer, 2005), many rural communities in northern Australia see irrigated agriculture as a means of reversing the long-term trend for population decline and a critical element of broader regional development aspirations.

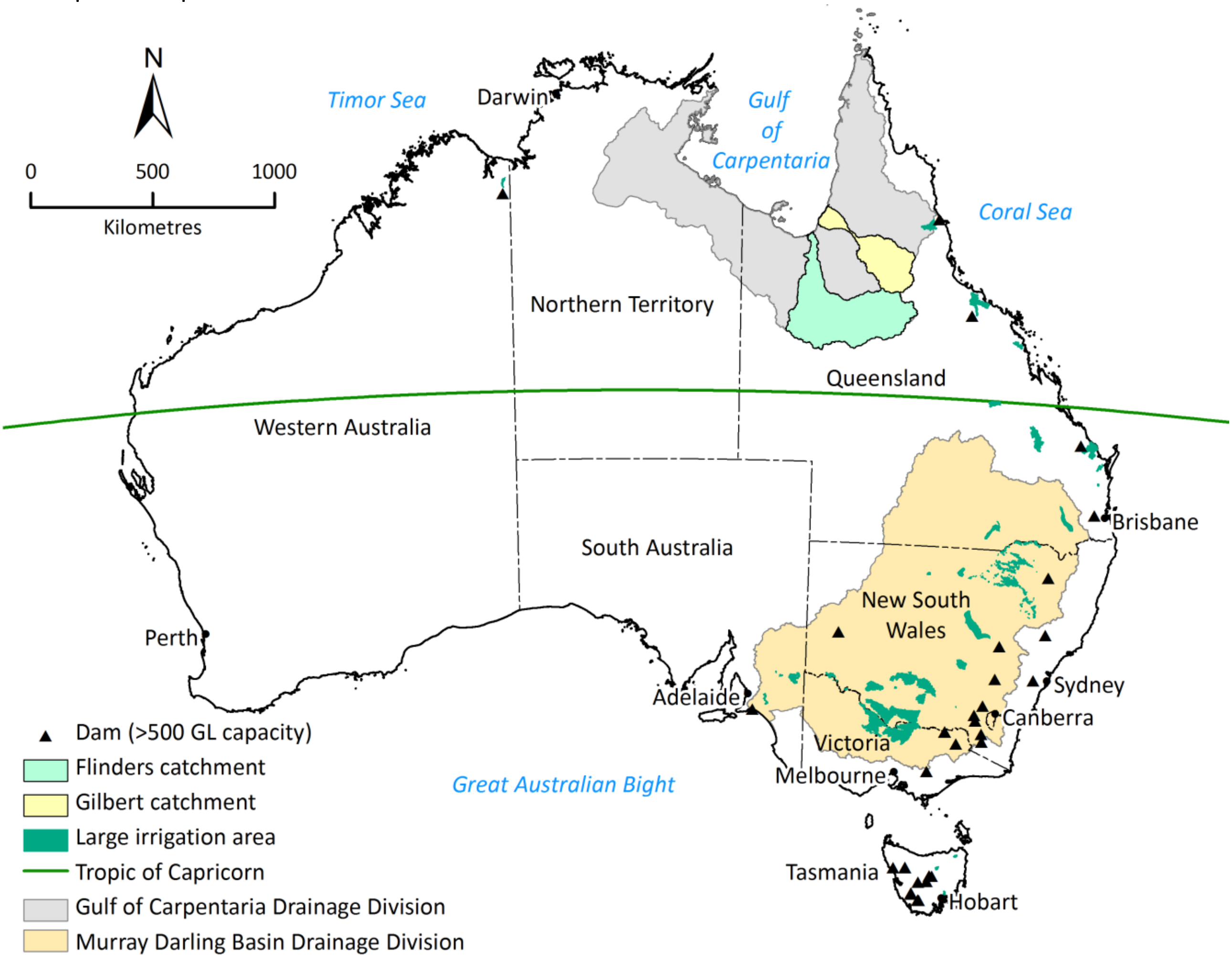

Figure 1.1 Major dams (greater than 500 GL capacity), large irrigation areas and selected drainage divisions across Australia

The Flinders and Gilbert catchments of the Flinders and Gilbert Agricultural Resource Assessment are also shown.

Development of northern Australia is not a new idea. Initiatives to develop cultivated agriculture in the tropical north of Australia have a long history. Many of these attempts have not fully realised their goals, for a range of different reasons (Davidson, 1965; Kelly, 1966; Davidson, 1969; Lacey, 1979; Woinarski and Dawson 1997; Cook, 2009). Even as early as the 1930s, the view of northern Australia as a ‘problem region’ was well established – the tropical environment made the region’s full integration into the nation difficult (Courtney, 1977).

However, northern Australia is now seen to be located in the right place at the right time (PMC, 2012). With growth in Asia and the Tropics, the global economic centre of gravity is shifting towards Australasia and so the tyranny of distance is being replaced by the advantage of relative proximity. However, the relatively unspoilt natural features and cultural heritage of northern Australia have highly significant intrinsic values that warrant careful protection. The sustainable development of northern Australia will be assisted by evidence-based decisions that explicitly recognise the trade-offs and synergies involved in developing these lands.

The efficient use of Australia's natural resources by food producers and processors is likely to increase the importance of understanding and sustainably managing Australia's soil, water and energy resources. Finely tuned strategic planning will be required to ensure that investment and government expenditure on development is soundly targeted and designed. In terms of knowledge about and development of the natural resource base, northern Australia presents a relatively 'blank slate', with few 'legacy issues', particularly when compared to southern Australia. This presents a globally unique opportunity to strategically consider and plan the development of a vast area of Australia.

1.2 Flinders and Gilbert Agricultural Resource Assessment

The Flinders and Gilbert Agricultural Resource Assessment (the Assessment) – part of the NQIAS mentioned in Section 1.1 – provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water resource development in the catchments of the Flinders and Gilbert rivers in north-west Queensland, an area known locally as the 'Gulf region'. While the focus is on two specific catchments, the techniques and approaches have been developed so that they can be applied elsewhere in northern Australia.

The Flinders and Gilbert catchments were chosen because they are in a part of northern Australia where there has been a long-standing interest in irrigated agriculture and the government and local community believe there is opportunity for agricultural development. Pastoral settlement in these catchments dates back to the 1860s (Morwood, 1990) but in recent years there have been numerous calls by local landholders, shire councils and development advocates (such as the Mount Isa to Townsville Economic Development Zone (MITEZ) and Gulf Savannah Development (GSD)) for irrigation investment in the region.

These two catchments face many of the same barriers to investment as other regions across northern Australia, but have the advantage of being relatively close (about six to eight hours drive) to the two largest population centres in northern Australia, Townsville and Cairns. They are suitable candidates for a large-scale assessment of the economics and sustainability of irrigated agriculture.

The Assessment set out to determine what soil and water resources are available for irrigated agriculture and to determine the extent to which irrigated agriculture is economically viable and sustainable.

Additionally, the Assessment was designed to:

- address explicitly the needs and aspirations of local development – such as those identified by GSD and the MITEZ – to expand irrigated agriculture and to intensify beef production in north Queensland
- meet the information needs of governments as they assess sustainable and equitable management of public resources with due consideration of environmental and cultural issues
- meet the due diligence requirements of private investors, by exploring questions of profitability, environmental integrity and income reliability of agricultural and other developments.

The Assessment commenced in January 2012 and was completed in December 2013. Workshops to communicate results and outcomes were held in early 2014.

1.2.1 SCOPE OF WORK

The Assessment undertook a number of activities that together were designed to explore the scale of the opportunity for irrigated agricultural development in the Flinders and Gilbert catchments. The full suite of activities is outlined below, in Chapter 2 and a series of technical reports produced as part of the Assessment (listed in Appendix A).

The Assessment did not seek to advocate irrigation development or assess or enable any particular development; rather it sought to identify the resources that could be deployed in support of potential irrigation enterprises, and the scale of the opportunities that might exist. In doing so, the Assessment sought to quantify the monetary and non-monetary values associated with existing use of those resources, to enable a wide range of stakeholders to assess for themselves the costs and benefits of given courses of action. The Assessment is essentially a resource assessment, the results of which can be used to inform planning and investment decisions by citizens, councils, and state and federal governments. Importantly, the Assessment does not seek to replace any planning processes, or to recommend changes to existing plans or planning processes.

The emphasis was on surface water resources. Groundwater was not assessed for use as a resource; rather the potential for dominant groundwater processes to change under irrigation development was investigated.

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

The Assessment did not assume a given regulatory environment. The Assessment evaluated the availability and use of resources in accordance with existing regulations, but also examined resource use unconstrained by regulations, so as to allow the results to be applied to the widest range of uses possible, for the longest time frame possible.

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

Functionally, the Assessment adopted an activities-based approach to the work (which is reflected in the content and structure of the outputs and products) with the following activities: agricultural productivity; aquatic and riparian ecology; climate; flood mapping; geophysics; groundwater; Indigenous water values; instream waterholes; irrigation infrastructure; land suitability; river modelling; socio-economics; and water storage.

In order to meet the requirements specified in the contracted 'Timetable for the Services', the Assessment provided the following key deliverables (listed in full in Appendix A):

- Technical reports present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the activities of the Assessment has a corresponding technical report.
- Each of the two catchment reports (i.e. this report and another for the Flinders catchment) synthesises key material from the technical reports, providing well-informed but non-scientific readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture.
- Two overview reports – one for each catchment – are provided for a general public audience.
- A factsheet provides key findings for both the Flinders and Gilbert catchments for a general public audience.

1.3 Report objectives and structure

This report is one of two catchment reports. The content reflects the activities undertaken by the Assessment, synthesising information from the technical reports (see Appendix A) so that people can answer questions such as the following in the context of their particular circumstances in the Gilbert catchment:

- What soil and water resources are available for irrigated agriculture?
- What are the existing ecological systems, industries, infrastructure and values?
- What are the opportunities for irrigation?
- Is irrigated agriculture economically viable?
- How can the sustainability of irrigated agriculture be maximised?

The structure of each catchment report is as follows.

1.3.1 PART I INTRODUCTION

This part provides background, context and a general overview of the Assessment:

- Chapter 1 covers the background and context of the Assessment.
- Chapter 2 provides a high-level outline of the methods used by the Assessment. This information is designed to assist in understanding the limitations to – and uncertainty associated with – the information provided by the Assessment.

Key findings can be found in the front materials of this report.

1.3.2 PART II INFORMATION FOR ASSESSING POTENTIAL SCHEME-SCALE AND FARM-SCALE IRRIGATION DEVELOPMENTS

This part summarises information from the technical reports for each activity and provides tools and information to enable stakeholders to see the opportunities for development and the risks that attend to them. Using the establishment of a 'greenfield' (not having had any previous development) irrigation development as an example, Figure 1.2 illustrates many of the complex considerations required for such development – key report sections that inform these considerations are also indicated.

- Chapter 3 is concerned with the physical environment and seeks to address the question of what soil and water resources are present in the Gilbert catchment, describing:
  - geology – focusing on those aspects of geology that are important for understanding the distribution of soils, groundwater flow systems, suitable water storage locations and rocks of economic importance
  - soils – covering the distribution of key soil attributes and the general suitability for irrigated agriculture
  - climate – outlining the general circulatory systems affecting the catchment and providing information on key climatic parameters of relevance to irrigation under current and future climate
  - hydrology – describing and quantifying the hydrology of the catchment, specifically focusing on assessing the surface water resources under current and future climate.
- Chapter 4 is concerned with the living and built environment and provides benchmark information about the people and ecology of the Gilbert catchment. Specifically, it discusses:
  - contemporary ecology
  - Indigenous pre-history and colonial history
  - Indigenous water values, rights and interests, and Indigenous development aspirations
  - catchment profile – describing the current demographics and existing industries and infrastructure of relevance to irrigation development in the Gilbert catchment.

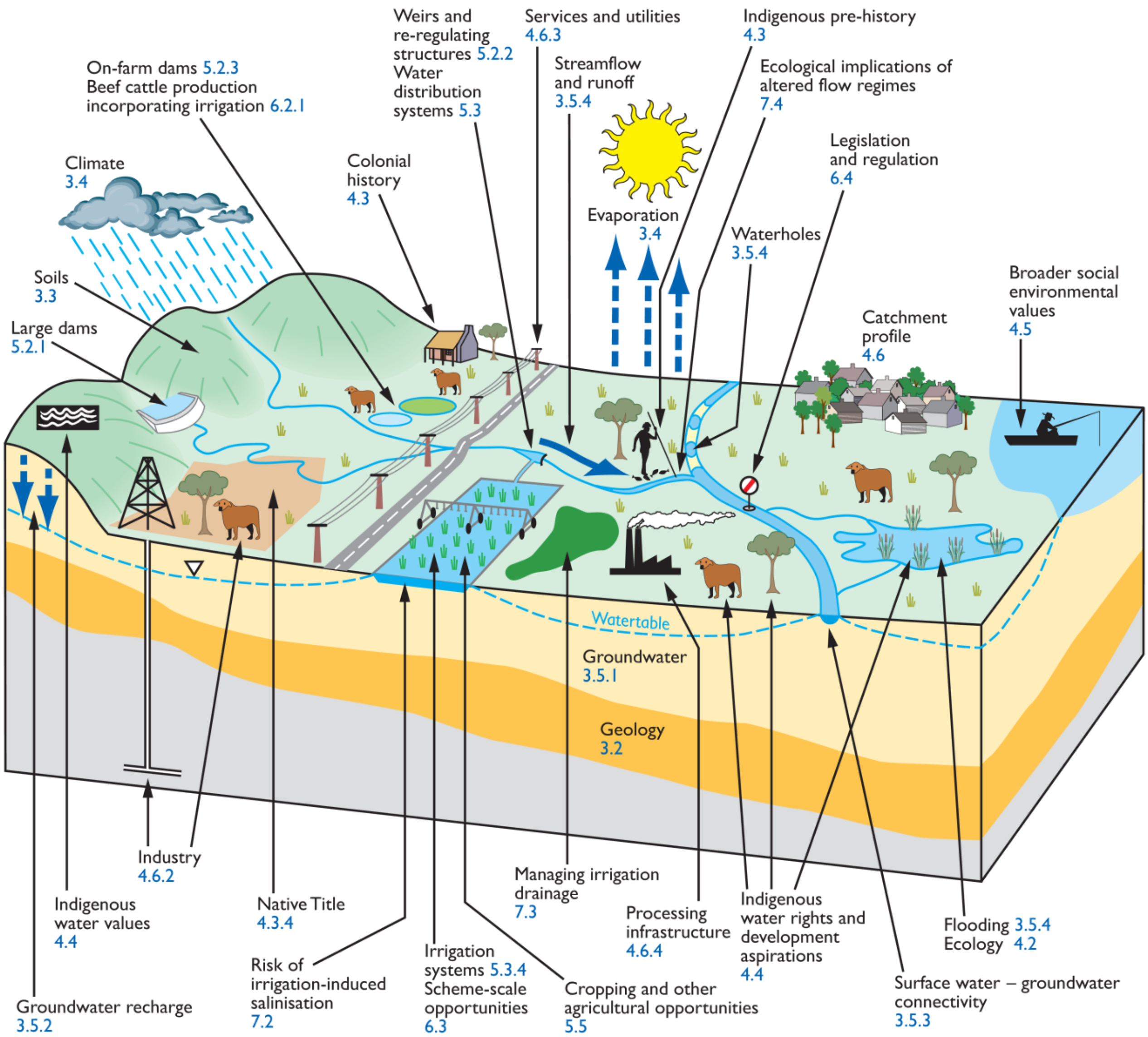

Figure 1.2 Schematic diagram of key components and concepts in the establishment of a greenfield irrigation development

- Chapter 5 presents information about the opportunities for irrigated agriculture in the Gilbert catchment:
  - water storage opportunities – examining large dams and on-farm water storage opportunities in the Gilbert catchment and quantifying the amount of water that could be regulated (i.e. made available for irrigation)
  - water distribution systems (i.e. conveyance of water from a dam and application to the crop) – examining the costs and losses associated with conveying water from a dam and its application to a crop
  - cropping and other agricultural opportunities – examining the cropping opportunities and considerations and lessons learned from experiences in the Gilbert catchment and providing maps of land suitability for selected crops.
- Chapter 6 covers economic opportunities and constraints for irrigation development:
  - economic analysis of costs and benefits conducted at the scale of farm, scheme and statistical division (SD)
  - legislative and regulatory opportunities and impediments

- impacts of capital costs, water availability, crop type, irrigation system, and commodity price on the viability of irrigation development.

- Chapter 7 covers how to maximise the sustainability of irrigated agriculture by considering:
  - the risk of rise in watertable level
  - the potential for increased groundwater discharge to rivers in the Gilbert catchment
  - the risk of increased sediment, nutrients and pesticide loads from irrigation to the Gilbert River
  - the impacts of altered flow regimes on aquatic and riparian ecology.

1.3.3 PART III CASE STUDIES

This part provides an assessment of three geographically distinct illustrative case studies for the catchment.

Part III builds on Part II, using the case studies to demonstrate the use of the tools and information provided in Part II. These case studies represent an integrated evaluation of the scale of opportunity for irrigation development in selected geographic areas of the catchment, and enable an assessment of the viability of irrigation and its sustainability.

The case studies are provided to illustrate the potential for application of the knowledge developed in the Assessment. The Assessment is not advocating these developments – or types of development – nor is it saying they are more or less likely than other developments.

In this report about the Gilbert catchment, case studies are presented in chapters 8 to 10:

- Chapter 8 – the potential development of a dam at Green Hills station on the Gilbert River. This case study assesses a cotton – peanuts – sorghum (forage) rotation, with a cotton gin at Charters Towers.
- Chapter 9 – the potential development of two dams, one on the Einasleigh River at Dagworth Station and the other on the Gilbert River at Green Hills station. This case study assesses the benefits of an irrigated sugarcane precinct with a sugar mill located at Georgetown.
- Chapter 10 – the use of the existing Kidston Dam on the Copperfield River to potentially irrigate Rhodes grass grown around the town of Einasleigh, for local markets.

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2 Key concepts and Assessment methods

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This chapter defines a number of key concepts and provides a high-level description of the methods used by the Flinders and Gilbert Agricultural Resource Assessment (the Assessment), focusing particularly on the Gilbert catchment.

2.1 Key concepts

A number of key concepts provide a critical basis fundamental to the Assessment – these are outlined below. The reader is also directed to the glossary, units of measure and geological time scale sections contained in Appendix B.

2.1.1 GILBERT CATCHMENT AND THE ASSESSMENT AREA

As already described in Chapter 1, the Gilbert catchment lies within an area known locally as the Gulf region (Figure 2.1), loosely defined as comprising the Settlement Creek, Nicholson, Leichhardt, Morning Inlet, Flinders, Norman, Gilbert, Staaten, Mitchell and Coleman catchments. The Gilbert catchment, the focus of this report, is shown in Figure 2.2.

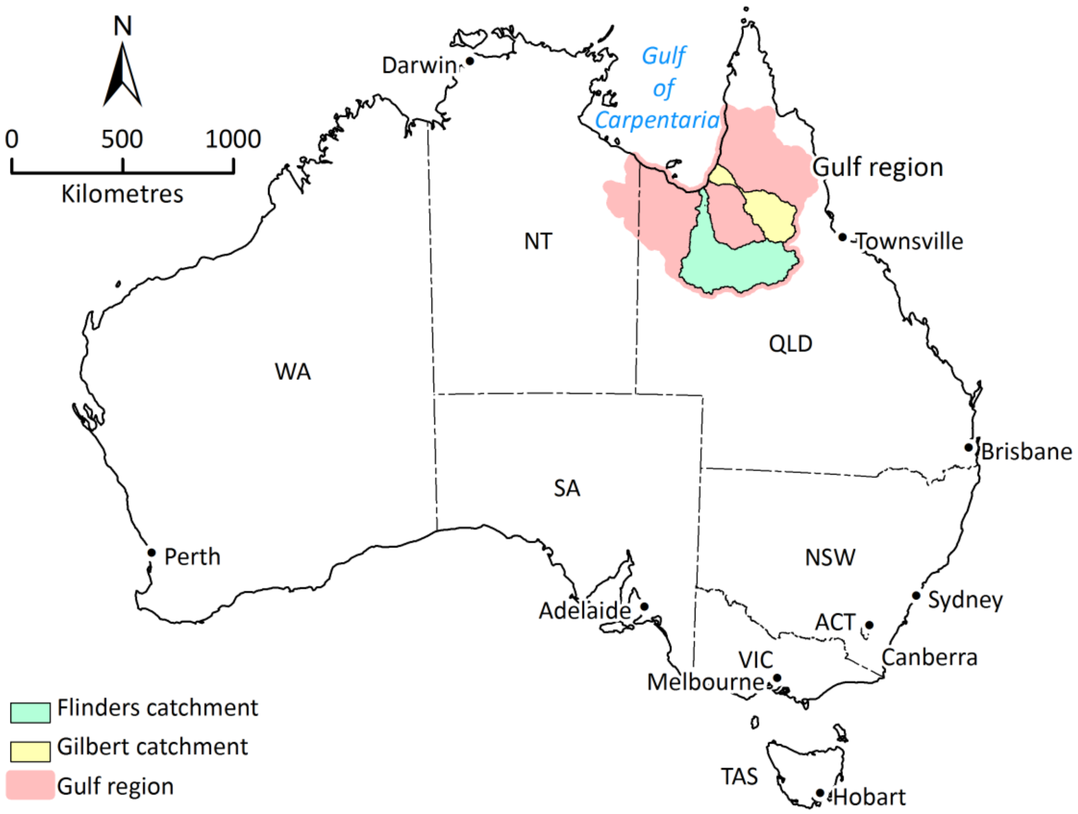

Figure 2.1 The Flinders and Gilbert catchments within the Gulf region of northern Australia

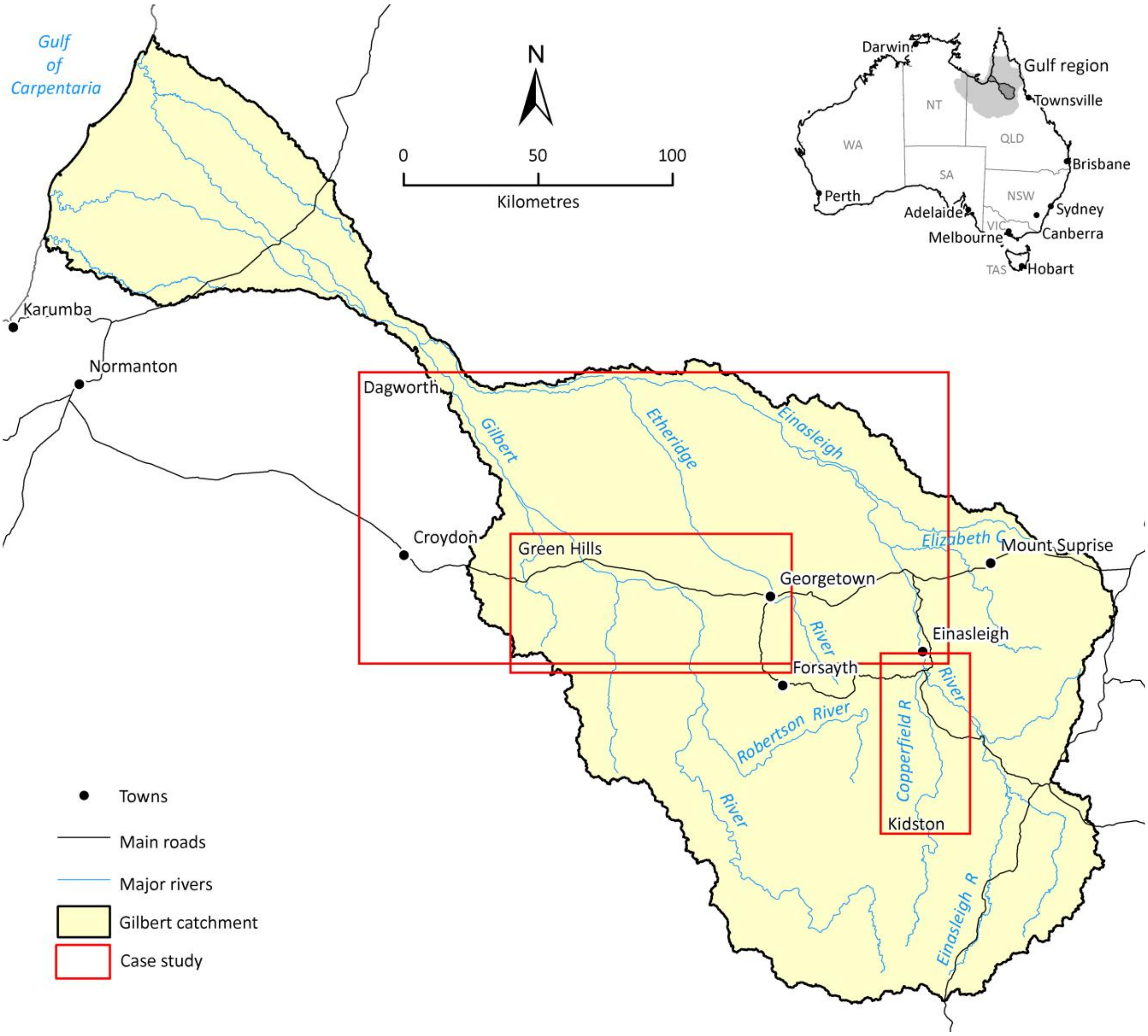

Figure 2.2 The Gilbert catchment

2.1.2 WATER YEAR AND WET AND DRY SEASONS

The Gulf region experiences a highly seasonal climate, with the majority of rain falling between December and March. Unless specified otherwise the wet season is defined as being the six-month period from 1 November to 30 April and the dry season is the six-month period from 1 May to 31 October. All results in the Assessment are reported over the 'water year', defined as the period 1 July to 30 June and which allows each individual wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons). This is the best option for reporting climate statistics in northern Australia and from a hydrological and agricultural assessment viewpoint.

2.1.3 SCENARIO DEFINITIONS

The Assessment, considered three different scenarios of climate and surface water, groundwater and economic development, as used in the Northern Australia Sustainable Yields Project (CSIRO, 2009a, b, c):

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

As the primary interest was in evaluating the scale of the opportunity for irrigated agriculture development under the current climate, the future climate scenario (Scenario C) was secondary in importance to scenarios A and B. This balance is reflected in the allocation of resources throughout the Assessment.

Scenario A

Scenario A included historical climate and current development. The historical climate data were of 121 years (water years from 1 July 1890 to 30 June 2011) of observed climate (rainfall, temperature and potential evaporation for water years). All results presented in this report are reported over this period unless specified otherwise. Current development is the current level of surface water, groundwater and economic development that was defined as that of 1 July 2013. The Assessment assumes that all current entitlements are being fully used. Scenario A was used as the baseline against which assessments of relative change were made. Historical tidal data were used to specify downstream boundary conditions for flood modelling undertaken by the Assessment.

Scenario B

Scenario B included historical climate and future irrigation development (see the case studies in chapters 8 to 10), undertaken by the Assessment through discussion with stakeholders. Scenario B used the same historical climate data as Scenario A. Future irrigation development is described by each case study storyline, and river inflow and agricultural productivity were modified accordingly.

Scenario C

Scenario C included future climate and current development. It was based on a 121-year climate data sequence scaled for ~2060 conditions. These climate data were derived from a range of global climate model (GCM) projections for a 2 °C global temperature rise scenario which encompassed different GCMs for this single global warming scenario – the projections were then used to modify the observed historical daily climate sequences. The current level of surface water, groundwater and economic development were assumed. Tidal level data were manipulated to reflect a ~2060 sea-level rise (i.e. the median date at which the GCMs reach a 2 °C global temperature rise).

2.1.4 ILLUSTRATIVE CASE STUDIES

The Assessment considered three case studies in the Gilbert catchment, as described in chapters 8 to 10. The purpose of the case studies is to evaluate the scale of opportunity for irrigation in key geographic areas of the catchment. By analysing water storage options and potential crops, they enable assessments of the viability and sustainability of irrigated agriculture.

Three case studies were undertaken in the Gilbert catchment:

- Green Hills dam and irrigated three-crop rotation
- Dagworth and Green Hills dams and irrigated sugarcane
- Kidston Dam and irrigated Rhodes grass.

2.2 Assessment methods

The Assessment set out to provide information to enable people to answer five questions for their particular circumstances about irrigation in the Gilbert catchment:

- What soil and water resources are available for irrigated agriculture?
- What are the existing ecological systems, industries, infrastructure and values?
- What are the opportunities for irrigation?
- Is irrigated agriculture economically viable?
- How can the sustainability of irrigated agriculture be maximised?

To provide information to enable people to address these questions, work was undertaken across five broad topics by 13 scientific activities (Table 2.1).

Table 2.1 Assessment questions, topics and activities

TOPIC	ASSESSMENT QUESTION	SCIENTIFIC ACTIVITY
Resource assessment	What soil and water resources are available for irrigated agriculture?	Climate, geophysics, land suitability, river modelling: calibration, flood mapping, instream waterholes, groundwater
Existing environment	What are the existing ecological systems, industries, infrastructure and values?	Aquatic and riparian ecology, Indigenous water values, socio-economics: costs and benefits
Irrigation opportunities	What are the opportunities for irrigation?	Water storage, agricultural productivity
Economic viability	Is irrigated agriculture economically viable?	Socio-economics: costs and benefits
Sustainability	How can the sustainability of irrigated agriculture be maximised?	Aquatic and riparian ecology, groundwater, socio-economics: triple-bottom-line accounting

The remainder of this chapter broadly describes the methods used by the Assessment, presenting them in line with the five questions and focusing particularly on the Gilbert catchment. For a more comprehensive, detailed technical description of the methods, see the suite of companion technical reports presented in Appendix A.

2.2.1 WHAT SOIL AND WATER RESOURCES ARE AVAILABLE FOR IRRIGATED AGRICULTURE?

The question 'What soil and water resources are available for irrigated agriculture?' is addressed in Chapter 3, 'Physical environment of the Gilbert catchment'.

It describes the information and methods needed to (i) understand the geology (including the subsurface stratigraphy or underlying geological organisation), (ii) identify, map and quantify the available soil resources, (iii) develop future climate scenarios and (iv) determine the characteristics of the catchment's water resources (or hydrology).

Geology of the Gilbert catchment

To understand the underlying geological organisation of the Gilbert catchment, the Assessment made extensive use of existing geological maps (available at 1:250,000 scale) and region-scale radiometric datasets (i.e. data measuring radioactivity). Radiometric surveys infer the spatial distribution of radioactive elements that are released from rocks and re-distributed during weathering and erosion, and consequently are very useful in understanding the distribution of soils. Radiometric data are available across the entire Gilbert catchment. These existing datasets were central to understanding the distribution of groundwater, soil and better water storage locations in the Gilbert catchment. In some instances the existing geological and radiometric data were supplemented with electromagnetic data acquired as part of an airborne geophysical survey undertaken as part of the Assessment. The survey was flown over the Assessment area between 26 November 2012 and 12 December 2012, and over 1830 km of data were acquired. The survey flight lines are shown in Figure 2.3. These datasets are presented in the companion technical report about geophysics (Munday et al., 2013), and are publically available for future studies from the Assessment website at <http://www.csiro.au/FGARA>.

Soils of the Gilbert catchment

The lack of soil information across most of northern Australia is a key impediment to planned agricultural development. Prior to the Assessment, soil across the Gilbert catchment was mapped at a 1:1,000,000 scale based on land system mapping, though small specific areas had been mapped at a finer scale (i.e. 1:100,000 to 1:250,000) through additional measurements or simply reinterpretation of the land system mapping undertaken by CSIRO in the 1950s. This scale of soil mapping is typical of most regions across northern Australia. The Assessment therefore used a combination of legacy data obtained from previous work and new data collected as part of this Assessment (Figure 2.3).

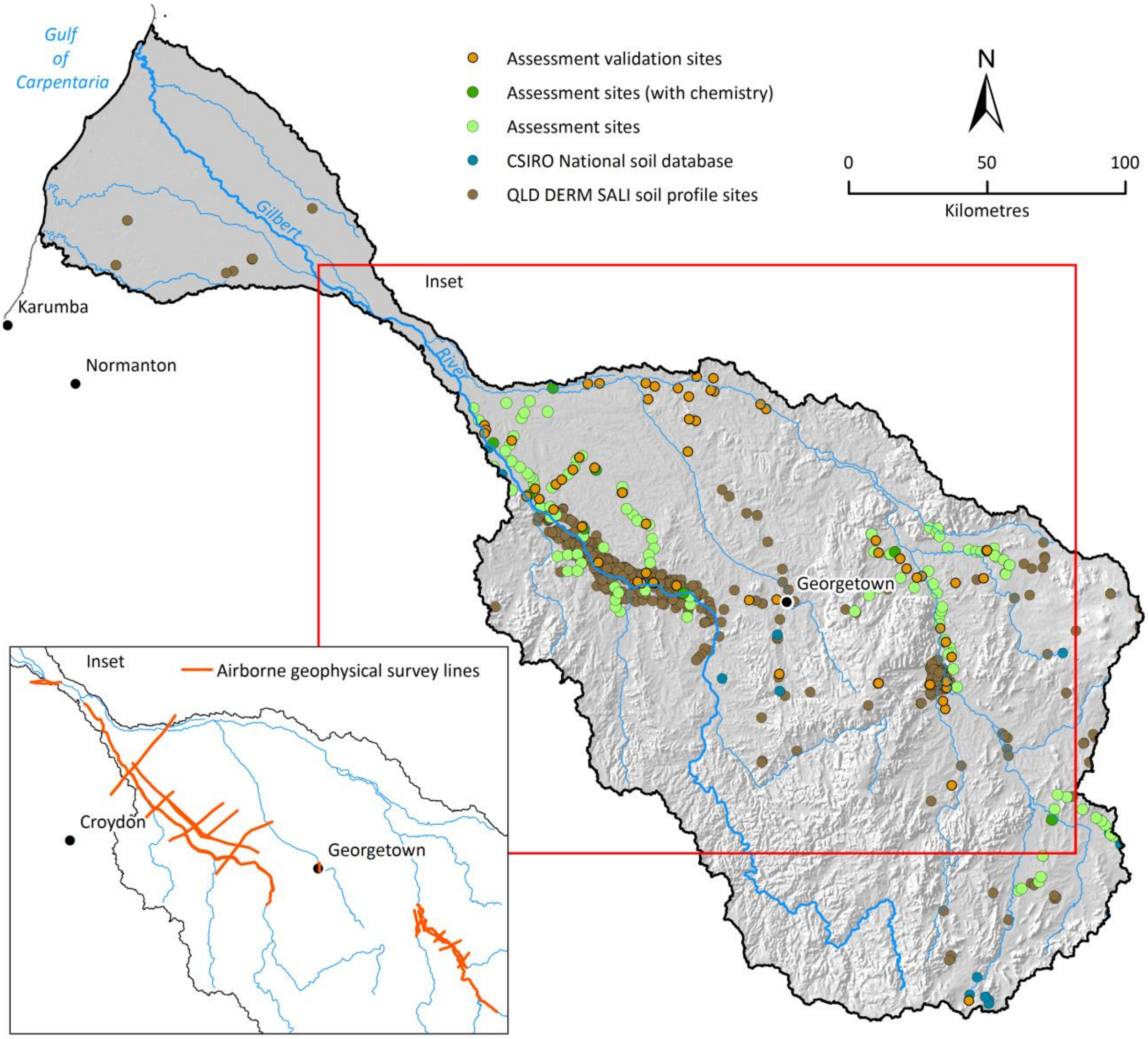

Figure 2.3 Soil sampling sites and airborne geophysical survey flight lines of the Gilbert catchment
Soil sampling sites include legacy data (from the Queensland Government's Soil and Land Information database (SALI; Queensland Government, 2000) and CSIRO National soil database). The inset shows the location of airborne electromagnetic survey lines in the Gilbert catchment.

The Assessment used digital soil mapping (DSM) – a relatively new technique for mapping soils and land suitability (Figure 2.4). This technique is typically cheaper, faster and more efficient and objective than traditional soil survey techniques. It also enables scientists to calculate the uncertainty in the resulting soil maps, which is not possible using traditional soil survey approaches. Use of digital soil mapping at the large scale required for this Assessment was a world-first application of the technique.

The DSM undertaken in the Assessment was underpinned by a variety of spatial data layers, including satellite imagery, most of which can be related to soil formation processes (e.g. elevation). These were used as spatial data input for a new spatial statistical method that identifies the best locations to sample in order to capture the most variability within and across the input spatial data. In doing so, the new statistical method takes into account existing soil measurements and site accessibility. During a ten-week period, more than 500 person-days were spent in the field sampling and measuring soil. Soil samples were sent to CSIRO and Queensland Government laboratories for analysis. Soil data collected and measured in the field were then used in conjunction with spatial data layers (i.e. these were used as spatial covariates) to develop statistical models to enable field measurements to be extrapolated across the entire Gilbert catchment. This process created 16 digital soil maps of different soil attributes (e.g. percentage clay in soil, soil depth and soil texture) at a resolution of 30 by 30 m (pixels) for the Gilbert catchment. Note that while the maps were generated at a resolution of 30 by 30 m, the maps were produced with varying degrees of uncertainty across the catchment. The DSM methods are described in more detail in the companion technical report about land suitability (Bartley et al., 2013).

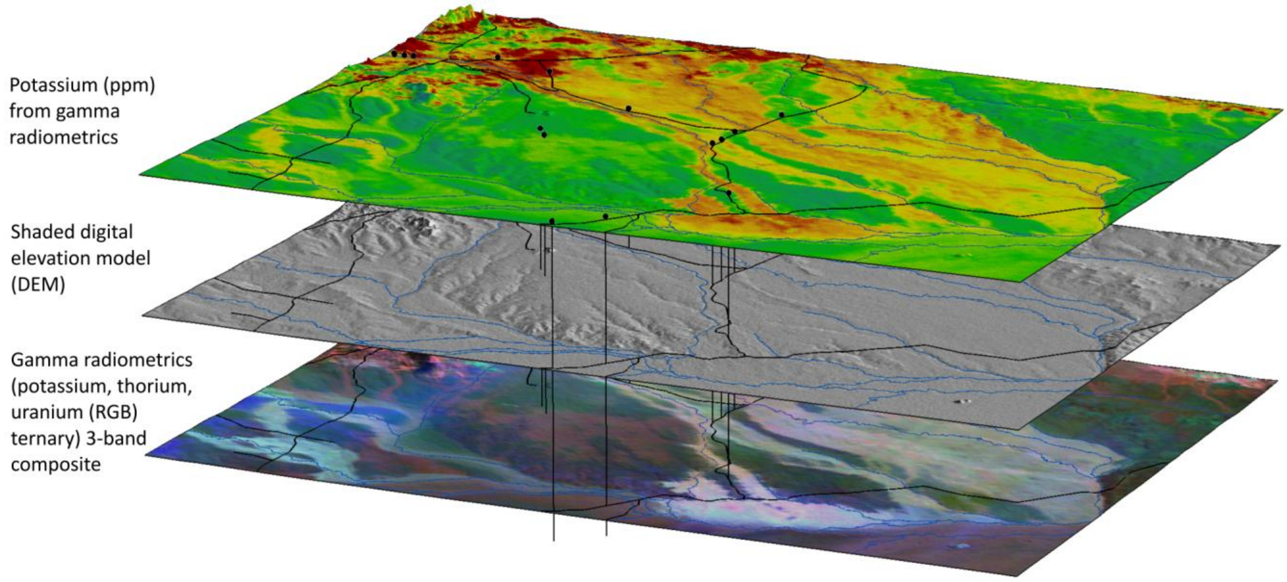

Figure 2.4 Schematic representation of digital soil mapping method

Climate information and climate scaling for future climates

Climate variables are generally considered, together with soil data, to be the most important environmental factors in determining the suitability of particular locations for agriculture. Rainfall is especially important because it is so very closely linked to hydrology and water availability. Understanding climate, and especially its variability, is critical for assessing semi-arid and subtropical sites in northern Australia for irrigated land use.

One of the limitations to hydrological and agricultural assessments in northern Australia is the lack of climate data – compared with other parts of Australia, particularly the southern more closely settled areas, climate data are sparse. Between 2000 and 2007 the Gilbert catchment had about five rainfall stations (greater than 70% complete) per 10,000 km^2. This compares to 20 rainfall stations (greater than 70% complete) per 10,000 km^2 over the same period for the Murrumbidgee catchment (a sub-catchment of the Murray–Darling Basin of comparable size to the Gilbert catchment). Figure 2.5 compares the distribution of rainfall data in the Gilbert catchment and how this has changed over time. The spatial density of other climate variables, such as evaporation is much lower and typically confined to towns whereas rainfall data have been collected at a number of properties throughout the catchment.

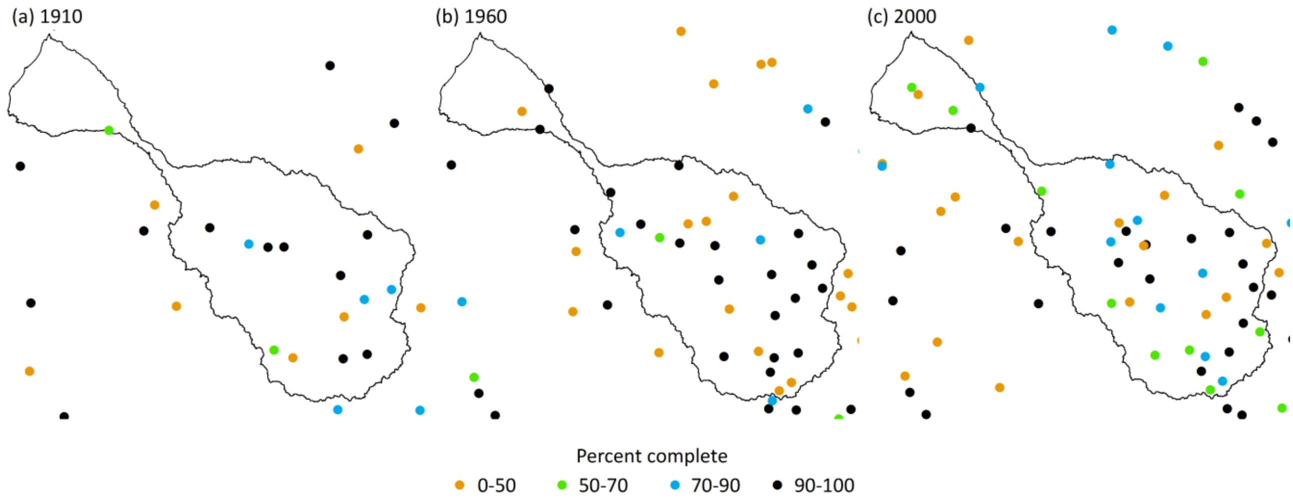

Figure 2.5 Availability of rainfall data availability in the Gilbert catchment
This is a decadal analysis of the location and completeness of Bureau of Meteorology stations measuring daily rainfall used in the SILO database. The decade labelled '1910' is defined from 1 January 1910 to 31 December 1919, and so on. At a station, a decade is 100% complete if there are observations for every day in that decade. The analysis for the decade starting in 2000 only extends to 2007.

To maintain consistency, all Assessment activities used the same climate data. These were assembled using daily gridded data from the SILO database – an enhanced climate data bank containing datasets that are based on historical climate data provided by the Bureau of Meteorology (Jeffrey et al., 2001) – from between 1 July 1890 and 30 June 2011, referred to herein as Scenario A (as described in Section 2.1.3).

The primary focus of the Assessment was on assessing the opportunity for irrigated agriculture with currently available environmental resources. However, given current projected changes in temperature and rainfall in the coming decades, and the sensitivity to that change by Australian agriculture and the natural resource base on which it depends, the Assessment also considered the effects of climate change. Determining these effects involved using information from 15 global climate models (GCMs) representing a world where the global average surface air temperatures are 2 °C higher relative to ~1990 global temperatures. The scale of GCM outputs is too coarse for use in catchment and point-scale hydrological and agricultural computer models, so they were transformed to catchment-scale variables using a simple scaling technique to create a 'synthetic' dataset of future climate. This dataset was used as input to the hydrological and agricultural computer models used in the Assessment for scenarios C and D. The methods by which the future climate data were generated are described in more detail in the companion technical report about climate data (Petheram and Yang, 2013). This method is consistent with other large scale hydrological analyses that have been undertaken in northern Australia (CSIRO 2009a, b, c) and elsewhere in Australia.

Hydrology of the Gilbert catchment

The availability of water across the Gilbert catchment was primarily assessed using three types of numerical hydrological models: (i) river system models, (ii) conceptual rainfall-runoff models and (iii) hydrodynamic models.

River system models simulate the dynamics of a river network by representing the river as a series of 'nodes and links' that mimic hydrological processes and water management decisions such as water diversions and storage in reservoirs. The Assessment translated an existing model (the Water Resource Plan Flinders Integrated Quantity and Quality Model (IQQM)) into a new kind of river system model (eWater Source; referred to herein as Source). The Assessment also incorporated additional nodes into the new models to improve their spatial resolution in key areas (e.g. within the vicinity of potential dam sites and irrigation areas). The increased resolution was desirable because it better considered rainfall gradients, and also enabled a wider range of development options to be examined. The models were calibrated using climate and observed streamflow data, some of which dated back to the 1960s. The models were calibrated using a new approach, which jointly calibrated the routing, loss and rainfall-runoff model parameters. The Sacramento conceptual rainfall-runoff model was used to provide inflows to the Source river model.

One of the challenges in undertaking hydrological modelling across northern Australia is that considerable uncertainty arises due to the difficulties in measuring streamflow in remote environments. Consequently, quantifying uncertainty is critical in assessing the sustainability of water resources under climate and development scenarios. A new approach was employed to provide estimates of uncertainty in streamflow. This resulted in an ensemble of 50 river system models, each one statistically plausible, based around uncertainty in the streamflow rating curve data. For more detail about the methods used for the river modelling, see the companion technical reports about river model calibration (Lerat et al., 2013) and river system modelling for the Assessment case studies (Holz et al., 2013).

One of the limitations of river system and conceptual rainfall-runoff models is that they cannot be used to model the spatial extent of flood inundation. In the Gilbert catchment this is important because the coastal floodplains flood regularly. Flooding can be catastrophic to agricultural production in terms of loss of stock, fodder and topsoil and in damage to crops and infrastructure. Flood flows are important from an ecological perspective because they provide an opportunity for normally disconnected wetlands to be connected to the main river channel. The high biodiversity found in many unregulated floodplain systems (i.e. where there is no flow-controlling infrastructure or diversion) in northern Australia is thought to largely depend upon these ‘flood pulses’, which allow biophysical exchanges to occur between the main channel and wetlands.

A combination of two-dimensional hydrodynamic modelling (MIKE 21) and remote sensing (MODIS and Landsat TM imagery) was used to quantify floodplain inundation, the connectivity (in terms of extent, timing and duration) of the main river channels to offstream wetlands and to assess how this connectivity might change as a result of upstream regulation. Flood maps derived from the satellite imagery were used to define the hydrodynamic modelling domain and help parameterise, calibrate and post-audit the two-dimensional hydrodynamic model. For more detail about the methods used for floodplain inundation mapping and modelling, see the companion technical report about floodplain inundation (Dutta et al., 2013).

During the dry season, rivers in the Gilbert catchment break up into a series of waterholes. Many aquatic biota in the Assessment area survive the long dry season by using refugia (habitat for species to retreat to, persist in) provided by these waterholes. The Assessment investigated the potential impacts of climate and development on instream waterhole persistence. In doing so it developed and tested methods for identifying and tracking the persistence of waterholes in the Gilbert catchment using freely available Landsat TM data. Relationships were then developed between streamflow as simulated by the river system models and waterhole persistence. The resulting relationships enable assessment of the persistence of waterholes under future climate and development scenarios. For more detail about the methods used for determining instream waterholes see the companion technical report about in-stream waterholes (McJannet et al., 2013).

The Assessment also carried out investigations to determine whether the persistence of permanent waterholes in the Gilbert catchment was likely to be due (at least in part) to natural groundwater inflows. The purpose of this was to inform water resource planners and managers about the potential impact of current and future groundwater development on the hydrology and associated ecosystem health of permanent instream waterholes. This involved an assessment of the nature of surface water – groundwater connectivity at five river sites and in 19 waterhole sites in the Gilbert catchment during the dry season. Major ion chemistry, and naturally occurring radioactive and stable isotopes of water were used to assess the likelihood of groundwater presence in these rivers and waterholes. For more detail about the methods used for determining surface water – groundwater connectivity see the companion technical report about surface water – groundwater connectivity (Jolly et al., 2013).

It is important to note that groundwater was investigated with respect to surface water – groundwater connectivity; groundwater was not assessed specifically for use as a resource. However, some of the results described in this report may be useful for this purpose.

2.2.2 WHAT ARE THE EXISTING ECOLOGICAL SYSTEMS, INDUSTRIES, INFRASTRUCTURE AND VALUES?

The question 'What are the existing ecological systems, industries, infrastructure and values?' is addressed in Chapter 4, 'Living and built environment of the Gilbert catchment'. This chapter benchmarks the existing natural and human environment of the Gilbert catchment. In developing greenfield irrigation areas it is important to understand the natural environment and the ways it is valued by Indigenous and non-Indigenous people, what infrastructure may exist to support greenfield irrigation developments and what existing industries may be benefited or impacted by future irrigation development.

Ecology of the Gilbert catchment

Any proposal for irrigation development in the Gilbert catchment needs to be considered in the context of baseline ecological data and experiences drawn from other similar water developments. Consequently the Assessment undertook a review and identification of the ecological assets (e.g. important species or habitats) in the Gilbert catchment. It included identifying important habitats by searching a range of lists, databases and other sources (e.g. records from the Queensland Museum and the Regional Ecosystem dataset). Relative to catchments in southern Australia and even relative to many catchments in northern Australia (e.g. Daly, Mitchell and Fitzroy), there is a general paucity of ecological information for the Gilbert catchment. Unfortunately ecological research undertaken elsewhere in northern Australia has limited relevance for use in the Gilbert catchment and is not usually specifically targeted to answer questions related to irrigation development. Consequently consultation with experts and local community members was undertaken to try and provide further information in identifying important ecological assets and function within the Gilbert catchment.

To complement the review of existing studies and records and consultation with experts and local community members, field sampling was undertaken as part of the Assessment. The field sampling employed a suite of survey methods to generate a list of fish and aquatic invertebrate (i.e. an invertebrate that is large enough to be seen with the naked eye) communities. Methods used included backpack electrofishing, visual observation, gill netting, baited fish traps, kick samples of benthic (i.e. bottom) habitats within waterholes and 'sweeps' of edge habitat, waterhole bottom areas and vegetated macrophyte areas (a macrophyte is an aquatic plant that grows in or near water and is either emergent, submergent, or floating).

The review of records was important in identifying distribution and movement patterns of fish in the catchment, in particular for the freshwater sawfish (*Pristis microdon*), which is listed variously as vulnerable or critically endangered and the giant freshwater whipray (*Himantura dalyensis*) which is listed as vulnerable. This review also highlighted distribution of other fish species known to migrate along river extent, to complete important life cycle processes (e.g. barramundi, *Lates calcifer*).

For more detail about the methods used for determining ecological responses to changes in flow see the companion technical report about ecological responses to changes in flow (Waltham et al., 2013).

Indigenous water values, rights and interests and Indigenous development aspirations

Indigenous people have lived in Australia for many thousands of years, developing strong custodial connections to important places and significant wider knowledge of the landscape. This history is relevant to regulatory and land tenure issues, to current Indigenous and non-Indigenous residence patterns in the area and to the development aspirations Indigenous people have. Indigenous people also have specific values, rights and interests in water that water resource developers and managers need to consider. These are addressed by existing native title, environmental and heritage laws and water planning processes, but are not fully encompassed by them. The Assessment acknowledged these issues and undertook research to begin to address them. Further details are contained in the companion technical report about Indigenous water values, rights and interests (Barber, 2013).

The goal of the Indigenous component of the Assessment research was to provide general foundations for understanding Indigenous people's relationships with water in the two catchments, and to inform future discussions about particular developments. The geographic context and scope of the research task was crucial to how it was conducted. Taken as a whole, the Flinders and Gilbert catchments are characterised by: large geographic scale; a dispersed Indigenous population with significant internal political complexity; and poor documentation of existing Indigenous values, rights and interests. Significant changes to water use upstream would affect Indigenous groups downstream, further suggesting that a catchment-scale investigation was the appropriate course.

The overall timeframe for the NQIAS meant that a ‘rapid response’ scoping assessment was undertaken. This approach focused on participation by key senior individuals from the relevant Indigenous groups to generate a representative set of issues and perspectives, and had been used previously (Barber and Jackson, 2011). Knowledge was shared and collated to create a common baseline for further consideration, discussion and decision making; the data taken as an appropriate indication of catchment-scale issues. However, although the method provides foundations for wider Indigenous group and catchment-based consultation, prioritisation and decision-making processes, it cannot substitute for them. The Assessment did not seek formal Indigenous group positions on any matters raised, nor should the opinions expressed by individual research participants be taken as the final positions of those individuals. The findings indicate that ongoing group, community, and catchment-based planning processes will be crucial to further progress with respect to Indigenous people, to Indigenous water values, rights and interests, and to water and agricultural development proposals in the catchments.

Existing published information about Indigenous people and water in the Gilbert catchment is extremely limited. The available literature was reviewed, focusing on key evidence for past habitation, on exploration and colonisation processes, and on the contemporary situation with respect to Indigenous land ownership, residence, and access. Further external expertise was sought through desktop studies of two specific areas – cultural heritage and Indigenous water policy and law. These outputs (McIntyre-Tamwoy et al., 2013; Jackson and Tan, 2013) are contained in appendices to the companion technical report about Indigenous water values, rights and interests (Barber, 2013). This work provided the necessary context for the primary analysis of Indigenous water values, rights and interests and Indigenous development aspirations.

In terms of fieldwork, key local and regional Indigenous organisations were identified and contacted through an iterative series of internet searches and telephone referrals. Senior individuals nominated by those organisations were then approached for interview. Key topics related to water and development were then investigated in formal, semi-structured, face-to-face interviews and key comments and opinions recorded. The final number of individuals interviewed from any group depended on the group size and individual availability for interview, but at least one key senior representative from all of the major groups represented in the catchment was approached for interview, making a total of 25 participants. Comments were checked and confirmed with research participants prior to use in the reporting phase, and the resulting information and analysis were then combined into a draft research report. This draft was subjected to professional review and also circulated to research participants and Indigenous organisations. This provided further time for data confirmation, feedback, and comment prior to finalisation of the Assessment technical report Indigenous water values, rights and interests (Barber, 2013).

Catchment profile – demographics, existing industry and infrastructure

Recent literature and numerous databases were examined to provide an understanding of demographics, existing industries and infrastructure and the critical thresholds for important community infrastructure (such as schools and hospitals) of the Gilbert catchment – this is information that may help inform and enable new irrigation development.

Existing water entitlements and irrigation in the Gilbert catchment

Existing water entitlement information was obtained from the Queensland Government. Information about existing irrigation and irrigation practices in the Gilbert catchment was obtained during visits to the catchment and discussions with local community members and Queensland Government regional extension officers.

2.2.3 WHAT ARE THE OPPORTUNITIES FOR IRRIGATION?

The question 'What are the opportunities for irrigation?' is addressed in Chapter 5, 'Opportunities for irrigation in the Gilbert catchment'. It considers: (i) water storage opportunities in the GIlbert catchment, (ii) costs and losses involved in water being conveyed to the irrigation field and (iii) cropping opportunities.

Water storage opportunities

Incremental releases of water in a catchment for consumptive use may preclude the development of large water storages in the future. Consequently the Assessment provided a comprehensive overview of the different water storage options in the Gilbert catchment, to help enable decision makers take a long-term view of water resource development and to help inform future allocation decisions.

The Assessment investigated six potential dam locations within the Gilbert catchment (some with multiple sites) – all had been identified by previous studies, ranging from isolated references to potential locations through to detailed hydrological and geotechnical investigations. A difficulty in comparing the outcomes of these studies was that they were undertaken by a wide range of organisations, at different periods of time, using different methods and to varying degrees of rigour.

As part of the Assessment, all available published and unpublished literature about the previously identified potential dam locations was accessed from the Queensland Government and SunWater archives. This literature was reviewed and all locations were reassessed using a consistent set of methods including updated data where available. The majority of potential storage locations were visited by an experienced water infrastructure planner and engineering geologist as part of the Assessment, but no additional geotechnical information was acquired. Geotechnical information is expensive and time consuming to acquire and was beyond the scope of this Assessment.

To ensure that no potential dam location options had been overlooked, the DamSite model was applied to the catchment. This model automatically locates favourable locations within the landscape as sites for intermediate to large water storages. The DamSite model was used to assess over 100,000 potential dam sites in the Gilbert catchment. Only 'new' sites identified by the modelling to be more favourably located than already known potential dam sites were investigated further.

Three potential dam sites in the Gilbert catchment were short-listed for further analysis on the basis that each was deemed to be the most likely site to proceed in three distinct geographical areas. The selected sites were Dagworth, Green Hills and Kidston. The investigations of the three short-listed options sought to assess supply potential and to develop conceptual arrangements for each of the potential storage developments, as well as preliminary cost estimates based on current construction costs. Further details can be found in the companion technical report about water storage options (Petheram et al., 2013).

Tomkins (2013 – companion technical report) collated historical sediment yield data from ten studies across northern Australia, including one study from the Flinders River at Glendower. Using these data a relationship was developed between sediment yield and catchment area. This relationship was used to estimate the rate of sediment infill for each of the potential dam sites.

A desktop assessment was undertaken of potential environmental issues associated with potential dam sites in the Gilbert catchment. The dearth of environmental information available for the catchment limited the level of detail that could be achieved. An assessment of potential impacts was based on fish distribution and passage (for which reasonable information exists) and inundation of vegetation communities – regional ecosystems – which had been mapped in suitable detail by the Queensland Government across much of the Assessment area. General environmental issues that commonly arise in dam developments in similar habitats elsewhere, particularly the Burdekin Falls Dam reservoir (officially known as Lake Dalrymple) and the Ord River Dam reservoir (officially known as Lake Argyle) were also considered.

A broad-scale assessment of the suitability of offstream water storage locations in the Gilbert catchment was undertaken using available soil data from the top 1.5 m of the soil profile. Due to the non-availability of information below 1.5 m of the top of the soil profile, this suitability assessment does not give consideration to the nature of subsurface material below that depth, with the exception of general information from broad-scale geological mapping. Further details can be found in the companion technical report about water storage options (Petheram et al., 2013).

Water distribution systems – conveyance of water from the storage and application to the crop

In all irrigation systems water is required to be diverted from rivers or dams through artificial and/or natural water distribution systems before ultimately being used on-field for irrigation purposes. Some proportion of the water diverted for irrigation is ultimately lost during conveyance to the field and before it can beneficially be used by a crop to meet its water requirement needs. These losses of efficiency of irrigation delivery need to be taken into account when planning potential irrigation systems and developing likely irrigated agriculture areas.

No irrigation system research has previously been undertaken in the Gilbert catchment and the time frames of the Assessment did not permit on-ground research into irrigation systems. Consequently a brief discussion of the above items is provided based on relevant literature from elsewhere in Queensland, Australia and overseas.

Cropping and other agricultural opportunities

In the Gilbert catchment there is currently little irrigated or dryland cropping. Consequently there are few data on crop growing seasons, crop yields or water use. The production potential of a range of agricultural enterprises was determined for the Gilbert catchment using simulations generated by the Agricultural Production Systems Simulator (APSIM; Keating et al., 2003) crop model. APSIM was used to simulate biophysical processes in farming systems, using climate and soil data collated by the Assessment as well as previously collected data, to determine water use and potential crop yield under Scenario A. The crop types investigated were determined in consultation with local and jurisdictional interests and in conjunction with the Assessment soil scientists. For crop types not within the APSIM modelling framework, a combination of local and expert knowledge and available crop yield records from the catchment (or areas of similar climates) were used to estimate production potential – optimal APSIM model results are achieved when local data are used to parameterise the model. Therefore the Assessment collected data from on-farm trials in the Assessment area to parameterise and validate the model. For the Gilbert catchment, climate, soil, crop biomass and crop yield data were collected from rice and mungbean crops grown in the Richmond district. Production risk presented by climate change was modelled using the 121-year future daily climate data sequences. Non-climate related production risks (e.g. pests) were assessed through consultation with local irrigators and by drawing on the extensive experience within CSIRO of cropping in northern Australia. More details about the methods used for undertaking the APSIM modelling are provided in the companion technical report about agricultural productivity (Webster et al., 2013).

Farm-gate crop gross margins were developed using a bottom-up approach for selected crops in the Gilbert catchment. Key components of a crop gross margin are yield, crop price, variable cost and irrigation use. In the absence of local information, likely crop water use and crop yield were estimated using APSIM. Variable or direct costs (e.g. pumping costs, fertilisers, chemicals harvesting etc) and crop prices were obtained from a range of sources, including: (i) published gross margin budgets from New South Wales Department of Primary Industries (NSWDPI, 2013), Queensland Department of Agriculture, Fisheries and Forestry (DAFF, 2013), ABARES (2013) and Queensland Department of Agriculture, Fisheries and Forestry staff (pers. comm.), and (ii) reports such as and Mason and Larard (2011). Further details can be found in the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013).

Land suitability maps were developed for combinations of crop type, irrigation system and season combinations using digital soil and climate data generated as part of the Assessment (Section 2.2.1) in conjunction with a set of rules. In all, 76 land use (i.e. crop type, irrigation system and season combinations) maps were modelled as part of the Assessment. The land suitability mapping was undertaken across the Gilbert catchment at a resolution of 90 by 90 m pixels, but the mapping had most certainty in those areas with the greatest density of soil sampling. It is important to note that the suitability of a land use to an area also depends on a range of other factors such as frequency of flooding, risk of secondary salinisation (i.e. an increase in the salt content of the soil), downstream impacts and non-biophysical characteristics such as economics, availability of labour and production risks. These additional factors were not considered in the land suitability mapping undertaken by the Assessment. Information about these additional factors are found elsewhere in the report. More details about the methods used for the land suitability mapping can be found in the companion technical report about land suitability (Bartley et al., 2013).

2.2.4 IS IRRIGATED AGRICULTURE ECONOMICALLY VIABLE?

The question 'Is irrigated agriculture economically viable?' is addressed in Chapter 6. It presents an evaluation of the economic costs and benefits from irrigation development.

Quantifying the costs and benefits of new irrigation development in the Gilbert catchment required a multi-scale approach. Consequently the economic analysis of costs and benefits was conducted at the scale of farm, scheme and statistical division (SD). Farm-scale developments are those between 100 and 1000 ha, while irrigation developments between 5000 and 40,000 ha are representative of the size of scheme-scale irrigation developments. Statistical division is an Australian Bureau of Statistics geographical classification – Queensland's North West Queensland Statistical Division in this case, which covers 308,098 km^2 and contains the shires of Cloncurry, Flinders, McKinlay, Richmond, Carpentaria, Doomadgee, Mornington and Mount Isa.

The analysis considered the impact of capital costs, water availability, crop type, irrigation system, and commodity price on the viability of irrigation development. At both farm and scheme scale, financial evaluations were conducted to ask whether an irrigation project offers an acceptable return from a funds-owner perspective. Legislative and regulatory opportunities and impediments are also presented.

Fundamental to the economic analysis undertaken in the Assessment is the concept of net present value NPV), which is described below.

Net present value

Net present value (NPV; a standard method for using the time value of money to appraise long-term projects by measuring the differences between costs and revenues in present value terms) was used to facilitate comparisons between development options.

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

The discount rate is an interest rate and is used to indicate the desired return on investment. The internal rate of return (IRR) is presented as supplementary information to the NPV. The IRR is the discount rate which causes the NPV to become zero. The project's IRR needs to be above the discount rate for the project to be considered viable.

Farm-scale economic opportunities

The farm-scale economic analyses computed the change in profitability attributable to adopting irrigated enterprises in the Gilbert catchment. Two broad options were considered.

The first assessed the benefits of introducing irrigation into an existing beef enterprise, representative of a typical beef cattle property in the catchment. Here the impact of introducing irrigated forages on the performance of a beef operation in the Gilbert catchment was undertaken using the Integrated Analysis Tool: North Australia Beef Systems Analysis (IAT-NABSA; McDonald, 2012) – a tool that integrates data about animal, pasture and crop production with labour and land requirements, accounts for revenue and costs, and evaluates these against existing land, labour and financial resources. Three different irrigated fodders were evaluated and the profitability of different degrees of water reliability was assessed for the most profitable fodder.

The second assessed the benefits of introducing irrigation for cropping as a separate enterprise to an existing beef enterprise. A generic analytical framework was developed to account for the capital and ongoing operating costs associated with the development of grazing land to irrigated cropping land at the scale of a single farm business in the Gilbert catchment. The gross margins developed for a range of crops were compared to the returns that would be required to achieve a viable investment under a range of investment scenarios. The impact of reliability of supply of water was also investigated.

For the farm-scale investment analysis, the project was assessed over 15 years, with a discount rate of 5% and some additional analyses at 7%.

Scheme-scale economic opportunities

A generic scheme-scale financial analysis was undertaken, initially treating the whole scheme as a project conducted from the standpoint of a single developer who incurs all of the costs and receives all of the benefits. The purpose of the analysis was to explore the range of prospectively profitable situations.

The analysis at this scale included farm-scale costs and benefits and consideration of the infrastructure construction and operational requirements for a scheme-scale development – including capital and operating costs associated with large dams, channels, area works, such as roads, and overhead costs. For the scheme-scale analysis, a project period of 30 years was selected, which is less than the actual working life of many of the scheme-scale assets, but once a project life has exceeded 30 years the analysis will be relatively insensitive to the choice of a longer project period due to the discounting of future costs and benefits. The residual value of assets with a working life greater than 30 years was computed and incorporated in the analysis.

For the scheme-scale analysis a discount rate of 7% was selected as this is more consistent with the return expected by private investors in agricultural industries. Sensitivity testing was performed at 12%. For more detail see the companion technical report about the costs and benefits of irrigation (Brennan Mckellar et al., 2013).

Regional economic opportunities

Regional economic analysis at the scale of statistical division (SD) was undertaken to explore the importance of the prevailing economic environment in influencing the economic viability of investment in irrigated agricultural development in the Gilbert catchment. Data on costs of dam construction, scheme-scale water distribution networks, construction of downstream processing facilities, ancillary investments in roads, and agricultural output were drawn from the farm- and scheme-scale analyses. The investment and associated expansion in agricultural output were modelled using TERM, a dynamic multi-regional Computable General Equilibrium (CGE) model of the Australian economy (Wittwer, 2012). CGE modelling in this context was undertaken for Queensland's North West statistical division. This type of modelling serves to provide regional and national perspectives on economic costs and benefits, as well as showing how these outcomes depend on underlying economic conditions.

Opportunities and impediments

The Assessment also investigated other factors that could enable or impede irrigation development, including:

- documenting the current policy environment that regulates the development of irrigated agriculture.
- investigating the infrastructure enhancements that might be required to support new irrigated enterprises
- identifying other transition issues that could influence the rate and extent of uptake of irrigation in the catchment, such as the level of agricultural skills and services available to support irrigated development

- auditing the provision of ecosystem services, which provides a scientific evidence base for evaluation of the institutional and governance aspects of policy change.

2.2.5 HOW CAN THE SUSTAINABILITY OF IRRIGATED AGRICULTURE BE MAXIMISED?

The question 'How can the sustainability of irrigated agriculture be maximised?' is addressed in Chapter 7. Many Australians believe that northern Australia holds iconic ecological and heritage status that should be carefully managed. These strongly held perspectives as well as experiences with irrigation developments in southern Australia and parts of northern Australia mean that any proposed irrigation development should be accompanied by an assessment of its sustainability. Chapter 7 considers the risk of irrigation-induced salinisation, irrigation drainage management and impacts to the catchment's ecology by examining: (i) the risk of rising watertable levels and the potential for increased groundwater discharge to rivers, (ii) assessing and managing the impacts of sediments, nutrients and agropollutants to receiving waters of the Gilbert catchment and (iii) the ecological implications of altered flow regimes.

Assessing the risk of rise in watertable level

The sustainable management of water resources is made particularly challenging by the uncertainties associated with groundwater resources. For example, the time lags associated with lateral groundwater flow can take many decades to manifest as an environmental problem (e.g. dryland salinity, over-allocation). Thus it is important that the groundwater-related environmental risks are understood as early as possible in the planning process of any proposed irrigation development. One of the key risks of irrigation is secondary salinisation induced by the evaporative concentration of salts at the surface following rise in watertable level.

Assessing the risk of rise in watertable level using conventional numerical groundwater flow models is impracticable in the Gilbert catchment because of the lack of groundwater data. Hence, to calculate the rate of rise in watertable level beneath irrigation areas within the Gilbert catchment, a new analytical solution that incorporates the effect of river boundary conditions was developed as part of the Assessment. More details are provided in the companion technical report about surface water – groundwater connectivity (Jolly et al., 2013). Using this approach it was possible to evaluate the maximum (steady state) rise in watertable level as a result of introducing new irrigation developments of varying areas situated at various distances from the river edge. The time scales during which the head and flux responses occur were also investigated. In the absence of groundwater data, a sensitivity analysis approach was undertaken by varying the distance from the river, the size of the irrigation area, the recharge rate, aquifer transmissivity and aquifer-specific yield. The range of values used in the sensitivity analysis was deemed to represent practical field conditions that are likely to be encountered in the Gilbert catchment and was guided by the limited available groundwater data, bore logs and experience elsewhere.

Assessing the risk of increased sediment, nutrients and pesticide loads from irrigation to the Gilbert River

Little information is available describing the current or historical water quality of the Gilbert River, its associated estuaries and coastal areas. Previous agricultural irrigation developments in tropical Australia have been associated with decreased river and offshore water quality (Brodie et al., 2010, 2013; Lewis et al., 2009). These reductions in water quality are directly related to the removal of pre-existing ground cover and the application of fertilisers and pesticides.

Time and resource constraints meant that the likely contribution of sediment, fertiliser and pesticide to the Gilbert River was limited to estimates provided by the Export Coefficient Model (Johnes, 1996; Letcher et al., 2002).

Information on fertiliser and pesticide usage and erosion rates for a selection of possible land uses was collected from the scientific literature, expert interview and publicly available databases. Information was also collected on the relationships between nutrient, sediment and pesticide runoff losses and land management approaches in similar systems. A simple formula was used to calculate the percentage of total applied fertiliser and pesticide likely to leave the land during rainfall or irrigation runoff events. In conjunction with estimates of the maximum and minimum area dedicated to each proposed crop or pasture, the total load of sediment, nutrient and pesticide entering the river can be estimated (e.g. tonnes of nitrogen, phosphorus, sediment or pesticide) for baseline and development scenarios.

The additional load contributed to the river under an irrigated land use was compared with baseline estimates, to provide an indication of potential water quality change.

Assessing the impacts of altered flow regimes on aquatic and riparian ecology

Understanding ecological and cultural requirements is particularly important in setting rules about water extraction and diversion (i.e. how much water can be taken and the time at which it should be taken). Although interactions between flow and biota occur at all magnitudes of flow, these interactions are arguably the most sensitive at the low-flow and high-flow extremes of the flow regime (Poff and Zimmerman, 2010). Two key ecological considerations during these periods in northern Australia are wetland connectivity (during the wet season) and waterhole persistence (during the dry season).

The Assessment examined the impacts on the aquatic and riparian ecology resulting from alterations to flow that are likely to arise from potential irrigation development scenarios. Previous research and experience of north Queensland rivers and irrigation areas, indicated that potential reductions to dry-season waterholes and first-flush flows at the end of the dry season, are periods of greatest stress in aquatic ecology (Butler et al., 2009).

As part of the Assessment a field investigation program was undertaken to examine the key determinants of dry-season waterhole function along the Gilbert River and its tributaries. The waterholes chosen ranged in riparian condition, connectivity with the base Gilbert River channel, size, habitat features (sandy, large woody debris), geology (bedrock, alluvial sand) and elevation within the catchment. The mix of conditions was necessary in order to specifically examine how reduced waterhole size and persistence might affect key water quality and ecological processes within the Gilbert catchment.

Target waterholes were visited repeatedly between October 2012 and May 2013. At each waterhole, a comprehensive suite of physico-chemical properties were assessed. Some measurements were made on-site or in the laboratory from material collected at the waterholes, while a range of others were collected repeatedly over time by data loggers installed by the Assessment team. Unfortunately the low rainfall over the 2012–2013 wet season meant that this work was inconclusive and water level loggers at the sites could not be used to quantify the inflows required to fill or flush the waterholes.

2.2.6 CASE STUDIES

The Assessment considered three case studies in the Gilbert catchment, as described in chapters 8 to 10. The purpose of the case studies is to evaluate the scale of opportunity for irrigation in key geographic areas of the catchment. By analysing water storage options and potential crops, they enable site-specific assessments of the viability and sustainability of irrigated agriculture. Each case study includes:

- a storyline to set the scene and characterise the case study
- a description of the soils in the area
- an assessment of the area’s climate suitability for the development
- a description of the configuration of the irrigation development
- a financial analysis
- an assessment of potential on-site and off-site impacts
- concluding remarks.

The geographic areas of the case studies were determined by the location of the more promising water storage options in the Gilbert catchment. The storyline for each case study is a narrative about a potential development and is based on a range of information including consultation with local stakeholders, local knowledge and aspirations, biophysical opportunities, market and infrastructure factors, and transport logistics. The case studies are illustrative only; the Assessment is not recommending these developments – or types of development – for the Gilbert catchment.

Overview

Section 2.2.6 describes – at a high level – the methods used in the case study analysis. Central to this analysis was the Source river model of the Gilbert catchment developed as part of the Assessment (see companion technical reports about river model calibration (Lerat et al., 2013) and river system modelling for the Assessment case studies (Holz et al., 2013)). This river model provided the framework for exploring each case study within a whole-of-river-system context. This enabled the evaluation of trade-offs in crop water demand, crop yield, water availability, and impacts of development on downstream users and flow regimes.

Another important tool in this analysis was the APSIM crop model (Keating et al., 2003). The APSIM crop model enabled a detailed farm-scale evaluation of crop water use and crop yield. The profitability of the irrigation development was assessed within a financial framework described by the companion technical report about the costs and benefits of irrigation (Brennan McKellar et al., 2013). Ecologically relevant hydrological metrics were used to interpret the impacts of changes to streamflow downstream of the irrigation developments.

The case study methods are further described in four sections:

- how the crop water demand and crop yield were calculated
- how the Source river model was configured and used to evaluate the availability of water supplied to the irrigation development
- the framework for the financial analysis
- the methods used to assess the on-site and off-site changes of an irrigation development and subsequent changes in streamflow.

Determining crop water demand and crop yield

The crop model component of Source has only limited capability to evaluate crop yield. Consequently, the APSIM crop model was used to estimate water demands that were used to (i) calibrate the crop demands in Source and (ii) evaluate the sensitivity of the crop yield to the availability of water as determined by Source.

Ensuring consistency between Source and the Agricultural Production Systems Simulator crop model

The Source crop model component uses the FAO 56 method (Allen et al., 1998) to estimate crop water requirement in order to calculate water demands. This calculation requires a crop coefficient (Kc) that is unique to each crop and its stage of growth from sowing to maturity. This is a widely accepted method for determining crop water requirements in a simple way. However, obtaining realistic values for Kc is not simple, especially where crops are to be grown in environments where few measurements have been made of crop water use. For the Assessment, daily Kc values were obtained for each crop for specific sowing dates, based on outputs from the APSIM crop model. This approach ensures that the quantity and timing of Source crop water requirements were very similar to those generated by APSIM. For more detail, see the companion technical report about river system modelling for the Assessment case studies (Holz et al., 2013).

Evaluate the response of crop yield to water stress

To compute crop yield for each case study, two approaches were adopted.

The first approach was used to select the size of the scheme using a computationally efficient statistical model that related modelled APSIM crop yield to crop water use (i.e. the sum of irrigation water and rainfall) and climate parameters (Figure 2.6). Knowledge of the physiology of each crop was used to ensure appropriate climate parameters were captured in the statistical model. For example, rice yields are sensitive to frosts during flowering and grain development; therefore, minimum temperatures were considered at these important developmental stages. This first approach was used where crop yields had to be quickly calculated for a large number of Source river model simulations. For more detail, see the companion technical report about river system modelling for the Assessment case studies (Holz et al., 2013).

Once the size of the scheme was selected using the first approach, then a second computationally intensive, but preferable, approach was used. This involved passing the time series of water availability from the Source river model back into the APSIM crop model, so as to capture the reductions in crop yield due to water stress (more accurately than the statistical model can).

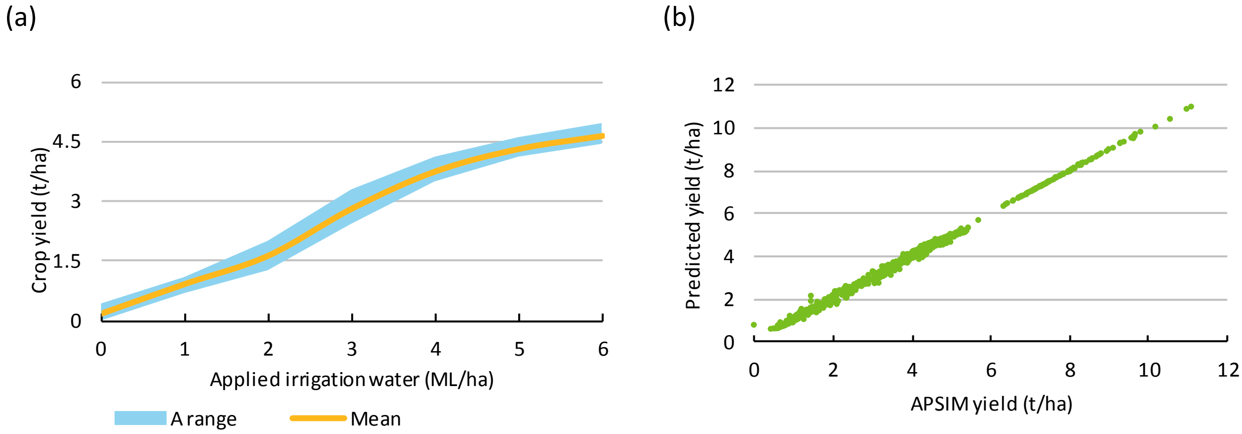

Figure 2.6 Crop yield (peanuts) and applied irrigation water
(a) Crop yield plotted against applied irrigation water, and (b) crop yield calculated using the Agricultural Production Systems Simulator (APSIM) crop model plotted against that calculated using the statistical model, for peanuts at Georgetown under Scenario A. A range is the 20th and 80th percentile. Scenario A is the historical climate (1890 to 2011).

Evaluating the water available for a new irrigation development

Reconfiguring the Source river model

The Source river model of the Gilbert catchment detailed in Lerat et al. (2013) was reconfigured to incorporate the water for new entitlement holders announced in the 2013 water release (80 GL in total). A guiding principle of water planning is that new allocations should not alter the water reliability of existing entitlement holders. Hence, for each case study, the Source river model was configured so that downstream entitlement holders would not be affected by the irrigation development in the case study. For this reason, strategic water reserves that were held in the original Water Resource Plan IQQM model and transferred across to the Source river model (Lerat et al., 2013) were removed from the model, so the area of irrigated land was not limited by hypothetical water users (Holz et al., 2013).

Selecting the appropriate size of the irrigation development and farmer risk profile for a greenfield site

One of the challenges in evaluating whether an irrigation development is profitable is matching the size of the irrigated area to the reliability of water supply. Ultimately, this is a financial decision and should be evaluated within a financial framework (see companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013)). Such assessment is, however, complicated by the need sometimes to plant crops before the wet season ends (e.g. in the Gilbert catchment cotton should be planted in January to maximise radiation) and before post – wet season dam levels are known; in other words, how much risk should farmers be prepared to take on so as to achieve greatest profit? It is also complicated in that often the economic optimum (i.e. the planted area that returns the greatest profit) is not equivalent to the agronomic optimum (i.e. the planted area that returns the greatest yield per hectare). Sometimes it is preferable to plant a larger area and impose water stress on a crop, in order to achieve a higher profit.

To account for these complexities, numerous river model simulations were undertaken for each case study using the baseline model under Scenario B. Each of these simulations sought to explore a different irrigation area (i.e. a maximum planted area in each year) and different level of farmer risk. In the Gilbert catchment, there is not a community of irrigators whose risk behaviour could be replicated in the Source river model. Different levels of farmer risk were instead explored in terms of a ‘crop area decision’, which measured by a value in ML/ha. For a given crop area decision, the crop area that could be planted is assessed in relation to the available water resource at sowing date. The area planted each year is the smaller of the maximum developed area, or the volume of water in the storage at sowing minus losses between the dam and the field, divided by the crop area decision. Low values for crop area decision result in a larger planted area than high values for crop area decision, and consequently represent a higher risk. Values for the crop area decision that are greater than the maximum crop water requirement effectively reserve water for the next cropping season.

For each river model simulation, annual crop yield was computed using the statistical relationship between water that could be supplied to the crop and site-specific climate parameters. The resulting annual crop yields and annual water use from the Source river models were used to compute annual gross margins and net present value (NPV) at the farm and scheme scale (see Section 2.2.4). The purpose was to approximately identify the most profitable irrigation area and crop area decision (i.e. level of farmer risk) for more detailed analysis.

The more detailed analysis was undertaken for a chosen combination of irrigation area and crop area decision. This approach was identical to the more general analysis, except that the annual crop yields were estimated by passing the water supplied to the irrigation development (as evaluated by the Source river model) directly into the APSIM crop model, rather than using the statistical method. The statistical method for computing annual crop yield was used to explore the uncertainty in NPV as a result of uncertainty in streamflow data for the chosen combination.

Financial analysis

A financial analysis was undertaken at the farm and the scheme scale. To rapidly assess numerous river model simulations for many different irrigation areas, all costs – with the exception of water supply infrastructure and access roads – were reduced to either a per hectare or per megalitre cost. The primary assumption is that within the range of irrigation areas investigated in the Assessment, these costs scale linearly. Cost estimates for roads, area works, water infrastructure, irrigation system and pumping costs were obtained from Chapter 5. Gross margins were calculated annually using crop yield (tonnes per hectare), water supply and crop price. Gross margins are also provided in Chapter 5.

To assess the profitability of an irrigation development at the farm and scheme scale, the NPV was calculated using a discount rate of 7% (see Chapter 7) over a 30-year investment period. One of the complications of this type of analysis is that some of the assets have a service life longer than the investment period (e.g. large dams typically have a service life of about 100 years). To compute the residual value of these assets at the end of the investment period, a straight line depreciation approach was adopted. For the farm-scale analysis, the average farm size was assumed to be 500 ha.

On-site and off-site changes

Assessing the risk of rise in watertable level and change in groundwater discharge to rivers

As described in the companion technical report about surface water – groundwater connectivity (Jolly et al., 2013), a new analytical modelling approach was developed to evaluate the maximum (steady state) rise in watertable levels as a result of new irrigation developments near a river. Previous analytical solutions could not evaluate rise in watertable levels with a river nearby. For each case study, the time taken for the watertable to rise to its maximum level was evaluated, as well as the magnitude and timing of groundwater discharge to the river.

The analytical model was used to assess the risk of watertable levels w2rising for the area given irrigation development. Annual deep drainage rates were calculated by assuming a percentage of annual rainfall and irrigation water were lost to deep drainage. Volumetric annual time series of irrigation water were extracted from the Source river model. Texture-based relationships in the literature and nearest bore log data were used to estimate values for the model parameters: aquifer parameters, saturated hydraulic conductivity and specific yield.

Ecological changes in response to altered flow regimes

The ensemble of 51 Source river models was used to assess the possible changes to streamflow downstream of each irrigation development for each case study. For each simulation, the change in waterhole area (McJannet et al., 2013), inundated area (Dutta et al., 2013) and ecologically relevant hydrological metrics were computed at gauging stations downstream of the irrigation development under scenarios A and B. The results of the ensemble of metrics under scenario A and B were compared and used by aquatic ecologists to provide a scientific commentary of the likely ecological changes resulting from altered to flow regimes (see the companion technical report about waterhole ecology (Waltham et al., 2013)).

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Part II Information for assessing potential scheme-scale and farm-scale irrigation developments

Chapters 3 to 7 provide information that people can use to assess potential scheme-scale and farm-scale irrigation developments in the Gilbert catchment. This information covers:

- the physical environment (Chapter 3)
- the people and ecology (Chapter 4)
- opportunities for irrigated agriculture (Chapter 5)
- irrigation costs and benefits (Chapter 6)
- sustainability of irrigated agriculture with respect to groundwater and ecology (Chapter 7).

Readers can use chapters 3 to 7 to plan and make decisions regarding irrigation developments that might be suitable for their circumstances.

Part III of this report presents three case studies, which demonstrate how readers could use the information in chapters 3 to 7 to assess irrigation developments in selected geographic areas of the catchment. The case studies are illustrative only; the Assessment is not recommending these developments – or types of development – for the Gilbert catchment.

3 Physical environment of the Gilbert catchment

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Chapter 3 examines the physical environment of the Gilbert catchment and seeks to identify the available soil and water resources. It provides fundamental information about the geology, soil and climate and also the river and groundwater systems of the catchment. These resources underpin the natural environment and existing industries, providing physical bounds to the potential scale of irrigation development – key components and concepts are shown in Figure 3.1.

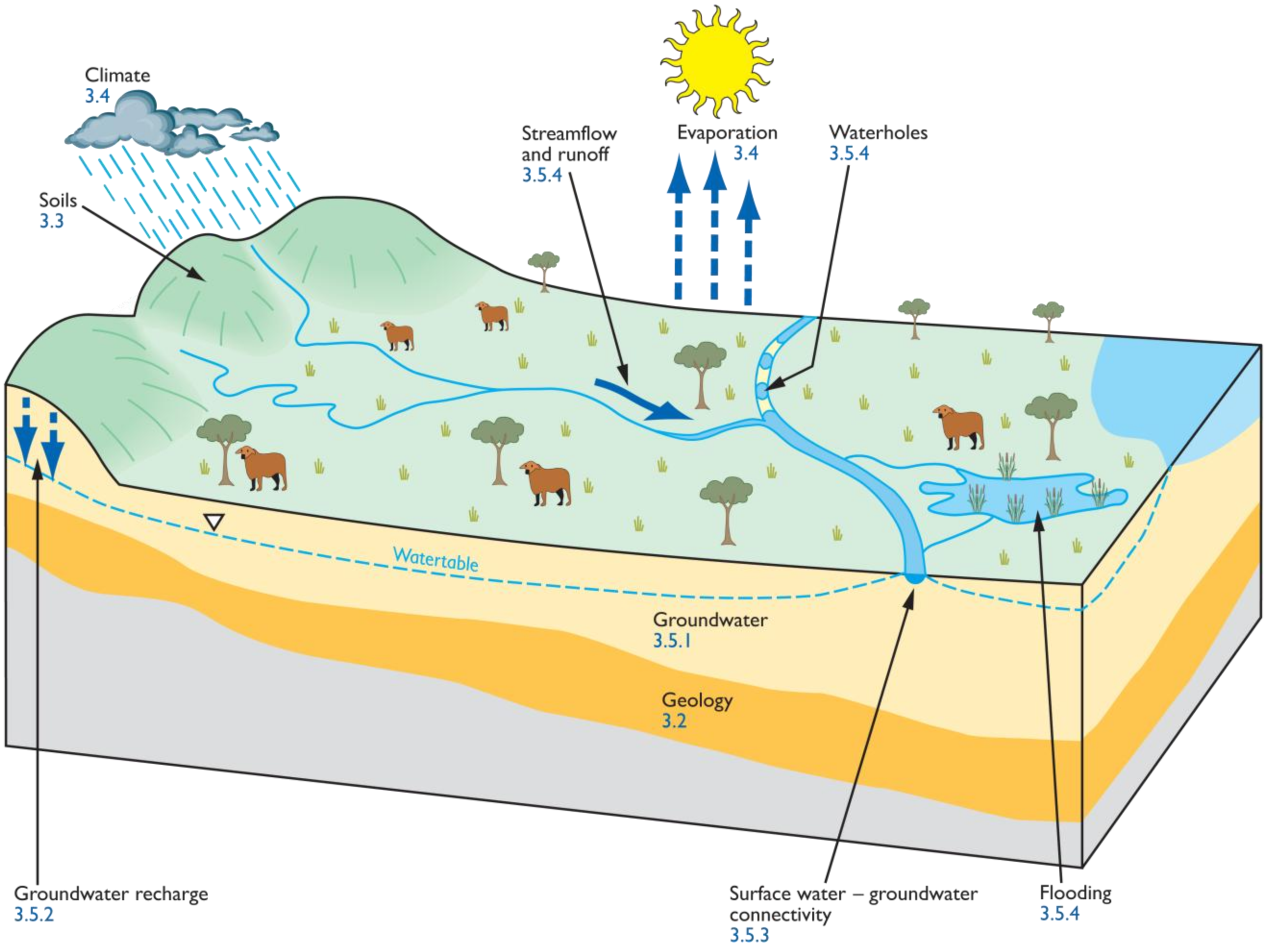

Figure 3.1 Schematic diagram of key natural components and concepts in the establishment of a greenfield irrigation development

3.1 Summary

The physical environment of the Gilbert catchment provides both opportunities and challenges for potential developers. There are alluvial soils suitable for a variety of cropping near suitable sites for large dams (see Chapter 5) but the climate and hydrology are highly variable and careful water and environmental management will be critical to long-term viability. Where water is available to overcome a frequent soil water deficit, the climate of the Gilbert catchment is generally suited to growing a wide range of crops. Irrigation development will need skilful producers to realise the potential of the catchment.

3.1.1 GEOLOGY AND SOILS

About 20% of the Gilbert catchment contains soils that are at least moderately suitable for irrigated agriculture. The most suitable are the recent alluvial soils adjacent to the Gilbert and Einasleigh rivers upstream of their confluence. These soils are deep (greater than 1.5 m) and generally extend about 1 km from the river. Elsewhere in the Gilbert catchment the agricultural potential is low.

3.1.2 CLIMATE

The Gilbert catchment has a hot and dry semi-arid climate. The climate is highly seasonal with an extended dry season. It receives, on average, 775 mm of rain per year, 93% of which falls during the wet season. Mean daily temperatures and potential evaporation are high relative to other parts of Australia. On average, potential evaporation is over 1800 mm/year, meaning evaporative water loss from open water storages is more than twice average annual rainfall.

The variation in rainfall from one year to the next is high compared to elsewhere in Australia and is high by world standards. While the length of consecutive dry years is not unusual, the intensity of the dry years is high compared to other parts of Australia.

This suggests that agriculturalists in the Gilbert catchment would need especially well-developed drought contingency plans.

3.1.3 HYDROLOGY

The timing and event-driven nature of rainfall events and high potential evaporation rates across the Gilbert catchment have important consequences for the catchment’s hydrology. Approximately 98% of all runoff in the Gilbert catchment occurs during the wet season, and runoff and streamflow are highly variable between years. Water storages are essential for dry-season irrigation.

The catchment has two major rivers, the Gilbert and the Einasleigh, with a combined streamflow at their confluence of, on average, 3706 GL/year. Notably, the median annual streamflow at the confluence is 2585 GL, i.e. in half the years the streamflow is less than 2585 GL (or only 70% of the average), demonstrating high flow variability, and years with very high streamflow can skew the average upwards. Alluvial groundwater resources are likely to be of limited extent and recharge rates low, with the exception of the basalt provinces in the east of the catchment.

Most rivers in the catchment are ephemeral, flowing less than 50% of the time, and are reduced to a series of persistent waterholes during the dry season. Most of the waterholes are maintained by streamflow, rather than groundwater, and act as important refugia for aquatic biota (see Chapter 4).

In the Einasleigh River catchment some waterholes are sustained during the dry season by groundwater inflow.

3.2 Geology

Geological history (or palaeogeography) is closely linked to resources like valuable minerals, coal, groundwater and soil, which are all important considerations when identifying suitable locations for large water storages and understanding past and present ecological systems and patterns of human settlement.

The Gilbert catchment is broadly comprised of four types of rocks and sediments: (i) igneous and metamorphic rocks, (ii) sedimentary rocks, (iii) basaltic rocks and (iv) unconsolidated sediments.

Igneous and metamorphic rocks are found in the Georgetown Inlier which forms the majority of the catchment area. It contains several units that are resistant to erosion and form areas of higher relief that are suitable for siting of dams. These include the granite and volcanic fields of the Kennedy Province and intrusive granite within the Etheridge Province. They can be generally characterised as high strength and resistant to erosion. Consequently they tend to form areas of higher relief and are often generally suitable for siting large dams. These rocks have very low primary porosity (<2%), with pores that are very small and not interconnected. For this reason they do not hold much groundwater and are essentially impermeable. Where these rocks are fractured, however, they can contain amounts of water that, while not large, can have local importance. Because they are resistant to erosion they tend to have shallow soils. Metamorphic rocks in the Georgetown Inlier vary in strength and consequently their resistance to erosion is variable. In the western part of the catchment these rocks are of low to intermediate metamorphic grade (phyllite and schist) and, with some exceptions, tend to form areas of low relief. In the eastern part of the catchment metamorphic grade is higher forming rocks such as gneiss with higher topographic relief. Soils developed over the Georgetown Inlier are usually shallow and not suitable for irrigation except for upland areas in the southern part of the catchment where soils are deeper and moderately suitable for some crops, albeit with limitations.

Major ore bodies in the Gilbert catchment are generally limited to the very old igneous and metamorphic rocks (i.e. older than Permian) of the Georgetown Inlier, where hot fluids have been transported from great depths and minerals in the fluids precipitated in the joints and fractures of these rocks. The formation of major ore bodies is facilitated by cracking of the crust, folding and mountain building activity, where the older the rock the greater the chance that it would have been exposed to these activities. Few rocks in the Gilbert catchment younger than Permian age have been folded or shattered.

Sedimentary rocks of 'clastic' origin occur in the Great Artesian Basin (GAB) and Karumba Basin. These rocks are typically made of fine (i.e. silt and clay) and coarse (i.e. sand and gravel) sediments that have been highly compressed and the pore spaces filled with mineral cements, resulting in reduced porosity and moderate aquifer yields.

The GAB is comprised of sedimentary rocks including mudstone, siltstone and sandstone. Outcrop areas of the GAB are relatively small in the Gilbert catchment. Mudstone and siltstone are the dominant rock types in the northern part of the catchment. Sandstone outcrops on the south-western margin and dips below the ground surface to the west of the catchment. At depth, this sandstone is an important aquifer in the GAB. Recharge of the groundwater takes place by infiltration of rainfall and streamflow. Although it forms areas of high relief, the sandstone is usually not suitable for dam construction because of its location in the upper reaches of the catchment and also because it sometimes overlies low strength metamorphic rocks.

Sedimentary rocks in the Karumba Basin outcrop in the northern part of the catchment. Rock types range from sandstone to mudstone. They are usually deeply weathered and of low strength. Small-scale groundwater extraction from these rocks may be feasible. The terrain underlain by rock of the Karumba Basin is usually not suitable for large dams because of the low topographic relief. Soils developed over these rocks may be moderately suitable for irrigation for some crops, albeit with limitations.

Basaltic lava flows have affected the upper and middle reaches of the Einasleigh River and some of its tributaries. There are two sources of basalt: one near the headwaters of the Einasleigh, Flinders, Clarke and Basalt Rivers and the other centred on Undara Volcano to the east of the Einasleigh River. Basalt has flowed down former river valleys and flood plains forming lava fields and, in some cases, blocking former river channels and causing river diversions. The basalt has had an adverse effect on several potential dam sites because of its potentially high permeability and the altered stream gradient where river diversion has taken place.

Unconsolidated sediments are ‘loose’ grains or aggregates. When they comprise mainly sand or gravel, they often form highly porous, high yielding aquifers. Those comprising mainly clay often have low porosity and low permeability and low aquifer yield. Unconsolidated alluvial sediments (i.e. deposited by rivers) form a large area downstream of the Gilbert–Einasleigh confluence in the northern part of the catchment and smaller areas along the middle reaches of the Gilbert and Einasleigh rivers. Alluvial areas may be moderately suitable for some crops with limitations.

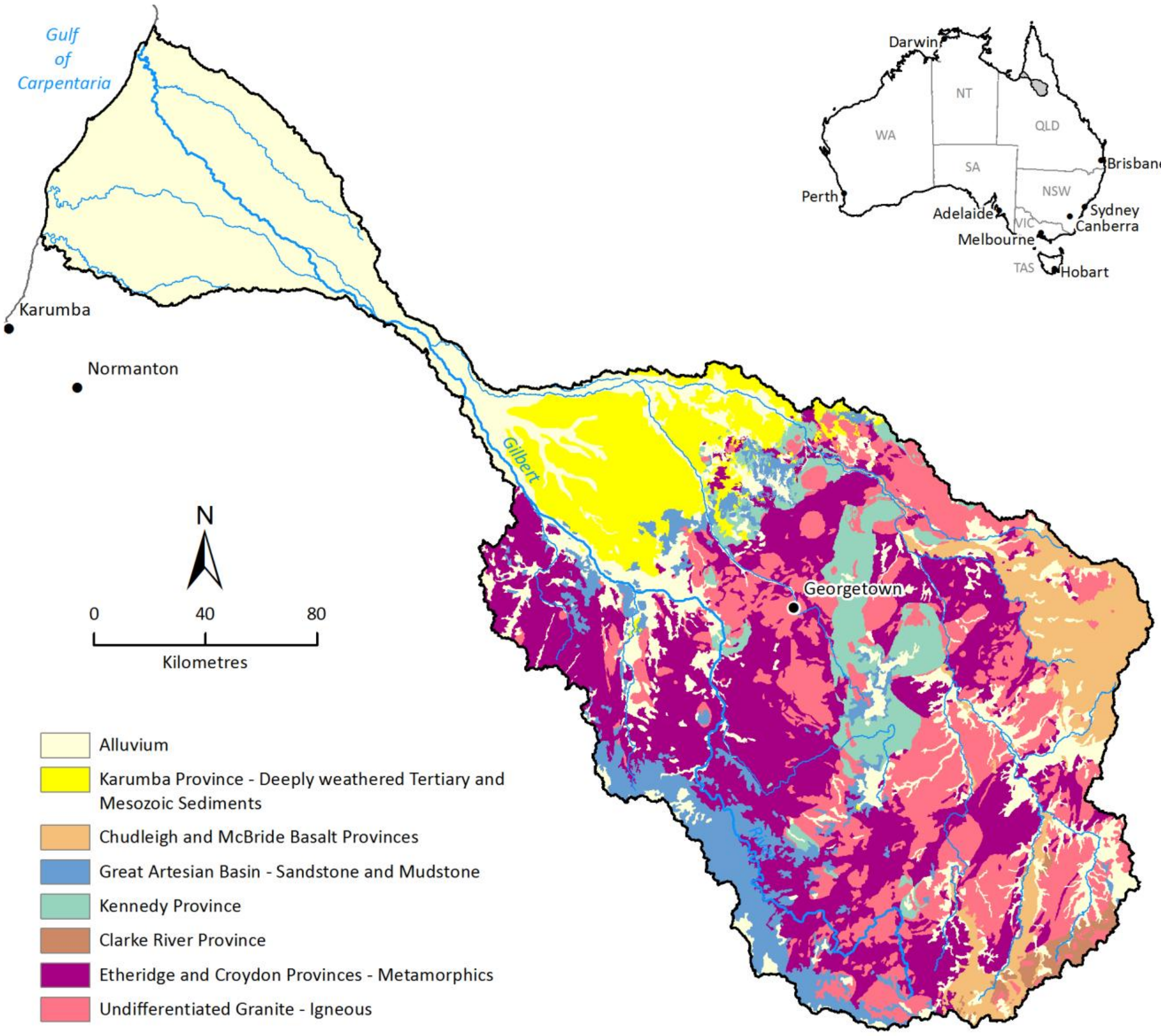

Figure 3.2 Simplified surface geology of the Gilbert catchment

3.3 Soils of the Gilbert catchment

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

This section briefly describes the spatial distribution of soil groups (Section 3.3.1) and soil attributes (Section 3.3.2) in the Gilbert catchment. The management considerations are also summarised.

Unless otherwise stated, the material in Section 3.3 is based on findings described in the companion technical report about land suitability (Bartley et al., 2013). The technical report includes detailed descriptions of the main geomorphic landscape units found in the Gilbert catchment.

3.3.1 SOIL CHARACTERISTICS

The soils most suitable for irrigated agriculture in the Gilbert catchment are the recent alluvial soils adjacent to the Gilbert and Einasleigh rivers upstream of their confluence. These soils are very deep (greater than 1.5 m) and generally extend about 0.5 to 2 km from the river. Elsewhere in the Gilbert catchment the agricultural potential is low.

As part of the Assessment, the soils in the Gilbert catchment were categorised into eight groups, referred to as soil generic groups (SGGs), as listed in Table 3.1. These provide a means of grouping together soils with broadly similar properties and management considerations (Table 3.1). The distribution of these soils and their attributes in the Gilbert catchment closely reflects the geology and landform. The suitability of these soils for irrigated agriculture is discussed below. Figure 3.3 shows the spatial distribution of SGGs across the Gilbert catchment.

Soils of the uplands are dominated by the shallow sandy and stony soils (~24%) on the resistant quartz-rich granite and volcanic rocks of the Kennedy Province, undifferentiated granites of the Georgetown Inlier, the metamorphic rocks in the Croydon, Etheridge and Clark River Provinces with higher relief, and the scarp of the dissected tablelands on the deeply weathered sediments in the Karumba Province and the Great Artesian Basin. These shallow and rocky soils have very low to low soil water storage (<75 mm), frequent rock outcrop, predominantly steep slopes subject to erosion, and have no potential for agricultural development.

Relatively large areas of sand or loam over friable or earth clay (~27%) and friable non-cracking clay or clay loam soils (~24%) are associated with the gentle slopes of the less resistant intermediate to basic igneous and metamorphic rocks. These soils are also associated with the alluvial plains throughout the catchment (flooded and non-flooded) and the basalt in the east and north-east of the catchment. Soils on the igneous and metamorphic rocks with a moderately deep (0.5 to1 m), moderately low to moderate soil water storage (50 to 100 mm) and gentle slopes are well suited to intensive horticulture, however these soils are frequently highly fragmented resulting in few areas suitable for large-scale agricultural development. The largest contiguous areas suitable for a wide variety of spray and drip irrigated crops are the sand or loam over friable or earth clay and friable non-cracking clay or clay loam soils on the broad (0.5 to 4 km from the river channel) alluvial plains of the Gilbert and Einasleigh rivers, particularly upstream of their confluence. The area adjacent to the Gilbert River channel was subject to previous investigation for agricultural development. Soils are very deep (>1.5 m) with predominantly moderate soil water storage (75 to 100 mm). The sandy surfaced soils have lower soil water storage and may be subject to short term water logging within the soil profile, particularly in the lower catchment towards the coast and lower landscape positions. Soils subject to regular or occasional flooding adjacent to the river channel have moderate to high nutrient levels while the high level flood free sandy surfaced soils are generally low in soil nutrients. The basalt areas of the Chudleigh and McBride Basalt provinces in the north-east and east of the catchment are dominated by clay loams and non-cracking clay soils and minor cracking clay soils with high nutrient levels. These basaltic soils are generally unsuitable for cropping and horticultural tree crops due to the large amounts of rock on the surface and throughout the soil profile which is generally uneconomical to remove.

The slow permeability cracking clay soils (~9%) are dominant on the broader (1 to 3 km wide) alluvial plains draining the basalts in the upper Einasleigh River catchment to the east and minor occurrences on the sparsely treed to treeless gently undulating plains and rises (Downs) on sedimentary rocks of the Great Artesian Basin at Abingdon. The moderately well drained slowly permeable brown cracking clays with a soft surface are similar to the cracking clay soils of the Rolling Downs in the Flinders River catchment. These cracking clay soils have moderate to moderately high water holding capacity (100 to 125 mm) and a restricted rooting depth due to very high salt levels in the subsoil and decomposed rock usually at less than one metre. The naturally high salt levels in the subsoil may cause salinity issues on lower slopes due to possible seepage resulting from over irrigation. Minor rill and gully erosion is evident on steeper slopes (>3%) while shallower soils and abundant fine gravel is common on upper slopes and ridge crests, particularly adjacent to the weathered plateaus and hills. Overall, these soils require further investigation to assess the likelihood of salinity developing under irrigated cropping. The cracking clay soils on the alluvial plains draining the basalts are suited to a variety of grain, forage and pulse crops. These alluvial plains are predominantly narrow (less than 0.5 km) with some broader plains (1 to 3 km) around Einasleigh township and further upstream. The area around Einasleigh has been previously investigated for agricultural development. The seasonally wet and permanently wet soils (~2%) on the alluvial plains in the lower catchment towards the coast have limited potential for agricultural development.

The red, yellow and grey loamy and earthy soils (~10%) are mainly associated with plains and dissected tablelands on the deeply weathered sediments of the Karumba Province between the confluence of the Gilbert and Einasleigh rivers and the uplands of the Great Artesian Basin in the western part of the catchment. These moderately permeable soils have variable soil depth over short distances but are predominantly moderately deep (0.5 to 1 m), and occasionally deep (1 to 1.5 m) on the flat plateaus of the Great Artesian Basin. These moderately deep soils grade to the shallow and stony soils on the scarps and rises of the deeply weathered plateaus mentioned in the report earlier. Soil water storage is low to moderate (50 to 100 mm) with higher water storage (75 to 100 mm) on the deeper soils. Well drained red loamy and earthy soils occur on the rises and edges of the plateaus while imperfectly drained yellow and grey soils occur on the plains and lower landscape positions. An attribute of all of these soils is that they are nutrient deficient, hence irrigated cropping would require very high fertiliser inputs when soils are initially developed. After the initial high application, fertiliser rates follow recommended crop requirements. On the deeper of these soils representing approximately 50% of the deeply weathered sediments, irrigation potential is limited to spray and drip irrigated crops. Seepage from irrigation development above scarps may contribute to rising water tables and salinity issues below the scarps, particularly at the break of slope.

Sand or loam over sodic and intractable clays (~4%) is mainly associated with lower slopes on the granites and granodiorites of the Georgetown Inlier and occasionally the alluvial plains of the creeks and rivers. These slowly permeable soils predominantly have low soil water storage (50 to 75 mm) and are subject to erosion on slopes. Agricultural potential is low.

Deep sandy soils (~0.5%) occur on the beach ridges along the coast. These highly permeable soils are usually fragmented into small isolated areas and together with very low soil water storage (<50 mm) have very limited agricultural potential.

Table 3.1 Soil generic group (SGG) classes of the Gilbert catchment

SOIL GENERIC GROUP DESCRIPTION	GENERAL DESCRIPTION	LANDFORM	OCCUR-RENCE (%)	MAJOR MANAGEMENT CONSIDERATIONS
Sand or loam over friable or earth clay	Strong texture contrast between the A and B horizons, but A horizons generally not bleached. B horizon not sodic and may be acid or alkaline. Moderately deep to deep.	Undulating plains to hilly areas on a wide variety of parent materials.	27%	The soils are potentially suitable for agriculture; steep slopes, small isolated areas, erosion, shallow soil and rock may limit development in uplands.
Friable non-cracking clay or clay loam soils	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.	Plains and plateaus along with some steeper country on intermediate to basic rocks and fine grained sedimentary rocks.	24%	Generally of high agricultural potential because of their good structure, and their moderate to high chemical fertility and water holding capacity. Soils on young basalt landscapes in the catchment are frequently shallow and rocky. Uplands may have steep slopes.
Seasonally wet soils	A wide variety of soils grouped together because of their seasonal or permanent inundation. No discrimination between saline and freshwater.	Coastal areas to inland wetlands, swamps and drainage depressions. Mostly unconsolidated sediments, usually alluvium.	2%	Require drainage works before development can proceed but usually impractical to drain on broad flat plains. Acid sulphate soils and salinity are associated problems in some areas. Generally unsuitable for crop development.
Red, yellow or grey loamy soils	Well drained, neutral to acid soils with little or only gradual increase in clay content at depth. Shallow to deep.	Level to gently undulating plains and plateaus.	10%	Have moderate to high agricultural potential when spray or trickle irrigation is applied due to their good drainage. Low to moderate water holding capacity; often hard setting. Low soil nutrients.
Deep sandy soils	Moderately deep to deep sands. May be gravelly.	Sandplains and beach ridges; aeolian and fluvial siliceous sediments.	0.5%	Low agricultural potential due to excessive drainage and poor water holding capacity. Low soil nutrients. Subject to wind erosion.
Shallow sandy/stony soils	Very shallow to shallow <0.5 m. Usually sandy or loamy, but may be clayey. Generally weakly developed soils that may contain gravel.	Crests and slopes of hilly and dissected landscapes associated with quartzose sandstone, quartz-rich rocks (granites, rhyolites) or eroding lateritic scarps.	24%	Negligible agricultural potential due to lack of soil depth and presence of rock. Often steep slopes prone to erosion.
Sand or loam over sodic/intractable clay	Strong texture contrast between the A and B horizons; A horizons usually bleached. Subsoil usually sodic. Usually alkaline but occasionally neutral to acid subsoils. Moderately deep to deep.	Lower slopes and plains in a wide variety of landscapes.	4%	Generally of low 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. Sandy surfaced soils have low soil water holding capacity.

Table 3.1 Soil generic group (SGG) classes of the Gilbert catchment (continued)

SOIL GENERIC GROUP DESCRIPTION	GENERAL DESCRIPTION	LANDFORM	OCCUR-RENCE (%)	MAJOR MANAGEMENT CONSIDERATIONS
Cracking clay soils	Clay soils with shrink–swell properties that cause cracking when dry. Usually alkaline and moderately deep to very deep.	Floodplains and other alluvial plains. Undulating to Rolling Downs country (formed on Mesozoic fine grained sedimentary rock). Minor occurrences in basalt landscapes.	8.5%	Generally have a moderate to high agricultural potential. The flooding limitation will need to be assessed locally. Most soils are high in salt (particularly those associated with the Downs) which limits crop rooting depth (<1 m) and moderate to moderately high water holding capacity (75 to 120 mm). Gilgai and coarse structured surfaces may occur. Surface stone common near plateaus.

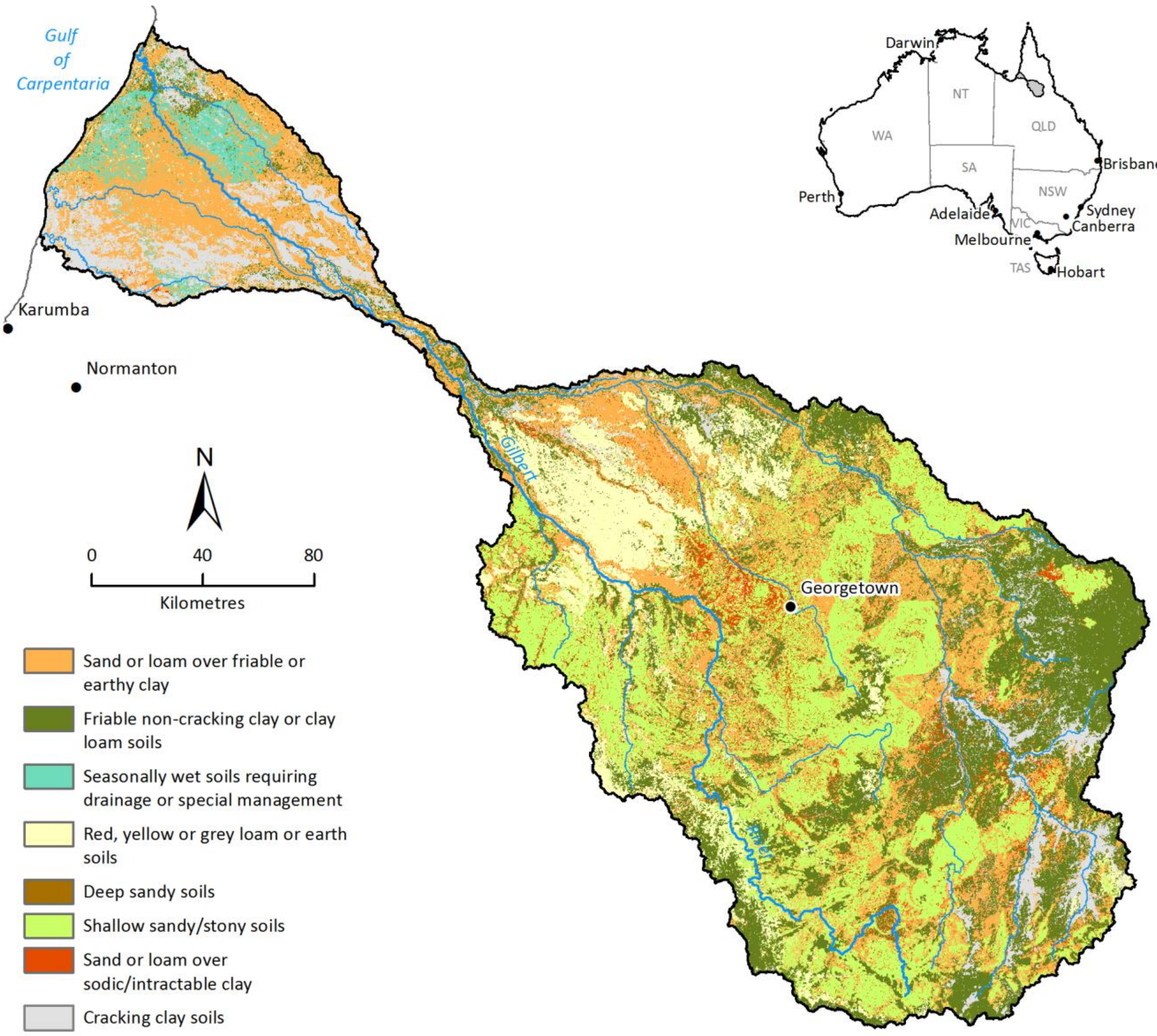

Figure 3.3 Map of soil generic group (SGG) classes for the Gilbert catchment

3.3.2 SOIL ATTRIBUTE MAPPING

Using a combination of field sampling and digital soil mapping (DSM) techniques, the Assessment mapped 16 attributes affecting the agricultural suitability of soil for the Gilbert catchment. Maps for six key attributes are presented below (Figure 3.4 to Figure 3.9):

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

An important feature of these maps is the indication of the certainty of the estimate of each attribute, shown by a second map. In most cases, the standard deviation (SD) is used to express the certainty. The SD is a statistic that indicates the variation from the mean or expected value. The larger the SD relative to the expected value the larger the uncertainty in the prediction. The certainty in class-based soil attributes (i.e. surface texture and permeability) is expressed using a 'confusion index'. The confusion index is the ratio of the second highest classification probability to the highest classification probability and takes a value between zero and one. When the two values are similar, this value is close to one and there is less certainty about the predicted class; when the probability of the first class is much higher than the probability of the second class, the confusion index is close to zero, and there is greater confidence in the predicted class.

Surface soil pH

The pH value of a soil is a numerical expression of the intensity of acidity (or alkalinity) that influences soil conditions and plant growth (Rayment and Lyons, 2011). The coarse-textured freely-draining soils prevalent in the Gilbert catchment leach base cations (e.g. potassium, sodium, calcium, magnesium) and as a result tend to be acidic with a pH range typically between 5.5 and 7.0 (Figure 3.4a). The sharp linear boundary of modelled pH in the lower catchment towards the coast may reflect the influence of the climate (e.g. Prescott Index) covariate data in the prediction. The reliability of prediction is generally good and is typically within the confidence range of field pH measurements (Figure 3.4b). Reliability is strongest in the alluvium in the southern upland zone, and weakest in the lower catchment, where the apparent linear artefact is strongly expressed, indicating that the DSM has been generally weaker in this part of the catchment.

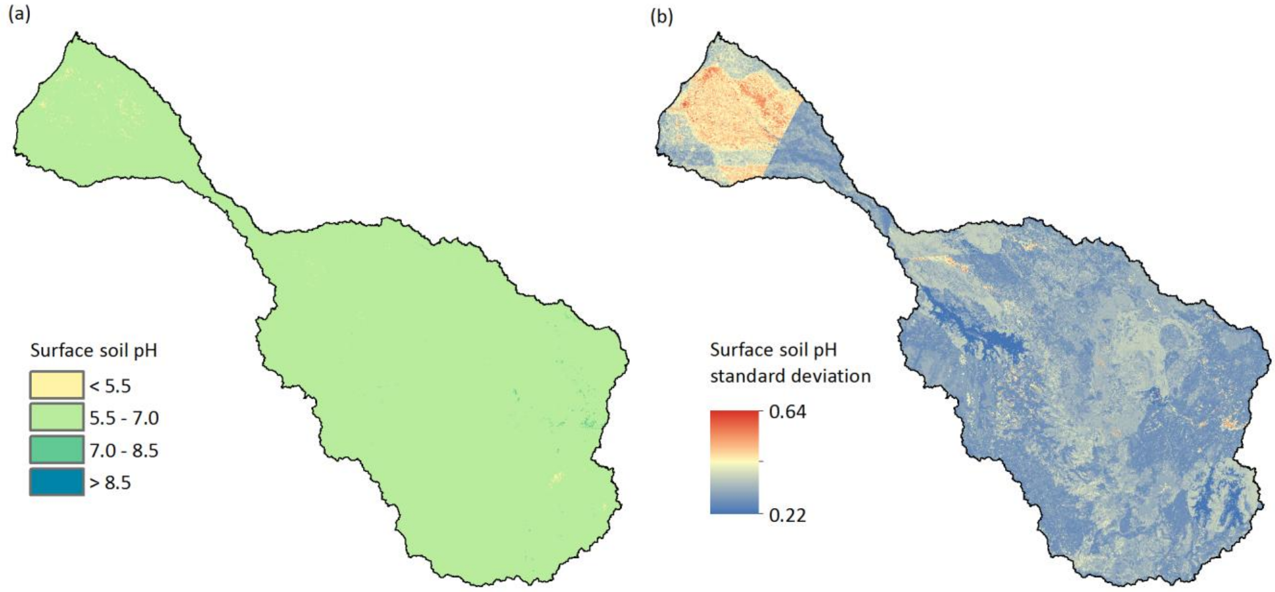

Figure 3.4 Surface soil pH of the Gilbert catchment
(a) Surface soil pH as predicted by the digital soil mapping (DSM). (b) Statistical accuracy of the prediction using standard deviation.

Minimum soil depth

Soil depth defines the potential root space and the amount of soil from where plants obtain their water and nutrients. The minimum soil depth is described as some soils may be deeper than the length of the drill rig corers used in this study (1.5 m). Soils developed on the resistant high strength granite and metamorphic uplands to the east and west are shallowest (<0.5 m) where fresh weathering and soil erosion are most active. Most of the soils in the Gilbert catchment are 0.25 to 1.5 m deep reflecting the high variability in geology, landform and soil generic groups (SGG). Very deep soils (>1.5 m) are typical of the soils on alluvium and the seasonally or permanently wet soils in the lower catchment (Figure 3.5a). Soil depth is important because it influences plant rooting depth and soil water holding capacity. The certainty associated with mapping of soil depth in the Gilbert catchment is variable and tends to be better along the major drainage lines (Figure 3.5b).

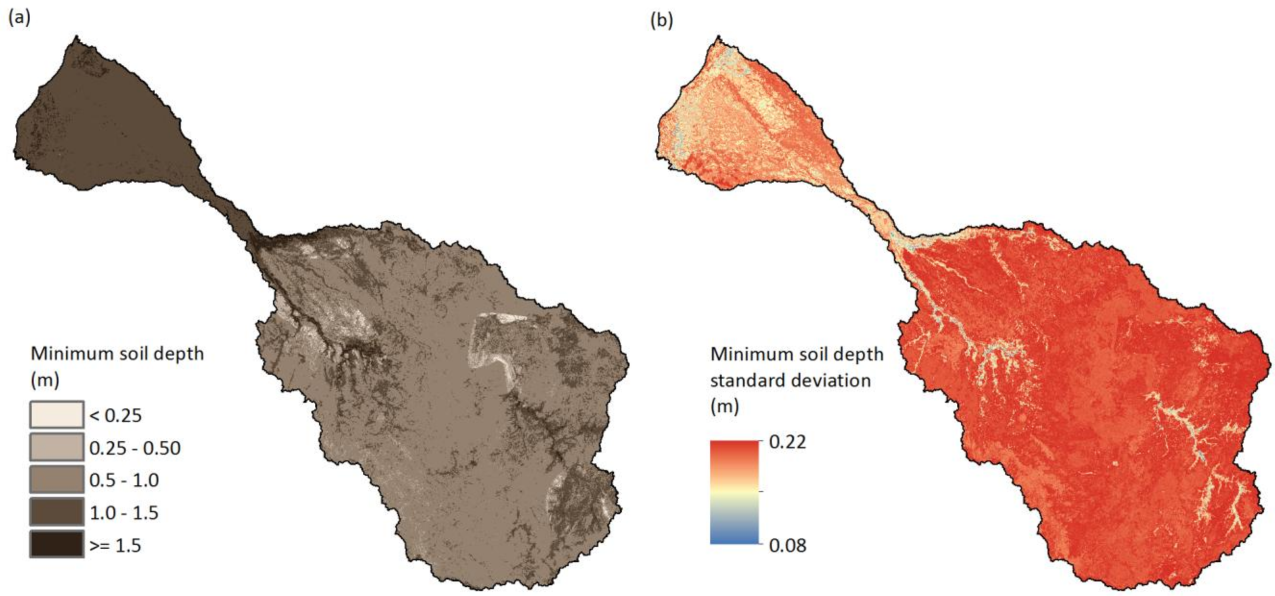

Figure 3.5 Minimum soil depth of the Gilbert catchment
(a) Minimum soil depth as predicted by the digital soil mapping (DSM). (b) Statistical accuracy of the prediction using standard deviation.

Soil surface texture

Soil texture refers to the amount of sand, silt and clay sized particles that make up the mineral fraction of a soil. Light soils are generally those high in sand and heavy soils are dominated by clay. The surface texture of soils upstream of the confluence of the Gilbert and Einasleigh rivers is dominated by sands and loams (Figure 3.6a). The loams are generally associated with the drainage areas, whereas the sands are associated with the sandstones of the Karumba Province and Great Artesian Basin, and the quartz-rich granites, volcanic and metamorphic rocks in the higher elevation areas. Clays dominate in the eastern areas associated with the basalt rocks and alluvial plains downstream of the confluence of the Gilbert and Einasleigh rivers. Upstream of the confluence, soils on the alluvium are dominated by loam and sand surface textures. This is likely to reflect the high energy of the river system in flood, which is sufficient to transport and deposit the coarser textures that dominate upstream. Surface texture influences soil water holding capacity, soil permeability, soil drainage, water and wind erosion, workability and soil nutrient levels. The certainty of surface texture class mapping is variable throughout the catchment (Figure 3.6b).

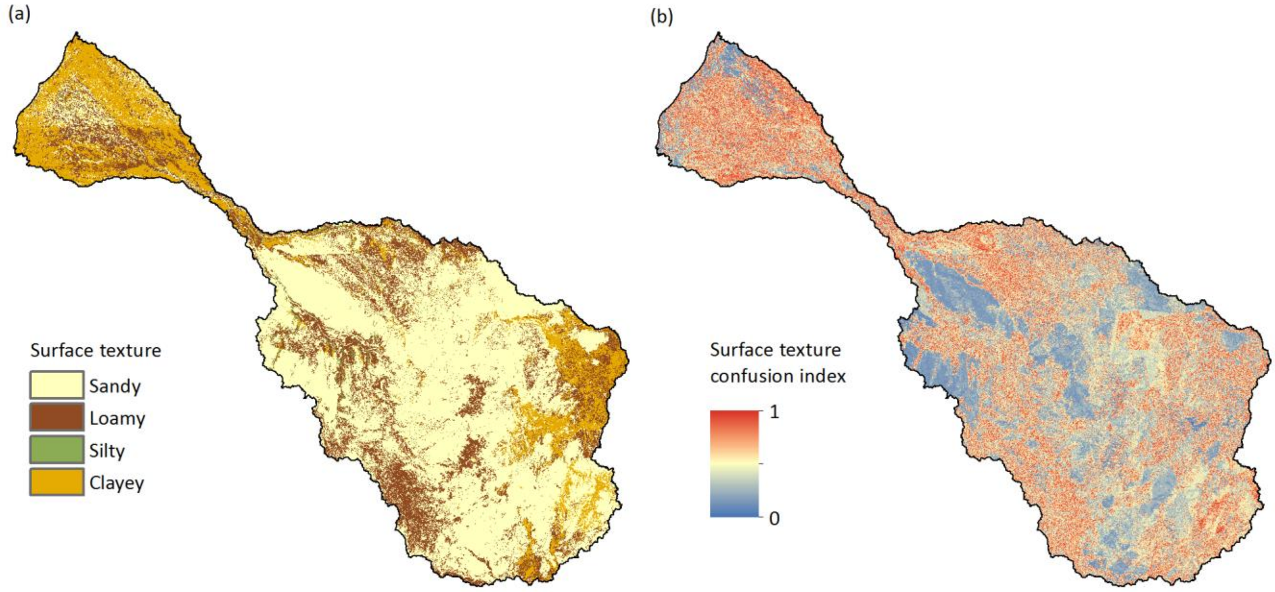

Figure 3.6 Surface texture of soils in the Gilbert catchment
(a) Surface texture of soils as predicted by the digital soil mapping (DSM). (b) Reliability of the prediction using a confusion index (see Bartley et al. (2013) for a full description of confusion index calculations).

Permeability

Permeability is a measure of how easily water moves through a soil. The cracking clay soils in the lower reaches of the Einasleigh River and in the alluvial areas of the catchment's coastal floodplains have low permeability (Figure 3.7a). The cracking clay soils associated with the basalt also have low permeability. The soils of the mid to upper reaches of the Einasleigh River tend to be coarser in texture and have moderate permeability. The soils on the elevated alluvial plains adjacent to the Gilbert River have high permeability reflecting the coarse grained sediments deposited under high energy streamflow. The remainder of the catchment is dominated by moderately permeable soils. Flood and furrow irrigation is most successful on soils with low and very low permeability to reduce root zone drainage (i.e. water in the soil that passes below the plant root zone), rising water tables and nutrient leaching. Spray or drip irrigation is more efficient on soils with moderate to high permeability. Permeability mapping certainty is best adjacent to the lower-lying river channels, and is generally poor in the uplands parts of the catchment where there were few measurements (Figure 3.7b).

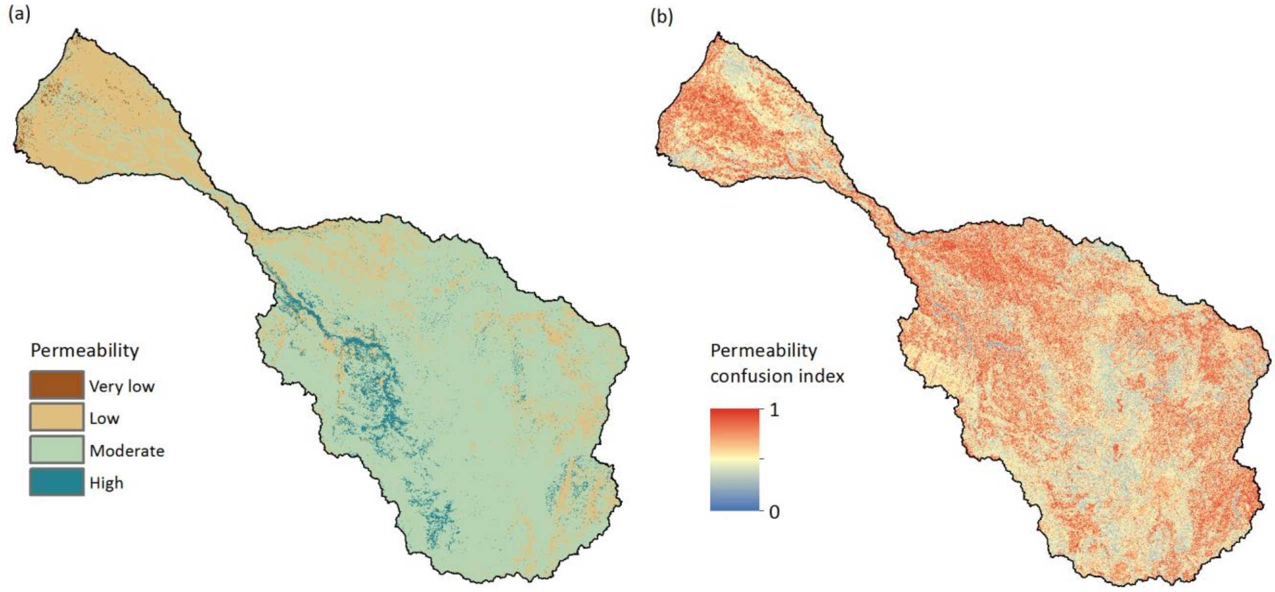

Figure 3.7 Soil permeability of the Gilbert catchment
(a) Soil permeability as predicted by the digital soil mapping (DSM). (b) Reliability of the prediction using a confusion index (see Bartley et al. (2013) for description of confusion index calculations).
Permeability classes are very low (drainage time = months), low (drainage time = weeks), moderate (drainage time = days) and high (drainage time = hours).

Plant available water capacity to 100 cm

The plant available water capacity (PAWC) is the maximum amount of water the soil can hold for plant use. PAWC 100 is the maximum amount of water that the top 100 cm of soil can hold for plant use; the higher the PAWC 100, the greater the capacity of the soil to supply plants with water. For irrigated agriculture, it determines irrigation frequency and volume; low PAWC 100 soils require more frequent watering and lower volumes per irrigation. For dryland agriculture, PAWC 100 determines the capacity of crops to grow between rainfall events.

The PAWC 100 was highest on very deep cracking clay soils, seasonally wet soils and sand or loam over friable or earth clay soils of the coastal floodplains of the Gilbert catchment and in those areas immediately adjacent to upper reaches of the Einasleigh River (Figure 3.8a). The PAWC 100 is typically the lowest on the shallow sandy and stony soils on the resistant granite and volcanic rocks, the metamorphic rocks with higher relief, and the scarp of the dissected tablelands on the deeply weathered sediments (Figure 3.2). The basalt derived soils of the Chudleigh and McBride Basalt provinces (Figure 3.2) are also characterised as having moderate PAWC 100 (75 to 100 mm) as a result of the basalt weathering to fine textured, moderately deep soils. However, these soils contain large amounts of rock, which reduces their PAWC and is problematic for cultivated agriculture. Figure 3.8b indicates a reasonable degree of certainty in the predictions across most of the Gilbert catchment. Certainty in the predicted PAWC 100 values is lowest in those parts of the Gilbert catchment with higher relief and where the PAWC 100 is relative low (i.e. less than 75 mm).

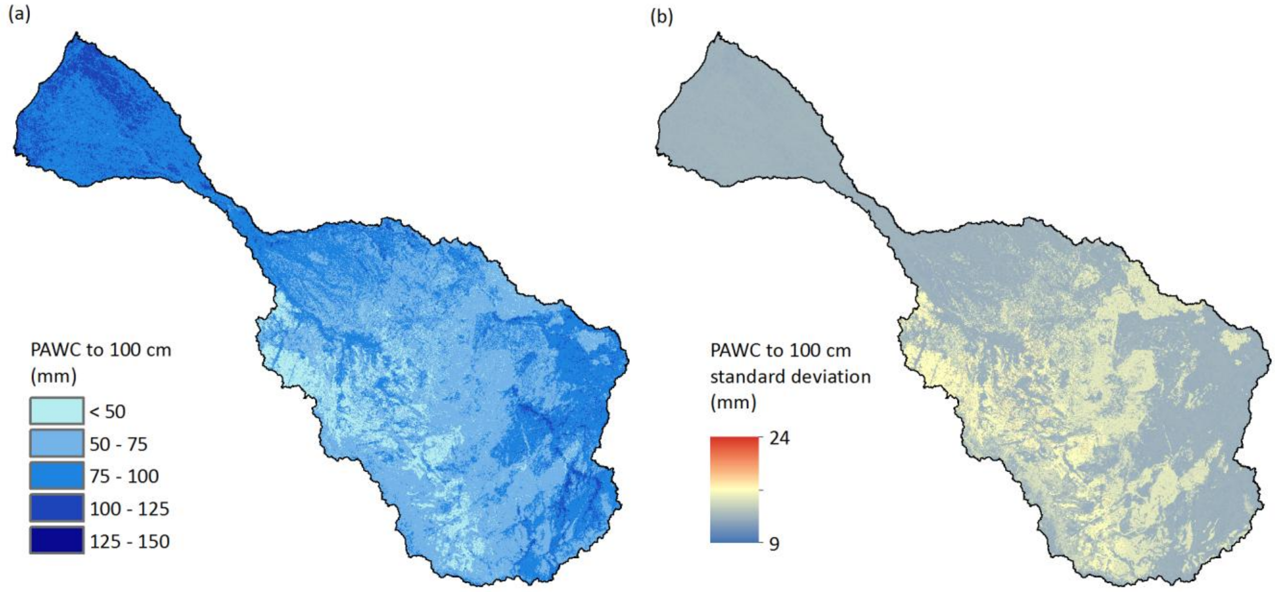

Figure 3.8 Plant available water capacity in the Gilbert catchment
(a) Plant available water capacity in the upper 100 cm of the soil profile (PAWC 100) as predicted by the digital soil mapping (DSM). (b) Statistical accuracy of the prediction using standard deviation.

Electrical conductivity

Electrical conductivity (EC) is a measure of the quantity of soluble salts in the soil and helps to indicate salinity. In this Assessment, EC was mapped for only the top 10 cm of soil. High EC in the soil can inhibit plant growth. Throughout the Gilbert catchment, the EC values in the top 10 cm are low (i.e. less than 0.15 dS/m) (Figure 3.9a). There are small areas of soil with higher EC values on the coastal floodplain associated with tidal influences and seasonally wet soils. Local areas of high EC can occur at locations in the landscape. A 'salt bulge' between 0.6 and 0.9 m depth on the cracking clay soils on the Rolling Downs at Abingdon station is normal. Minor natural springs and salinity also occurs at the base of the deeply weathered scarps and dissected plateaus. Excess root zone drainage under poor irrigation management may contribute to rising shallow or perched water tables and mobilise salts to the surface. The risk of secondary salinity from improper irrigation management needs to be highlighted if irrigation development occurs on the Rolling Downs and on the deeply weathered plateaus. Management will require appropriate soil water and ground watertable monitoring. The certainty of the EC prediction is good throughout the Gilbert catchment (Figure 3.9b).

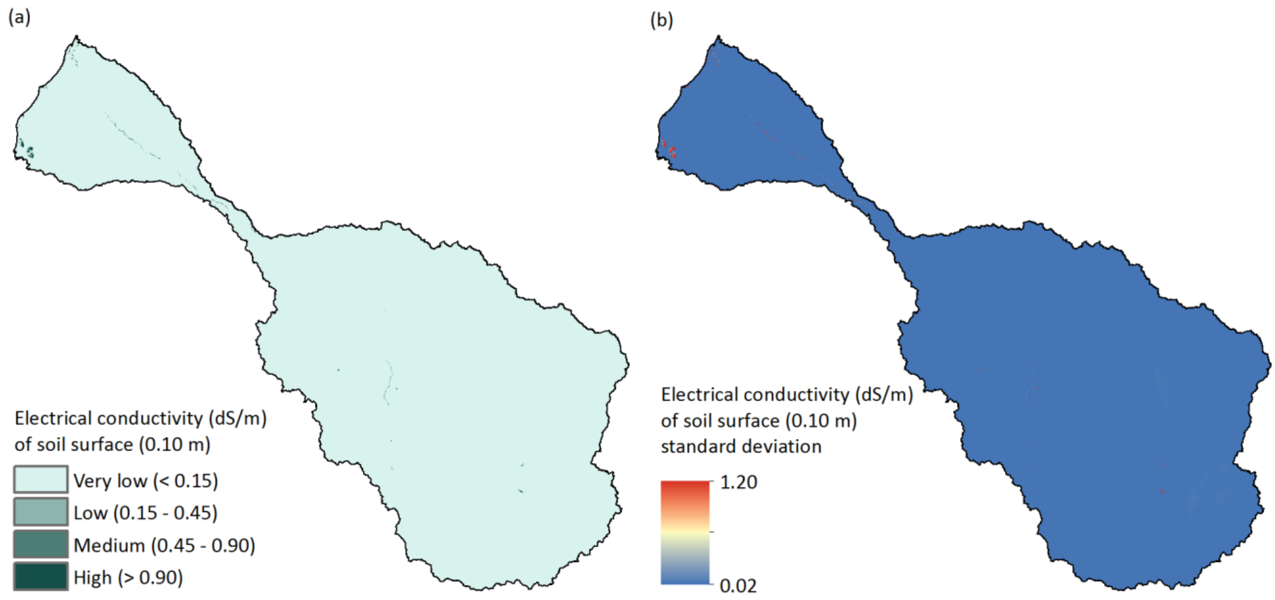

Figure 3.9 Electrical conductivity in the top 10 cm of soils of the Gilbert catchment
(a) Electrical conductivity (EC) – a measure of salinity given as decisiemens per metre (dS/m) – as predicted by digital soil mapping (DSM). (b) Statistical accuracy of the prediction using standard deviation.

3.4 Climate

The mean annual rainfall in the Gilbert catchment is moderate (775 mm) and it has a very high seasonality. Mean daily temperatures are high and radiation moderately high relative to other parts of Australia. Where water is available to overcome a frequent soil water deficit, the climate of the Gilbert catchment is generally suited to growing a wide range of crops.

Unless otherwise stated, the material in Section 3.4 is based on findings described in the companion technical report about climate data (Petheram and Yang, 2013).

3.4.1 GENERAL CIRCULATION OVER NORTHERN AUSTRALIA

Northern Australia has a highly seasonal climate. Between the months of December and April a broad area of low atmospheric pressure (or trough) moves south of the equator and intermittently crosses the northern shores of Australia (Figure 3.10). When this trough, commonly referred to as the monsoon, comes close to or crosses over land it brings humid conditions with showers, thunderstorms and widespread rain to northern Australia. The position and timing of the trough is highly variable from one wet season to another (Bonell et al., 1983), resulting in large differences in rainfall from one year to the next. The shallow and unstable air associated with this north-westerly 'monsoonal' flow does not penetrate deep inland and generally favours the development of thunderstorms in inland areas. This can result in heavily localised rainfall; across most of northern Australia average rainfall declines away from the coast. In years when the monsoonal trough does not extend over northern Australia, 'well organised rainfall' (i.e. widespread, as opposed to localised and spatially variable convective rainfall) does not occur.

During June to September the monsoon trough follows the sun, moving north of the equator; high pressure cells (anticyclones) also move northward (Figure 3.11). The withdrawal of the summer monsoon is associated with a reversal of the zonal wind direction (from westerly to easterly) and south-east trade winds gradually prevail over tropical Australia. On the east coast between Cardwell and Cooktown (the Wet Tropics) orographic uplift of the south-east trade winds results in year round and high rainfall (Sumner and Bonell, 1986). On the western side of the range there is a very steeply declining rainfall gradient. Having lost most of their water, the trade winds sweep across the rest of the Gulf region, resulting in mainly mild, dry south-easterlies over the Assessment area during the dry season.

Tropical cyclones

Monsoonal rain is supplemented by heavy and often widespread rainfall from tropical cyclones and tropical depressions. Approximately 90% of cyclones occur between the start of December and the end of April (Hobbs, 1998). The frequency of occurrence and paths of tropical cyclones vary greatly from one year to the next. During La Nina periods they may occur 2-4 years in 10 in the Gilbert catchment, but during El Nino years tropical cyclones are less frequent (see Petheram and Yang (2013) for a discussion on cyclones and El Nino and La Nina).

Cyclones rapidly weaken when they cross the coast from sea to land and become a rain depression. Key regional centres in the Gilbert catchment (i.e. Mount Surprise, Einasleigh, Georgetown, Forsayth) are largely buffered from the most damaging winds by their distance from the coast, but the rain depressions bring flood risks. Although many tropical depressions do not fully develop into tropical cyclones they are typically accompanied by large-scale convection and heavy rain, which contribute significantly to wet-season rainfall in the Gulf region.

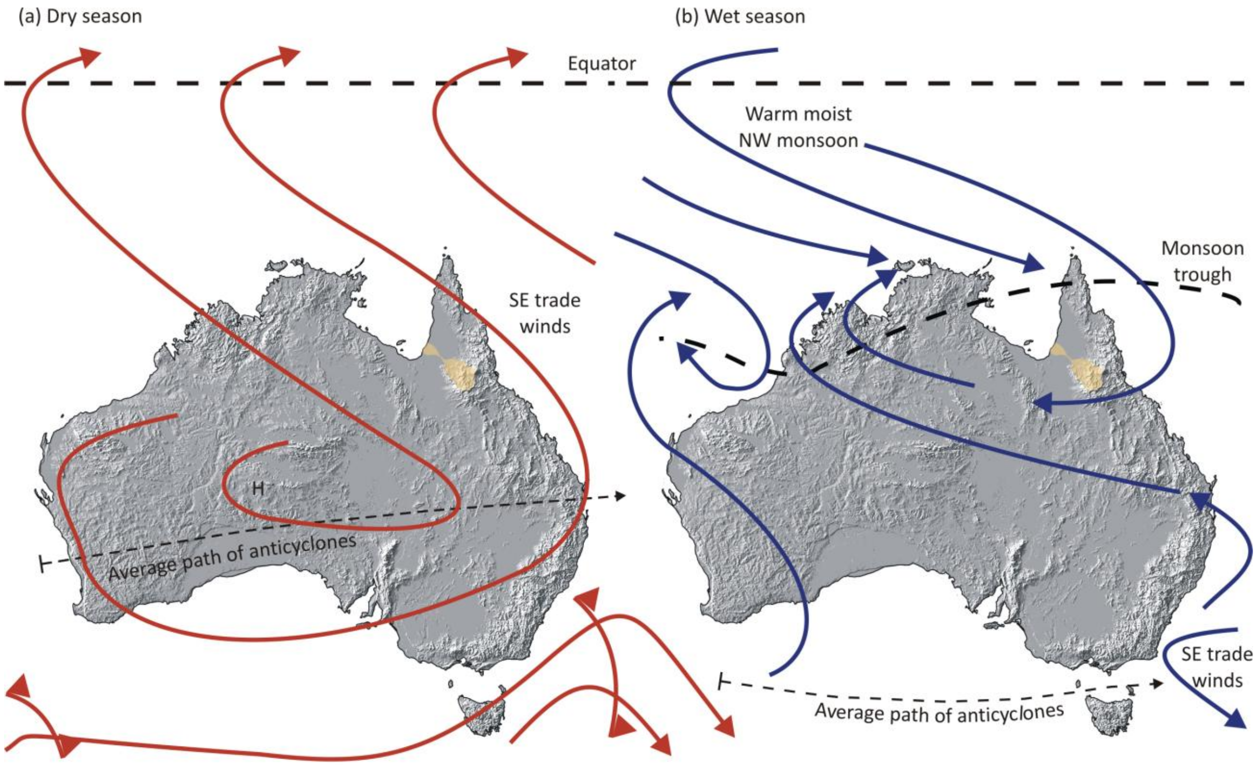

Figure 3.10 Typical synoptic systems influencing the Gilbert catchment
(a) Mid-dry-season influences. (b) Mid-wet-season influences. The Gilbert catchment is shown by light brown shading. Adapted from BoM (1998), Warner (1986) and Petheram and Bristow (2008).

3.4.2 SPATIAL PATTERNS OF RAINFALL AND POTENTIAL EVAPORATION

Rainfall

Under Scenario A (i.e. 1 July 1890 to 30 June 2011) the mean annual rainfall and median annual rainfall spatially averaged across the Gilbert catchment are 775 mm and 739 mm, respectively. The mean represents the commonly used ‘average’. The median is the number at which there are as many years above it as below it. The median is lower than the mean because very wet years bias the mean upwards, but have little effect on the median.

Spatially, mean annual rainfall varies from about 1050 mm near the coast to about 650 mm in the south-east of the Gilbert catchment (Figure 3.11). The median rainfall exhibits a very similar pattern to mean annual rainfall.

During the dry season, rainfall generally decreases in a northerly direction as the south-east trade winds rapidly lose their water as they cross the Great Dividing Range and sweep across the Gulf region (Figure 3.12).

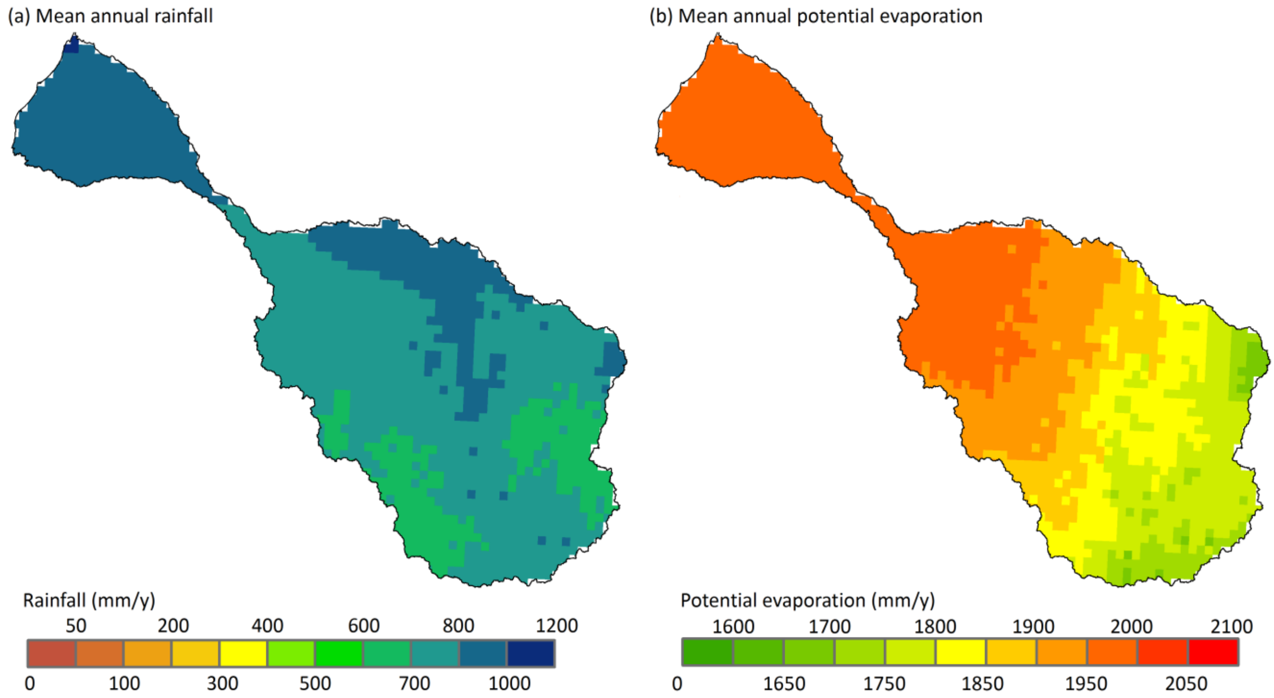

Figure 3.11 Mean annual rainfall and potential evaporation under Scenario A
(a) Mean annual rainfall and (b) mean annual potential evaporation.

Potential evaporation

Evaporation is the process by which water is lost from open water, plants and soils to the atmosphere; it is a 'drying' process.

There are three major ways in which evaporation affects a region's potential for irrigation: losses that lower runoff and drainage and, hence, the ability to fill water storages (Section 3.5); losses from water storages (Section 5.2) and; influence on crop water requirements (Section 5.5).

Potential evaporation (PE) is defined as the amount of evaporation that would occur if an unlimited source of water were available. The Gilbert catchment has a mean annual potential evaporation of 1868 mm (for the years 1965 to 2011). Hence on average, the mean evaporative water loss from open storages in the Gilbert catchment is about 1870 mm, or about two and a half times the mean annual rainfall additions; evaporation exceeds rainfall by almost 1100 mm.

Preliminary estimates of mean annual irrigation demand and net evaporation from water storages are sometimes computed by subtracting the mean annual (seasonal) evaporation (Figure 3.12) from the mean annual (seasonal) rainfall (Figure 3.13). This is commonly referred to as the mean annual (seasonal) rainfall deficit (Figure 3.14).

A commonly used method for characterising climates is the United Nations Environment Program aridity index (UNEP, 1992). It indicates that 95% of the Gilbert catchment is semi-arid (Petheram and Yang, 2013).

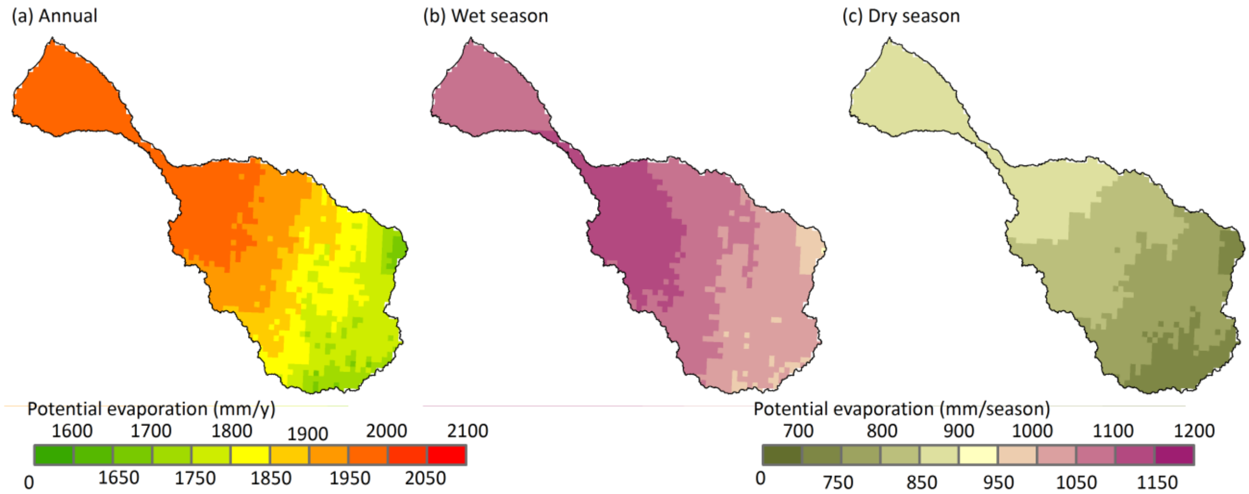

Figure 3.12 Potential evaporation under Scenario A for the Gilbert catchment
(a) Annual evaporation. (b) Wet-season evaporation. (c) Dry-season evaporation.

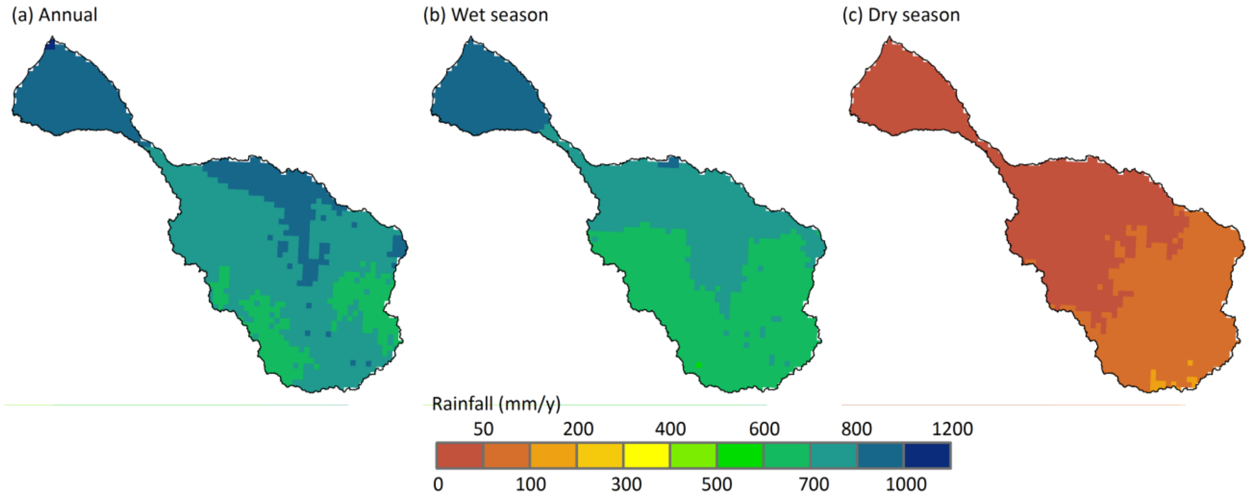

Figure 3.13 Rainfall under Scenario A for the Gilbert catchment
(a) Annual rainfall. (b) Wet-season rainfall. (c) Dry-season rainfall.

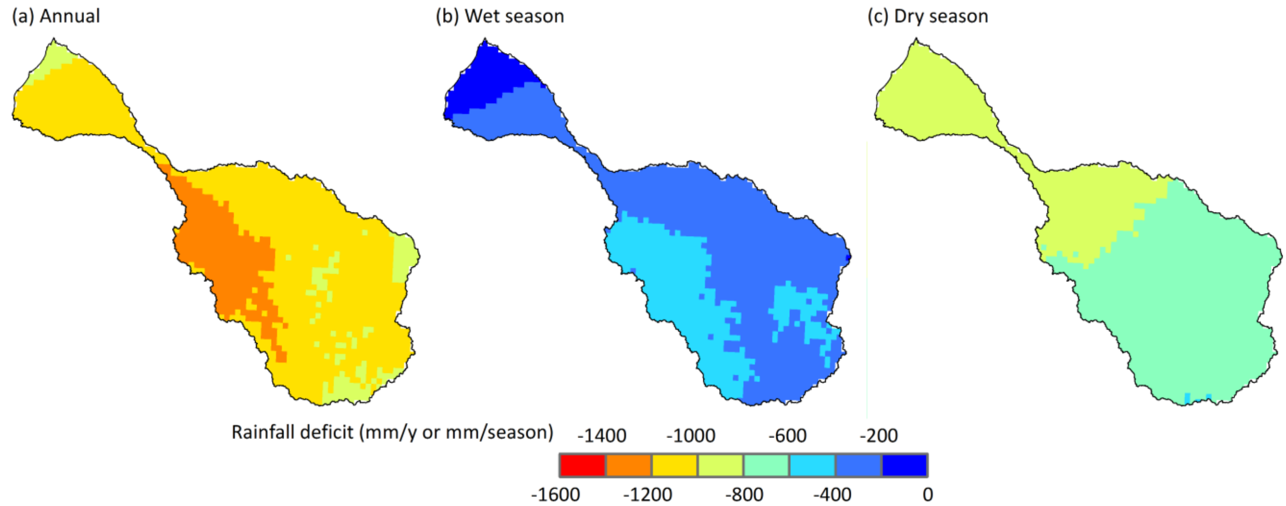

Figure 3.14 Rainfall deficit under Scenario A for the Gilbert catchment
(a) Annual rainfall deficit. (b) Wet-season rainfall deficit. (c) Dry-season rainfall deficit.

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

The Gilbert catchment experiences a highly seasonal climate with an extended dry season. In the absence of groundwater, year round cropping would require the construction of surface water storages. The Gilbert catchment also exhibits high variability in rainfall from one year to the next. As a consequence, dryland farming in the Gilbert catchment is likely to be more risky than in many parts of southern Australia with the same mean annual rainfall (see Section 5.5) and the rest of the world with the same climate type as northern Australia (Petheram et al., 2008). The highly variable rainfall and high PE amplifies the variability of streamflow. As discussed in Section 3.5, higher variability in streamflow means that, all other factors being equal, water from a large reservoir can be supplied less reliably.

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

In the Gilbert catchment 93% of rain falls during the wet season (November to April). The highest median monthly rainfall in the Gilbert catchment occurs during January and February, with a median monthly value of about 200 mm (Figure 3.15). The months with the lowest median rainfall are July and August, with less than 0.5 mm rainfall falling each month.

Potential evaporation also exhibits a seasonal pattern. During the months of October to January PE exceeds 180 mm/month. It is lowest during June. Months where PE is high correspond to those months where the demand for water by plants is also high. Mean wet-season and dry-season potential evaporation in the Gilbert catchment are 1067 mm and 815 mm respectively (Figure 3.12). In Figure 3.15, the blue shading represents the range under Scenario A (A range). The upper limit of the A range is the value at which rainfall or PE is exceeded one year in five and is known as the 20% exceedance. The lower limit of the A range is the value at which rainfall or potential evaporation is exceeded four years in five and is known as the 80% exceedance. The upper limit of the A range indicates the variation in monthly values from one year to the next. Compared to rainfall, the variation in monthly potential evaporation from one year to the next is small (Figure 3.15b).

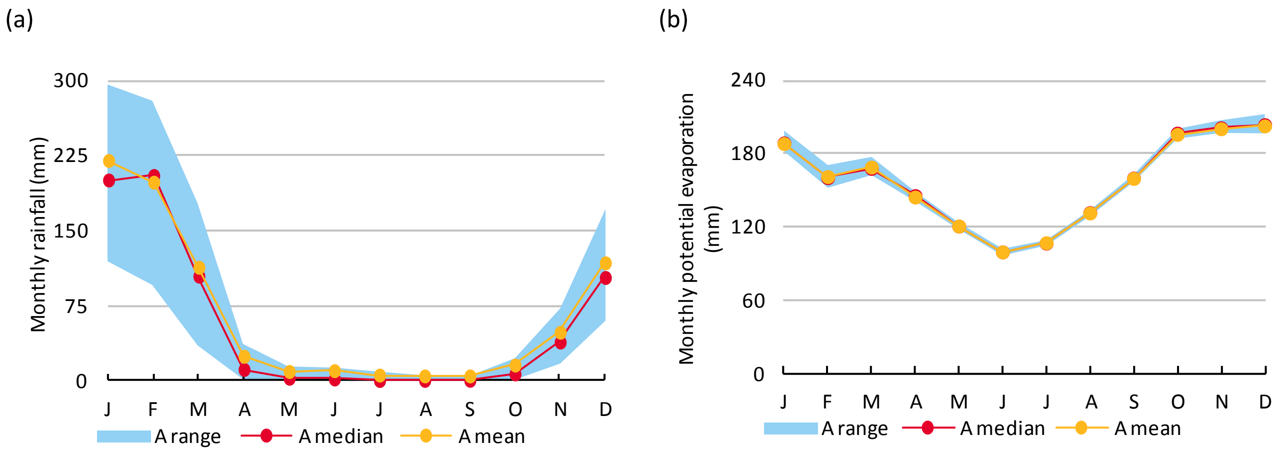

Figure 3.15 Rainfall and potential evaporation under Scenario A averaged across the Gilbert catchment
(a) Monthly rainfall. (b) Potential evaporation. Scenario A is the historical climate (1890 to 2011). The A range is the 20th to 80th percentile exceedance.

Under Scenario A, the Gilbert catchment exhibits considerable variation from one year to the next (Figure 3.16). The highest catchment average annual rainfall (2187 mm) occurred in 1974, and was nearly three times the median annual rainfall value (i.e. 739 mm). The ten-year running mean provides an indication of the sequences of wet or dry years (i.e. variability at decadal time scales). For an annual time series the ten-year running mean is the average of the five years of data either side of every annual data point. Under Scenario A, potential evaporation exhibits much less inter-annual variability than rainfall.

(a) (b)

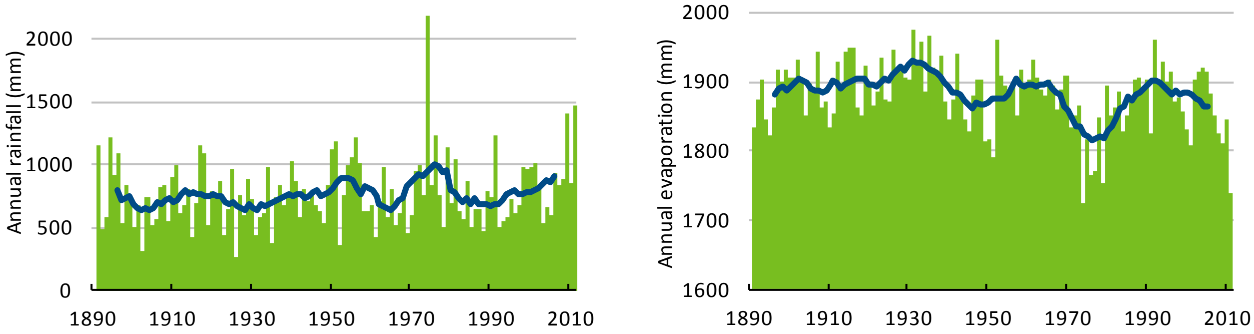

Figure 3.16 Mean annual rainfall and potential evaporation averaged over the Gilbert catchment
(a) Mean annual rainfall under Scenario A. (b) Potential evaporation under Scenario A. The blue line represents the 10-year running mean.

The variation in rainfall from one year to the next (inter-annual variation) in the Gilbert catchment is higher than most other rainfall stations around Australia with the same mean annual rainfall. The coefficient of variation (CV) provides a measure of the variability of rainfall from one year to the next, where the larger the CV value, the larger the variation in annual rainfall relative to a location's mean annual rainfall – it is calculated as the standard deviation of mean annual rainfall divided by the mean annual rainfall. In Figure 3.17, the CV of annual rainfall is shown for rainfall stations with a long-term record around Australia. The implications of these results are that dryland farming in the Gilbert catchment is likely to be more risky than in many parts of southern Australia with the same mean annual rainfall (see Section 5.5.4 about dryland farming in the Gilbert catchment). The high variability in rainfall means that streamflow is also highly variable. As discussed in Section 3.5.3, this has implications for the reliability with which irrigators can access water.

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

(a) (b)

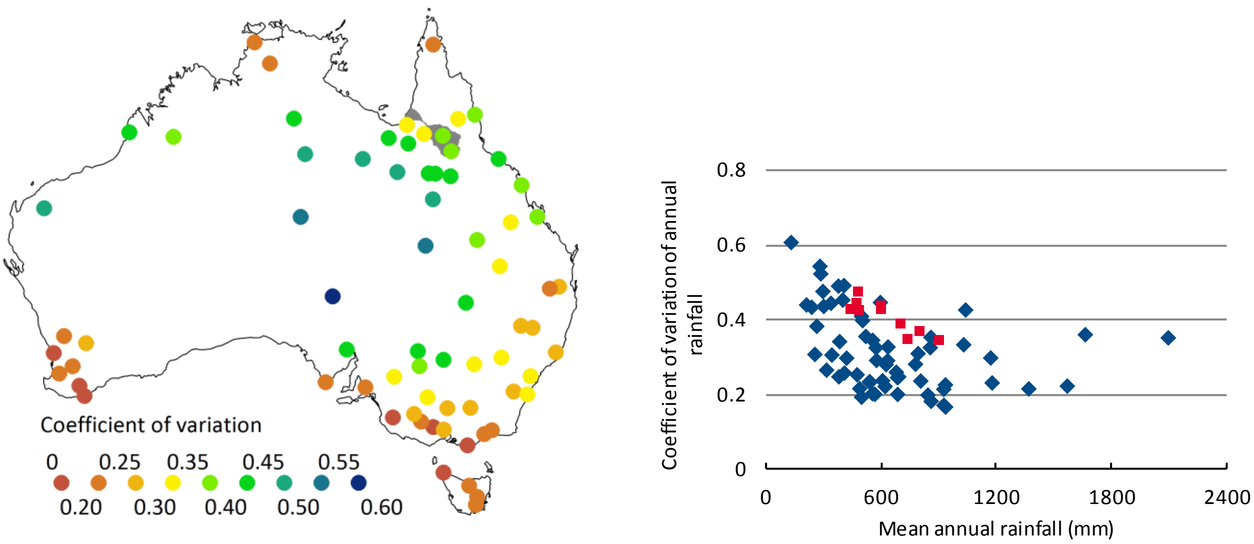

Figure 3.17 Rainfall variability around Australia under Scenario A
(a) Coefficient of variation (CV) of annual rainfall for 71 high quality rainfall stations from around Australia under Scenario A. The grey polygon indicates the extent of the Gilbert catchment. (b) The coefficient of variation of annual rainfall plotted against mean annual rainfall for 71 rainfall stations from around Australia – red squares indicate rainfall stations within 100 km of the Flinders and Gilbert catchments.

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

Of these influences, the ENSO is a phenomenon that is considered to be the primary source of global climate variability over the two- to six-year timescale (Rasmusson and Arkin, 1993) and is reported as being a significant cause of climate variability for much of eastern and northern Australia. One of the modes of ENSO, El Niño, has become a term synonymous with drought in the western Pacific and eastern and northern Australia. Rainfall stations along eastern and northern Australia have been observed to have a strong correlation (0.5 to 0.6) with the Southern Oscillation Index (SOI), a measure of the strength of ENSO, during spring suggesting that ENSO plays a key role in between-year rainfall variability (McBride and Nicholls, 1983).

Runs of wet and dry years

The Gilbert catchment is likely to experience runs of dry years of greater severity than many centres in the south-east and south-west of Australia. This suggests that agriculturalists in the Gilbert catchment would need to operate under especially well-developed drought contingency plans.

The Gilbert catchment is characterised by irregular periods of consistently low rainfall when successive wet seasons fail, as well as the typical annual dry season. Runs of wet and dry years, referred to here as wet and dry spells, are shown as annual differences from the median rainfall for the Gilbert catchment in Figure 3.18. A spell of consistently dry years may be associated with drought (though an agreed definition of drought continues to be elusive). In this figure it can be seen that there were long runs of dry years centred on 1900, 1930, 1960 and the mid-1980s in the Gilbert catchment. Annual rainfall in the six years prior to June 2011 was above the median annual value.

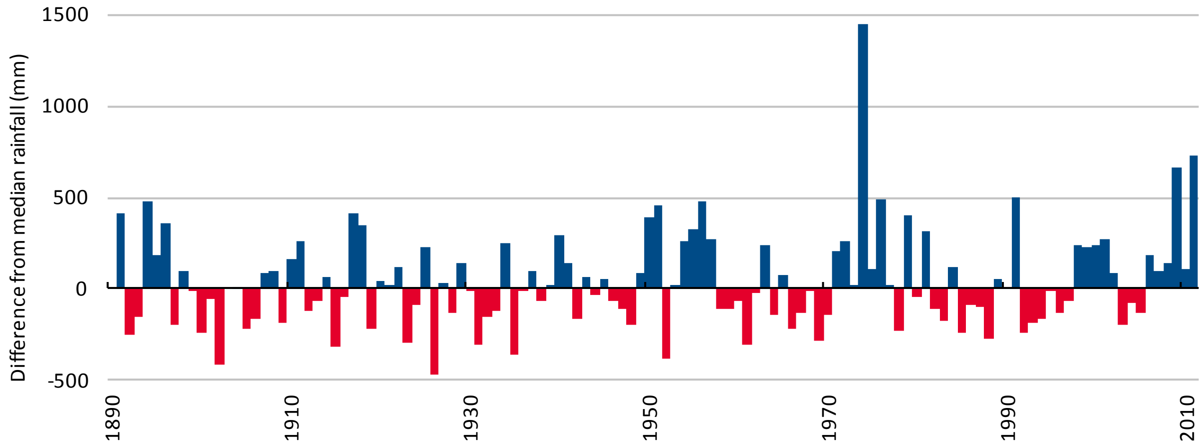

Figure 3.18 Runs of wet and dry years in the Gilbert catchment
Wet years are shown by the blue columns and dry years by the red columns.

The duration of runs of dry years in the Gilbert catchment is comparable with other agricultural areas of Australia, such as the Murray-Darling (Petheram and Yang, 2013). The duration of wet spells is also comparable. The magnitude of dry years (i.e. the 'dryness' of a run of dry years) in the Gilbert catchment was found to be higher than the magnitude dry years in south-east and south-western Australia. This means that when it is dry (i.e. annual rainfall is below the median annual rainfall), it is typically very dry.

Dry run severity is a combination of the dry run length and dry run magnitude. Because the Gilbert catchment had a normal dry run length and high dry run magnitude, the severity of runs of dry years was also found to be high.

3.4.4 OTHER CLIMATE FACTORS

Of all the climate factors affecting hydrology and agriculture, rainfall is usually the most important. Rainfall is the main determinant of runoff and groundwater recharge (water that actually replenishes the underlying groundwater system) and water is a fundamental requirement for plant growth. For this reason, reporting of climate parameters is heavily biased towards rainfall data. Nevertheless, other climate parameters are important for agriculture. These include temperature and solar radiation. Temperature is an important factor in controlling changes in plant development, while radiation or sunlight is essential in photosynthesis, which enables plants to capture carbon dioxide from the atmosphere and convert it into carbohydrates. In general, higher crop yields are achieved by harvesting more short wave radiation. Data on these other climate parameters are presented in the companion technical report on climate data (Petheram and Yang, 2013).

3.4.5 CHANGES IN RAINFALL AND POTENTIAL EVAPORATION UNDER A FUTURE CLIMATE

The effects of projected climate change on rainfall and PE are presented in Figure 3.19 to Figure 3.21. This analysis used 15 global climate models (GCMs) to represent a world where the global average surface air temperatures are 2 °C higher relative to ~1990 global temperatures. Because the scale of GCM outputs is too coarse for use in catchment and point-scale hydrological and agricultural computer models they were transformed to catchment-scale variables using a simple scaling technique and referred to as GCM-ESs. See Petheram and Yang (2013) for further details. For each GCM the simple scaling technique was applied to the Scenario A climate data to create a future climate time series of equivalent length, referred to as Scenario C.

In Figure 3.19 the 15 GCM-ESs' rainfall and PE projections are spatially averaged across the Gilbert catchment and the GCM-ESs are ranked in order of increasing mean annual rainfall. In this figure it can be seen that about half the projections for GCM-ESs indicate an increase in mean annual rainfall and half indicate a decrease in mean annual rainfall. However, it should be noted that about 60% of GCM-ESs mean annual rainfall projections are within ±10% of the historical mean. For a two degree warming scenario it is possible for ±10% trends in rainfall to be generated by internal variability modelled by the GCMs (Cai et al., 2010, 2011). Hence it can be argued that based on the selected 15 GCM-ES the consensus result is that mean annual rainfall in the Gilbert catchment is not likely to change under Scenario C.

The spatial distribution of mean annual rainfall under Scenario C is shown in Figure 3.20. In this figure only the second 'wettest' GCM-ES (i.e. Scenario Cwet), the middle or 8th wettest GCM-ES (i.e. Scenario Cmid) and the second 'dryest' (i.e. Scenario Cdry) GCM-ESs are shown.

Figure 3.21a shows mean monthly rainfall under scenarios A and C. The data suggest that under Scenario Cmid mean monthly rainfall will be similar to the mean monthly rainfall under Scenario A. Under scenarios Cwet, Cmid and Cdry the seasonality of rainfall in northern Australia is similar to that under Scenario A.

Potential evaporation

The mean annual change in GCM-ES PE shows projected PE increases of about 3 to 9%. Under scenarios Cwet, Cmid and Cdry PE exhibits a similar seasonality to that under Scenario A. However, different methods of computing evaporation give different results. Consequently there is considerable uncertainty on how PE may change under a warmer climate. See Petheram et al. (2012) and Petheram and Yang (2013) for a more detailed discussion.

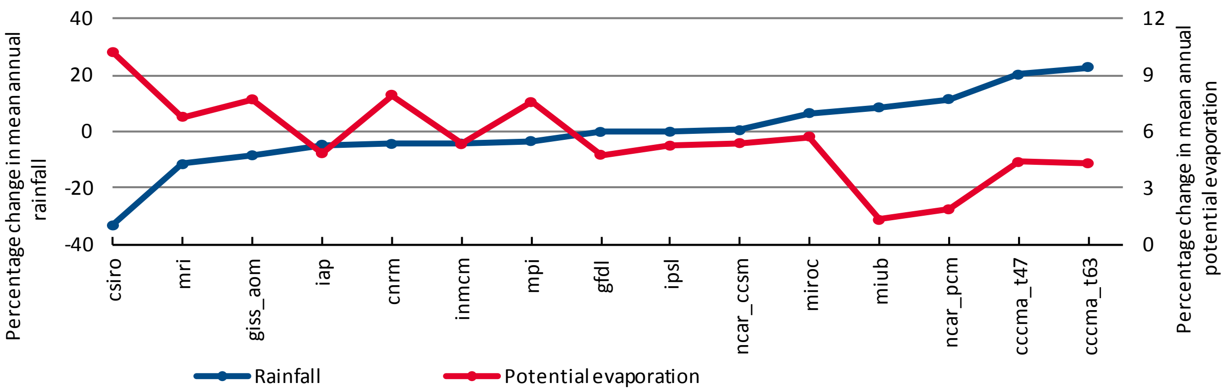

Figure 3.19 Percentage change in mean annual rainfall under Scenario C relative to Scenario A
The blue line shows mean annual rainfall and the red line shows potential evaporation (PE). GCM-ESs are ranked by increasing rainfall.

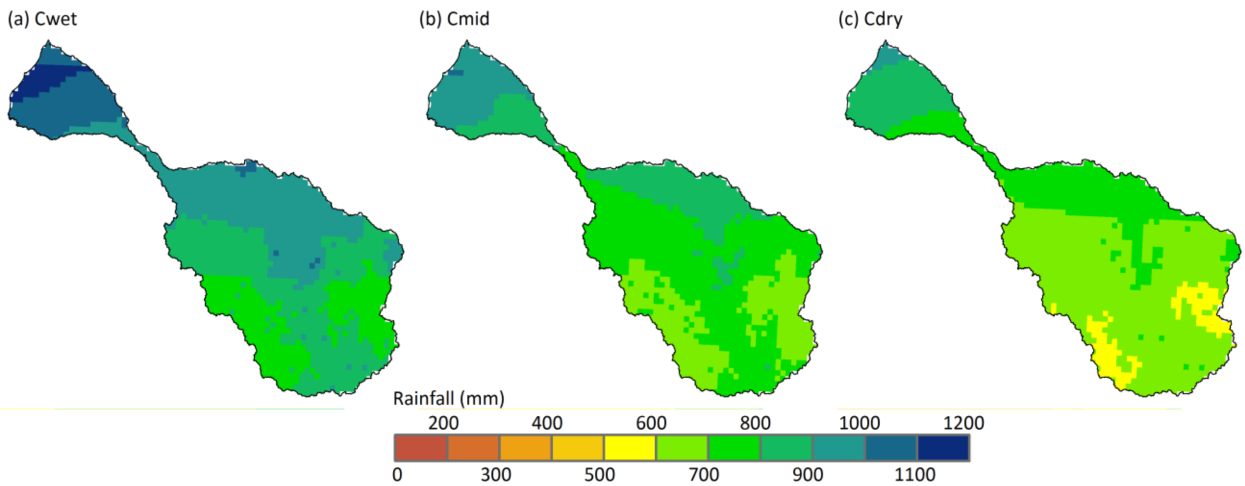

Figure 3.20 Spatial distribution of mean annual rainfall across the Gilbert catchment under scenarios Cwet, Cmid and Cdry

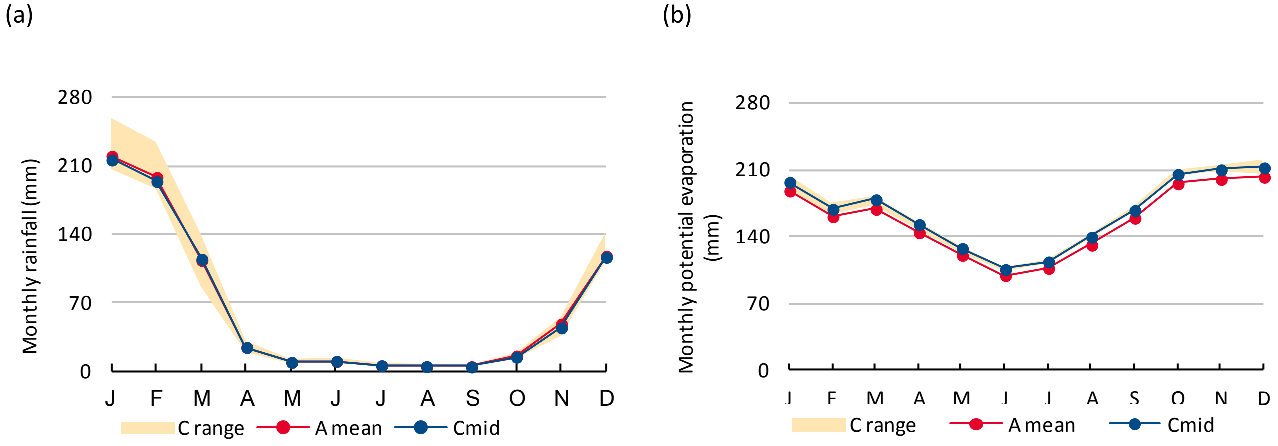

Figure 3.21 Mean monthly rainfall and potential evaporation for the Gilbert catchment under scenarios A and C
(a) Mean monthly rainfall. (b) Potential evaporation. C range is based on the computation of the 10th and 90th percentile monthly values separately – the lower and upper limits in C range are therefore not the same as scenarios Cdry and Cwet.

3.5 Hydrology

The timing and event-driven nature of rainfall events and high potential evaporation rates across the Gilbert catchment have important consequences for the catchment's hydrology. The spatial and temporal patterns of rainfall and potential evaporation across the Gilbert catchment are discussed in Section 3.4. Rainfall can be broadly broken into evaporated and non-evaporated components. The non-evaporated component can be broadly broken into overland flow and recharge (Figure 3.22). Recharge replenishes groundwater systems, which in turn discharge into rivers and the ocean. Overland flow and groundwater discharge into rivers combines to become streamflow. Streamflow in this report is defined as a volume per unit of time. Runoff is defined as the millimetre depth equivalent of streamflow. Flooding is a phenomenon that occurs when the flow in a river exceeds the river channel's capacity to carry the water and water spills onto the land adjacent to the river.

Section 3.5 covers the remaining terms of the terrestrial water balance (accounting for water inputs and outputs) of the Gilbert catchment, with particular reference to those processes and terms that are relevant to irrigation at the catchment scale. Information is firstly provided on groundwater, groundwater recharge and surface water – groundwater connectivity. Runoff, streamflow, flooding and persistent waterholes in the Gilbert catchment are then discussed.

Figure 3.22 shows a schematic diagram of the water balance of the Gilbert catchment, along with estimates of the catchment averaged mean annual value for each term and an estimate of the uncertainty. The 'water balance' comprises all the water inflows and outflows to and from a particular catchment over a given time period.

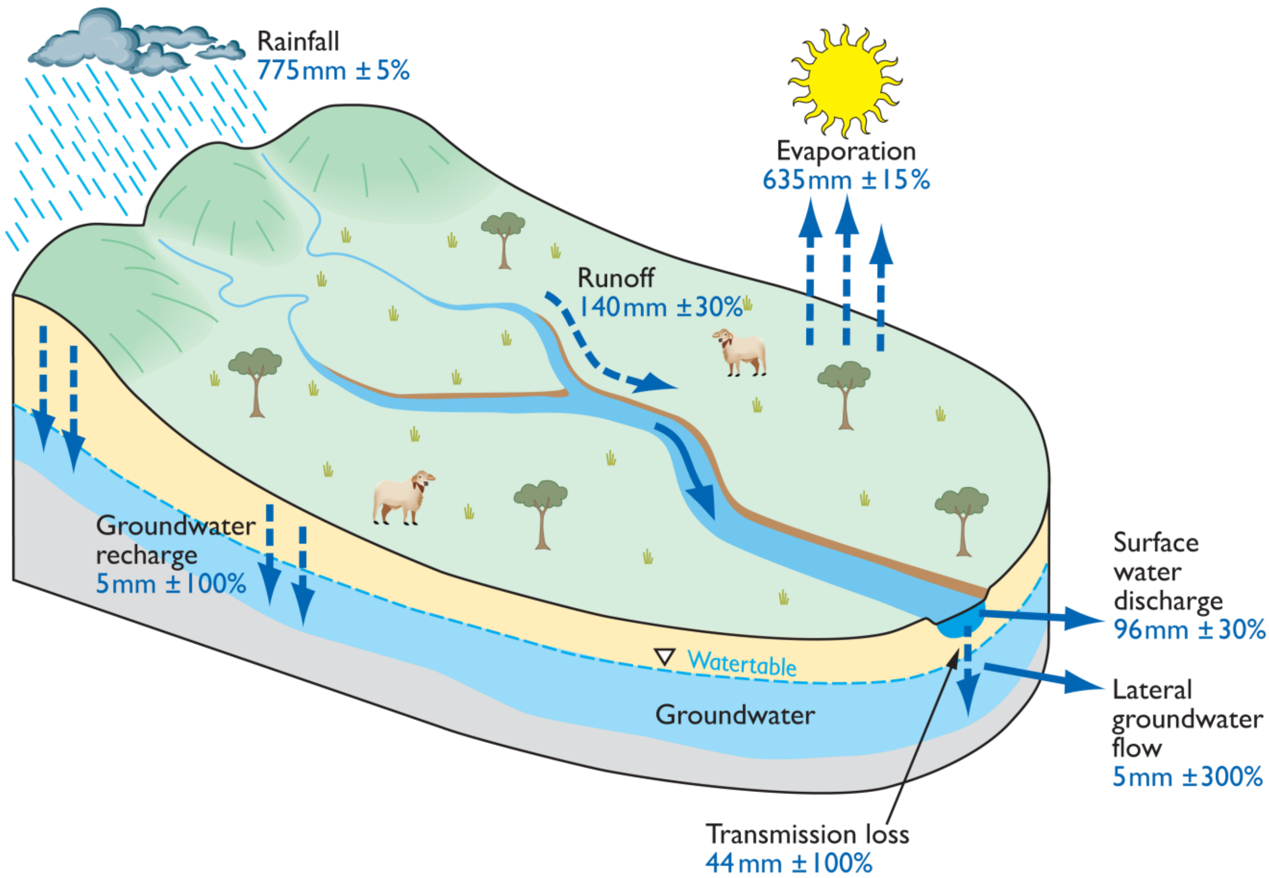

Figure 3.22 Schematic diagram of terrestrial water balance in the Gilbert catchment
Numbers indicate mean annual values spatially averaged across the catchment under Scenario A.

3.5.1 GROUNDWATER

The distribution of groundwater within a catchment is determined largely by the characteristics of the rocks within which water is stored. Groundwater aquifers in the Gilbert catchment can be broadly considered to occur in three types of rocks and sediments: (i) igneous and metamorphic rocks, (ii) sedimentary rocks, and (iii) unconsolidated sediments. The distribution and characteristics of these rocks is covered in Section 3.1

Unless otherwise stated, the material in Section 3.5.1 is based on findings described in the companion technical report about surface water – groundwater connectivity (Jolly et al., 2013).

Geological formations

The major aquifer systems in the Gilbert catchment are shown in Figure 3.23 and found in the geological Carpentaria Basin, and the basalt aquifers associated with the Chudleigh and McBride Provinces (Figure 3.2). The Carpentaria Basin is one of four major sub-basins of the GAB and is referred to as a regional scale groundwater system; the distance between the recharge zones and discharge zones is in the order of hundreds of kilometres or more and the time taken for groundwater to discharge following recharge is in the order of centuries. Overlying the Carpentaria Basin are unconsolidated alluvial sediments, within which local scale groundwater systems can form. Local scale groundwater systems are in the order of 1 to 10 km in size and are not well characterised in the Gilbert catchment, except for the Gilbert River bedsands which have been developed for local irrigated agriculture (see QDNR, 1998; AGE, 1999).

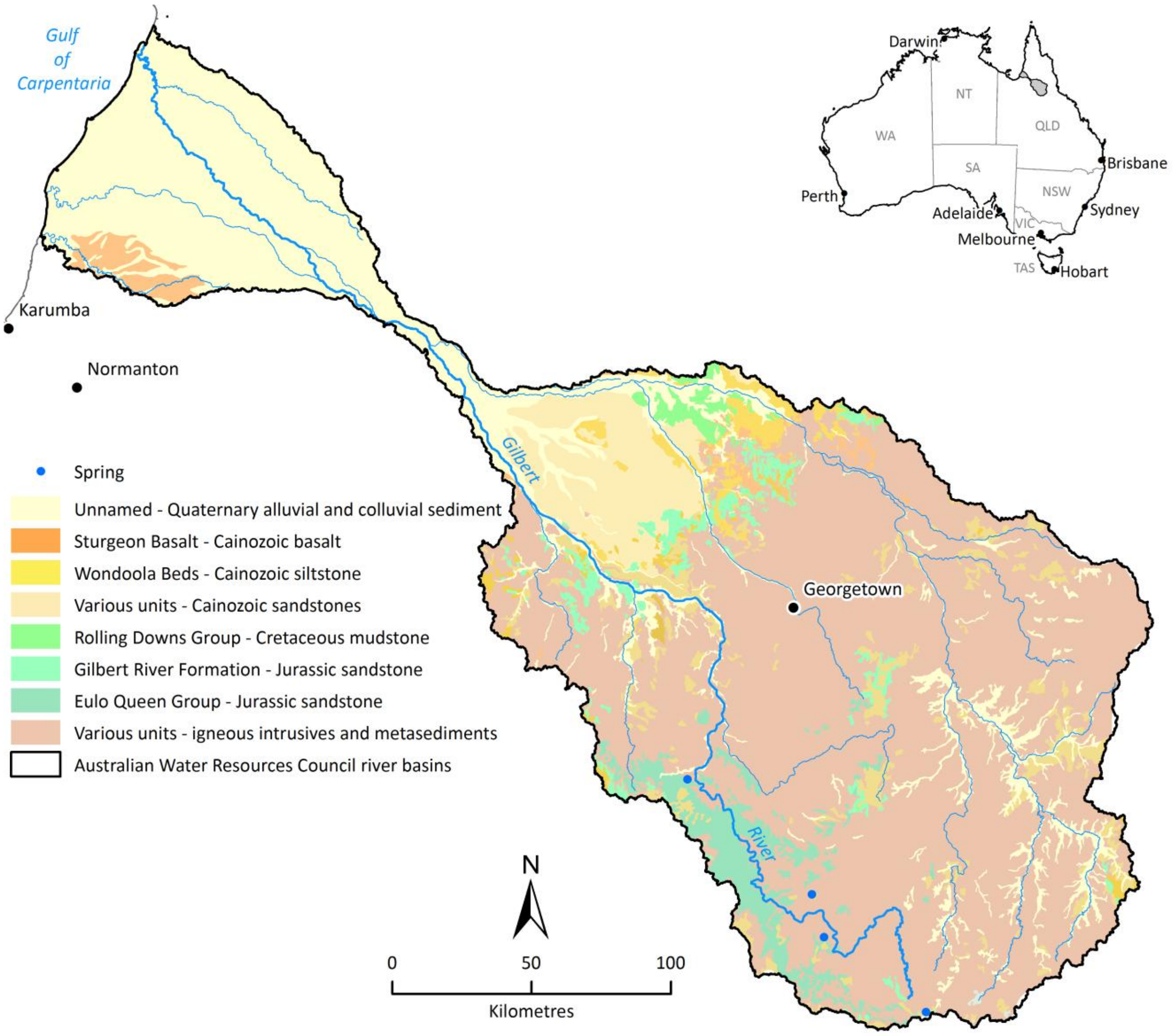

Figure 3.23 Major aquifers of the Gilbert catchment
Springs of the Great Artesian Basin are also shown. Adapted from Figure FL-2 in CSIRO (2009).

The GAB is comprised of a series of aquifers and aquitards within sedimentary sequences (series of different sedimentary rock formations) of siltstone, sandstone and mudstone. In the Carpentaria Basin these include the Eulo Queen Group and Gilbert River Formation which are generally overlain by the Rolling Downs Group (Figure 3.24). Where the rocks of these aquifers outcrop the GAB aquifers are recharged (Figure 3.25). Where it does not outcrop, the Gilbert River Formation is confined and often artesian (groundwater levels above the ground surface) in nature.

A comprehensive assessment of the GAB has recently been undertaken. There are insufficient data upon which to assess the 'sustainable' yield of the Carpentaria Basin.

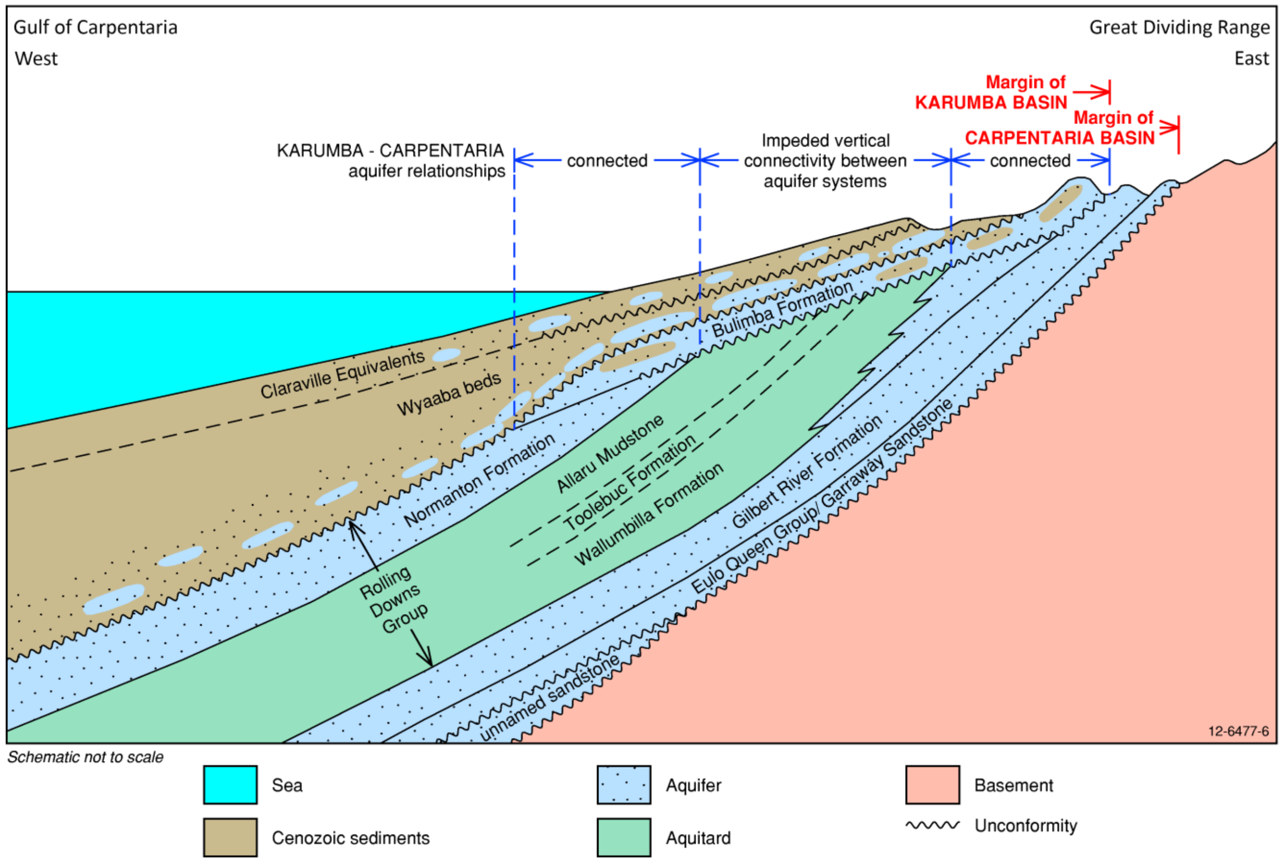

Figure 3.24 Schematic cross-section highlighting the connectivity between aquifers of the Carpentaria and Karumba basins of the Great Artesian Basin

Source: Figure 5.14 in Smerdon et al. (2012).

Figure 3.25 shows groundwater salinity (as EC and presented as dS/m) for all bores contained in the Queensland Department of Natural Resources and Mines' groundwater database (DNRM, 2013) that have measured EC values (either field- or laboratory-based or both). The bores have measurement dates of between 1966 and 1999 and screen various aquifers of the GAB and local scale systems. Despite this confounding factor a pattern is evident, with fresher groundwater (0 to 1.50 dS/m) in the central and southern part of the catchment in the Gilbert River alluvium and in the GAB recharge beds, and more saline groundwater (greater than 5.00 dS/m) in the regolith and coastal aquifers in the north-west of the catchment and in the Einasleigh Metamorphics and McBride Basalt west of Einasleigh.

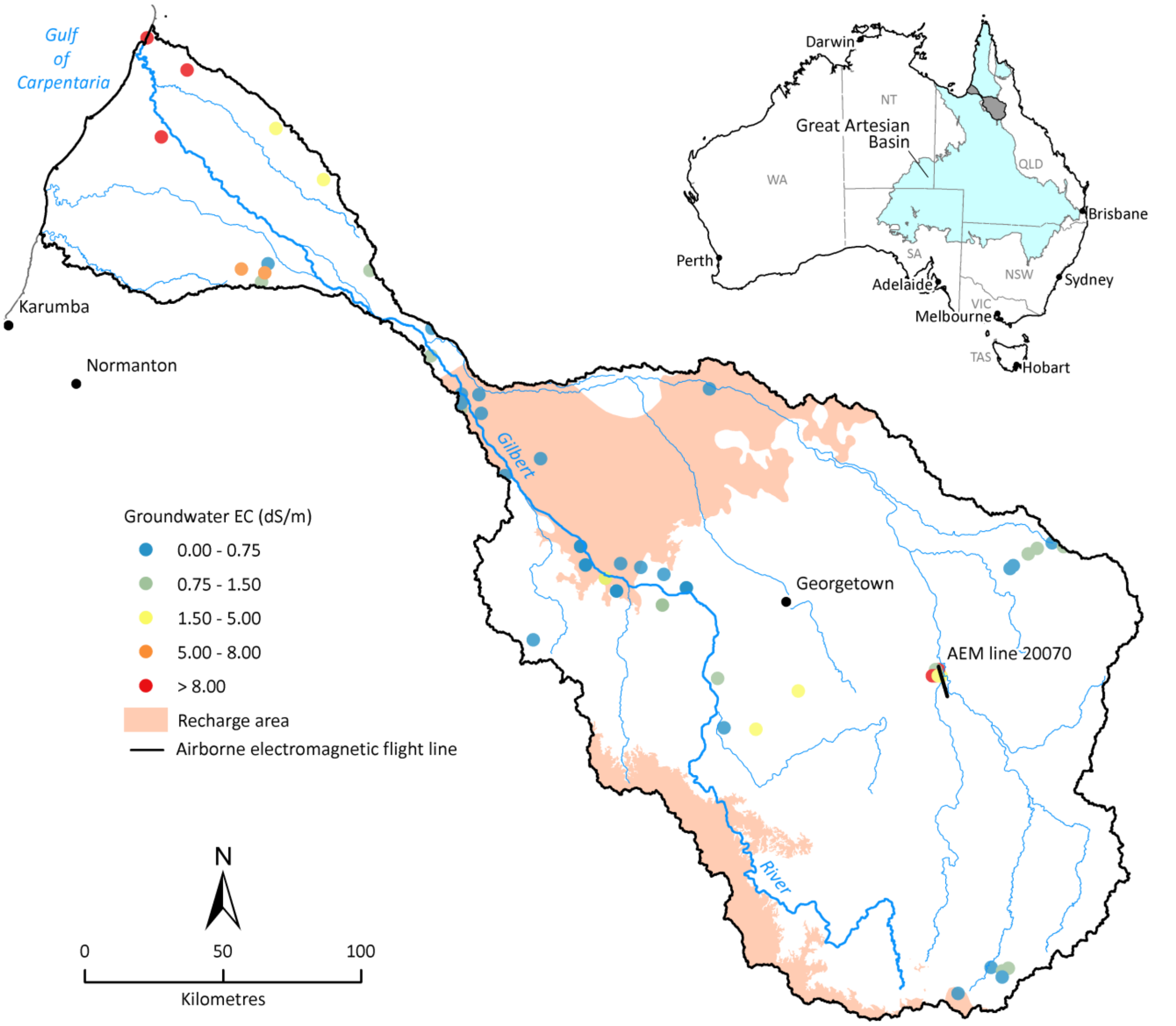

Figure 3.25 Groundwater salinity in the Gilbert catchment with the recharge area of the Great Artesian Basin and the location of airborne electromagnetic flight lines shown in Figure 3.26 and Figure 3.27
Map shows electrical conductivity (EC) as a measure of salinity. Based on or contains data provided by the State of Queensland (Department of Natural Resource and Mines) [2012]. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for direct marketing or be used in breach of the privacy laws.

Basalt aquifers

Recent drilling by the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA) has suggested that the Chudleigh and McBride Basalt provinces are the only fractured rock formations in the Gilbert catchment that have notable groundwater supplies (Bruce Pearce, pers. comm.). As described in Section 3.5.3 the Assessment found 'persistent' waterholes in this area, that are likely to be, in part, supplied by groundwater discharge from these basalt formations.

Alluvial aquifers

The total saturated volume of the Gilbert River bedsands had been previously estimated as being between 17 and 20 GL (QDNR, 1998; AGE, 1999). The GAB outcrops adjacent to the Gilbert River bedsands were determined as having a low hydraulic conductivity, were low yielding and only marginally exceeded the guideline values (0.65 dS/m) for irrigated cropping (PPK, 1999). In the same study the groundwater beneath the Einasleigh Common was assessed and found to exist within thin layers of both alluvium as well as regolith associated with the Einasleigh Metamorphics. The strata between the topsoil and basement rock was determined to not contain any significant aquifers and groundwater quality was variable and poor (PPK, 1999). In addition, an airborne electromagnetic (AEM) survey carried out in the Gilbert catchment as part of the Assessment collected data of the conductivity of the ground as it varies with the depth below the ground surface. The survey included a flight line (20070) of the Einasleigh Common. Figure 3.26 shows a conductivity-depth section which transects the Copperfield River and shows the ground conductivity of the soils and regolith of the Einasleigh Common area north and south-east of the town are relatively high. These observations accord with information collected over these areas in separate studies, which suggest that a combination of high subsoil salinity and saline groundwater exists. The measured EC of the groundwater in the PPK study generally exceeded the guideline value for drinking water (0.8 dS/m) and, for the majority of bores, the groundwater was determined to be unsuitable for irrigation.

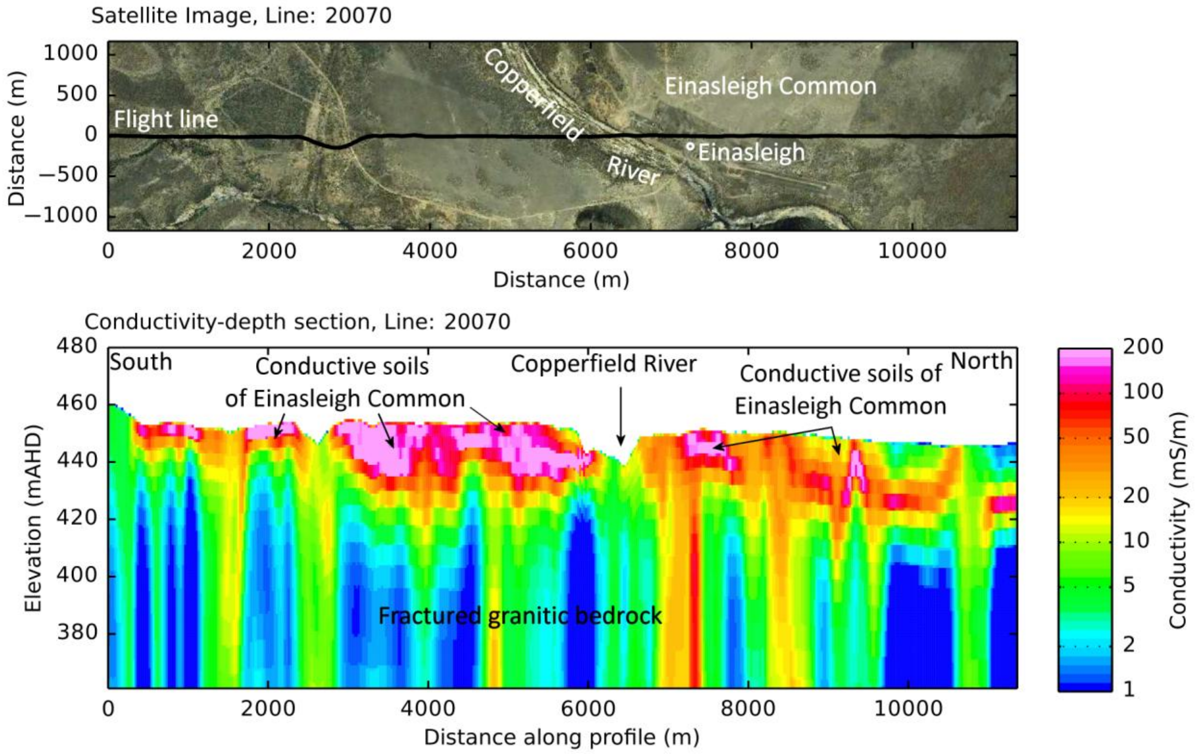

Figure 3.26 Satellite image and conductivity-depth section for flight line 20070
Location of flight line on a satellite image is shown in upper panel. This flight line transects the Copperfield River and the township of Einasleigh and extends across Einasleigh Common to the north (right side of section) and south (left side of section). High conductivities greater than ten metres thick are noted over the Common. Location of flight line is shown on Figure 3.25.

3.5.2 GROUNDWATER RECHARGE

Recharge rates are likely to be very low (less than 5 mm/year) across most of the catchment, with some areas of higher recharge (5 to 80 mm/year) beneath the coastal deposits of the lower reaches of the Gilbert catchment, and in the recharge areas of the GAB.

It is important to quantify groundwater recharge because it is often used to inform how much groundwater can be ‘sustainably’ extracted over a period of time. Groundwater recharge, however, is very difficult to measure, in part because it is usually a small percentage of the water balance (i.e. typically 0.1% to 10% of rainfall). It is also highly variable between locations and times of measurement and also varies depending upon the type of measurement technique (Petheram et al., 2002). Under rainfed conditions the three factors controlling mean annual recharge across most of Australia are: mean annual rainfall, land use and soil type (Petheram et al., 2002). Under irrigation, recharge is also heavily influenced by management practices such as method of water application, timing and amount of irrigation.

Groundwater recharge under existing conditions in the Gilbert catchment

There are no known measurements of recharge in the Gilbert catchment and there are few measurements to parameterise and calibrate groundwater recharge models (Crosbie et al., 2009). As such it is only possible to provide indicative information on recharge rates under existing conditions in the Gilbert catchment.

Figure 3.27 shows a groundwater recharge map derived using a simple regression model that relates recharge to broad soil type, land use and mean annual rainfall (Leaney et al., 2011; best estimate). This map shows that recharge rates are likely to be very low (less than 5 mm/year) across the catchment, with some areas of higher recharge (5 to 80 mm/year) beneath the coastal deposits of the lower reaches of the Gilbert River, and in the recharge areas of the GAB (Figure 3.25). The range in values in the GAB recharge areas (5 to 40 mm/year) is consistent with the estimates previously reported by Kellett et al. (2003) and Smerdon and Ransley (2012).

No mathematical relationships exist for the soils found on the Chudleigh and McBride Basalt provinces in the eastern boundary of the Gilbert catchment. However, soils in these types of landscapes are known to be highly permeable and digital elevation models (digital representation of the elevation of the ground surface) and visual inspections indicate that few drainage lines are present on top of these landscapes. These lines of evidence suggest that recharge rates under these basalt provinces are likely to be high relative to the rest of the Gilbert catchment. The hypothesis that these basalt provinces are a zone of high recharge is further supported by the perennial nature and measurements of river water chemistry taken in rivers draining these provinces. In the absence of further information, groundwater recharge on the Chudleigh and McBride Basalt provinces was assumed to be equivalent to the non-evaporated component of rainfall. This hypothesis, however, requires testing.

It is important to note that the estimates depicted in Figure 3.27 are indicative of diffuse recharge (relatively slow and uniform infiltration of water that drains below the root zone over large areas) rates across the broad landscape and may not necessarily apply to areas of localised recharge (infiltration of water that drains below the root zone in concentrated areas) such as in the alluvium of waterholes, streams or rivers or to areas with preferential flow paths such as faults. In theory, based on experience in southern Australia, recharge rates in these localised areas are likely to be higher. However, this theory has not been tested widely in northern Australia.

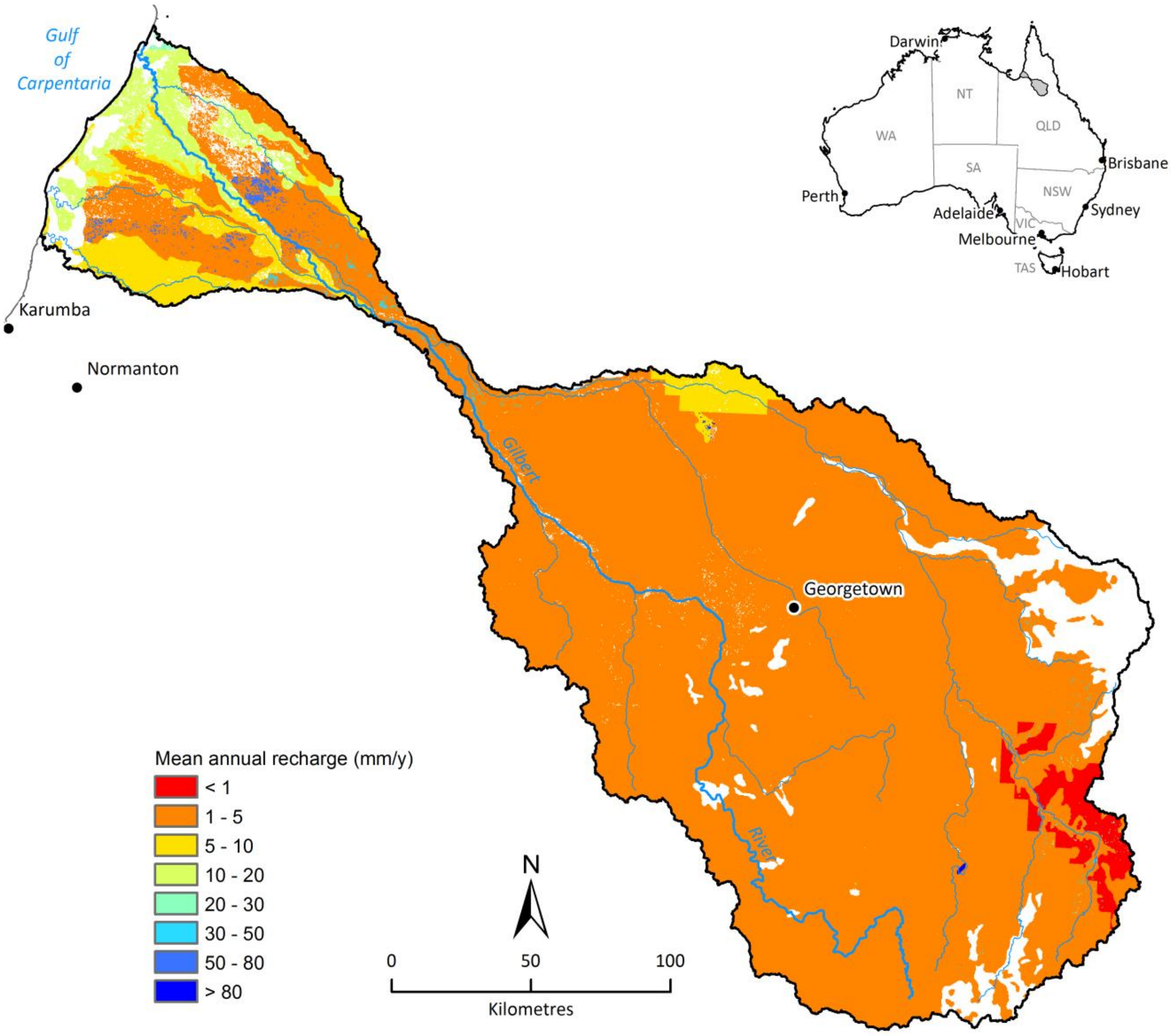

Figure 3.27 Map of mean annual groundwater recharge in the Gilbert catchment under Scenario A
Derived using a simple regression model that relates recharge to broad soil type, land use and mean annual rainfall (Leaney et al. (2011); best estimate). The white areas do not have any recharge estimates due to a lack of suitable regressions.

Groundwater use

According to the Queensland Department of Natural Resources and Mines' groundwater database (DNRM, 2013), there are more than 400 registered groundwater bores in the Gilbert catchment. Groundwater is contained within the Jurassic-Cretaceous age GAB aquifers, in the outcropping Palaeozoic and Precambrian age fractured rocks, and in the Cenozoic age sediments that are comprised of the Tertiary age fluvial (associated with rivers and streams) and marine deposits and the Quaternary age alluvium of the past and present rivers in the catchment (Figure 3.23).

Surface water – groundwater connectivity

The only rivers in the Gilbert catchment that show evidence of strong surface water – groundwater connection are those that drain the Chudleigh and McBride Basalt provinces (Figure 3.2). This is evident from surface water chemistry sampling and analysis of hydrograph data undertaken as part of the Assessment. Consequently the development of groundwater resources in these basalt provinces is likely to reduce baseflow in these rivers.

Surface water chemistry sampling undertaken as part of the Assessment indicated a high likelihood of groundwater inflow at only one of five river sites (River Site 1 on the Gilbert River) and four of 19 waterhole sites (waterholes 1, 3, 8 and 12). The results of this assessment are shown in Figure 3.28. River Site 1 is located downstream of an area where the Gilbert River Formation outcrops in the alluvium and this presumably supplies the baseflow in the dry season (as per the conceptual model of CSIRO, 2009). Waterhole 1 is located in a highly complex geological area just to the north of Einasleigh comprised of Einasleigh Metamorphics and an intrusion of Caterpillar Microgranite. It is not clear which of these fractured rock formations is the origin of the groundwater. Waterhole Site 3 is located on one of the upper tributaries of the Einasleigh River which drains an area comprised of Chudleigh Basalt flows and a Dido Tonalite intrusion. It is most likely that the Chudleigh Basalt is the origin of the groundwater. Waterhole Site 8 is located on one of the middle tributaries of the Einasleigh River in an area dominated by the McBride Basalt flows and smaller areas of the Einasleigh Metamorphics. Waterhole Site 12 is similar to River Site 1 in that it is located downstream of an area where the Gilbert River Formation outcrops in the Gilbert River alluvium and this presumably supplies the baseflow in the dry season.

However, the chemistry utilised in this component of the Assessment is practical for detecting the inflow of groundwater to surface water that has been subject to reasonably long flow paths (has spent months to thousands of years in the subsurface) as would be expected for example in alluvial and fractured rock systems. What the chemistry is not practical for is identifying the inflow of other highly localised groundwater systems, where subsurface flows are in the order of days to months. These highly localised parafluvial groundwater systems exist in the fluvial plain (riverbed sediments) within the river channel. It is possible that parafluvial groundwater (surface water that enters the subsurface through the fluvial plain sediments in the river channel and discharges down plain within the river channel in areas of topographic relief or low points) could further support waterholes in the Gilbert catchment. However, this was not assessed and would require further investigation.

The Assessment also analysed streamflow hydrograph data (applying an alpha value of 0.925 to the Lyne and Hollick (1979) method) and found that the baseflow index (i.e. the proportion of slow to total streamflow) at all except three streamflow gauging stations in the Gilbert catchment is low (i.e. less than 0.2). This is indicative of rivers for which groundwater discharge constitutes a very small proportion of the overall streamflow. The three exceptions had a baseflow index of between 0.2 and 0.3. Two of these stations are located on Elizabeth Creek that drains the Chudleigh Basalt Formation. Using the same method in those rivers where groundwater is known to contribute a large proportion of streamflow, the baseflow index is typically between 0.4 and 0.6 (e.g. the Daly River in the Northern Territory and the Jardine River on Cape York Peninsula).

The persistence of waterholes in the Gilbert catchment is discussed further in Section 3.5.3 and in the companion technical report about instream waterholes (McJannet et al., 2013).

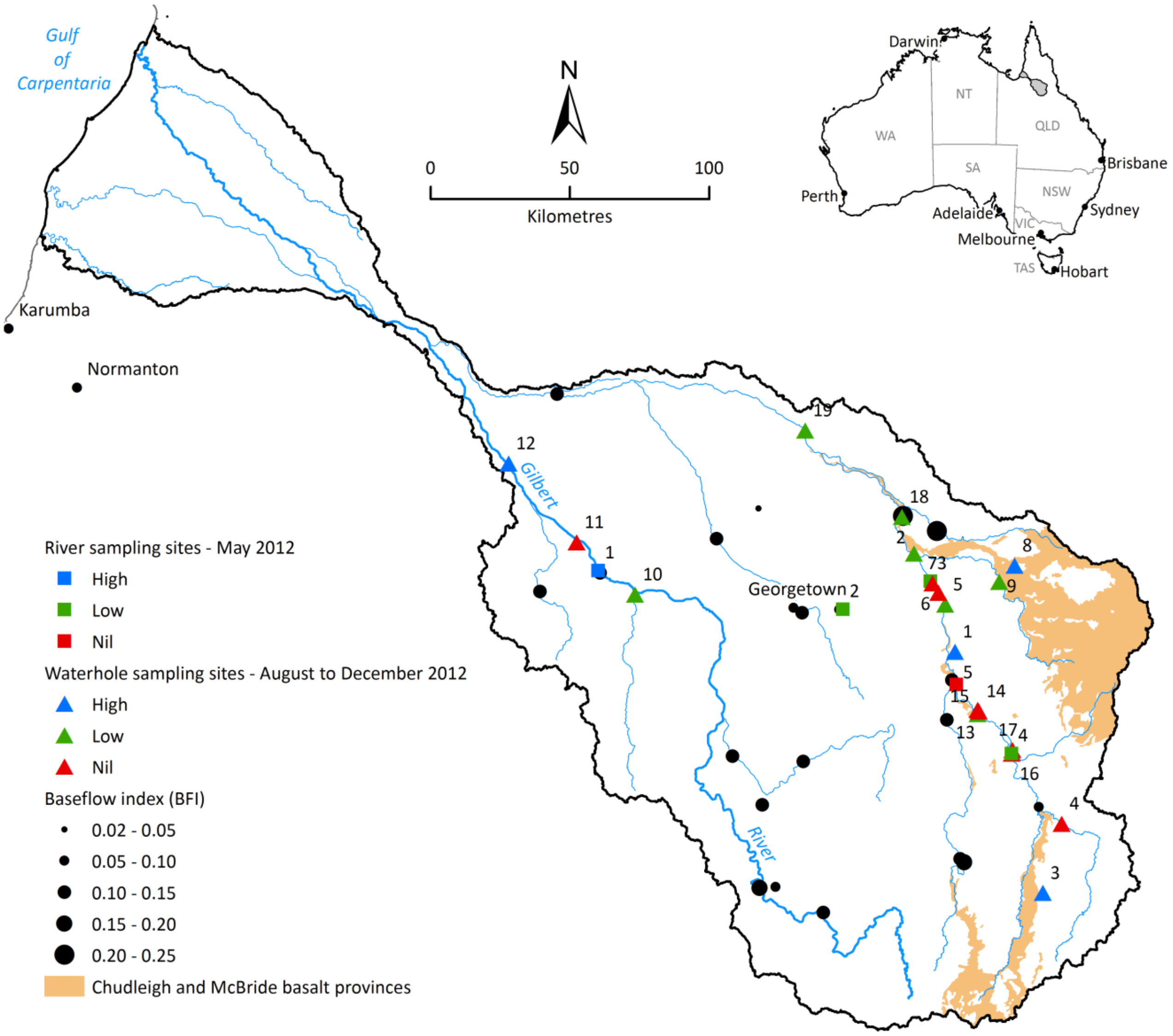

Figure 3.28 Likelihood of groundwater inflow at river and pool sampling sites in the Gilbert catchment
Baseflow index (BFI) is the slow response component of streamflow expressed as a ratio of the total flow. The smaller the BFI the faster the water levels rise and fall.

3.5.3 STREAMFLOW

The Gilbert catchment is comprised of two major rivers, the Gilbert and the Einasleigh. At the confluence of the Gilbert and Einasleigh rivers, the mean annual streamflow is about 3706 GL. Due to a couple of very wet years 'biasing' the mean, this amount of water is more than 40% larger than the median annual streamflow (2585 GL). Although the Gilbert catchment is named for the Gilbert River (named after the explorer Gilbert), the median annual streamflow in the Einasleigh River is about two and a half times that of the Gilbert River.

The streamflow characteristics of the Gilbert and Einasleigh rivers are quite different, with the Einasleigh River and some of its upper tributaries draining the basalt country in the eastern parts of the Gilbert catchment (Figure 3.29). This results in extended flows during the dry season in some reaches of the Einasleigh River and its tributaries. In contrast the Gilbert River and Etheridge River (a major tributary of the Einasleigh River) are highly ephemeral and do not flow for more than half the year on average. At Strathmore Station the Gilbert and Einasleigh rivers converge before forming a river delta 100 km wide and then flowing into the Gulf of Carpentaria. There are no gauging stations below the confluence of the Gilbert and Einasleigh rivers and hence runoff and streamflow estimates in the lower part of the catchment are very uncertain.

Figure 3.29 illustrates the main river channels in the Gilbert catchment and shows the location of streamflow gauging stations used in the calibration of hydrological models for the Assessment. The location of these stations is biased to the headwater areas where river reaches are typically more suited for locating streamflow gauging stations.

Figure 3.30 and Figure 3.31 illustrate the change in catchment area along the Gilbert River and Einasleigh River respectively. Large increases in catchment area occur where large tributaries join these rivers.

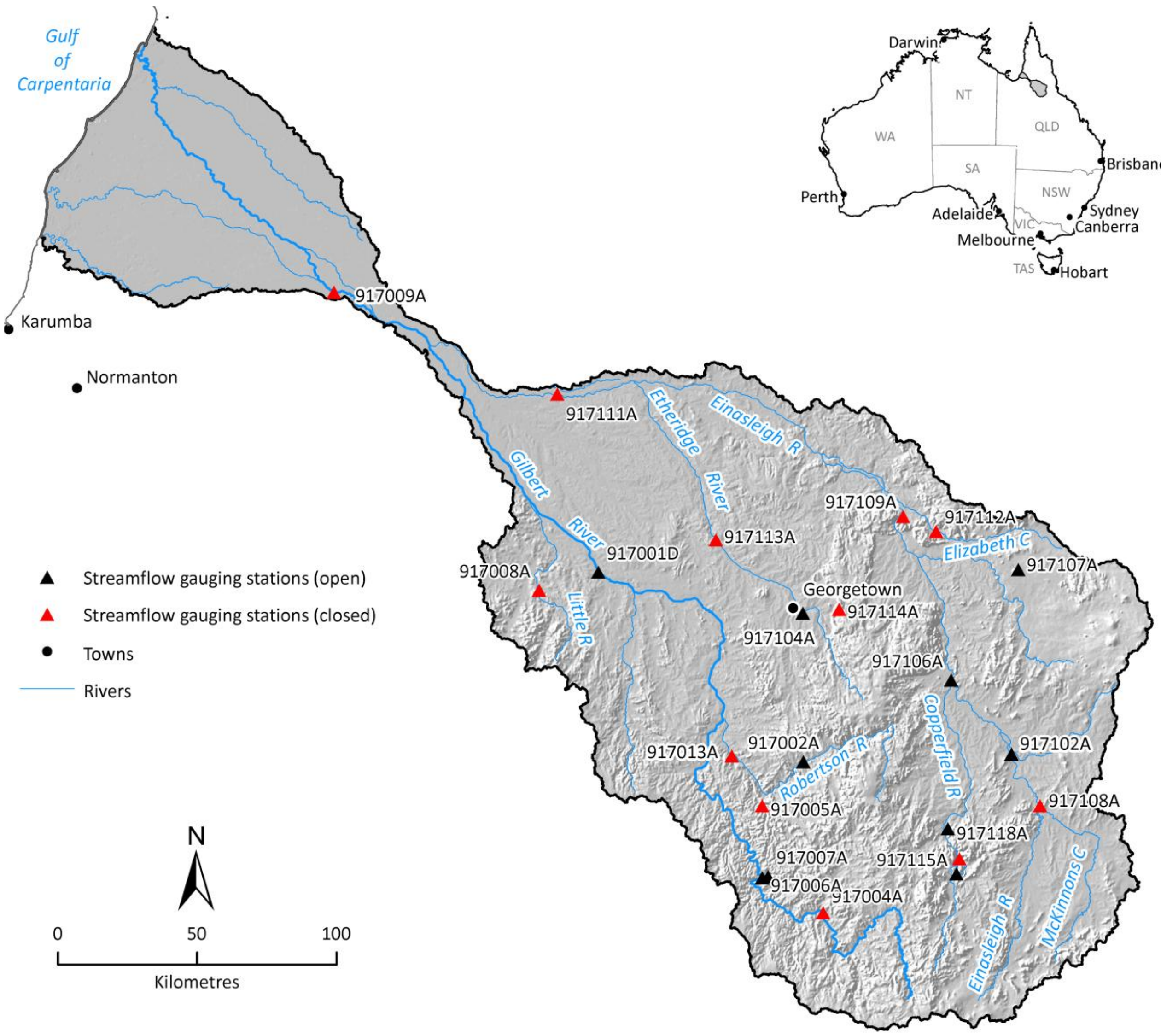

Figure 3.29 Main rivers and streamflow gauging stations of the Gilbert catchment

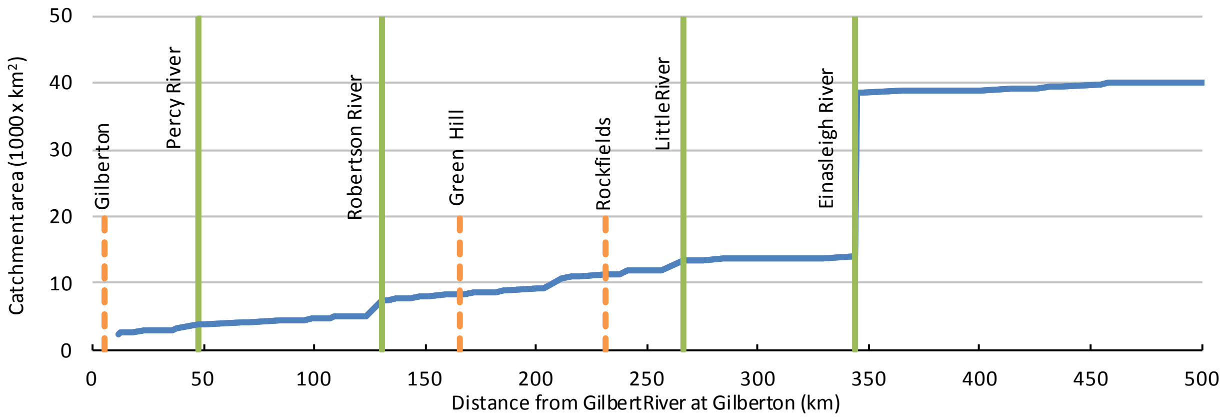

Figure 3.30 Change in catchment area along the Gilbert River from Gilberton

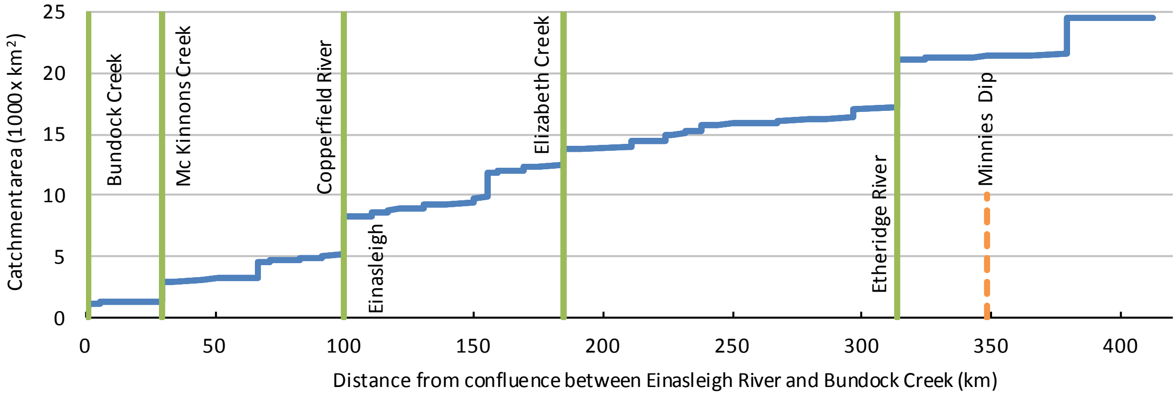

Figure 3.31 Change in catchment area along the Einasleigh River from the confluence of the Einasleigh River and Bundock Creek

Catchment runoff

The mean annual runoff averaged over the Gilbert catchment under Scenario A is 140 mm, which is middle of the range compared with other catchments in northern Australia (Petheram et al., 2009). Above station 917009A mean annual runoff is 130mm. The mean annual runoff from some catchments on the Cape York Peninsula and the north-east Queensland coast exceeds 400 mm and 2000 mm runoff, respectively. Figure 3.32 shows the spatial distribution of mean annual rainfall and runoff under Scenario A (1890 to 2011) across the Gilbert catchment. Mean annual runoff broadly follows the same spatial patterns as mean annual rainfall; runoff is highest near the coast and lowest in the southernmost parts of the catchment.

The certainty of runoff is lowest below the confluence of the Gilbert and Einasleigh rivers, where there are no streamflow gauging stations.

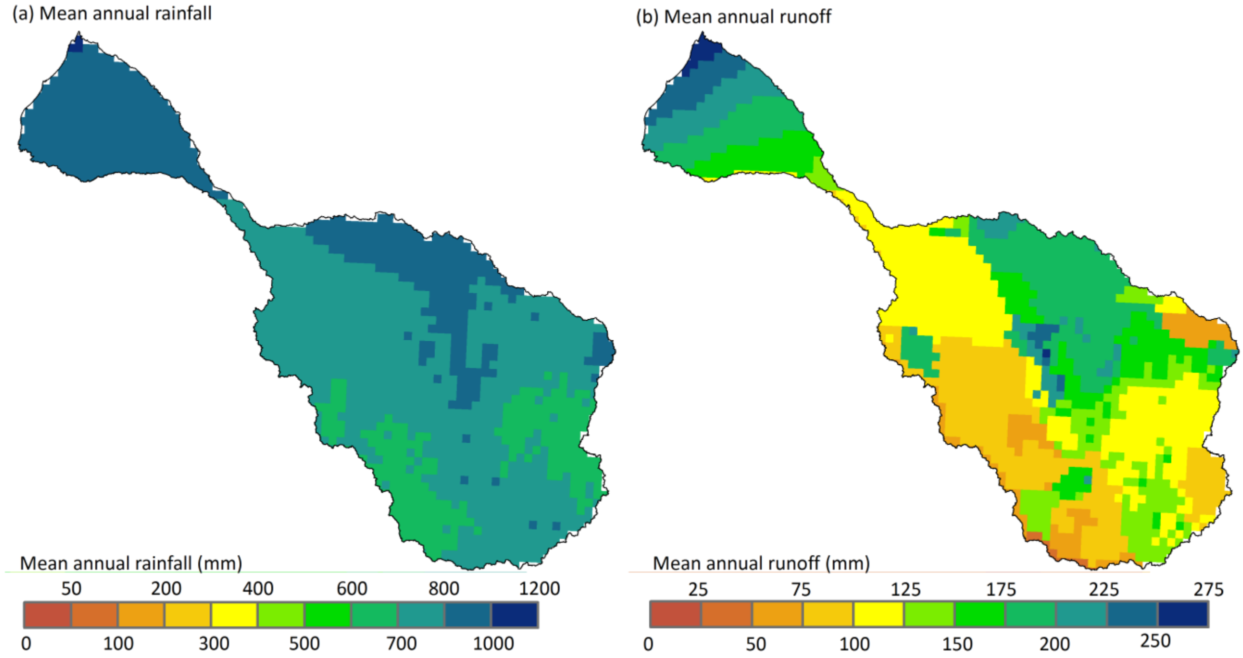

Figure 3.32 Mean annual rainfall and runoff across the Gilbert catchment under Scenario A

Mean monthly and annual runoff data in the Gilbert catchment are highly skewed. Consequently it is more appropriate to report median values for runoff and streamflow than mean values, which can be highly misleading. The median can also be referred to as the 50% exceedance. Other exceedance numbers provide further insights into the reliability of runoff, an important consideration when assessing the profitability of an irrigation enterprise. Figure 3.33 shows the spatial distribution of the 20%, 50% and 80% annual exceedance runoff under Scenario A. The 20%, 50% and 80% annual exceedance runoff averaged across the Gilbert catchment is 196 mm, 100 mm and 47 mm respectively. That is, runoff spatially averaged across the Gilbert catchment will exceed 196 mm one year in five, 100 mm half the time and 47 mm four years in five. It should be noted that runoff estimates below streamflow gauging station 917009A (Figure 3.29) are particularly uncertain.

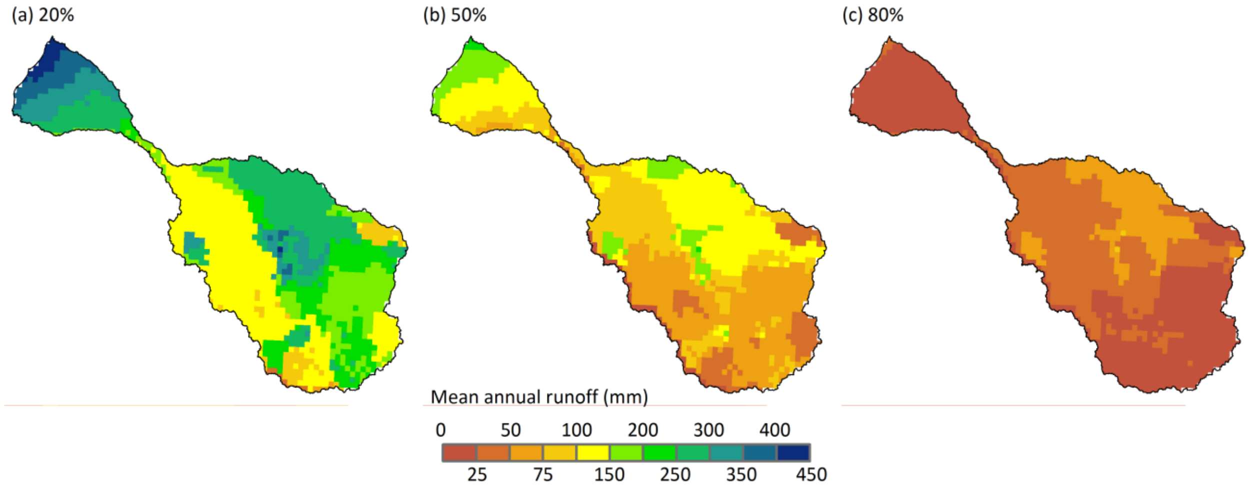

Figure 3.33 Map showing 20%, 50% (median) and 80% exceedance annual runoff across the Gilbert catchment under Scenario A

Intra and inter-annual variability in runoff

As with rainfall, runoff and streamflow in the Gilbert catchment are highly variable within years and between years. Approximately 98% of all runoff in the Gilbert catchment occurs during the wet season (Figure 3.34), which is very high compared to rivers in southern Australia (Petheram et al., 2008). As a result most rivers in the Gilbert catchment are ephemeral, which means that (where groundwater is absent), water storages are essential for dry-season irrigation. Figure 3.34a illustrates that during the wet season there is a high variation in monthly runoff from one year to the next. For example during the month of February, in 20% of years average runoff exceeded 90 mm and in 20% of years it was less than 7 mm. It is important to consider the reliability of monthly inflows to farm dams in conjunction with crop growing seasons when assessing the suitability of an area for irrigation.

The largest catchment average annual runoff under Scenario A was 1231 mm in 1974. The smallest catchment average annual runoff under Scenario A was 4 mm in 1935. The coefficient of variation of annual runoff in the Gilbert catchment is 1.1. Based on data from Petheram et al. (2008) the variability in runoff in the Gilbert catchment is comparable to the annual variability in runoff of other rivers in northern and southern Australia with a comparable mean annual runoff. It is, however, two to three times more variable than rivers from the rest of the world of the same climate type as the Gilbert catchment. One implication of this is that, all other factors being equal, water storages need to be larger in the Gilbert catchment than other countries of a similar climate, to consistently meet a given demand.

Figure 3.35 shows the Gilbert River during the dry season (October 2012) downstream of the Rockfields streamflow gauging station (917001D).

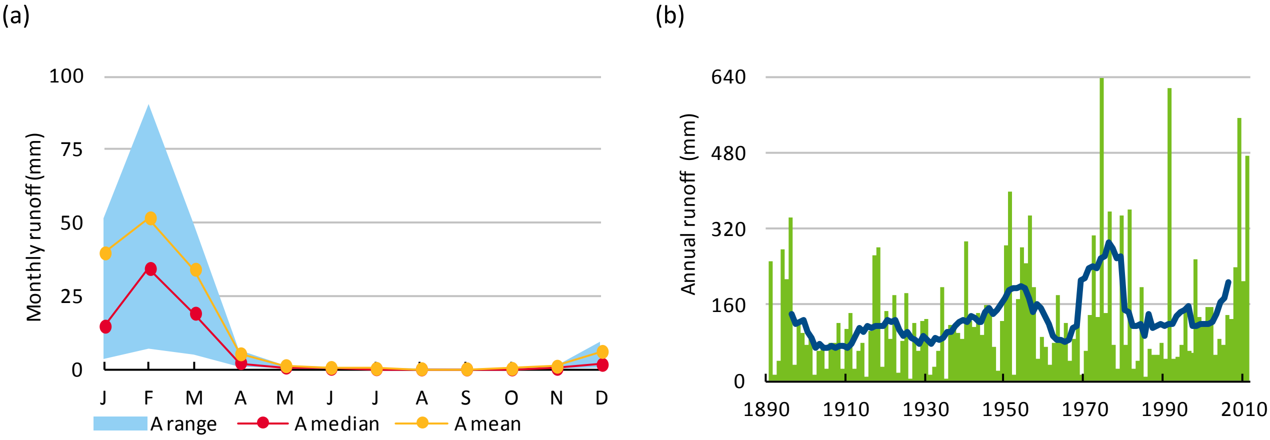

Figure 3.34 Runoff in the Gilbert catchment under Scenario A
(a) Monthly runoff averaged across the Gilbert. (b) Time series of annual runoff averaged across the catchment. In the water year of 1974 the catchment average annual runoff under Scenario A was 1231 mm.

Figure 3.35 Gilbert River downstream of Rockfields streamflow gauging station (October 2012)
Photo: CSIRO.

Streamflow

Table 3.2 provides key summary metrics for all streamflow gauging stations in the Gilbert catchment (location of stations shown in Figure 3.29). At all locations there are large differences between the mean annual flow and the median annual flow, a consequence of several very wet years biasing the mean upwards, but having little effect on the median annual flow. For example the mean annual flow at 917111A (Figure 3.29), the most downstream gauge on the Einasleigh River, is 2513 GL, yet the median annual streamflow is 1822 GL. On the Gilbert River the most downstream gauge is 917001D. Here the mean annual streamflow is 1072 GL, yet the median annual streamflow is 697 GL. At Miranda Downs (917009A) below the confluence of the Gilbert and Einasleigh rivers, the mean annual streamflow and the median annual streamflow is 3706 GL and 2585 GL respectively.

Table 3.2 and Figure 3.36 indicate that the largest streamflow occurs in the lower reaches of the Einasleigh and Gilbert rivers, with the median annual streamflow in the Einasleigh at 917111A about two and a half times that of the Gilbert at 917001D. The streamflow discharged into the Gulf of Carpentaria is uncertain as there are no streamflow gauging stations below the confluence of the Gilbert and Einasleigh rivers. Further, the landscape of the coastal floodplains of the Gilbert catchment is very different to that of the mid to upper reaches making it difficult to extroplate model results to the lower Gilbert catchment.

The cease-to-flow column in Table 3.2 indicates the percentage of time that no streamflow was observed at each of the streamflow gauging stations in the Gilbert catchment. This was determined using observed data; streamflow less than 0.1 ML/day was assumed to be equal to zero. The baseflow index provides a measure of the proportion of 'slow' or delayed streamflow as a proportion of total streamflow. It was was determined using observed streamflow data and the Lyne and Hollick (1979) method (using an alpha value equal to 0.925). The baseflow index at all except three streamflow gauging stations in the Gilbert catchment is less than 0.2, which is indicative of rivers that rise and fall relatively quickly. In these river reaches the time over which water can be extracted is limited and a large water pumping capacity to storage volume is required. This is discussed in more detail in Chapter 5.

Figure 3.36 shows how median annual streamflow in the Gilbert catchment increases towards the coast. Figure 3.37 shows the 20% and 80% annual exceedance streamflow in the Gilbert catchment.

Table 3.2 Streamflow summary metrics at gauging stations in the Gilbert catchment under Scenario A

These data are shown schematically in Figure 3.36 and Figure 3.37. 20th, 50th and 80th refer to the 20th, 50th and 80th percentile exceedance, respectively.

STATION ID	STATION NAME	CATCH-MENT AREA (km^2)	STREAMFLOW (GL)						CEASE-TO-FLOW (%)	BASEFLOW INDEX
			Max-imum	20th	50th (median)	80th	Min-imum	Mean		
917001D	Gilbert River at Rockfields	10,987	11,288	1,519	697	344	49	1,072	48%	0.15
917002A	Robertson River at Robin Hood	1,019	1,474	226	73	29	1	138	74%	0.15
917004A	Gilbert River at Gilberton	1,892	1,455	209	105	40	1	158	65%	0.13
917005A	Agate Creek at Cave Creek Junction	218	237	31	15	5	0	20	86%	0.14
917006A	Gilbert River at Percy Junction	3,317	3,145	533	183	76	2	334	60%	0.18
917007A	Percy River at Ortana	526	510	58	26	10	1	42	79%	0.1
917008A	Little River at Inorunie	436	537	137	68	25	3	85	75%	0.14
917009A	Gilbert River at Miranda Downs	38,619	32,954	5,279	2,585	1,071	93	3,706	NA	NA
917013A	Robertson River at North Head	1,888	2,279	333	124	47	1	209	68%	0.15
917102A	Einasleigh River at Carpentaria Downs	3,225	30,677	4,619	1,806	416	9	3,150	NA	NA
917104A	Etheridge River at Roseglen	867	1,212	246	92	36	2	153	73%	0.11
917106A	Einasleigh River at Einasleigh	8,244	7,355	969	403	108	3	729	50%	0.15
917107A	Elizabeth Creek at Mount Surprise	651	504	67	30	5	1	40	32%	0.28
917108A	Mckinnons Creek at Possum Pad	NA	1,323	213	66	14	0	135	81%	0.07
917109A	Einasleigh River at Cowana Lake	12,146	9,395	1,359	660	213	9	1,000	32%	0.21
917111A	Einasleigh River at Minnies Dip	21,284	20,758	3,590	1,822	617	36	2,513	29%	0.15
917112A	Elizabeth Creek at Cabana	1,288	1,278	183	93	27	2	119	30%	0.21
917113A	Etheridge River at Huonfels	2,358	2,730	601	254	90	10	382	66%	0.13
917115A	Copperfield River at Spanner Waterhole	1,199	1,270	241	74	15	1	159	55%	0.16

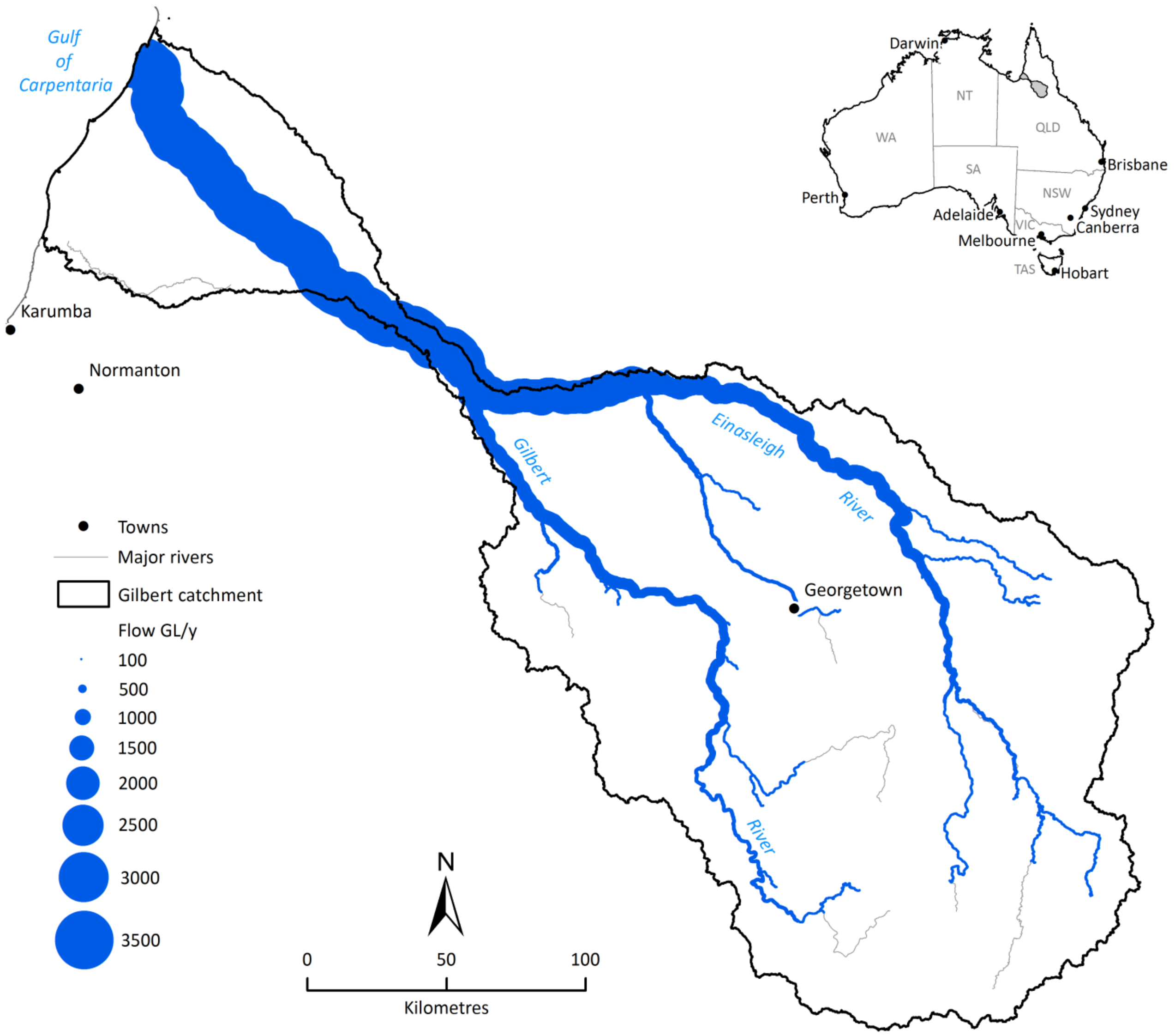

Figure 3.36 Median annual streamflow (i.e. 50% exceedance) in the Gilbert catchment

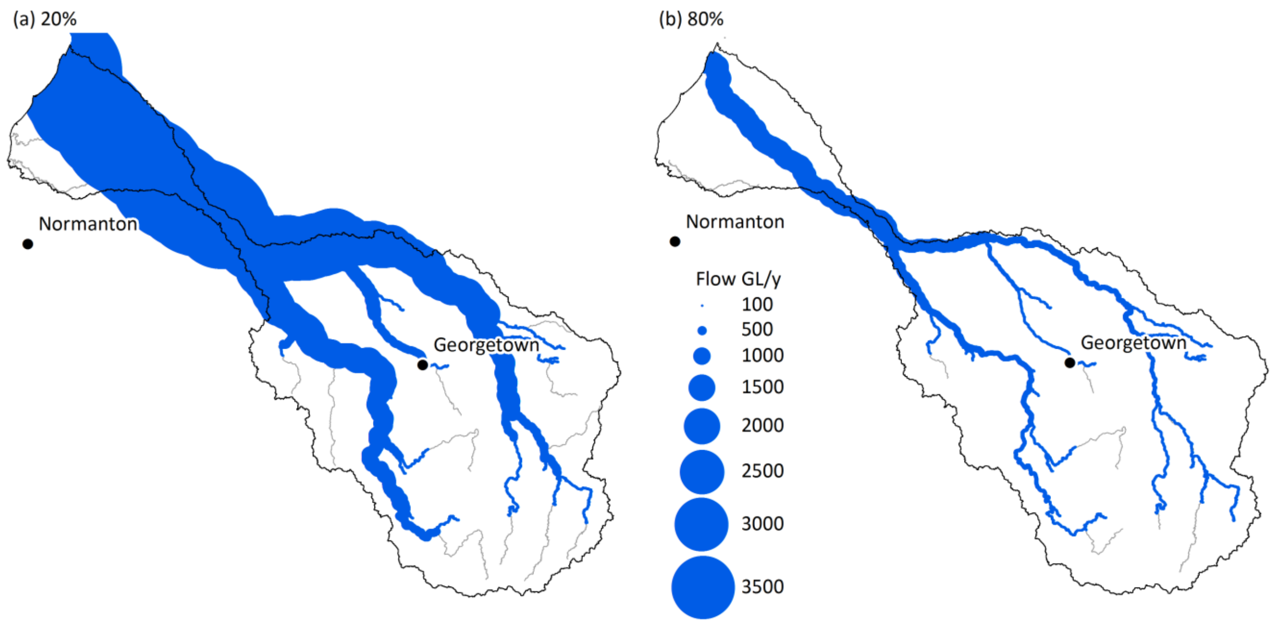

Figure 3.37 20% and 80% exceedance of annual streamflow in the Gilbert catchment

Flooding

The coastal floodplains of the Gilbert catchment regularly flood over large areas of land, and flooding may extend many tens of kilometres inland (Figure 3.38). Characterising these flood events is important for a range of reasons. Flooding can be catastrophic to agricultural production in terms of loss of stock, fodder and topsoil and damage to crops and infrastructure; it can isolate properties and disrupt vehicle traffic. However, flood events also provide an opportunity for offstream wetlands to be connected to the main river channel, which is important for aquatic animals to achieve important lifecycle stages (Waltham et al., 2013). The high biodiversity found in many unregulated floodplain systems in northern Australia is thought to depend largely on these ‘flood pulses’, which allow for biophysical exchanges to occur between the main channel, coastal wetlands (tidal and freshwater).

Unless otherwise stated, the material in this section based on findings described in the companion technical report about floodplain inundation (Dutta et al., 2013).

The coastal floodplains of the Gilbert catchment are particularly susceptible to flooding (Figure 3.38). Above the confluence of the Gilbert and Einasleigh rivers, however, satellite imagery indicates that these rivers rarely break their banks. This is consistent with observations from a number of local landholders, who anecdotally reported that the last time these large rivers broke their banks in their mid-reaches was during the largest flood event on record in 1974. It should be noted, however, that the results presented in Figure 3.38 are different to the results of flood mapping undertaken by the Queensland Flood Reconstruction Authority, who appear to have taken a more conservative approach (see Dutta et al., 2013 for comparison).

Dutta et al. (2013) describe relationships between the inundated area of the coastal floodplain and simulated streamflow at the gauging station below the confluence of the Gilbert and Einasleigh rivers (i.e. 917009A). These relationships may be used to infer how the inundated area of the coastal floodplains of the Gilbert catchment may change as a result of future irrigation development or climate change.

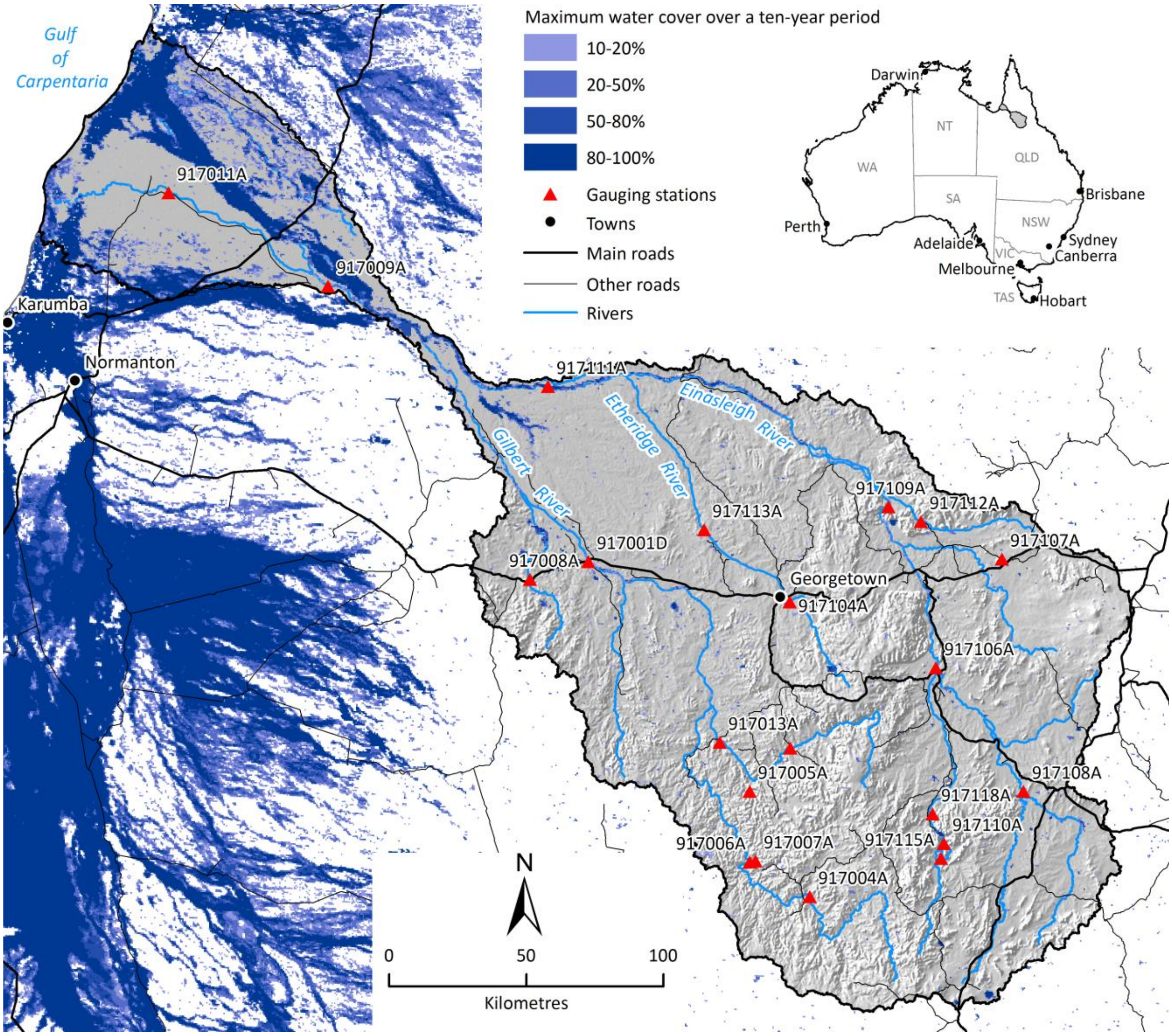

Figure 3.38 Flood inundation map of the Gilbert catchment
Data captured using MODIS satellite imagery. This figure illustrates the maximum percentage of MODIS pixel inundated between 2000 and 2010.

Figure 3.39 indicates the spatial extent and temporal variation in inundation in coastal floodplains of the Gilbert catchment for selected flood events, based on computer model simulations (see Dutta et al., 2013)

Where the duration of flooding is less than five days, this is indicative that the pasture grass would be likely to be covered in silts. Where pastures are inundated with stagnant water for a period greater than five consecutive days the above-ground biomass may die, though this may extend to two weeks if the pasture is aerated. Where the period of inundation is greater than 20 consecutive days the root mass may die. This does, however, vary between pasture species. The largest flood event recorded at streamflow gauging station 917001D and 917111A, the most downstream station in the Gilbert catchment, was in 1974. The largest flood event in recent years occurred in early 2009, resulting in extensive and prolonged flooding in the lower reaches of the Gilbert catchment (Figure 3.39).

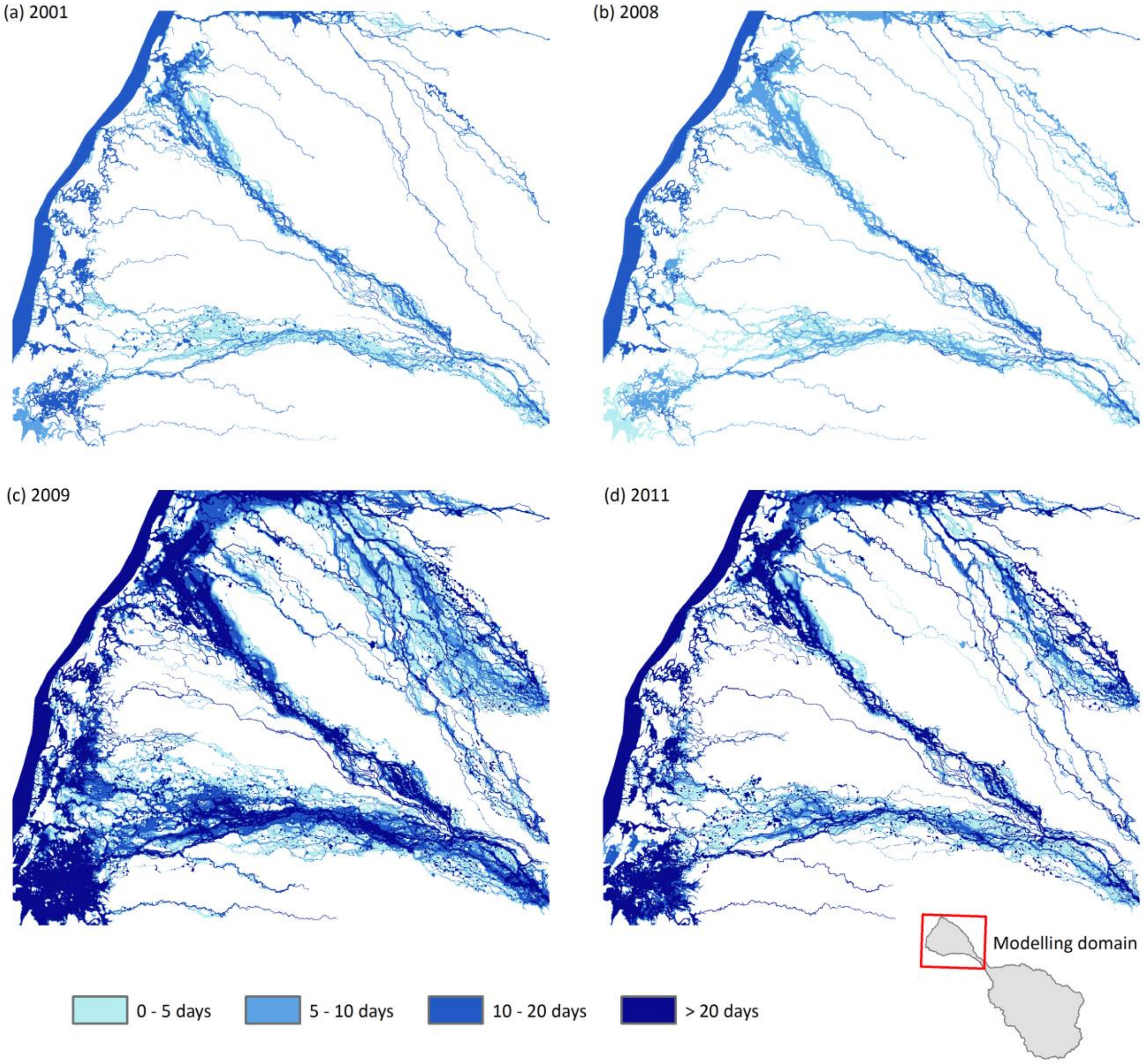

Figure 3.39 Spatial extent and temporal variation of inundation during simulated flood events of (a) 2001, (b) 2008, (c) 2009 and (d) 2011

Instream waterholes during the dry season

Unless otherwise stated, the material in this section is based on findings described in the companion technical report about instream waterholes (McJannet et al., 2013).

The majority of gauged rivers in the catchment of the Gilbert River do not flow for at least 50% of the time and the majority of gauged rivers in the catchment of the Einasleigh River do not flow for at least 30% of the time (Table 3.2). There is little evidence that 'persistent' waterholes in the catchment of the Gilbert River receive water from groundwater discharge (see Section 3.5.1). These waterholes are likely to be filled by streamflow during the previous wet season. Within the catchment of the Einasleigh River, waterholes located downstream and within rivers draining the Chudleigh and McBride Basalt provinces may be sustained during the dry season by groundwater inflow. Consequently pumping groundwater from the basalts will reduce the persistence of a number of waterholes in the catchment of the Einasleigh River.

Waterholes that 'persist' from one year to the next provide key aquatic 'refugia' that are considered to be ecologically important for sustaining ecosystems. For those waterholes likely to be filled by surface water flow the following conceptual model is proposed.

With the onset of the wet season, water flows down the rivers and an undefined amount seeps into the river bedsands. Water seeping into bedsands is commonly referred to as ‘transmission loss’. Transmission loss is very difficult to measure and is thought to be greatest during the first streamflow events of each wet season, when the watertable within the bedsands is at its lowest. Once streamflow ceases at the end of the wet season, the rivers break up into a series of waterholes during the course of the dry season. These waterholes disappear with time with water being lost through evaporation and seepage (Figure 3.40). In many cases the water level within the waterhole is in equilibrium with the watertable within the bedsands. Discharge from a watertable varies logarithmically with depth (Thorburn et al., 1991); much greater discharge occurs from a shallow watertable than a deeper watertable. Consequently the water level in a waterhole may fall at a faster or slower rate than would be expected, depending upon the depth of the water beneath the surface of the bedsands and the relative volumes of water lost through evaporation from the waterhole and the water in the bedsands. Pumping water from bedsands would result in the water level in nearby waterholes falling at greater than expected natural rate.

The ecological importance and functioning of key aquatic refugia are discussed in greater detail in the companion technical report about waterhole ecology (Waltham et al., 2013).

The formations of waterholes following a cease-to-flow were captured using Landsat TM satellite imagery and are illustrated in Figure 3.40 for a selected reach of the Gilbert River (Figure 3.41).

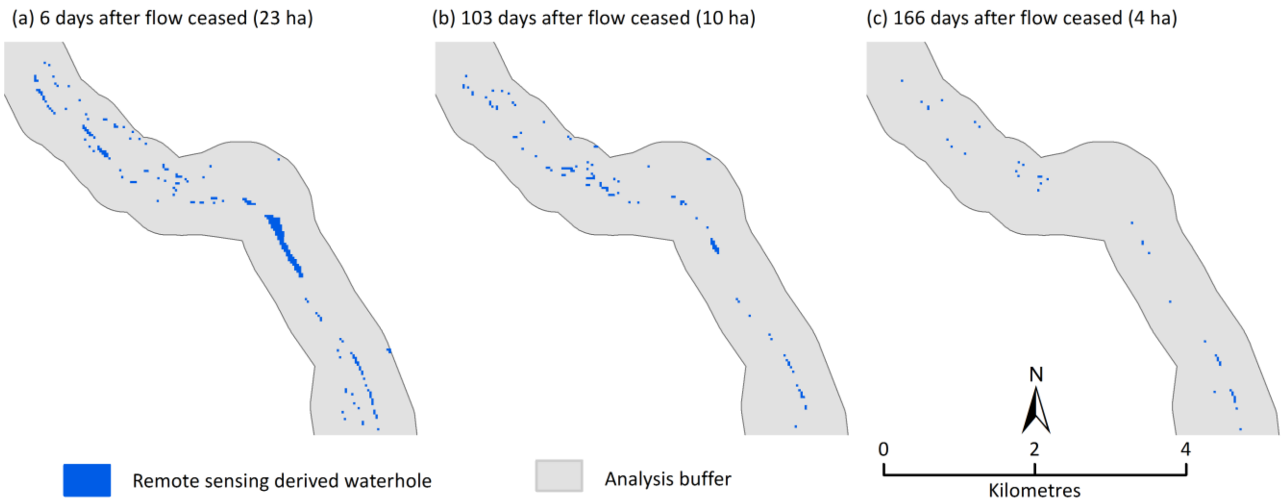

Figure 3.40 Instream waterhole evolution
Mapping of instream waterhole evolution for location labelled ‘A’ in Figure 3.41 on the Einasleigh River reach. This figure shows the area of waterholes at a given time after flow ceased and the ability of the water index threshold to track the change of waterhole area and distribution.

Figure 3.41 illustrates waterholes (greater than 0.36 ha) for key reaches in the Gilbert catchment that were evident in the satellite imagery more than 90% of the time between 2003 and 2010. These were considered to be ‘persistent’ waterholes and hence key aquatic refugia in the Gilbert catchment. McJannet et al. (2013) describe relationships between time elapsed since the last streamflow event and reach waterhole area. These relationships can be used to infer how the persistence of waterholes may change with future irrigation developments or climate change.

In the Gilbert River reach (Figure 3.41) there are relatively few key aquatic refugia mapped and those that do exist are small. In this reach it is possible that large persistent waterholes do not form in the same locations from year to year as a consequence of mobile bedsands and little groundwater discharge.

Figure 3.41 shows that the Einasleigh River has numerous small and intermediate sized key aquatic refugia and that the lower reaches of the Einasleigh River also support three refugia that fit into the largest size class (greater than 7.5 ha). The formation of waterholes in the upper and mid-reaches of the Einasleigh River is in part a result of perennial flow from those rivers draining the Chudleigh and McBride Basalt provinces (e.g. Elizabeth Creek) and in part due to geological controls over waterhole formation. In the lower reaches of the Einasleigh River the persistent waterholes are likely to exist in part due to groundwater discharging from the Chudleigh and McBride Basalts flowing downstream and in part due to geomorphological controls.

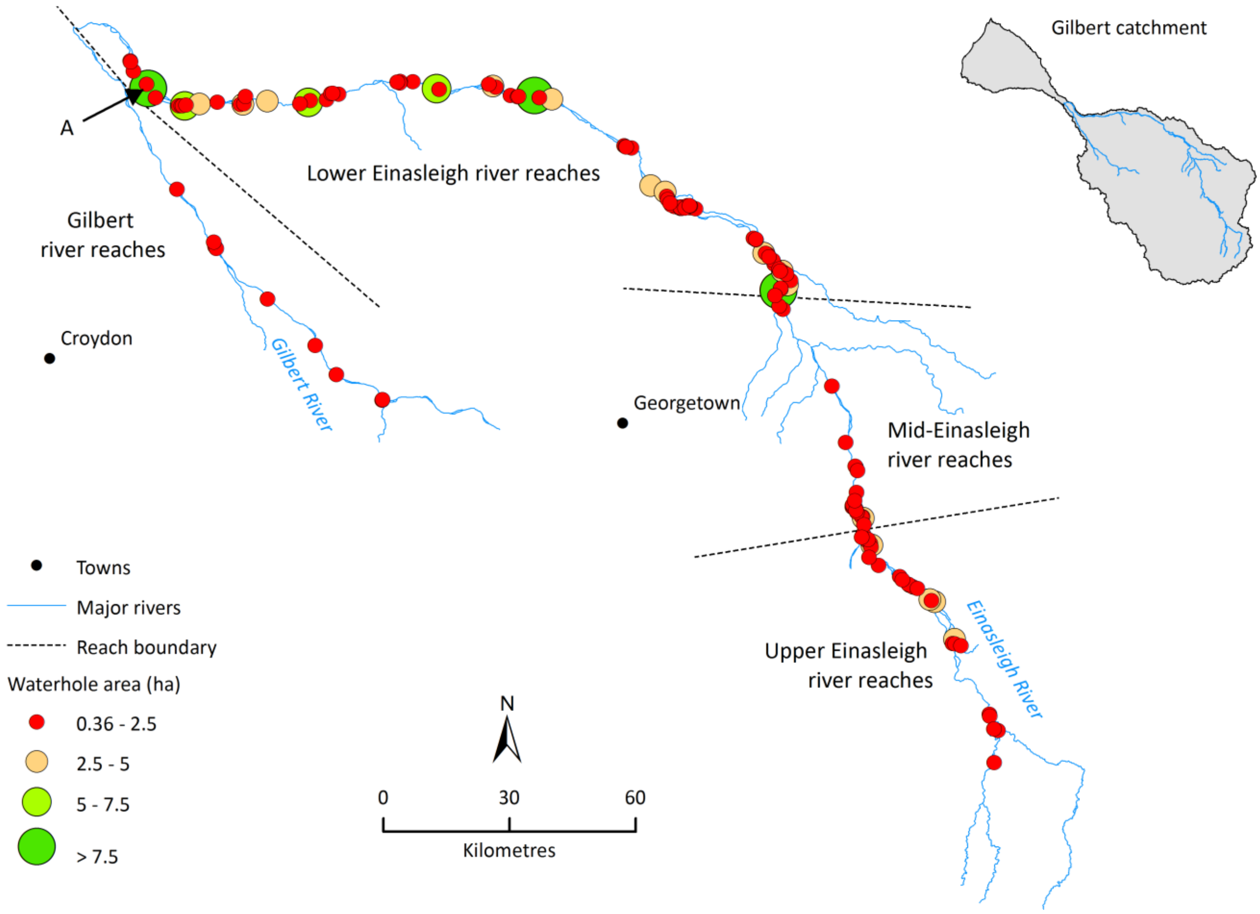

Figure 3.41 Location of key aquatic refugia identified in the Gilbert catchment
Key aquatic refugia are defined as those waterholes which are present for more than 90% of the time. Letters represent reaches shown in more detail in Figure 3.40. Inset shows the river reaches that were examined.

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4 Living and built environment of the Gilbert catchment

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Chapter 4 surveys the existing living and built environment of the Gilbert catchment.

When establishing a greenfield irrigation development, it is important to understand the living environment and the ways it is valued by its inhabitants and users. Indigenous and non-Indigenous perspectives are examined and native title is also considered within the context of the catchment.

To provide understanding of the built environment (existing industries and infrastructure), the chapter covers the demographics, regional profile and the critical thresholds for important community infrastructure (such as schools and hospitals) of the Gilbert catchment – this is information that may help inform and enable new irrigation development.

The key components and concepts of Chapter 4 are shown in Figure 4.1.

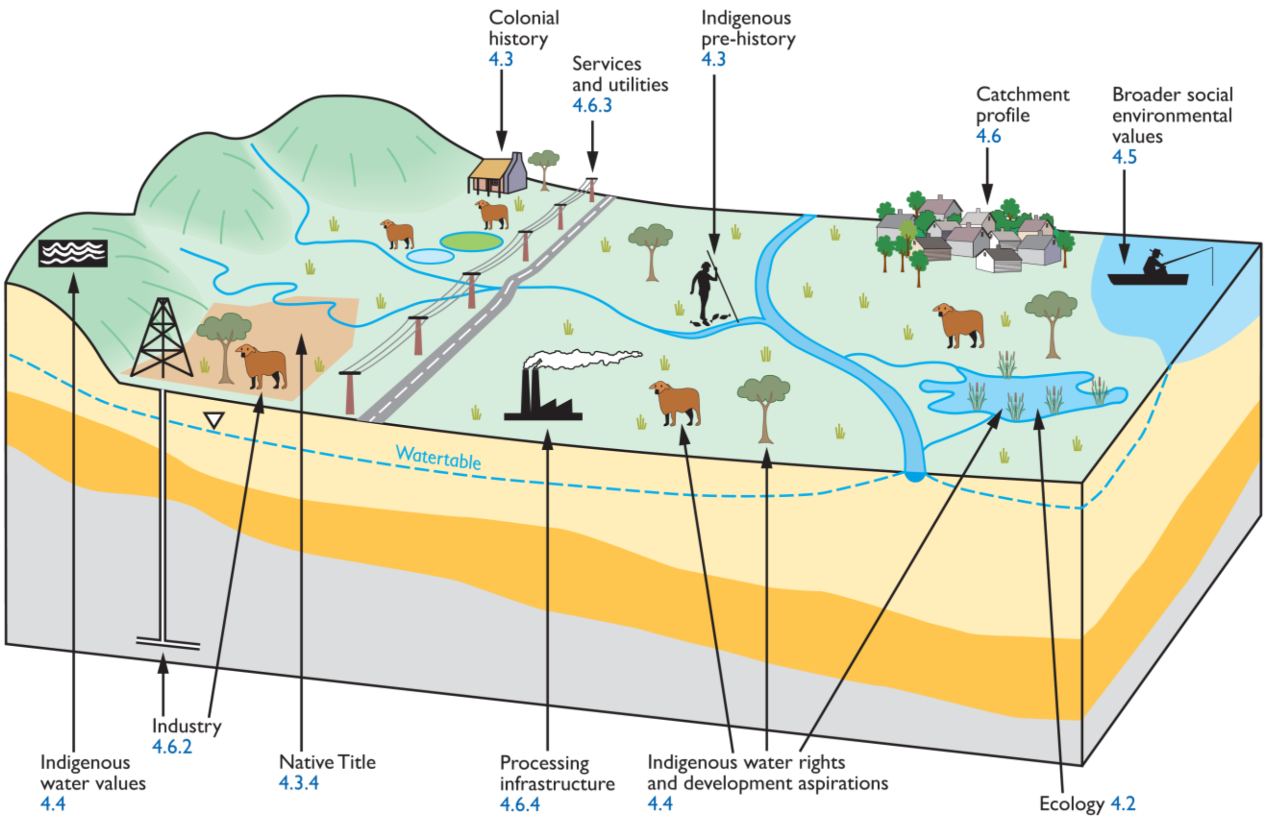

Figure 4.1 Schematic diagram of key components of the living and built environment to be considered in the establishment of a greenfield irrigation development

4.1 Summary

The living and built environment of the Gilbert catchment comprises the ecology of the region, its communities and the infrastructure that supports them. Understanding these components of the environment is fundamental to effectively managing the opportunities and risks associated with new development.

4.1.1 ECOLOGY

The semi-arid natural environment of the Gilbert catchment is largely defined and limited by water availability. The growth and survival of many species and communities are sensitive to changes in water quality and volume, especially in the waterholes that provide refuge during the dry season. Extraction of water necessarily changes streamflow regimes, but the impacts of water extraction on the environment can be minimised by restricting extractions to periods of peak flow, following the first major first flush.

Some ecological considerations for prospective developments include:

- vegetation communities with an ‘of concern’ conservation status that could be inundated following dam construction
- responses of freshwater and marine ecosystems and fishery production to changes in streamflow, fish passage and sediment and nutrient load
- two biodiversity hotspots in the upper Gilbert catchment that could be affected by catchment land use changes
- important waterholes that act as dry-season refugia for aquatic biota and which are potentially vulnerable to changes in water volume and quality, especially turbidity and nutrients.

4.1.2 COMMUNITY

The community seeks sustainable resource developments that balance economic and environmental needs. Population in the Gilbert catchment is declining and existing infrastructure could accommodate small increases in population growth.

Significant Indigenous connections with country remain in the Gilbert catchment. This chapter outlines a range of ways to formalise and refine Indigenous water values and involve Indigenous groups in water planning. Indigenous priorities include:

- protecting cultural heritage (major concerns include ongoing damage to known existing sites and lack of documented heritage knowledge about traditional lands, both of which hamper Indigenous capacity to respond to current development proposals)
- securing sufficient water to maintain healthy landscapes
- securing sufficient water to support current and future Indigenous needs, some of which relate to economic activity such as pastoralism, ecotourism and agriculture.

4.1.3 INDUSTRY AND INFRASTRUCTURE

A range of significant economic activities in the Gilbert catchment, including mining, livestock and hay production, tourism, fisheries, and mango production, are dependent on water. Trade-offs may need to be assessed to maximise the contribution of specific water-based developments to the region.

The Gilbert catchment’s one major dam, Kidston Dam (officially known as the Copperfield River Gorge Dam), is used for limited stock and domestic water supply, and recreation. A number of dam sites have been identified and proposed. Irrigated agriculture in the catchment is currently limited and very little infrastructure is present to support irrigation development.

4.2 Ecology of the Gilbert catchment

4.2.1 INTRODUCTION

Streamflow characteristics (the magnitude, duration, timing rates of change and frequencies of flow events) have been linked to the ecology and health of river systems worldwide. Although flow regimes (timing, size, duration) are important they cannot be considered in isolation from other aspects of freshwater habitat quality as these aspects are inherently linked. Streamflow influences river geomorphology, water quality and thus, riverine habitat availability and quality. Agricultural water resource developments have the potential to cause environmental disturbances, resulting from changes in the hydrology, water quality and ecology of aquatic systems. Beside the effects of the impoundments themselves and changes in flow regimes, water resource developments are usually accompanied by a host of other ancillary impacts such as road networks and crossings, invasive species introduction and changes to water quality. This section examines the proposed water resource development in the Gilbert catchment within the context of river health and ecology and key environmental assets (e.g. important species or habitat) that require protection. Details are contained in the companion technical report about waterhole ecology (Waltham et al., 2013).

4.2.2 CONTEMPORARY ECOLOGY

It is useful to consider proposals for irrigation development in the context of baseline ecological data and experiences drawn from similar water developments. Streamflow in the Gilbert catchment, like many other north Queensland catchments, is strongly seasonal. Low water volumes and poor water quality in remnant waterholes and reaches in the dry season limit the growth and survival of many species (DERM, 2011). Further stressors, especially those affecting reductions in waterhole size and volume, may significantly reduce aquatic habitat quality and suitability. In other north Queensland streams affected by irrigation development (e.g. in the irrigation districts of the lower Burdekin coastal floodplain and the upper Walsh River) reductions in water quality are the dominant factor affecting poor faunal health and driving ecosystem processes (Burrows, 2004; Burrows and Butler, 2007; Butler, 2008; Butler et al., 2007; Pearson et al., 2003; Perna, 2003). Significant extractions of water associated with agricultural development may reduce waterhole size and render them less resilient to seasonal conditions. In particular, smaller waterholes are more prone to increases in temperature and turbidity (cloudiness) and decreased dissolved oxygen (Butler et al., 2007, 2009), all of which impair ecological processes.

Irrigation developments that alter the degree of shading provided by riparian (streamside) vegetation and contribute to increase nutrient loading runoff exacerbate these water quality issues (Burrows and Butler, 2007; DNRMW, 2006). This effect is caused by loss or reduction of coverage of riparian vegetation and instream aquatic weeds, both of which are linked to land use practices, elevated nutrient loading, and impact of weeds and changes in flow regime (Butler et al., 2007).

The majority of streams in the Gilbert catchment are seasonal or ephemeral (i.e. they only flow following rainfall). Movement of biota and energy (e.g. nutrients) between streams and stream reaches occurs during the limited periods of higher streamflow in the wet season (Figure 4.2a). During times of high streamflow, connectivity occurs along the entire river length and laterally to off-channel water bodies and wetlands. This connectivity provides important migration opportunities for aquatic animals to adjacent wetlands for growth and escape from predators and to the sea to complete life cycle stages. The return migration is challenged by the low relief of much of this catchment and barriers including road crossings (Figure 4.2b). When surface flow ceases, the river exists as a series of isolated waterholes that become critical freshwater refugia (habitat for species to retreat to, persist in) for fish and other aquatic wildlife. Aquatic fauna need to be well adapted to these natural variations in flow, and any additional human or climate induced changes.

(a)

(b)

Figure 4.2 Gilbert River
(a) Expansive shallow baseflow river channel during the dry season. (b) Road crossings pose barriers to fish passage.

The Gilbert catchment has several small perennial systems in the upper reaches of the catchment (e.g. Elizabeth Creek, Junction Creek, Bundock Creek) that contribute regular flow to downstream reaches. These systems help to maintain subsurface flow in the bed sands of downstream reaches and maintain waterhole water quality later into the dry season, by replacing 'stagnant' water with fresh water. These groundwater connections are particularly important in maintaining a significant number of permanent waterholes in the rivers of the Einasleigh catchment. Identification and protection of these waterholes is important for the management of refugia in the catchment.

Fish

An extensive review of available published reports and museum records revealed that 42 fish species have been recorded in the freshwaters of the Gilbert catchment. The number of fish species decreased with distance from the coast (Figure 4.3). In the Gilbert catchment potential dam sites in the headwater reaches are unlikely to pose an impediment to the three species of particular significance, barramundi (*Lates calcarifer*), freshwater sawfish (*Pristis microdon*) and freshwater whipray (*Himantura dalyensis*). Both barramundi and freshwater sawfish have been recorded around Georgetown and mid-reaches of the Einasleigh River, and therefore any barriers downstream would restrict migration in the catchment.

The freshwater fish species found in the Gilbert catchment include recreational species targeted by fishers and locals – sooty grunter (black bream), sleepy cod, barramundi and some catfish species. In addition, redclaw crayfish (*Cherax quadricarinatus*) is another species highly prized by fishers that occurs throughout the catchment. A complete list is provided in the companion technical report about waterhole ecology (Waltham et al., 2013).

The pattern of fish distribution in the catchment is attributable to the marine ancestry of many Australian freshwater fish and the many estuarine species that are occasionally found in lower freshwater reaches. This linkage between marine and freshwater systems highlights the importance of maintaining flow and connectivity between these environments in the Gilbert catchment. Barriers to fish movement may be created by dam and weir walls or by smaller structures such as road crossings and culverts, even if fish passage is only partially impaired. While fish passage may be reinstated by engineering options designed to allow fish to pass upstream, and provision of fish passage is required under the *Queensland Fisheries Act 1994* for all new instream structures, such options, beside being costly to construct and maintain, are nearly always inferior to natural fish passage. The challenge in the Gilbert catchment is to consider passage of fish as large as freshwater sawfish (up to six metres long, and with an unwieldy saw-like rostrum; Figure 4.3c) should any barrier to passage result from developments in the catchment.

Among the fish species present in the Gilbert catchment, three species stand out as being of particular significance with regard to the impact of fish passage barriers (Figure 4.3). The first is barramundi, an iconic species of northern Australia of considerable commercial and recreational value. Barramundi travel long distances to spawn in tidal waterways and then return (adults and juveniles) to freshwater wetlands and waterholes, often hundreds of kilometres upstream. They are known to reach the upstream areas around the Mount Surprise reach of the Einasleigh River, Georgetown on the Etheridge River and the middle reaches of the Gilbert River. Their exact upstream distribution may vary each year, but it does highlight the distance over which connectivity is necessary in the Gilbert catchment for fish passage.

The freshwater sawfish and freshwater whipray are two species of high conservation value that occur in the Gilbert catchment. Both are listed on the International Union for Conservation of Nature and Natural Resources (IUCN) *Red List of Threatened Species* (the world's most comprehensive inventory of the global conservation status of biological species) and the sawfish is also listed as vulnerable under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act). As large, bottom-dwelling species, they are not adept at negotiating physical barriers. In addition, both species utilise brackish and estuarine and coastal waters as part of their life cycle and are thus prone to localised exclusion from river reaches where barriers are constructed. As both species are relatively rare, hence their conservation status, their exact upstream distribution is difficult to define, and therefore their range (indicated in Figure 4.3) may in fact be more widespread. The whipray tends to prefer brackish waters so it is not found as far upstream as the sawfish and is not likely to be found above any of the potential impoundment sites identified by the Assessment (Section 5.2.1).

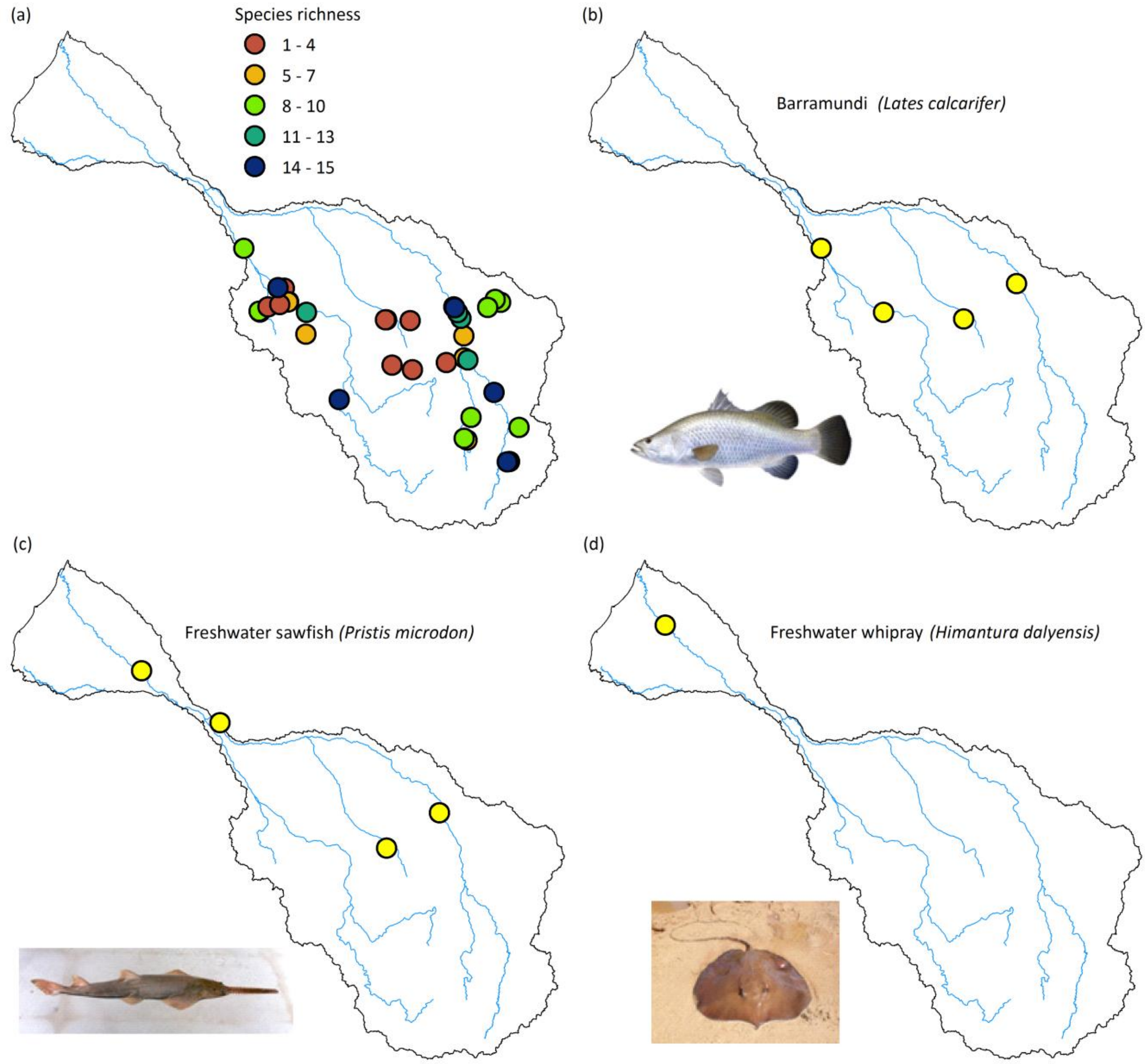

Figure 4.3 Fish distribution in the Gilbert catchment
(a) Number of species found in fish surveys. (b) Known extent of barramundi (*Lates calcarifer*); photo: <www.anima.net.au>. Used with permission. (c) Reliable captures or sightings of freshwater sawfish (*Pristis microdon*); photo: S. Peverell. Used with permission. (d) Reliable captures or sightings of freshwater whipray (*Himantura dalyensis*), photo: B. Pusey. Used with permission.

Other aquatic fauna

Along with fish, the waterholes within the Gilbert catchment provide refugia for a range of other aquatic wildlife (Rollason and Howell, 2010). The distribution and extent of freshwater turtles, for example, is not known precisely, though expert opinion suggests that five species are possibly present including yellow-faced turtle (*Emydura tanybaraga*), diamond-headed turtle (*Emydura subglosoba worrelli*), saw-shelled turtle (*Wollumbinia latisternum*) (Figure 4.4), Cann's long-necked turtle (*Chelodina canni*) and northern long-necked turtle (*Macrochelodina rugosa*) (J Schaffer (TropWATER, James Cook University), 2013, pers. comm.). Many freshwater turtles are affected by flow alterations, including the timing of flow and quantity of water (higher or lower than before development), the conversion of flowing river reaches to impoundments and access to suitable bankside nesting areas. Only a single freshwater turtle was captured during the Assessment (Figure 4.4). Turtles are not readily caught or observed in general fish or aquatic surveys, so are often neglected aspects of faunal knowledge. A survey using turtle-specific survey techniques would be required in situations where water resource developments are proposed.

Figure 4.4 Saw-shelled turtle captured in the Gilbert catchment
Photo: TropWATER, James Cook University. Used with permission.

A range of aquatic fauna, including freshwater frogs, crustaceans and crocodiles, utilise waterholes or require access to waterholes for survival or completion of important life stages, and are therefore at risk from flow alterations or barriers to movement. Thirty frog species have been recorded in the Gilbert catchment and the range maps presented in Vanderduys (2012) suggest the possibility of two more. Most are generalist species with non-specific requirements in terms of breeding and general habitat requirements. Many are especially common along watercourses in the Gilbert catchment but not entirely dependent on the riverine system (i.e. they are able to breed and survive in natural and artificial water bodies such as dams, springs, soaks and seasonally inundated clay pans (E Vanderduys (CSIRO), 2012, pers. comm.). A few species, such as burrowing frogs, are generally restricted to areas with sandy substrates. These species rarely breed in stream channels, preferring temporary water bodies such as flooded clay pans (Vanderduys, 2012). The sandstone frog (*Litoria coplandi*) is exceptional in that it is restricted to rocky waterholes and outcrops adjacent to permanent water (Vanderduys, 2012). The exotic cane toad (*Rhinella marina)* is also widespread and poses a major conservation management challenge. Cane toad populations increase when access to water increases (including water impoundments and irrigated farms) aiding their spread and survival (Urban et al., 2008).

Freshwater crabs (*Parathelphusidae*) are another relatively unknown fauna present in the Gilbert catchment. These crabs are highly adapted to deal with the ephemeral nature of streams, digging holes into stream banks in search of the watertable. Their survival is particularly vulnerable in situations where flow modification creates longer dry seasons or lowers the watertable such that crabs need to dig much deeper burrows. Many crab species have low fecundity with no real dispersal stage during reproduction, which means that river reach populations are more likely to be isolated (Yeo et al., 2007). In addition, many reptiles, including lizards and snakes, are thought to predate on freshwater crabs, along with invasive species such as feral pigs (*Sus scrofa*) and there is evidence in the Gilbert catchment of feral pig damage to river banks, presumably in search of crabs hidden within.

Freshwater crocodiles (*Crocodylus johnsoni*) are also resident in the Gilbert catchment, observed in nearly all waterholes investigated. The effect of changes in streamflow on freshwater crocodiles is not well understood, though it seems likely that populations in drying waterholes would show increased competition for food and space resources in response to overcrowding. The estuarine crocodile (*Crocodylus porosus*) is also resident in lower reaches of the catchment and, although they are known to migrate into freshwater regions, their upstream extent is not known.

Water quality

Irrigation development in the catchment is likely to influence waterholes, mostly notably by lowering water levels (which reduces the benefit of dilution in protecting water quality and aquatic health) and by altering water quality (irrigated farms generally result in elevated levels of sediments, nutrients and other contaminants such as pesticides in nearby streams). Different streams will be affected more by water extraction than by water quality and vice versa. The clearer waters of Gilbert catchment waterholes suggest that they are particularly vulnerable to even small increases of instream sediments and nutrients. Extraction of water at any time other than during high flows is likely to have a significant effect upon waterhole volume. Extraction of water during the important first flush events required to renew the streams and waterholes may also have significant ecological effects. Set rules on what constitutes the first flush and how much water is required to pass in order to flush the aquatic system are very difficult to determine. Studying changes in water quality due to first flush and early wet season events, and the response of the biota to such changes, was the intention of the Assessment but, at most sites, no streamflow occurred and other sites had limited flow. No site was sufficiently flushed for its water quality to return to what is considered normal wet-season conditions.

Throughout the Gilbert catchment, waterholes were found to be clear and remained clear for the duration of the Assessment (Figure 4.5). The most likely reason for this is the predominance of sands and loams in the region's soils coupled with high baseflow, especially in the Einasleigh River, which displaces turbid stormwater. The supply of groundwater inflow is a major driver in the clarification process of waterholes (Butler et al., 2007). The high water clarity is important in promoting aquatic vegetation in these waterholes, including algae growing on the bottom substrate that occurred at all waterholes. Aquatic vegetation is well known to provide shelter for small aquatic fauna from predation and is also the basis (nutrition and energy) for productive food chains. Although many might consider the clearer waterholes in the Gilbert catchment to be appealing and representative of better water quality, they are in fact, quite prone to rapid changes in water quality. For example, even small changes in turbidity can cause large changes in light climate and distribution within a clear waterhole. Where clear waterholes have developed extensive communities of submerged aquatic plants, as is often the case, large and rapid declines in light climate can quickly cause oxygen sags as the aquatic plant communities present consume rather than produce oxygen. Clear, non-flowing waterholes are also more prone to nutrient-induced eutrophication (excessive nutrients in water contributing to algal blooms) processes which also deplete dissolved oxygen levels in the water and/or promote excessive growth of aquatic plants, especially exotic aquatic plants such as para grass, hymenachne and water hyacinth. These are key issues where irrigation development can lead to increased nutrient runoff from irrigated farms. Each of these processes can lead to severe water quality-induced stress for aquatic biota and sometimes fish kills. Such changes in waterhole conditions have been documented in the lower Burdekin River irrigation district in response to the downstream delivery of turbid waters to previously clear river reaches (Butler et al., 2007; Burrows and Butler, 2007).

Given the short and irregular periods of streamflow throughout the catchment and the hot dry conditions that prevail for most of the year, water quality in the remnant waterholes that characterise rivers in the catchment is often quite stressful for aquatic biota living there, hence the importance placed upon examining water quality in this Assessment. Water quality is highly variable, but data collected for a number of parameters, especially temperature and dissolved oxygen, support the contention that water quality is currently stressful for aquatic biota and that any further significant reductions in flow and waterhole volume could exacerbate this situation. The situation is further complicated by the fact that typically, waterholes in the Gilbert catchment, like those in the dry tropics generally, show considerable variation in water quality between years, between waterholes and also within the same waterhole, especially as most of the waterholes studied showed varying degrees and durations of temperature stratification.

In the waterholes of the Gilbert catchment, temperature and dissolved oxygen are two parameters already at or approaching levels stressful to aquatic biota in many waterholes. Water temperatures show considerable variation among waterholes and within a waterhole, with surface waters usually warmer than the cooler bottom waters. In a number of waterholes, surface water temperatures are reaching critical levels for the survival of fish (Burrows and Butler, 2012). In such situations, fish need to seek more favourable areas within a waterhole where water temperature is cooler – typically the deeper water. This is a problem as the bottom waters often have very low dissolved oxygen concentrations, so by moving away from the warm surface waters fish expose themselves to low-oxygen waters in the cooler deeper sections of the waterhole. As waterholes continue to dry and water depth decreases, more of the waterhole reaches critical thresholds for temperature and dissolved oxygen. Increased water extraction simulates this reduction and refugia for biota within a waterhole become fewer and less viable.

The Assessment set out to examine changes to water quality and instream habitat suitability as the dry season progressed and waterhole volume declined and also to study how water quality responded to inflows early in the wet season. However, the 2013 wet season failed to deliver any substantive flows through the Assessment sites. Some water flow occurred during the Assessment following a small rainfall event in late December 2012, though flow was localised, did not proceed far downstream, and was not considered sufficient to flush out the waterholes, an ecologically important function. Water quality sampling in waterholes that experienced some inflows showed that the bottom and surface waters had become mixed but, in several cases, the flow was immediately followed by depleted dissolved oxygen concentrations that posed a threat to the survival of fish.

Figure 4.5 Example of a typically clear waterhole in the Einasleigh River, Gilbert catchment
Photo: TropWATER, James Cook University. Used with permission.

Coastal and near-shore marine environment

The Gulf of Carpentaria coastal zone provides key habitat and protection for the ecological functioning, integrity, and biodiversity values for a range of marine flora and fauna, including many commercially and recreationally targeted species (Blaber et al., 2010; Brewer et al., 1995; Stobutzki et al., 2001). Coastal floodplains are very productive habitats that are dependent on periodic flooding. When the frequency and magnitude of such pulses is reduced, so too is the accessibility of floodplains to fish, crustaceans and other biota. Loss or reductions in floodplain inundation would result in noticeable decreases in aquatic productivity (Arthington, 2008; Bunn and Arthington, 2002; Pearson et al., 2013). Also, in contrast to populist views that mangroves prefer seawater, they are actually most productive in moderately saline water and readily suffer drought stress when subjected to water with higher salt levels. Thus mangroves and coastal estuaries are more productive when they receive greater freshwater inputs and therefore any decisions about changes to flow resulting from water resource development should consider these issues.

A large body of research from temperate and tropical estuaries in Australia and elsewhere demonstrates a positive relationship between streamflow and fishery catches, especially for species of commercial and recreational importance (Buckworth et al., 2013; Meynecke et al., 2006; Robins et al., 2006; Staples and Vance, 1985). This is a common theme and should be seriously considered when assessing the economic merits and environmental impacts of water resource developments. Links between streamflow, floodplain connection and fisheries productivity may arise through different mechanisms such as nutrients stimulating primary production (food for fish, prawns and crabs), streamflow stimulating emigration from estuarine habitats for reproduction or increased catchability of species due to their movement into areas where they are more likely to be caught. The Gulf of Carpentaria prawn fishery is well known for the strong link between streamflow and fishery production, with a higher number of prawn landings following a high wet season flow (Staples and Vance, 1985). In fact, more recently this relationship has been used to develop sophisticated modelling tools in an attempt to determine the total allowable prawn catch each year (Buckworth et al., 2013). Section 4.6.2 provides an overview of the commercial fishing industry in the Gulf of Carpentaria. Elsewhere, streamflow has also been shown to contribute to increased growth of barramundi in the Fitzroy River system such that large flow events show a strong role in boosting fish populations over several subsequent years including during years of low recruitment (Robins et al., 2006).

Aquatic and bankside vegetation

The waterholes examined by the Assessment are characterised by a substrate of sand and silt material and exposed bed rock fields, varying extent of riparian (streamside) vegetation, bank erosion, width, depth, groundwater influence and flow regime. Each waterhole has varying depth, with several likely to persist through the dry season in most years, particularly in the perennial Junction and Elizabeth creeks and probably also in Bundock Creek. Intact riparian vegetation is important in filtering water flow before reaching main river systems, provides river banks with protection as root systems can withstand high flows and bank erosion, and provides food for aquatic food webs and also habitat for a range of terrestrial animals. Riparian vegetation also provides shading to waterholes (which are often naturally warm enough to be negatively affecting sensitive fish species). In situations where the vegetation is removed, these 'services' are compromised or lost completely. Loss or compromised integrity of riparian vegetation is evident at only a few reaches within the Assessment area, mainly associated with grazing, disturbance by feral pigs and the effects of invasive weeds. There is evidence of fallen timber in a number of waterholes; initially, aquatic plants are rare but as the dry season progresses they increase at several waterholes, presumably in response to the increasing availability of nutrients for growth.

Regional ecosystem (vegetation) communities that were present at each potential water storage site within the catchment were examined using the Queensland Herbarium's *Regional Ecosystem Description Database* (Queensland Herbarium, 2013) and were categorised as per Table 4.1. In general, most of the Gilbert catchment, within the Assessment area, includes 'not of concern' vegetation communities, which means that the area of remnant vegetation extends more than 30% of the pre-clearing extent across the catchment (Figure 4.6). However, the Assessment undertook a desktop assessment of vegetation communities located within the potential water storage sites, and many would inundate areas of 'of concern' vegetation because they contain riparian vegetation. Local vegetation surveys would be necessary to provide greater resolution of likely losses of vegetation communities as a result of inundation by a potential reservoir.

Table 4.1 Categories of regional ecosystem (vegetation) communities
These biodiversity codes come from the *Vegetation Management Act 1999.*

CATEGORY	DEFINITION	SUBCLASS*	AREA (ha)	PERCENTAGE OF CATCHMENT
Endangered	Remnant vegetation is less than 10% of its pre-clearing extent across the bioregion; or 10 to 30% of its pre-clearing extent remains and the remnant vegetation is less than 10,000 ha.	Dominant	1,354	0.0%
		Sub dominant	2,208	0.0%
Of concern	Remnant vegetation is 10 to 30% of its pre-clearing extent across the bioregion; or more than 30% of its pre-clearing extent remains and the remnant extent is less than 10,000 ha.	Dominant	847,050	18%
		Sub dominant	303,920	7%
No concern at present, least concern	Remnant vegetation is over 30% of its pre-clearing extent across the bioregion, and the remnant area is greater than 10,000 ha.	Dominant	3,442,160	74%
Non-remnant	Native vegetation		20,565	0.5%
Plantation	Plantation		98	0.0%
Water	Water		4,850	0.1%

* 'Dominant' subclass means greater than 50% of polygon contains the regional ecosystem mapping. 'Sub dominant' subclass means that less than 50% of the polygon contains the regional ecosystem mapping.

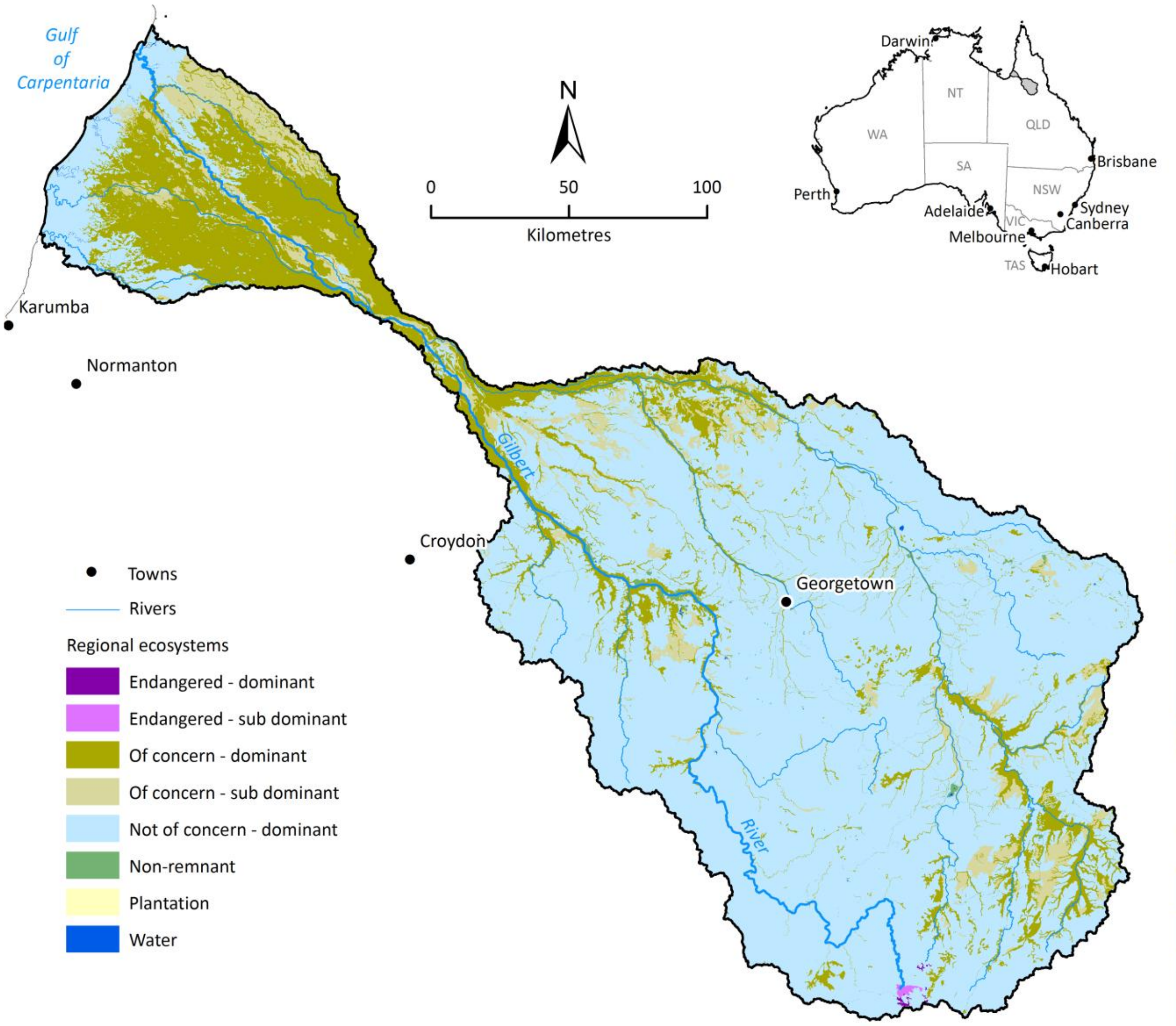

Figure 4.6 Status of regional ecosystem biodiversity for the Gilbert catchment
Definitions and data sourced from Queensland's *Regional Ecosystem Description Database* (Queensland Herbarium, 2013).

Conservation and protected areas

The extent of nature reserves, wetland systems (Figure 4.7) and regionally important vegetation ecosystems (Figure 4.6) is more extensive in the Gilbert catchment compared to adjacent catchments (Rollason and Howell, 2010). The upper eastern region of the Gilbert catchment is part of the Einasleigh and Desert Uplands bioregion (as defined by the Interim Biogeographic Regionalisation for Australia (IBRA; SEWPaC, 2013a)), which are biodiversity hotspots recognised for their mix of ecologically and geologically important features and habitats (Rollason and Howell, 2010). Undara Volcanic National Park (Figure 4.7a) is located in the far north-east corner of the catchment and has a high tourist potential because of the high wilderness and scenic amenity provided by the area (Rollason and Howell, 2010). This park supports a range of plant and animal communities and geological formations. It is also affected by weed invasion and impacts from introduced pest species including pigs which can destroy riparian and terrestrial vegetation in search of food (SEWPaC, 2013b). In addition, the *Register of the National Estate* (a list of natural, Indigenous and historic heritage places throughout Australia; DEWR (2007)) includes an additional two conservation areas in the upper catchment (Figure 4.7b). These conservation areas also support high biodiversity and are reportedly affected by catchment land use changes, including influences from changing fire regimes, weed and pest invasion, stock access, erosion and loss of ground cover (SEWPaC, 2013b).

A number of springs are located across the Gilbert catchment and, while typically small, each provides permanent (or nearly so) water habitat in an otherwise dry environment (Figure 4.7c). These landscape features generally contain specialist plants and animals. The Great Artesian Basin underlies most of the Gilbert catchment and the Queensland Government has mapped the wetlands and springs it forms (Figure 3.23) (Fensham and Fairfax, 2003). In the case of springs, the mapped data includes both permanent discharge (flow) features and those that have become inactive since European settlement (Ponder, 2002). The remaining springs are likely to be particularly vulnerable to disturbance from livestock, feral pigs, ponded pastures, bore-drain construction and cane toads (Burrows, 2004).

The coastal plains of the southern Gulf of Carpentaria include a sequence of wetland aggregations which are each recognised in the national *Directory of important wetlands in Australia* (SEWPaC, 2013b). This spread of wetlands provides habitat for coastal fish species, including many that are economically important (Rollason and Howell, 2010). The Southern Gulf Aggregation (Figure 4.7a) is the largest (545,353 ha) of these and is the most diverse natural wetland aggregation in Australia. Most of these aggregations cover intertidal flats, seagrass beds, tidal channels of mangroves, sand dune systems, and riverine lagoons, swamps and seasonally flooded wetlands. Another nationally important site (listed on the Register of the National Estate as an endangered species breeding colony) is Point Austin Little Tern Site (Figure 4.7b), a vegetated sand island approximately 43 km north-east of Karumba. This remote area is visited primarily by commercial barramundi and crab fishers. The island provides habitat for nesting little terns (*Sterna albifrons*), a bird species under major threat of extinction. Major threats to the population of this species are vehicles driven along nesting beaches and predation from dogs, foxes, birds of prey, rats and feral pigs (SEWPaC, 2013b).

Fish habitat areas (FHAs) have been declared throughout Queensland under the *Queensland Fisheries Act 1994* (Figure 4.7c). These FHAs enhance current and future fishing activities and protect important habitat for fish and other aquatic fauna (Beumer et al., 1997). The designation of these areas protects critical wetland habitats which sustain fish and invertebrate stocks (including prawns, crabs, worms, shellfish) upon which the recreational, commercial and Indigenous fishing sectors depend. Sea turtles, dugongs and an extensive number of shoreline birds also benefit from these coastal intertidal protection areas. There is one declared FHA located within the Gilbert catchment – the Staaten-Gilbert FHA (10,175 ha) located between 1 km south of the Gilbert River mouth to 8 km north of the Staaten River mouth. In the Gilbert catchment, the declared FHA extends a short distance upstream, while in the Staaten River it extends up the lower reach of the Staaten River main channel, Staaten North Branch and Vanrook Creek.

A series of marine reserves and coastal protection zones are present within the Gulf of Carpentaria, declared as part of the Commonwealth's marine reserve network. The designation of these marine reserves is in response to the need to maintain the long-term health and productivity of Australia's coastal marine environment (SEWPaC, 2012; Figure 4.7c). The Gulf of Carpentaria Marine Reserve is characterised by submerged patches, platform and barrier reefs that form a broken margin around the perimeter of the Gulf of Carpentaria. The offshore waters of the Gulf of Carpentaria are generally well-mixed, though heavily influenced by freshwater flows during the monsoon, and deliver considerable sediment and nutrient loads to the offshore waters (Burford and Rothlisberg, 1999; Section 5.2.1).

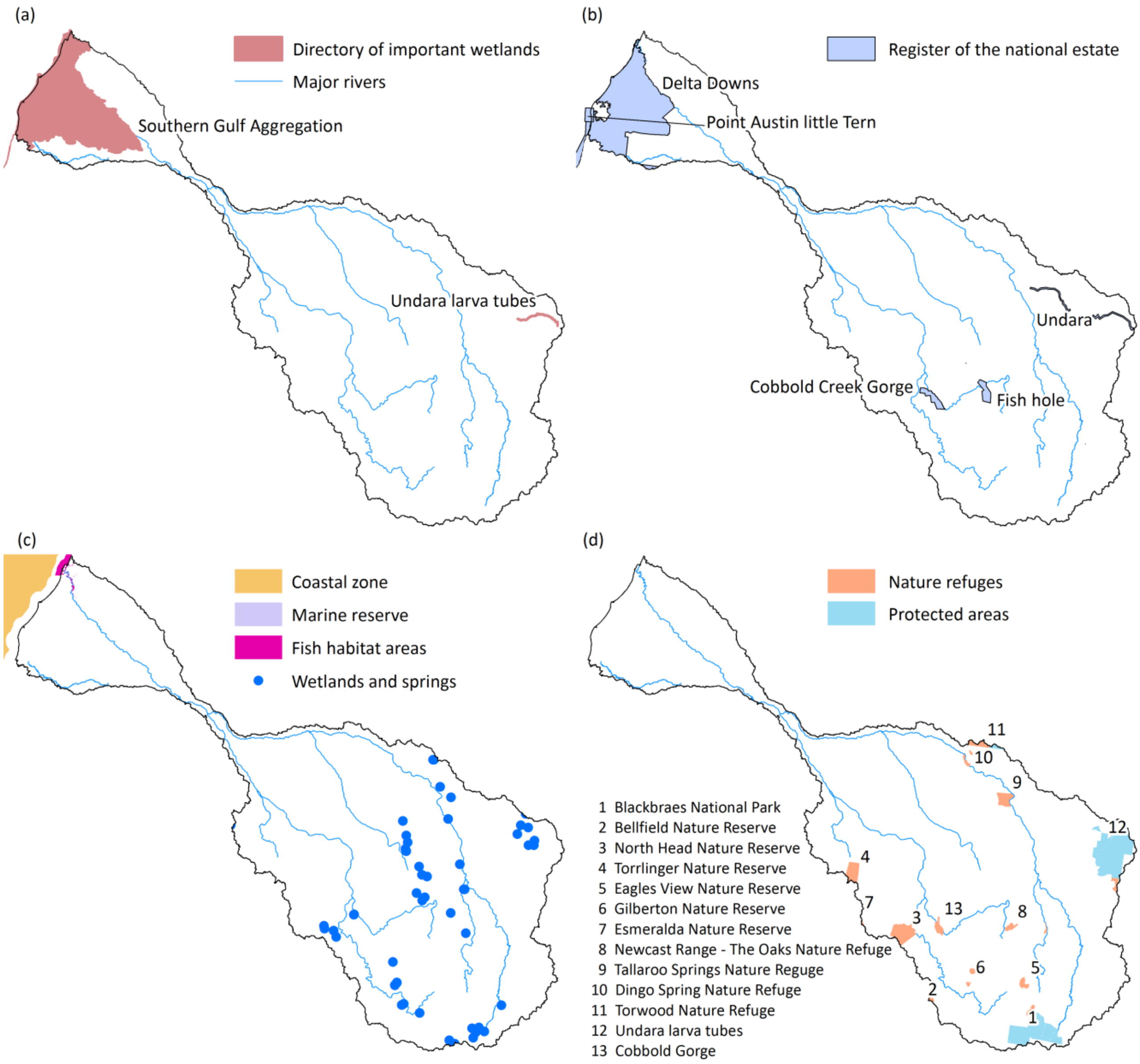

Figure 4.7 Spatial representation of important ecological assets across the Gilbert catchment
(a) *A directory of important wetlands in Australia* (SEWPAC, 2013b). (b) Register of national estate. (c) Marine conservation and coastal protection zones, described wetlands and springs. (d) Natural refuges and protection areas (data sourced from Australian and Queensland governments).

4.3 Indigenous pre-history and colonial history of the Gilbert catchment

4.3.1 INTRODUCTION

Understanding the past is important to understanding present circumstances and future possibilities. Section 4.3 provides some basic background information about the pre-history and history of the Gilbert catchment, particularly in relation to Indigenous Australians. This history is relevant to regulatory issues (e.g. cultural heritage and native title), to current Indigenous and non-Indigenous residents in the area and to future aspirations people may have. The sections below review some key evidence of past habitation by Indigenous people, the significance of water in past patterns of habitation, exploration colonisation processes, and the contemporary situation with respect to Indigenous land ownership and access agreements. This provides context necessary for the discussion of Indigenous water values, rights and interests and Indigenous development aspirations described in Section 4.4.

4.3.2 PRE-COLONIAL INDIGENOUS SOCIETY

The section below identifies four primary characteristics of pre-colonial Indigenous societies – long residence times, detailed knowledge of ecology and food gathering techniques, complex systems of kinship and territorial organisation and a sophisticated set of religious beliefs often known as Dreamings. The Gilbert catchment contains some archaeological evidence of Indigenous habitation stretching back many thousands of years but the published archaeological record for many locations is relatively sparse (McIntyre-Tamwoy et al., 2013). This reflects a lack of attention by both researchers and the wider non-Indigenous population and, to a far lesser degree, the impacts of colonisation and pastoral development. Sources about pre-colonial (and early colonial) Indigenous life are also relatively sparse but some observations from the early explorers are useful in a water resources context. Leichhardt skirted the eastern boundary of the shire of Etheridge and described human occupation around lagoons and waterholes:

> *Large lagoons full of fish or mussels form a greater attraction to the natives than a stream too shallow for large fish, and, from its shifting sands, incapable of forming large permanent holes. Wherever we met with scrub with a good supply of water, we were sure of finding numerous tracks of the natives, as game is so much more abundant where dense vegetation affords shelter from its enemies.*
>
> *April 13 entry (Leichhardt, 1846)*

More extensive material appears from the Jardine expedition of 1864. The expedition journeyed along the Einasleigh River (Byerley, 1949) and noted:

> *…a great many fishing weirs were observed in the channels of the river, from which it would appear that the blacks live much, if not principally, on fish. They were well and neatly constructed.*
>
> *11 September entry (Byerley, 1949)*

Four days later the Jardines again passed Indigenous people who were fishing in a large lagoon and, as no hostility was evident, the men were able to witness fish spearing using a long heavy four-pronged spear, barbed with kangaroo bones. On 18 October, the party observed a 'mob' of natives possessing reed spears and a large stone axe and cooking fish by a waterhole. Other observations (21 and 26 October) noted Indigenous people camped near waterholes and the 26 October entry goes on to describe that group as:

> *…puddling a waterhole for fish and possessing fishing nets differently worked to any yet seen, and very handsome; a sort of chain without knots.*
>
> *26 October entry (Byerley, 1949)*

Two other observations (14 and 18 October) note the absence of grass along the river due to fires lit by Indigenous people. This was most likely for hunting purposes but it is possible that burning along the river edges was a tactic to deter the presence of the cattle the Jardines were also moving. Wegner (1993, p. 27) also repeats an observation from the early colonial period that Indigenous people swam underwater down the flooded Einasleigh River to spear horses (Black, 1931). Extrapolating from the colonial material and examples from elsewhere, Wegner describes a picture along the Gilbert River of seasonal dependence on water resources:

> *The population [were] spreading across the land and into the ranges in the wet season, and contracting back to the rivers in the dry. Once the rivers had stopped running, they would have further contracted to the permanent waterholes and lagoons and the spring-fed creeks…*
>
> *p. 33 in Wegner (1993)*

Wegner goes on to identify the many aquatic and riparian foods in the area: mussels, waterlilies, crocodiles, edible plants, birds and game which needed water. Although the sources are fragmentary rather than systematic, the general picture they suggest is of active habitation of the Gilbert catchment by a substantial number of people who were residing close to water sources and using locally available technologies to exploit aquatic and riparian resources.

In terms of linguistic and territorial groups, Tindale identifies four main groups: the Ewamin, Tagalak, Jangaa and Wakamin but Wegner (1993) notes considerable overlap between the described territories of these groups in Tindale's account. Multiple names (and naming variants) are a common feature of early historical accounts of Indigenous Australians – the complex nature of Indigenous territorial and social systems meant that several (correct) alternative answers could be provided to questions about personal or group identity and associated territory. Larger regional Indigenous language groups contained named subgroups with stronger associations with particular parts of the overall territory. Individuals were also enmeshed within complex individual kinship relationships which followed systemic rules and conventions. Both the specific type of kinship system relating people and territory, and the size of the territories varied across Australia but the strong relationship between kinship and territory seems to have been universal (Keen, 2003).

The three elements above – long residence times, detailed knowledge of ecology and food gathering techniques, and complex systems of kinship and territorial organisation – relied on and supported a set of religious beliefs (now popularly known as the Dreaming) which explained the powers that created and still live in the world (Morphy, 1991; Myers, 1991; Roth, 1897). The stories of those powers were a source of spiritual and emotional connection as well as providing guidance on identity, language, law, important places and territorial boundaries, and material and economic relationships (Keen, 1994; Williams, 1986; Rose, 2000). From an Indigenous perspective, ancestral powers are still present in the landscape and are directly related to resource rights and to wider Indigenous relationships with land and water across Australia.

4.3.3 EXPLORATION AND COLONISATION

The first documented case of colonial presence in the area now encompassed by the shire of Etheridge was Leichhardt's 1845 expedition, and brief mentions of sightings of Indigenous people (but not significant contact) appear in journeys by Gregory (1856) and MacKinlay (1861). More substantial contact occurred with the Jardine (1864) and MacDonald (1865) expeditions, but the general character remained one of avoidance, armed defensiveness and occasional uses of gunfire and violence by the colonial parties (Wegner, 1993). The pastoral settlement of areas to the south and east of the Etheridge area occurred rapidly during the 1860s (Wegner, 1990) and Wegner (1993) notes that hostilities occurred through a result of colonial attitudes, cultural misunderstandings, and competition for food and water resources. The last was particularly important as pastoral homesteads and outstations were sited close to permanent water, leading to considerable conflict (Curthoys, 1987). As Wegner describes:

> *Keeping the blacks out meant shooting at any Aborigine to be found on the plains and river valleys necessary for grazing sheep and cattle, which was disastrous for a people who depended on the rivers and permanent creeks for most of the year.*
>
> *Wegner (1993)*

The pastoralists' cattle also trampled and ate traditional plant foods used by Indigenous people, necessitating their retreat to the higher ranges. These provided shelter, but in some places were waterless and therefore devoid of food. Attacks on cattle stations, their animals and their owners may have been both retaliation for past attacks by colonists and a direct attempt to gain food. The gold rushes of 1869 to 1870 brought police to the Gilbert catchment but Indigenous people were entirely unprotected from attacks by white colonists and miners, and pastoralists also remained vulnerable. That vulnerability is evident in the story of the desertion of Gilberton (Reynolds, 1993). The town was established and grew rapidly following the discovery of gold in the area in the late 1860s, numbering several thousand by the early 1870s. An initial attack by Indigenous people on a Chinese mining camp increased tension and fear but it was the news of gold on the Palmer River to the north in August 1873 that caused the majority of the population to leave. The remainder (approximately 100 people) included many Chinese miners but, when they departed following further attacks, the remaining Europeans also decided to leave when police were redeployed to the Palmer River. Reynolds (1993) deemed it probable that Gilberton was abandoned ‘largely through fear of the blacks’ and this is certainly how it is remembered in northern folklore. The ranges provided some protection to local Indigenous people for another decade but colonisation continued and mining resumed once the Palmer River rush had subsided. Mining was particularly problematic for Indigenous people, as armed men were scattered throughout a wide area, competing for resources and monopolising and polluting water supplies. Figure 4.8 shows a plate from an early text about mining in the Etheridge River and displays both the prominence of water for colonisers and some of the tensions created by their presence (Lees, 1899).

Figure 4.8 Photographic collage of early colonial mining on the Etheridge goldfields (Lees, 1899)
The lower left and top right panels involve activities (‘ground sluicing’ and ‘prospecting in the ridges’) which displaced Indigenous people and degraded water quality. The lower centre panel, entitled ‘danger’ contains an Indigenous man in the background aiming a spear at a miner.

By the mid-1880s, starvation, the threat of further violence and inconsistent access to water forced the remaining Indigenous inhabitants to settle on the fringes of various towns in the area. The number of Indigenous people living around Georgetown in particular was substantial, and complaints made by colonists about begging, prostitution and disease led to a range of government and police actions (Wegner, 1993). An Indigenous reserve was considered in 1887 to 1888 for Georgetown but dismissed on the grounds that the soil and climate was unsuitable for agriculture and so the government would bear the cost of establishment as well as feeding and clothing the residents (Wegner, 1993). The lack of a major reserve or mission substantially affected Indigenous population levels in the upper Gilbert catchment thereafter.

The use of Indigenous labour for domestic and stock work for much of the 20th century meant that some people were able to access the area, often from a base outside the catchment such as the reserve at Croydon or from locations further east.

4.3.4 CONTEMPORARY INDIGENOUS OWNERSHIP, MANAGEMENT, RESIDENCE AND REPRESENTATION

The pressures of colonial violence and forced relocations made the maintenance of pre-colonial connections and ways of life difficult. The colonial history and contemporary tenure regimes have significantly altered where people live. Places in the Gilbert catchment which were important residential sites in the past are now not permanently inhabited and, for a range of reasons, particularly accessibility, some may rarely be visited. However, areas which are not frequently visited may be crucial in people's lives, sustaining a distinct individual and group identity as well as connections to past ancestors and future descendants. People are connected to places through a combination of genealogical, traditional and residential ties. While some of these connections are formally recognised through government and/or legal processes, others are well known and locally respected but have yet to receive formal external recognition.

Ownership and management

There are three major ways in which contemporary Indigenous people from the Gilbert catchment exercise some degree of management control over large areas of traditional lands – native title, Indigenous land use agreements (ILUAs) connected with native title, and Indigenous-owned pastoral leases.

Figure 4.9 and Figure 4.10 show the current situation with respect to these tenure and management types. Detailed information about these categories appears in the companion technical report on irrigation costs and benefits (Brennan McKellar et al., 2013), but in summary, native title recognises prior Indigenous ownership of the land and a series of discrete rights relating to access and customary use of resources to satisfy the personal, domestic or non-commercial needs of rights holders, as well as water required for other activities directly related to native title rights and interests. ILUAs emerged from 1998 amendments to the *Native Title Act 1993*, and are voluntary agreements between claimant groups and interested parties for the use and management of lands or waters. ILUAs can be made before Native Title has been determined in a particular area. Pastoral leases owned by Indigenous people provide them with the same rights and constraints as other pastoral leaseholders.

Figure 4.9 shows the current situation with respect to native title in the Gilbert catchment. The Tagalaka people had their native title claim determined in late 2012. This claim includes provisions for non-exclusive hunting and fishing rights and for the right to take and use the water for personal, domestic and non-commercial communal purposes (*Owens on behalf of the Tagalaka People v State of Queensland*). A registered native title application by Ewamian people is likely to be declared soon and contain similar provisions as for the Tagalaka people. The country of the Kurtijar people located downstream on the Gilbert River do not have a current native title application registered but preparations to register an application are underway. Gugu Badhun and Yirendali applications overlap slightly on the upper edge of the Gilbert catchment boundary.

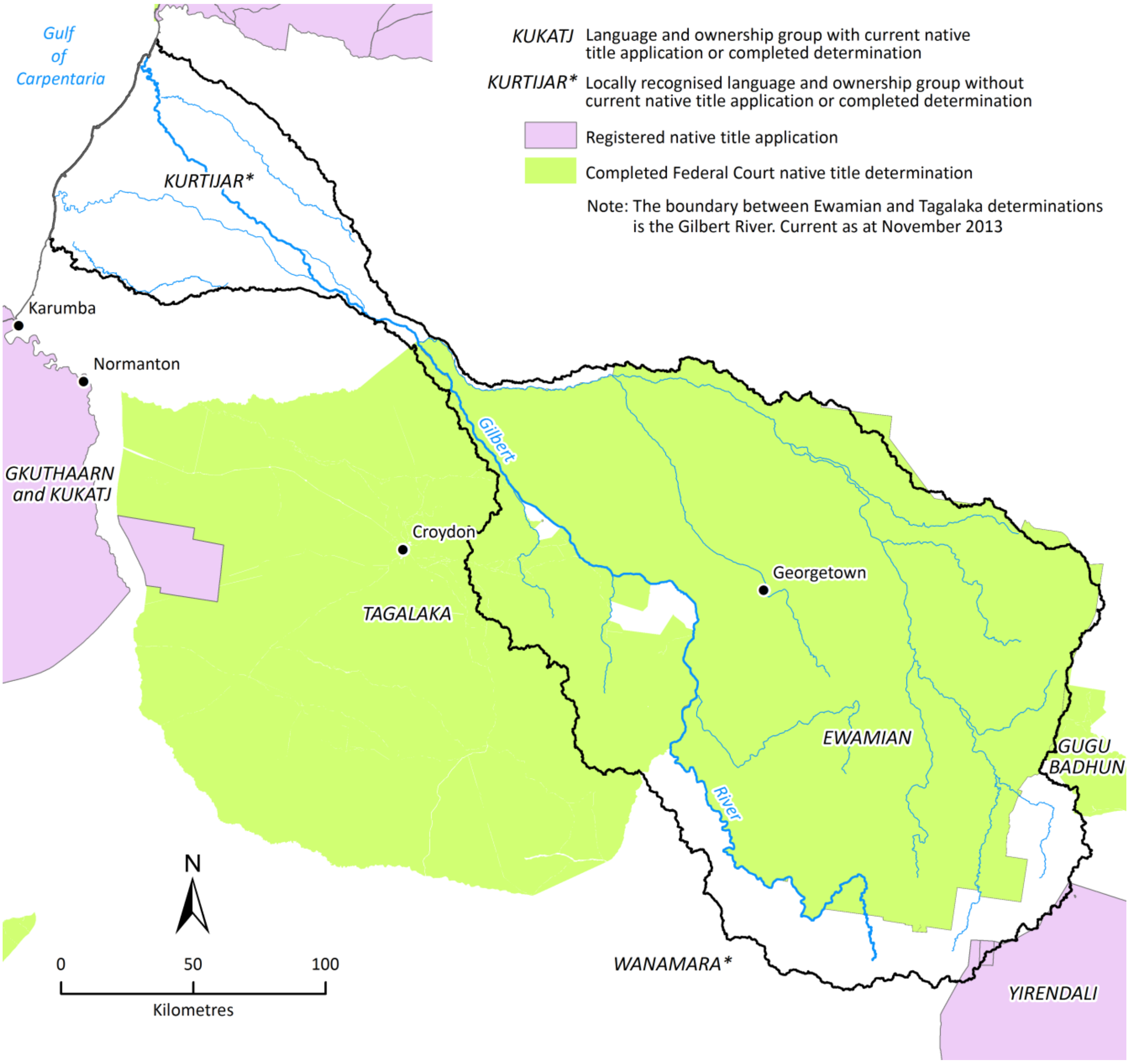

Figure 4.9 Current native title determinations and applications in the Gilbert catchment
Data source: National Native Title Tribunal and Native Title Register Queensland.

Figure 4.10 shows ILUA boundaries and pastoral tenure belonging to Indigenous people. ILUAs have been generated over both Ewamian and Tagalaka territory in the Gilbert catchment. In terms of pastoral tenure, assistance from funding bodies such as the Indigenous Land Corporation (ILC) have seen two significant rural properties return to Indigenous hands. The Kurtijar people own, reside upon and operate a major cattle station in the Gilbert catchment at Delta Downs. A partnership between the ILC, a conservation organisation and Ewamian people successfully purchased Tallaroo Station in 2012, where the Ewamian currently maintain a residential base for land management and pastoral activity. Middle Park pastoral station also adjoins the catchment and has been managed by Indigenous people through the Woolgar Valley Aboriginal Corporation since it was purchased by the ILC in 2000. It is leased for agistment purposes rather than regularly occupied.

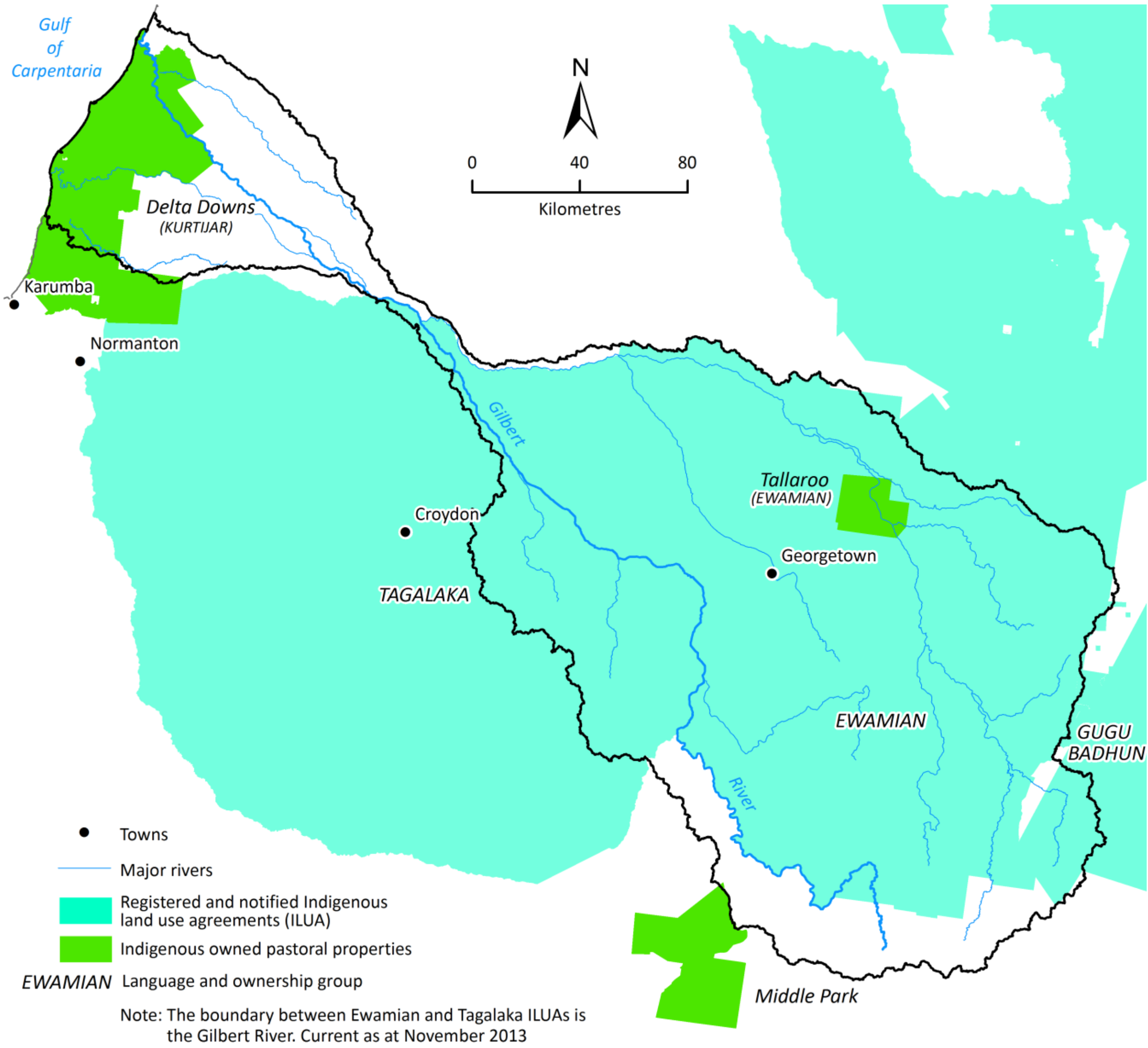

Figure 4.10 Indigenous land use agreements and Indigenous-controlled pastoral leases in the Gilbert catchment
Data source: National Native Title Tribunal and Queensland Government

Indigenous residence

Australian Bureau of Statistics census data in Table 4.3 (of Section 4.6.1) shows a significant decline in the overall population of the Gilbert catchment from 2001 to 2011. The Indigenous population has been more stable, and Table 4.3 includes Indigenous people who are part of recognised local ownership groups as well as residents who identify as Indigenous but have their origins elsewhere. Local ownership groups were the focus of the Assessment research effort. Indigenous residence is concentrated in the downstream shires – the proportion of the population that is Indigenous is comparable to Queensland as a whole in the Etheridge shire, while Carpentaria shire contains a high proportion of Indigenous people. The concentration of owners on the western side of the catchment means that residential location differs from the group and tenure boundaries identified above. For both the Ewamian and Tagalaka peoples, primary residential locations are outside the catchment. These patterns of residence and dispersal reflect a combination of involuntary relocation, voluntary movement to seek job and other opportunities, and kinship and family links. Research participants from every group expressed a strong desire for conditions that would enable more of their people to reside on their own traditional lands.

Indigenous governance and representation

Indigenous organisational and political structures within the catchments are quite diverse. Three levels of organisation are particularly relevant:

- local Indigenous corporations based on recognised traditional owner groups
- Indigenous land councils involved in native title and related management
- Indigenous representation in catchment management organisations.

Group-based local Indigenous corporations are often highly significant representative structures and were crucial in enabling the current study. The Ewamian and Kurtijar peoples both have local corporations with permanent offices and/or paid staff, while the Tagalaka people have a corporation without those resources. Land council affiliation is split – the Ewamian and Tagalaka are represented by the North Queensland Land Council (NQLC) and the Kurtijar by the Carpentaria Land Council Aboriginal Corporation. The Gilbert catchment is overseen by Northern Gulf Natural Resource Management (NGNRM), which has a separate Indigenous representative structure, the Northern Gulf Indigenous Savannah Group (NGISG). The NGISG is guided by a management plan and a board comprised of key representatives from the traditional owner groups with territory within the NGNRM catchments, including the Gilbert catchment. Although securing adequate resources is an ongoing challenge, Indigenous catchment management plans and aspirations have been clearly articulated by NGISG for the Gilbert and other catchments. These include care for the country, access, revival of cultural knowledge and traditions, partnerships, and policy development and implementation.

Table 4.2 summarises the existing situation in terms of ownership, residence, management, and representation. It shows significant variations in existing capacity, resourcing, and ability to participate in natural resource management decision making. Combined with the population profiles given above, it also suggests that groups will have different aspirations and orientations when it comes to the opportunities provided by development. Some will be more focused on opportunities and resources for existing residential populations; others will be focused on resettlement. Similarly, some groups already have entities such as Indigenous ranger programs that are a major aspiration for groups without such organisations. Certain situations, such as the lack of participation in water planning, are common across groups. However, the variations present here indicate the necessity for planning processes grounded in the specificities of local groups, and for catchment level coordination of that planning.

Table 4.2 Summary of Indigenous group tenure, residence, and natural resource management

	GROUP		
	Ewamian	**Tagalaka**	**Kurtijar**
Key townships	Georgetown	Croydon	Normanton
Significant number of people primarily identifying as group member	Yes	Yes	Yes
Group ownership of town land on traditional country	Yes	Yes	Yes
Infrastructure on town land	Yes	No	Yes
Local Indigenous corporation with paid staff and office	Yes	No	Yes
Ownership of significant rural land	Yes	No	Yes
Significant residential presence on traditional lands	No	Yes	Yes
Indigenous ranger program operating on traditional lands	Yes	No	Yes
Native title application currently registered	Yes	Yes	No
Native title claim determined	No	Yes	No
Current Indigenous land use agreements	Yes	Yes	Yes
Native title representation/assistance from land council	Yes – NQLC	Yes – NQLC	Yes – CLCAC
Formal Indigenous catchment and natural resource management entity	Yes	Yes	Yes
Indigenous representation in water planning	No	No	No

4.4 Indigenous water values, rights and interests and Indigenous development aspirations

4.4.1 INTRODUCTION AND INDIGENOUS ASSESSMENT CONTEXT

The Assessment investigated Indigenous water values, rights and interests in the catchment, Indigenous perspectives on natural resource development generally and local development opportunities and aspirations. Details are contained in the companion technical report about Indigenous water values, rights and interests (Barber, 2013). Prior to the Assessment, there was little information about Indigenous water issues in the Gilbert catchment and only a small amount about Indigenous perspectives on agricultural development generally. The Assessment directly addresses these data needs, as well as some key contextual issues:

- Indigenous peoples' responsibilities to culture and country
- potentially different understandings of the meaning of 'engagement' among Indigenous and non-Indigenous people

- challenges for operationalising Indigenous recognition within water planning
- key Indigenous sustainable development aspirations and planning pathways.

Considerable efforts were made during the Assessment to ensure key senior elders from all the relevant Indigenous groups were engaged in face-to-face consultations to establish a representative range of Indigenous values and opinions across the Gilbert catchment. This was complemented by further professional analyses of key issues – water planning, sustainable development and cultural heritage.

However, the Assessment was not governed by an Indigenous steering committee, does not provide formal Indigenous group positions about any of the issues raised and does not substitute for formal processes required by cultural heritage, environmental impact assessment or water planning legislation. Establishing Indigenous representative structures, obtaining formal Indigenous group positions and/or meeting formal legislative requirements were not objectives of the Assessment. Rather, the Assessment undertook scoping work carried out over a large and information-poor geographic region with complex, evolving and overlapping Indigenous jurisdictions and in which the prospective development areas and plans were yet to be finalised. Nevertheless, the Assessment does provide effective guidance for future planning and for formal negotiations with Indigenous groups by identifying key principles, important issues and potential pathways.

A series of key ideas provide a framing context for the Indigenous component of the Assessment, and the first of these is Indigenous connections with country. As a group, Indigenous people are socially and economically disadvantaged but also custodians of ancient landscapes. They therefore seek to balance short- to medium-term social and economic needs with long-term cultural, historical and religious responsibilities to ancestral lands. Indigenous country can provide practical economic and material support and so becomes a major focus for contemporary social and economic development ideas and aspirations. These combine economic viability and sustainability with a range of wider social, cultural and environmental goals – care for the country, respect for the knowledge and authority of elders, collective governance arrangements, meaningful employment for young people, and so on. Colonial conflict over water was intense and ongoing Indigenous priorities include securing sufficient water to maintain healthy landscapes, but also sufficient water to support current and future Indigenous needs, including Indigenous economic activity. In rural areas, this activity is often land-based and water dependent – pastoralism, ecotourism, agriculture. This increases the importance of securing water supplies.

The term ‘values, rights and interests’ is intended to encompass formally recognised rights and a range of broader values and attributes that are crucial to Indigenous people. Engagement with Indigenous people is a strong aspiration across government and key industries but models of engagement can vary considerably and competing understandings of what ‘engagement’ means (consultation, involvement, partnership, etc.) can substantially affect successful outcomes. Standard stakeholder models can also marginalise Indigenous interests, reducing what Indigenous people understand as prior and inalienable ownership rights to a single ‘stake’ equivalent to all others at the table. Indigenous development issues have been the topic of major recent forums at Mary River and Kakadu respectively (NAILSMA, 2012, 2013). The Kakadu forum emphasised attracting private investment on Indigenous lands, including the adoption of a ‘prospectus’ approach to communicate with investors.

Internationally, Indigenous water rights, values and interests have been outlined in a number of significant forums and documents (World Water Council, 2003) including some produced in Australia (NAILSMA, 2009; NAILSMA and UNU-IAS TKI, 2008). In terms of Australian water planning, the National Water Initiative led to government agreement that water plans must recognise Indigenous needs in terms of access and management. This incorporates Indigenous representation, incorporation of Indigenous social, spiritual and customary objectives, and recognition of native title needs and uses (Jackson and Tan, 2013). However, progress in implementing that recognition has been slow due to a lack of knowledge about those interests, competing water demands and the challenges of accommodating Indigenous perspectives in conventional planning frameworks. ILUAs can be used alongside water planning as one mechanism for water sharing and Australia’s largest and most complex ILUA, negotiated in the context of an irrigated agricultural proposal, is Ord Stage 2 in the Kimberley. It attempts to increase Indigenous access to water, as well as containing a range of measures to improve Indigenous participation in the agricultural sector (Jackson and Tan, 2013).

4.4.2 KEY WATER VALUES AND ISSUES FOR INDIGENOUS PEOPLE

Considerable primary data (in the form of comments collected from senior Indigenous group members and elders) were obtained by the Assessment – see companion technical report about Indigenous water values, rights and interests (Barber, 2013). It is difficult to summarise and condense this kind of primary data and still retain sufficient accuracy and specificity so the technical report is therefore a crucial supporting document for this catchment report. A small number of comments are replicated below to show the type of data obtained during the Assessment; they are complemented by a general analysis of key themes and issues emerging from the data.

Indigenous country: attachment, ownership and protection

> *Us Ewamian, we are all bird people. When people pass on, they become part of the country. When I look at the country I see my ancestors. That's why when I see irrigation, it is disturbing, because we also have that connection beneath the ground. As time goes on, that's where everything goes. It gets buried. It will affect all that, the country itself. The connection to the country is through the water, without that we don't have country. Without water - the rivers and waterholes, birthplaces and story places – we are nothing.*
>
> *Senior member of the Ewamian*

The interview data shows how Indigenous attachments to the country encompass a range of important facets and issues. These include:

- the significance of local histories and memories of the past in establishing local connections and authority
- the ongoing role of religious and spiritual beliefs (known as the Dreaming)
- the importance of hunting and fishing activity to Indigenous cultures
- the assumption of Indigenous ownership of land and water resources and the need for formal recognition of that ownership
- the existence of ongoing knowledge of group and language boundaries and identities
- intergenerational obligations to both ancestors and descendants to care for the country
- regional responsibilities to near neighbours and downstream groups to maintain the integrity of the country
- ongoing access issues to large tracts of traditional country subject to various forms of non-Indigenous tenure.

Protecting cultural heritage emerged as a key priority and two major cultural heritage issues were identified by research participants are (1) ongoing damage to known existing sites and (2) the lack of documented heritage knowledge about traditional lands which hampers Indigenous capacities to respond to current development proposals. Riverine and aquatic areas are known to be strongly correlated with cultural heritage sites and so the areas of development interest in the Gilbert catchment are likely to contain important cultural heritage (McIntyre-Tamwoy et al., 2013). Cultural heritage itself has a number of components – archaeological sites, places associated with traditional stories or traditional knowledge and places of historical or contemporary importance. The *Aboriginal Cultural Heritage Act 2003* protects heritage sites regardless of the tenure status of the land and protects areas whether or not they actually contain physical evidence of the past.

A second aspect of Indigenous care for traditional lands relates to conservation and land management. This includes formal activities through catchment management bodies and Indigenous ranger programs and a wide range of customary activities which may not be so visible. Indigenous rangers are shown to be a key focus for Indigenous employment and development aspirations, indicating the significance of conservation and land management activity.

Finally, principles of Indigenous ownership and care for country extend directly to non-Indigenous activities on Indigenous lands. Three principles identified and highlighted by the Assessment data are (i) consultation with the relevant owners, (ii) compliance with the terms of policies and agreements, and (iii) compensation for the access and use of resources. These principles have clear implications for native title, cultural heritage and environmental impact assessment, as well as for broader issues of sustainable development.

Water values, water planning and water development

> *Water is worth more than money. There are two good things about water, it can give life if it is respected, and take life if it is abused. A lot of people are careless, not thinking, drowning in the floods. Water gives life to everything, plants, bird life, animals, humans. It is the main resource for everything really.*
>
> *Senior member of the Kurtijar*

In relation to water values and issues, the Assessment clearly demonstrated the overall importance of water through clear statements of significance by research participants across the Gilbert catchment. This importance, combined with recent observations of seasonal and environmental change, provides the context for Indigenous attitudes to both water planning and to development impacts. The Gulf water resource planning process included the Gilbert catchment, but had a very limited Indigenous consultation process associated with it (Ayre and MacKenzie, 2012; MacKenzie, 2008). One result of this is that Indigenous knowledge of water planning in the area is relatively limited. However, principles for future consultation have been outlined (Ayre and MacKenzie, 2012; MacKenzie, 2008).

> *The Gilbert has so much water come down, in the wet season. I don't mind the catch and storage of the runoff, but it's not viable, not to weir and dam. There is too much sand in the wet season. It will cost so much money to dredge. Have a look at Kidston Dam in Copperfield. And then the water quality too, that is a problem.*
>
> *Senior member of the Ewamian*

Indigenous concerns about water development noted during the Assessment included the impacts of water extraction, dam scale and location, dam failure, inundation, effects on animals, the consequences of intensified land use (weeds, erosion, water quality, chemicals, salinity, etc.) and cumulative impacts from other industries, particularly mining. Indigenous research participants also noted particular Indigenous vulnerabilities to negative impacts, largely related to their position as long-term custodians and their marginalised socio-economic and educational status. This affected Indigenous assessments of the relative risks and benefits associated with development proposals.

4.4.3 INDIGENOUS DEVELOPMENT PLANS AND ASPIRATIONS

> *We need a ranger setup in the area. We want to protect where the farms are going to be – ferals, brumbies, protecting and shooting. Croydon people need to get priority, because they are living on the country. We've applied for a grant, $5 million over 5 years, to manage and develop the reserve lands, workshop and business ideas. This includes rangers – we spoke to Gulf Savannah about that – who would cover wider Tagalaka country.*
>
> *Senior member of the Tagalaka*

Indigenous people have a range of development plans and aspirations and these are informed by two primary interrelated goals:

- greater ownership of and/or management control over traditional lands
- the sustainable retention and/or resettlement of Indigenous people in the region.

The Assessment indicates that these underlying goals are shaped by a range of issues. Those affecting the sustainable and significant resettlement of the upper Gilbert catchment include: the social, economic and institutional investment in existing residential locations; land ownership and local recognition in the catchments; employment and training opportunities; intergenerational skill sharing and relocation adjustment issues for younger people; and access to social and health services in the catchment. There are clear relationships between rural land ownership, retention and/or resettlement aspirations and business development possibilities. Land ownership in towns can be useful but it is rural land ownership that appears to be particularly important in creating desirable conditions for resettlement. This is partly because of the business opportunities identified, which include pastoralism, agriculture, forestry (sandalwood and biodiesel), ecotourism and research. Problems with land ownership include skill and financial shortages and constraints on leases.

Indigenous employment and training is a crucial issue for Indigenous businesses and Indigenous roles in the wider regional economy. Concerns were expressed during the Assessment about whether promised jobs will materialise, about adequate certification for young people, and about the need for wider training in career development and money management. Work in natural and cultural resource management (NCRM) is particularly valued and Indigenous ranger programs play a crucial incentivising role, as well as a significant role in regional coordination. The Normanton rangers are well established, the new Ewamian rangers are maturing but currently based outside the Gilbert catchment and the Tagalaka people aspire to have a ranger program based at Croydon. The creation and/or sustainable funding of such programs were found to be a high priority for all the research participants in the catchment.

Wider natural and cultural resource development principles and aspirations were formally articulated at the recent Kakadu development forum (NAILSMA, 2013) and many of these are applicable to the Gilbert catchment. The forum emphasised:

- local Traditional Owners as the primary decision makers
- the significance of partnerships and shared benefit agreements
- value-adding and diversification for greater long-term sustainability.

Water planning and catchment management

In terms of water planning, a recent study documented attitudes in coastal communities around the Gulf of Carpentaria to specific tradeable water allocations reserved for Indigenous people (CLCAC, 2012). In general, Indigenous-specific tradeable water allocations are favoured. Some data on preferences for particular kinds of water development were gathered as part of this study, and the general trend from most to least favourable was:

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

Developments which provide amenity and recreational opportunities in locations which are geographically accessible to Indigenous people are also favoured.

In terms of Indigenous catchment management, the NGISG has a range of existing visions and plans requiring further resourcing and implementation (NGISG, 2010). Any significant development in the Gilbert catchment will place further management demands on the organisation, suggesting additional assistance may be necessary.

In summary, the Assessment demonstrates that formalising and refining Indigenous water values and water planning issues in the Gilbert catchment may require:

- formal planning discussions with Indigenous groups in the area
- recognition of Indigenous ownership through ongoing consultation, compliance and compensation
- further specification of cultural heritage impacts and current and potential future native title rights
- refinement of Indigenous rights, roles and responsibilities in water planning and resourcing of Indigenous involvement in water planning
- articulating water planning with irrigation development and catchment management processes
- addressing continuing Indigenous water research needs and information priorities.

Group- and community-based planning, resettlement and natural and cultural resource management

Improved catchment management and water planning processes generate better regional connectivity and coordination, but this relies on developing local capacity. Table 4.2 summarised the existing local capacity (comprised of Indigenous group tenure, residence, NCRM ability and catchment management arrangements). The diversity highlights the need for locally specific, group and community-based planning and prioritisation processes to take place in a regionally coordinated way. Strengthening local capacity will provide firm foundations for improved catchment-scale capacity. Models for further developing Indigenous capacity can be understood to lie along a similar spectrum to the one noted earlier about engagement – such models can range from Indigenous consultation to Indigenous participation through to full Indigenous control. Resettlement emerged as a significant aspiration for local Indigenous people in the Gilbert catchment. Re-settlers drawn from local Indigenous groups have additional cultural and affective motivations to stay in the area. This suggests that long-term residence may be created provided short-term adjustment issues can be managed and sustainable employment and residential conditions can be generated. However, successful retention and/or resettlement relies on understanding specific local conditions. This makes it crucial to undertake group consultation and community-based planning and prioritisation initiatives at a local scale.

The Assessment identified some specific initiatives which would simultaneously foster local capacity and regional coordination, enhancing the management of country and sustainable Indigenous livelihoods. In relation to land ownership and NCRM in key locations in the Gilbert catchment, these include:

- the establishment of an Indigenous ranger program for the Tagalaka people
- support for office and ecotourism infrastructure in the catchment for Ewamian people
- additional resources for appropriate entities (e.g. NGISG, the Normanton Rangers, CLCAC, NQLC, NAILSMA) to coordinate further Indigenous capacity building in local group prioritisation, catchment management and water planning.

Upgraded local Indigenous NCRM capacity would assist wider catchment management in a range of ways. Firstly, it would provide a firm foundation for formal catchment management processes. Secondly, it would enhance Indigenous capacity to engage with water planning processes. Thirdly, as is demonstrated by the Normanton rangers operating successfully on wider pastoral lands, ranger programs benefit regional pastoral and agricultural land management.

Water and irrigation development

With respect to water and irrigation development, key aspirations include:

- further formal group consultations about options, impacts and preferences
- appropriate cultural heritage surveys of likely areas of impact
- Indigenous employment and other benefits during construction
- the need for ongoing monitoring of impacts
- support for Indigenous roles in development projects that connect water development with both water planning and wider catchment management.

Indigenous business development

Current proposals for water-dependent businesses on Indigenous-owned lands (such as the Delta Downs and Tallaroo Stations) in the Gilbert catchment include:

- value-adding to pastoral operations
- agricultural cropping activity
- high value forestry (e.g. sandalwood) and biofuel production
- art and craft production
- ecotourism and cultural tourism
- income-generating environmental research partnerships.

Strong aspirations to develop such businesses are widespread, but identifying best options requires case-by-case planning and analysis of the specific situation for Indigenous groups. One potential challenge is diversification and its relationship to both skill base and governance. Undertaking multiple activities provides insurance against the failure of any single activity but also increases management complexity and the need for skills in multiple businesses. Balancing prioritisation and diversification is important in managing additional risks. Similarly, the collective management common to Indigenous-owned land and businesses can widen available skill sets but also increase the chance of disagreements over strategic priorities. All groups have multiple management roles but, based on geography, residence, assets, governance and/or skills, some may more easily be able to sustain multiple business activities, while others may be better off focusing on a single activity.

In terms of wider business partnerships, a range of options may be useful in improving the opportunities for business to understand and invest in Indigenous people and Indigenous lands in the Gilbert catchment. These include:

- the production of one or more regional prospectuses to define Indigenous assets and opportunities and to communicate with investors
- further information and training for Indigenous people about the opportunities and constraints of partnerships with private industry, including discussion of the effect of changes in Indigenous resource rights (acquisition of land, granting of native title rights, securing of water rights and allocations, etc.)
- wider regional non-Indigenous community training regarding partnerships with Indigenous people, including models for shared benefit agreements and partnership arrangements, employment and training opportunities, etc.
- creating incentives for Indigenous involvement, including relocation and resettlement allowances, pathways from training to jobs, employer incentives to hire and retain Indigenous staff, etc.
- training for younger Indigenous people about career planning, personal budgeting and money management as well as formal job skills.

A full analysis of the potential for Indigenous business development, partnerships and associated investment is well beyond the scope of this Assessment but the above points indicate some potential options and promising directions for further action in this area.

Indigenous water values, rights and interests and sustainable development

Studies of Indigenous water values, rights and interests have been completed elsewhere in the country but existing information from the Gilbert catchment is extremely limited. The Assessment addresses this issue, indicating the high value placed by Indigenous people on natural and cultural assets in general, and on water assets in particular. Indigenous people wish to protect the long-term health of their traditional lands and the resources, cultural heritage and ecosystems they contain. There are a range of formal rights and interests which aid this aspiration and need to be accounted for by decision makers. Indigenous people also have consistent views about involvement and rights in water planning and about the specifics of water development. These views reflect ongoing obligations to ancestors and descendants and to near and downstream neighbours, as well as strong views about balancing short-term opportunity with long-term sustainability.

The Assessment also addresses the poor level of knowledge regarding the Indigenous interests in sustainable development. Evidence from both regional northern forums and from local senior leaders in the Gilbert catchment indicates that Indigenous people have a strong desire to participate in a diverse range of sustainable economic activity. Private interests may drive water and agricultural development in the Gilbert catchment but Indigenous support for and contributions to that development would benefit greatly from additional government endorsement, enablement and strategic investment in complementary and related activities. Of particular importance are local group or community planning processes undertaken in a regionally coordinated way, and the resourcing of key priorities identified in such processes. Such support would allow Indigenous people to act as substantial enablers of appropriate sustainable development and implement a range of existing plans and aspirations regarding resettlement and retention, business development and employment, land ownership, and natural and cultural resource management.

4.5 Broader social environmental values

The perceptions and values that the broader community have about the environment and water resource development in the Gilbert catchment tend toward development that is sustainable and balances the economic needs of the community with the need to ensure the benefits of a healthy environment continue to flow to communities. Historically, management of water resources and river ecosystems in northern Australia was focused predominantly on resource development (Jackson et al., 2008). In recent decades the community values associated with water resource development have changed and diversified. Jackson et al. (2008) demonstrate that unregulated healthy river systems make an important contribution to human wellbeing and cultural identity. People have strong attachments to tropical rivers and wetlands and ecological and aesthetic values compete with development-focused values. Increasingly, local residents, recreational and commercial fishers, tourists and conservationists hold considerable amenity and lifestyle values for tropical rivers (Stoeckl et al., 2012), and communities are prepared to forgo direct private economic benefit to see healthy river systems that are managed for conservation (Zander et al., 2010; Zander and Straton, 2010).

4.6 Catchment profile

4.6.1 CATCHMENT DEMOGRAPHICS

The 2011 demographic profile of the shires within the Gilbert catchment is given in Table 4.3. Similar to many other non-mining regions of rural Australia, population is in decline with substantial decreases across both shires, from 39.3% (Etheridge shire) to 57.6% (Carpentaria shire) over the decade to 2011. The median age of the population is between 33 and 40 years old, but the median age is increasing in both shires. Median household income in 2011 was $724 and $997 per household per week, for Etheridge and Carpentaria shires respectively. Unemployment in the Etheridge shire is low relative to Queensland. The proportion of Indigenous people in Etheridge is comparable to Queensland, but the proportion in the Carpentaria shire is high relative to Queensland.

Table 4.3 Major demographic indicators for the shires in the Gilbert catchment in 2011

INDICATOR	UNIT	ETHERIDGE	CARPENTARIA	QUEENSLAND
Total population in 2011		894	2,054	4,330,000
Total population in 2001		1,474	4,844	3,370,000
Percentage change in population, from 2001 to 2011	%	–39.3%	–57.6%	–28.5%
Indigenous population, as percentage of total	%	3.5%	36.8%	3.6%
Median age	y	43	37	36
Change in median age, from 2006 to 2011	y	4.0	2.9	0.6
Unemployment rate, percentage	%	3.6%	5.7%	6.1%
Median weekly household income	$	$724	$997	$1235

Source: ABS (2011).

The Gilbert catchment is very remote, with a remoteness index of between 9 and 10. The Accessibility and/or Remoteness Index of Australia (ARIA) is an index with values ranging from 0 (high accessibility) to 15 (high remoteness) that classifies all localities in Australia. It is based on road distance measurements from all populated localities in Australia to the nearest service centres. As a reference, major Australian cities score around 0 to 0.2 while larger regional Australian towns score between 2.4 and 5.9 (Larson and Alexandridis, 2009).

Table 4.4 provides an overview of key features of the Gilbert catchment.

Table 4.4 Overview of catchment

AREA(km^2)	MAJOR TRIBUTARIES AND STREAMS	SHIRES	MAIN TOWNS	NATIONAL PARKS
46,400	Etheridge, Einasleigh, Smithburne, Gilbert	Etheridge, Carpentaria	Mount Surprise, Einasleigh, Georgetown, Forsayth	Undara Volcanic, Forty Mile Scrub, Blackbraes

Community infrastructure

Community facilities (e.g. hospitals, schools, ambulance, aged care, fire and rescue, postal services) play an important role in communities, and the closure of facilities can have substantial impact on regional and remote communities. The extent of community facilities can also affect the willingness of individuals to move to a region. On the other hand, population increases can trigger the provision of community facilities if current infrastructure is already at capacity or does not currently exist. An examination of schools and hospitals reveals that they are small in enrolment and admission numbers, respectively, and it would appear that small changes in population growth would be absorbed by existing facilities.

The prospect of increased population arising from irrigation development requires anticipation of the demand for community infrastructure, water, sewerage, transport, communications and energy. Infrastructure planners will need to be cognisant of future needs.

Schools, hospitals and housing

The Gilbert catchment has primary schools in Forsayth, Georgetown and Mount Surprise. Table 4.5 shows the size of these schools from 2009 to 2013. These schools have enrolments smaller than the current Queensland average of 423 students per school and are well below the size of recently opened schools. These figures suggest that, in the event of development-related population growth, new schools would not need to be opened on the basis that the current schools in the catchment are under the size associated with new openings. It appears that the ongoing sustainability of these schools may be enhanced by an increase in population.

Table 4.5 State school enrolments by school from 2009 to 2013 (preliminary)

SCHOOL	ANNUAL SCHOOL ENROLMENTS (BY YEAR)				
	2009	2010	2011	2012	2013
Forsayth State School	9	10	8	6	9
Georgetown State School	41	41	36	39	46
Mount Surprise State School	8	12	9	11	14

Source: Queensland Government (2013).

The catchment has medical clinics in Georgetown and Forsayth. Georgetown clinic had fewer than ten same-day admissions from 2009 to 2010 and fewer than ten overnight admissions. Data were not found for Forsayth (National Health Performance Authority, 2013).

Recent census data shows that the current pool of housing could absorb more population with approximately 20% of private dwellings unoccupied (Table 4.6). It appears unlikely that new schools and hospitals etc. would need to be constructed to support population increase from irrigation, given the construction thresholds shown in Table 4.7 and the current size of these facilities. These have been set by Economic Development Queensland (EDQ), which sets standards for the planning and provision of community facilities in urban development areas in Queensland (as presented in ULDA, 2012). However, the hospital (currently a clinic), police station, and school (currently with 47 pupils) would need capacity upgrades. EDQ (ULDA, 2012) states that these standards are indicative only and are generally taken from the *South East Queensland Regional Plan* (Department of Infrastructure and Planning, 2009). They do show, however, that new infrastructure provision does require substantial population triggers.

Table 4.6 Number and percentage of unoccupied dwellings and population for selected Statistical Local Areas

STATISTICAL LOCAL AREA	POPULATION	UNOCCUPIED DWELLINGS	PERCENTAGE OF DWELLINGS THAT ARE PRIVATE
Etheridge	894	72	17.3%

Source: ABS (2013).

Table 4.7 Population triggers for community infrastructure

FACILITY OR SERVICE	POPULATION TRIGGER FOR FACILITY
Primary schools (state)	1 per 3000 dwellings
Secondary schools (state)	1 per 8000 dwellings
Hospital (public)	Likely to serve a catchment of over 100,000 people

Source: ULDA (2012).

4.6.2 INDUSTRY

Economic activity in the Gilbert catchment and surrounds is dominated by mining and agriculture, but with important contributions from tourism and commercial fishing in the Gulf of Carpentaria. The value of these industries is summarised in Table 4.8 and further explained below.

Table 4.8 Value of major economic activity in the Gilbert catchment
For various financial years.

ECONOMIC ACTIVITY	GROSS VALUE ($ million)	SCALE	FINANCIAL YEAR	SOURCE
Hay production	$1.1	Gilbert catchment shires	2010–11	ABS (2012b)
Gulf of Carpentaria fisheries	$22.5	Gulf of Carpentaria	2011–12	Queensland Department of Agriculture, Fisheries and Forestry (2013)
Northern Prawn Fishery	$94.9	Gulf of Carpentaria and southern Timor Sea	2010–11	Skirtun et al. (2012)
Livestock (cattle)	$233.3	Gilbert catchment shires	2010–11	ABS (2012b)
Tourism	$2800	Tropical North Queensland Tourism Region	2011–12	Tourism Research Australia (2012)
Mining	$5400	North West Queensland Mineral Province	2008–09	Queensland Department of Natural Resources and Mines (2013)

Agriculture

Agriculture, broadly defined as the production of crops and the raising of livestock, is one of the key economic activities in the Gilbert catchment. The gross value of the major agricultural activities for the shires within the Gilbert catchment (Etheridge and Carpentaria) is summarised in Table 4.9. Beef production was worth a total of $233.3 million in the 2010–11 financial year across the Gilbert catchment if Carpentaria shire is included. The next largest value agricultural activity was hay production, valued at $1.1 million in the 2010–11 financial year. The other agricultural activity of value identified by the ABS (2012b) was horticulture (mangoes), worth about $0.5 million in the 2010–11 financial year.

Table 4.9 Major agricultural activities and their annual value for the shires in the Gilbert catchment, in the 2010–11 financial year

AGRICULTURAL ACTIVITY	ANNUAL VALUE ($ million)		
	Etheridge	Carpentaria	Total
Livestock (cattle)	$117.1	$116.2	$233.3
Hay production	$0.4	$0.7	$1.1
Horticulture (mangoes)	$0.5	$0.0	$0.5

Source: ABS (2012b).

Cattle grazing has been important to the Gilbert catchment since settlement in the 1800s.

A summary of cattle movements from properties within the Flinders and Gilbert catchments to other enterprises is contained in Table 4.10 for 2007 to 2011. The data do not distinguish between property type (breeding, backgrounding, finishing farm, feedlot). Most movements are between properties. A small number of cattle were exported live, either via Darwin or Townsville. Of the 350,797 cattle that went direct to abattoirs, 196,000 went to Townsville, 20,000 went to Mackay, 48,000 went to Rockhampton, 75,000 went to South-East Queensland, and 9,800 went to New South Wales.

Table 4.10 Cattle movements in the Flinders and Gilbert catchments, total from 2007 to 2011

SOURCE	DESTINATION					
	Abattoir	Export depot	Port	Property	Saleyard	European Union – accredited saleyard
Abattoir		1,418		2,004	282	499
Export depot	112	1,098	68,551	5,205	46	29
Property	350,797	280,636		2,712,897	109,644	342,903
Saleyard	910	99,317		56,405		40
European Union – accredited saleyard	4,119	218		16,018		

Live cattle exports from Australia grew strongly in the mid-1990s and have since then averaged around 200,000 head each year (Figure 4.11), with supply directly mainly to markets in South-East Asia and the Middle East. Greater diversity of markets would assist the industry, and this would be facilitated by the production of higher quality beef for the domestic market (Gleeson et al., 2012). As discussed elsewhere in the Assessment, irrigation may assist in meeting this goal.

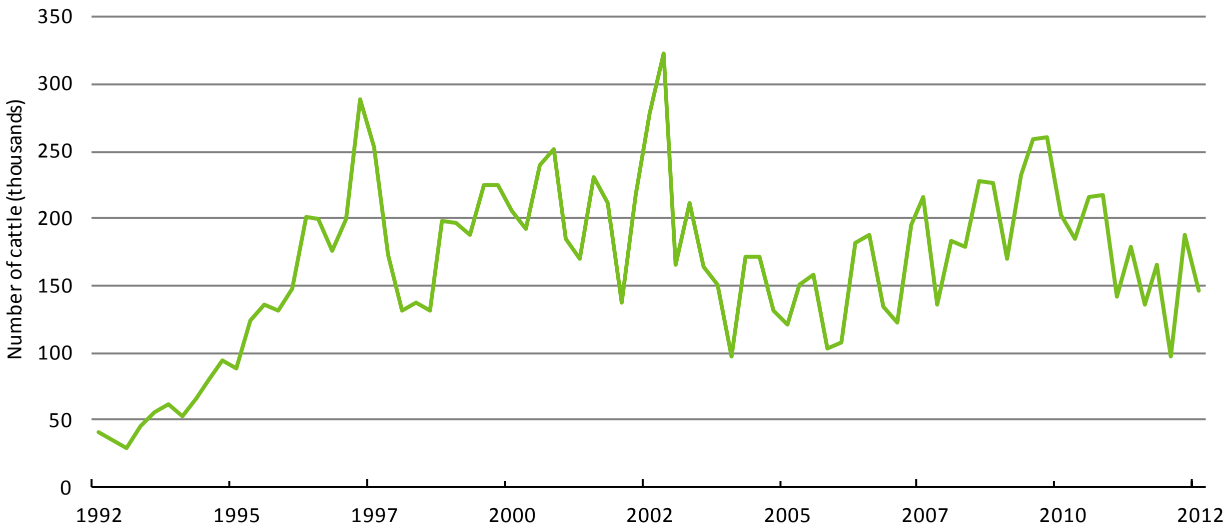

Figure 4.11 Total live cattle export from Australia, September 1992 to September 2012
Source: ABS (2012a).

Commercial fisheries

Two main recognised fisheries exist in the Gulf of Carpentaria, one of which has a number of sub-fisheries:

- Northern Prawn Fishery – the most important – valued at $94.9 million in the 2010–11 financial year, with a total of 54 vessels licensed to catch prawns (Skirtun et al., 2012)
- Gulf of Carpentaria Fishery, valued at approximately $22.5 million in 2011 (Queensland Department of Agriculture, Fisheries and Forestry, 2013) which has a total of 101 licence holders (Skirtun et al., 2012). This fishery has three sub-fisheries:
  - Gulf of Carpentaria Line Fishery (22 licences and a gross value of $1.5 million in 2011) (Queensland Department of Agriculture, Fisheries and Forestry, 2013)
  - Gulf of Carpentaria Inshore Fin Fish Fishery (76 licences and a gross value of $17 million in 2011) (Queensland Department of Agriculture, Fisheries and Forestry, 2013)
  - Gulf of Carpentaria Developmental Fin Fish Trawl Fishery (3 licences and gross value of $4 million in 2011) (Queensland Department of Agriculture, Fisheries and Forestry, 2013).

The Gulf of Carpentaria and the Northern Prawn fisheries are all managed under various State and Commonwealth arrangements ensuring their take is sustainable. The levels of catch are therefore relatively consistent from the early 2000s to the present (Skirtun et al., 2012; Queensland Department of Agriculture, Fisheries and Forestry, 2013).

The nearest port in the Gilbert catchment that services the Gulf of Carpentaria fisheries is Karumba, but the 2011 census does not identify the fishing industry as a significant employer in the town (ABS, 2011).

As discussed elsewhere in the Assessment, the development of irrigated agriculture, by affecting streamflow regimes, may impact on Gulf fisheries.

Tourism

Tourism is also an important activity in the Gilbert catchment and more broadly in the Tropical North Queensland Tourism Region of western Queensland, with approximately 4.6 million visitors to the Tropical North Queensland Tourism Region in 2011–12 financial year, spending approximately $2.8 billion (Tourism Research Australia, 2012). The Tropical North Queensland is the finest scale geography for which reliable tourism data is available and includes the popular tourist destination of Cairns; tourists visiting the Gilbert catchment are expected to comprise a small proportion of this total. Major attractions include the Undara Volcanic, Forty Mile Scrub and Blackbraes national parks and Blackbraes Resources Reserve.

Fishing and the general enjoyment of surface water are major attractors for tourism in the region, with 90% of tourists to the Gulf region citing fishing as the main reason for their visit (Abel et al., 2009). The development of water resources in the catchment may both positively and negatively impact on this, by altering natural flow regimes and, hence, fish stocks, or by providing new water bodies, perhaps artificially stocked with fish.

Mining

There are numerous mining and mineral exploration and development leases current in the Gilbert catchment (Figure 4.12) and there are a small number of exploration licences for petroleum, coal and geothermal energy (Figure 4.13). At a broader scale, the North West Queensland Mineral Province, centred on Mount Isa and Cloncurry, is an area receiving attention from the Queensland Government due to the relative level of under-exploration and the potential closure of a number of existing mines from 2015 to 2020 (Queensland Department of Natural Resources and Mines, 2013). The value of mine production in North West Queensland Mineral Province was $5.4 billion in the 2008–09 financial year, the most recently available data (Queensland Department of Natural Resources and Mines, 2013).

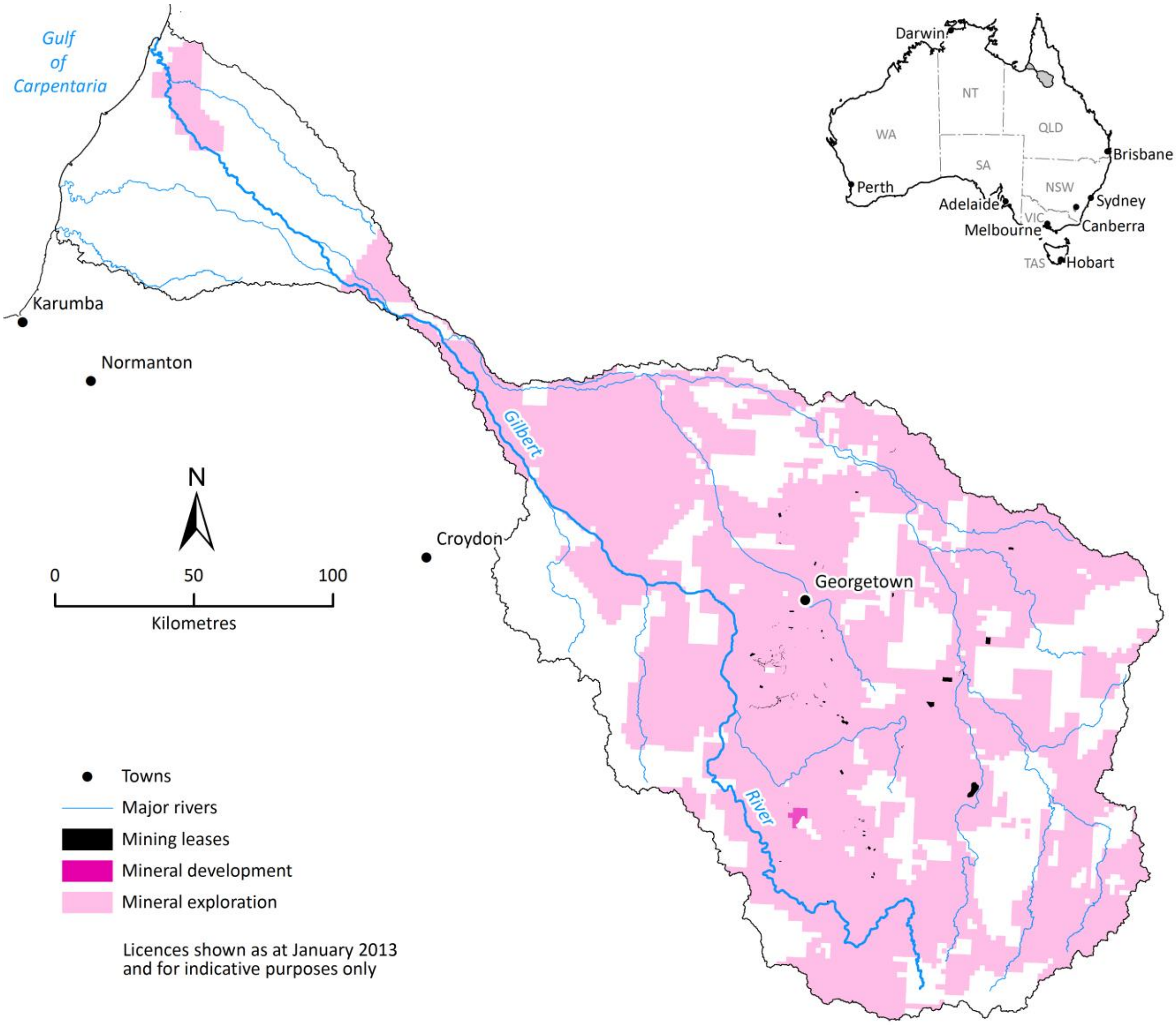

Figure 4.12 Current mining and mineral exploration and development leases in the Gilbert catchment
Data source: Queensland Department of Natural Resources and Mines.

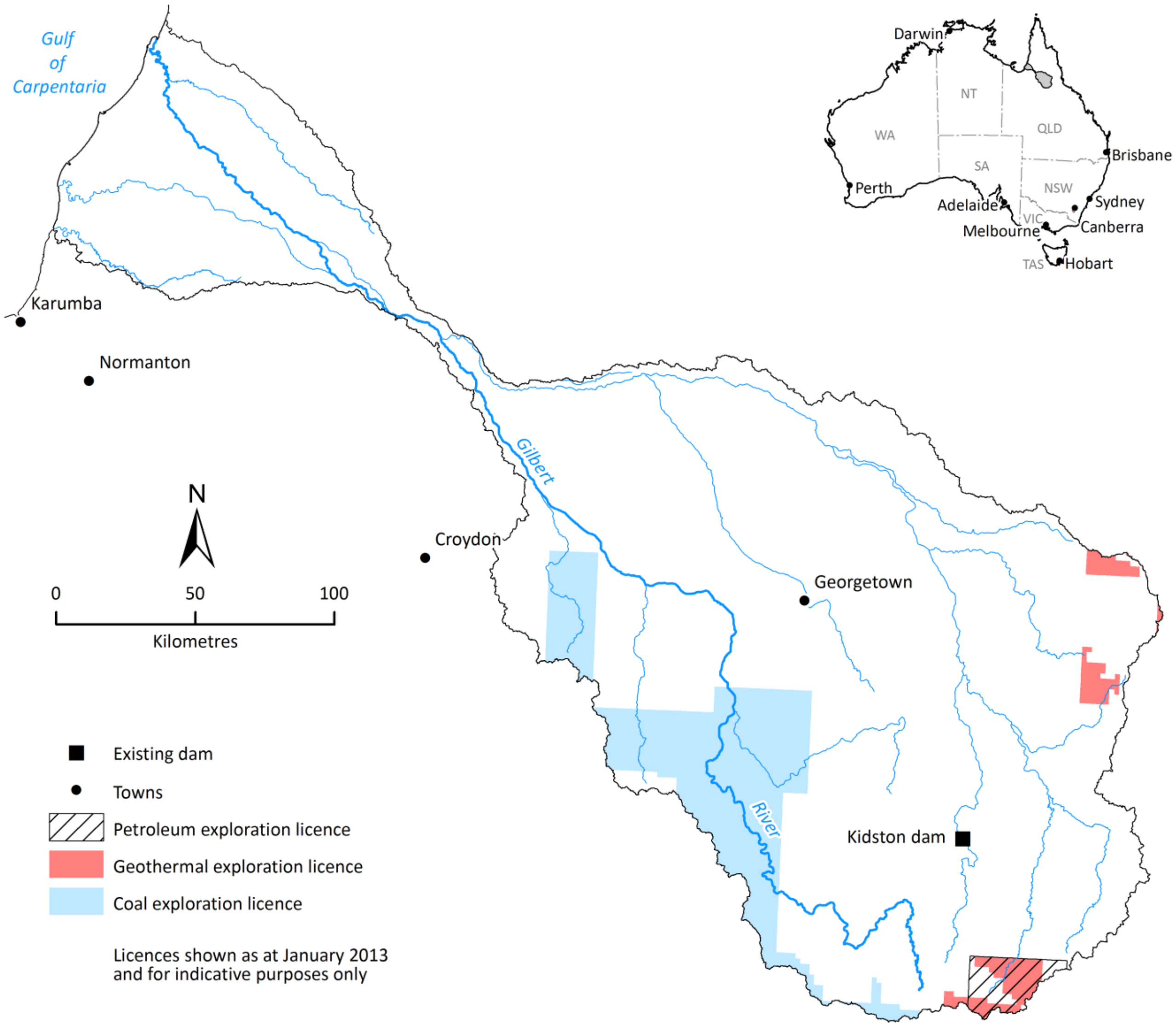

Figure 4.13 Petroleum, geothermal and coal exploration licences in the Gilbert catchment
Data source: Queensland Department of Natural Resources and Mines.

4.6.3 SERVICES AND UTILITIES

The Gilbert catchment has only one large dam (Table 4.11). A number of potential dam sites have been identified in the Gilbert catchment. These are discussed in Section 5.2.

Existing large water storages in the Gilbert catchment

Kidston Dam

Kidston Dam, officially known as the Copperfield River Gorge Dam, (Figure 4.13) is the only large dam in the Gilbert catchment. The dam is a roller compacted concrete (RCC) structure, the first constructed in Australia. It is 40 m in height above lowest foundation level with a 100-m-wide central overflow spillway and with a roller bucket energy dissipater (Figure 4.14). The dam has a river outlet with a 600-mm-diameter fixed cone regulating valve and two 500-mm-diameter outlet conduits, one of which services the water supply pipeline.

The existing Kidston Dam was constructed in 1984 to provide a water supply to the Kidston Gold Mine (Table 4.11). Under the terms of the lease of land covering the dam and storage area, the lease to the company ended when mining activity ceased in 2005. The dam is now owned by the state of Queensland and is managed by the Department of Energy and Water Supply. Since the closure of the mine, the only use of the dam has been to provide, via the original mine water supply pipeline, stock and domestic water supply to a number of properties downstream of the dam, a number of houses in the Kidston township and a small outback resort. In October each year approximately 3000 ML of water is released from the dam to top up the Einasleigh River downstream for use by local farmers and the Etheridge Shire Council. A proposal to raise the dam wall by 2 m is examined in Chapter 5.

Table 4.11 Summary of constructed dam in the Gilbert catchment. See Petheram et al. (2013) for more detail

NAME OF DAM	NEAREST TOWN	TYPE OF DAM	ORIGINAL PURPOSE	YEAR CONSTRUCTED	HEIGHT ABOVE BED LEVEL (m)	STORAGE CAPACITY AT FULL SUPPLY LEVEL (GL)	ANNUAL WATER YIELD* (GL)*
Kidston Dam (officially known as Copperfield River Gorge Dam)	Kidston	Concrete gravity – roller compacted concrete	Mining	1984	38	20.6	15

* Yield at 85% annual time reliability (does not take into account transmission losses).

The dam was designed to be constructed to a very tight time frame and to provide water supply to a mine whose operational life was expected to be only 15 to 20 years. Given the short mine life, the original designer adopted a low-cost approach where possible so that for some items, such as the dam outlet works, the provisions made were not of the standard normally adopted for a long-life asset. The intake provisions for the outlet works on the upstream face of the dam, for example, cannot readily be maintained or upgraded so serviceability issues are likely to impact upon the dam’s performance from time to time. Importantly however, SunWater (2005) concluded that the dam foundations and the main dam wall are of an adequate standard to ensure the dam’s stability over the long-term and are suitable to support raising the dam by 2 m as proposed.

Figure 4.14 Downstream face of Kidston Dam (officially known as Copperfield River Gorge Dam) on the Copperfield River
Photo: CSIRO.

Transport

Roads

Heavy road transport in the Gilbert catchment is usually via one of three multi-combination vehicle classifications (DTMR, 2013):

- B-Double (a combination consisting of a prime mover towing two semitrailers, with one semitrailer supported at the front by, and connected to, the other semitrailer)
- Type 1 road train (a rigid truck with one trailer with combination length of up to 31.5 m or a prime mover with two trailers with combination length of up to 36.5 m)
- Type 2 road train (a rigid truck with two trailers with combination length of up to 47.5 m or a prime mover with three or four trailers with combination length of up to 53.5 m).

Typical combinations of these vehicles are shown in Figure 4.15. The B-Triple is a B-Double with an additional 40-foot trailer. It is not as widely used for cattle transport compared to the other combinations in Figure 4.15. The freight vehicle access maps for Queensland for each combination are shown in Figure 4.16 and Figure 4.17. Road transport costs per kilometre vary with road grade and vehicle configuration. For unsealed roads and some stocking routes, average speed is 50 to 60 km/hour (at best) and costs per kilometre are higher. These road costs are shown Table 4.13 and should be doubled to accommodate an empty return trip. There is very limited backloading in the Gilbert catchment as cattle are usually moved closer to the coast, and farm inputs require a different type of a trailer. Improving the cost-effectiveness of road transport could be an important enabler of regional development. However, the cost of upgrading roads is substantial, as shown in Table 4.12.

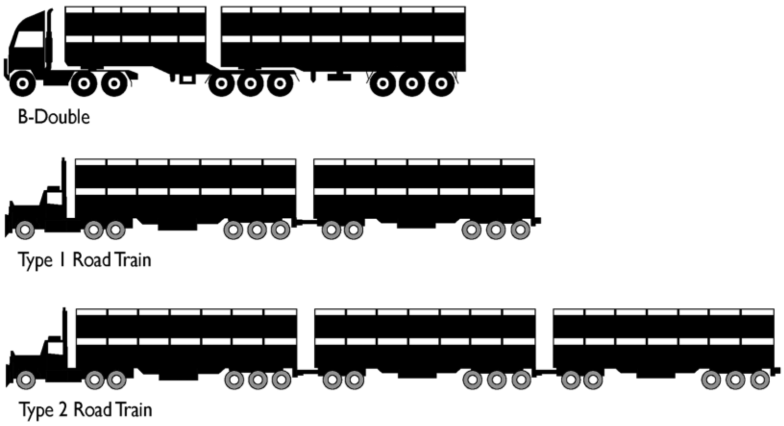

Figure 4.15 Multi-combination vehicles

Table 4.12 Estimated costs for road upgrades

ROAD TYPE	COST ($ per km)
Upgrading unsealed road to gravel road, or to sealed road without bridges	$300,000
Upgrading unsealed road to sealed road in hilly area involving bridges	$600,000
New high-grade main road	$20,000,000 to $50,000,000

Source: Albanese (2013), Cummings (2008), Wallace (2010).

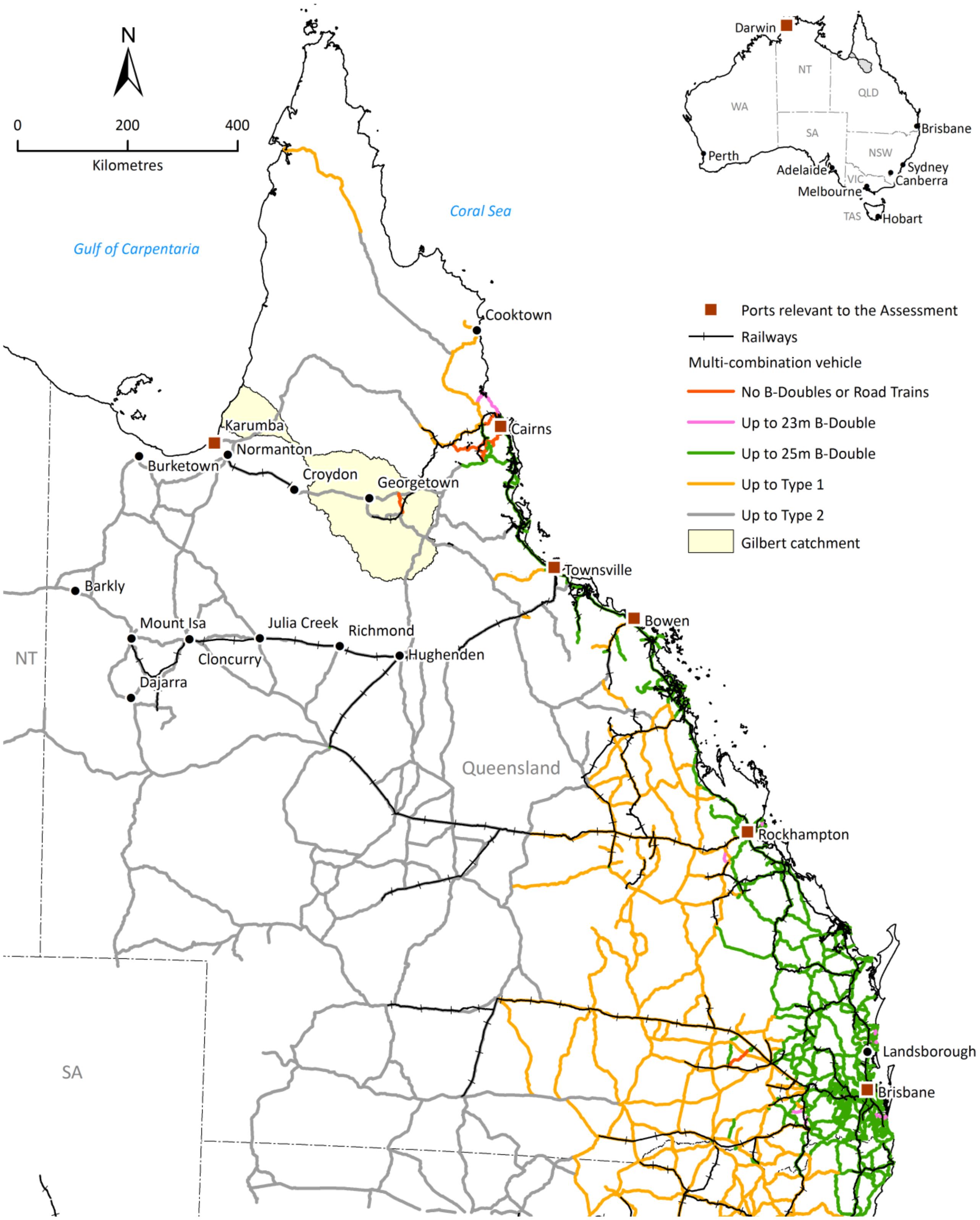

Figure 4.16 Queensland infrastructure map showing accessibility of heavy vehicles, ports and railways in Queensland and the Gilbert catchment

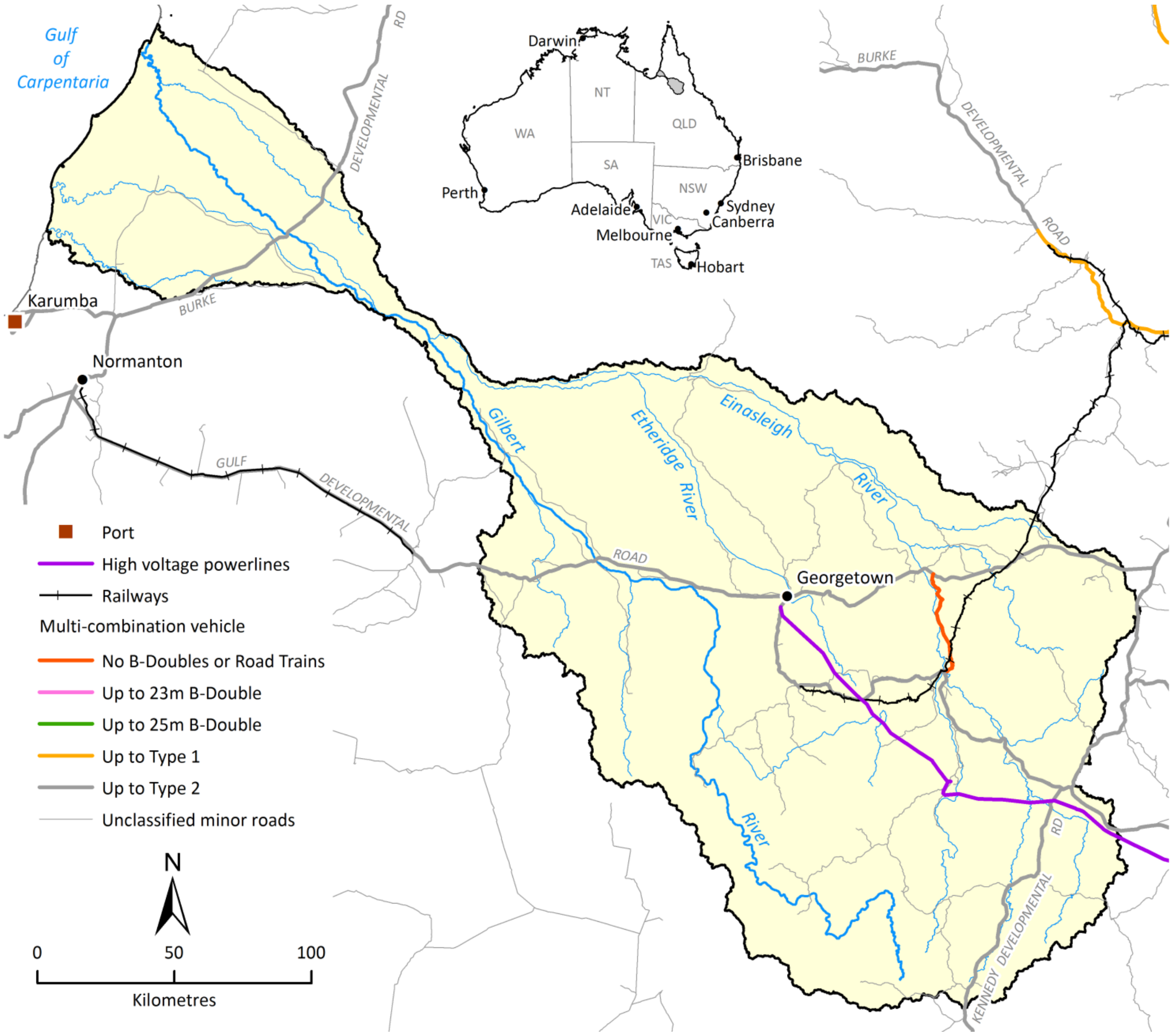

Figure 4.17 Gilbert catchment infrastructure map showing accessibility of heavy vehicles, ports, railways and high voltage powerlines

Table 4.13 Road transport costs per vehicle

These costs need to be doubled to accommodate an empty return trip.

TYPE OF VEHICLE	COST ($/km)	
	Sealed roads	Unsealed roads
B-Double	$2.35	$3.13
Type 1	$2.89	$3.74
Type 2	$3.43	$4.36

Potential irrigation areas in the Gilbert catchment rely on the Gulf Development Road for transport. Type 2 road trains travelling eastbound need to break down into Type 1 vehicles before ascending the mountain range into Mareeba. The trip between Mareeba and Cairns is limited to a B-Double. Type 2 vehicles can travel to the Port of Karumba.

Data from the Queensland Department of Transport and Main Roads (DTMR) were used to analyse historical closures of the main roads servicing the Gilbert catchment. The data recorded the days closed for each event, but the start and finish date were not always recorded, so a full breakdown by month was difficult to provide. For events with recorded start and finish dates, the closures (due to rain or flooding) mostly occurred from January to March. Table 4.14 shows the summary by year. The Gulf Development Road, which services the Gilbert irrigated areas, had the largest number of days closed compared to the other highways for each of the three years. In 2011 it was closed for most of the time through to April.

Table 4.14 Days that each major road servicing the Flinders and Gilbert catchments was closed
Major centres are shown on Figure 4.16.

MAJOR ROAD	SECTION	DAYS CLOSED, IN GIVEN YEAR		
		2009	2010	2011
Flinders	Townsville to Charters Towers	4	0	0
	Charters Towers to Hughenden	11	1	5
	Hughenden to Richmond	3	0	5
	Richmond to Julia Creek	16	1	0
	Julia Creek to Cloncurry	30	6	4
Gulf Development Road	Croydon to Georgetown	10	0	13
	Georgetown to Mt Garnett	2	6	2
	Normanton to Croydon	47	24	74
Barkly	Mount Isa to Camooweal	3	0	0.3
	Camooweal to Border	21	0	3
Landsborough	Winton to Kymuna	11	1	1
	Kymuna to Cloncurry	37	7	8
	Barceldine to Longreach	2	62	2
	Longreach to Winton	4	2	0

Rail

The only rail service in the Gilbert catchment is the Savannahlander tourist train, which runs to Einasleigh.

Ports

The nearest ports for the Gilbert catchment are Karumba and Townsville with the latter generally providing the greatest ease of access (Figure 4.16 and Figure 4.17). In the 2010–11 financial year, the Port of Townsville imported 5.8 million tonnes of commodities and exported 4.7 million tonnes. The exports included 51,076 head of cattle and 958,000 tonnes of sugar. The Port of Townsville has 11 berths with an average utilisation of 50.5%.

The Port of Karumba has been in operation since the late 1800s and in 1996 the entrance channel was developed to improve access. The major commodity passing through the port is zinc which has been exported through the port since 1999. Zinc slurry is piped about 300 km from where it is mined and loaded onto a transfer vessel for relay to deep water ships located in the Gulf of Carpentaria. Other products passing through the port include lead, general cargo, fuel and live cattle export but these combined make up only about 6% of total throughput (DTMR, 2012). The total volume of throughput at Karumba was just less than one million tonnes in the 2011–12 financial year, and has remained at this level since at least the 2007–08 financial year, except for a dip to 650,000 tonnes in the 2009–10 financial year (DTMR, 2012). Future expansion of the port to service increased trade in agricultural commodities would be difficult because there is limited land available in the main port area (Port of Karumba, 2002). The Port of Karumba is currently limited to 5000 tonne transfer ships, and there are no containerised or refrigerated facilities.

The Port of Cairns is closer to the Gilbert catchment than the Port of Townsville, by about 80 km. However, it is unlikely agricultural produce from the Gilbert catchment would be exported from the Port of Cairns because the roads into Cairns from the west do not allow Type 1 or Type 2 road trains.

Energy

The Ergon Far North (FN) western system takes in the Georgetown, Normanton, Croydon and Karumba communities. The area is served from the Ross Connection Point in Townsville where a 132-kV single circuit line owned by Ergon Energy to supply this area originates. Based on Ergon sub-transmission network asset plans, there are plans for network reinforcement over the next decade, but no plans for new high voltage (132 kV) transmission lines. Figure 4.17 shows the location of powerlines in the Gilbert catchment.

Examination of zone substation capacity and maximum demand forecasts reveal that any development close to the named townships are unlikely to encounter network capacity constraints in the near term. However, remotely located irrigation developments could require the upgrade of Single Wire Earth Return (SWER). It is likely that alternative energy solutions (e.g. solar photovoltaic, renewable/diesel hybrid power systems) will be more promising in these areas when compared to the high cost of new SWER network build.

4.6.4 PROCESSING INFRASTRUCTURE

Some agricultural products require processing to take place within the supply chain, and the location of processing facilities relative to the source of product is a significant profitability consideration. Products in this category include cotton, sugar and beef cattle.

Sugar milling

There are no sugar mills in the Gilbert catchment. The nearest sugar mill is Tableland Mill, located to the east of the Gilbert catchment in Mareeba. In 2012, the supply to this mill was 745,356 tonnes of cane harvested from 7207 ha (MSF Sugar, 2013).

The road journey from Georgetown to Mareeba is approximately 350 km. To minimise deterioration in the sugar content levels, sugar cane needs to be delivered to the mill within 16 hours after harvesting (Canegrowers, 2010).

Cotton gin

There is currently no cotton gin in the Gilbert catchment. The nearest gin is located in Emerald, located approximately 900 km to the south-east of the catchment in central Queensland.

Meat processing

Queensland meatworks at Townsville, Rockhampton and Biloela are the only export-certified meatworks in the northern part of Queensland (Gleeson et al., 2012). Live export ports are located at Karumba and Townsville. There are small processing works in north Queensland servicing local areas but kill numbers are small (i.e. less than ten head per week) (Gleeson et al., 2012). There are no substantial inland beef processing plants serving northern Australia (DAFF, 2012).

Feedlots

There is one small feedlot in the Gilbert catchment with a pen capacity of less than 1000 head. Larger facilities (greater than 10,000 head) exist at Townsville and near Mareeba, although the latter facility is currently closed for business.

4.6.5 CURRENT WATER USE

Current water entitlements in the catchment are shown in Table 4.15. The Water Resources (Gulf) Plan 2007 identified 15,000 ML/year as unallocated General Reserve (QWRGP, 2007). In 2012 and 2013 the entirety of this reserve was released for tender but only entitlements to 14,200 ML/year were issued. This appears in the table as 'New 2013 Irrigation'. Another recent development that is on 22 November 2013 a Public Notice was released by the Department of Natural Resources and Mines pertaining to the availability of 2000 ML of the unallocated strategic reserve (see <http://www.dnrm.qld.gov.au/water/catchments-planning/unallocated-water/public-notice>). The eligibility criteria are that the use is for town water supply and that there is a demonstrated demand.

In 2006 there were no groundwater volumetric licenses in the catchment for any use (QNRMW, 2006).

Actual water use as estimated in 2006 was lower than entitlements, as shown in Table 4.16

Table 4.15 Surface water entitlements and storages, ML/year

EXISTING IRRIGATION	NEW 2013 IRRIGATION	TOWN WATER SUPPLY AND INDUSTRIAL	STORAGES AND CAPACITY	UNALLOCATED GENERAL RESERVE	UNALLOCATED STRATEGIC RESERVE
			(ML/year)		
9,115	14,200	4,880	Mt Hogan Water Supply Dam: 700 Kidston Dam: 20,600	800	5,000 (of which 2,000 was made available for town water supply on 22 November 2013)

Source: QNRME (2004), QWRGP (2007), QGROP (2010).

Table 4.16 Water use and entitlements in 2006

TYPE OF USE	IRRIGATION	MINING	TOWN WATER SUPPLY	TOTAL
		(ML/year)		
Entitlement	15,045	4,650	140	19,835
Water use	5,300	100	100	5,500

Source: QNRMW (2006).

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5 Opportunities for irrigation in the Gilbert catchment

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Chapter 5 examines the opportunities for irrigated agriculture in the Flinders catchment. Evaluating the possibility of establishing a greenfield irrigation development requires an understanding of the development-related infrastructure required and its associated costs. This includes being able to answer questions such as:

- Where are the better locations in the catchment for storing water?
- How will water be conveyed from the water storage and applied to the crop, and what are the likely water losses?
- What land development is required for irrigation to take place?

It also requires an understanding of the crops likely to be suitable, their potential location within the catchment, the likely returns and production risks.

The key components and concepts of Chapter 5 are shown in Figure 5.1.

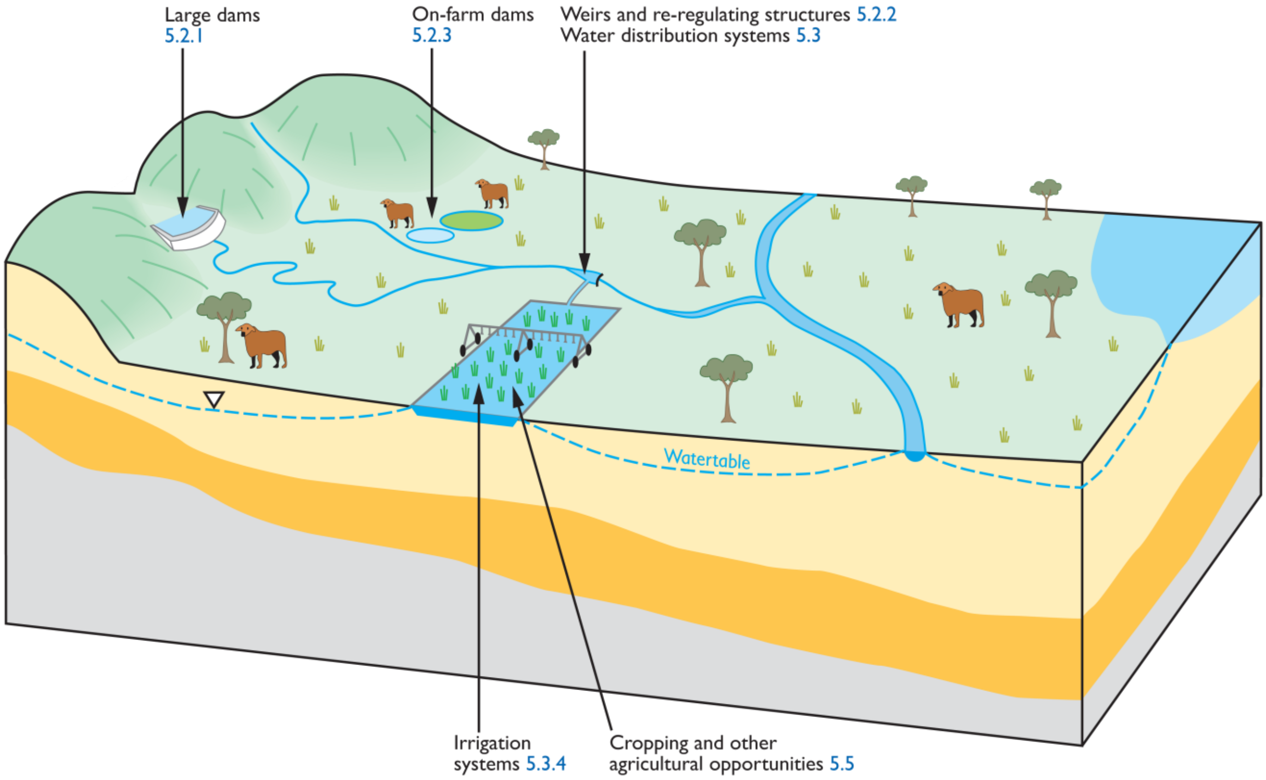

Figure 5.1 Schematic diagram of key engineering and agricultural components to be considered in the establishment of a greenfield irrigation development

5.1 Summary

This chapter establishes the scale and nature of the cropping opportunity in the Gilbert catchment, for both dryland and irrigated cropping, taking into consideration the availability of soil and water and potential water storage opportunities.

There is currently limited cropping in the Gilbert catchment – there is no dryland production for human food or fibre and less than 400 ha of irrigated production. The catchment has the theoretical potential to produce around 7 million tonnes of grain per year with a gross value of over $1.8 billion.

5.1.1 SOIL SUITABILITY

More than 2 million ha of the Gilbert catchment are at least moderately suitable (class 3 or above) for cropping. These soils have considerable limitations that lower production potential and require careful management. In this respect, they are similar to much of Australia's agricultural soils.

5.1.2 WATER STORAGE OPPORTUNITIES

The Gilbert catchment has a highly variable climate and potential evaporation rates that typically exceed rainfall by a factor of 2.4. In the absence of suitable groundwater, water storages are essential to enable irrigation during the dry season. Large, instream dams are the most promising water storage options in the Gilbert catchment. Several potential dam sites in the Gilbert catchment combine suitable topography and geology with sufficient water yield and proximity to suitable soils for irrigation. These are sites on the Einasleigh River at Dagworth station and the Gilbert River immediately downstream of Green Hills station; another option is to upgrade the existing dam upstream of Kidston Dam (officially known as the Copperfield River Gorge Dam, but referred to in the Assessment as Kidston Dam). The Green Hills site is promising for its proximity (around 15 km) to suitable areas for irrigation. The soils adjacent to the Gilbert and Einasleigh rivers are highly permeable, making offstream storage challenging.

5.1.3 DRYLAND CROPPING

A wide range of crops is potentially suited to dryland production in the Gilbert catchment. Break-even yields could be expected more than nine years in ten for short-season dryland crops such as mungbean and lablab, approximately three years in ten for dryland crops such as sorghum (grain) and sugarcane, and fewer than two years in ten for dryland cotton and maize.

High rainfall variability, combined with low soil water storage, means that continuous year-on-year dryland cropping is not feasible. Opportunistic cropping during favourable conditions is likely to be a more profitable and sustainable approach to dryland cropping.

If the approximately 2 million ha of suitable arable soil in the Gilbert catchment were, for example, devoted to dryland sorghum (grain), median potential regional production of around 7.6 million tonnes and a gross value of production of $1748 million are theoretically possible. Actual yields would be lower and would vary significantly from year to year. This estimate does not take into account any legislative or regulatory constraints on development; it is purely a biophysical estimate. Change in land use of this scale would have a considerable impact on cultural, social and environmental values and would transform the catchment.

5.1.4 IRRIGATED CROPPING

There is more soil suited to irrigation in the Gilbert catchment than there is water to irrigate it. If the most promising six instream storages were to exist, it would be possible to irrigate a maximum of approximately 4% of the catchment's suitable soils.

If this irrigation water (estimated to be approximately 250 GL from two potential dams alone, after evaporation, seepage, conveyance and field application losses) were, for example, devoted to irrigated sorghum (grain) production, there would be potential to produce 500,000 tonnes of grain over 70,000 ha, and with a gross value of around $130 million. Actual yields and areas sown would probably be lower and would vary significantly from year to year.

The volume of water available for irrigation will also vary year on year and, as a consequence, irrigated and dryland cropping are likely to closely co-exist.

5.2 Water storage opportunities

In a highly seasonal climate, such as that of the Gilbert catchment, and in the absence of suitable groundwater, water storages are essential to enable irrigation during the dry season and other periods when soil water is insufficient for crop growth.

The Assessment identified and assessed over 100,000 potential dam sites within the Gilbert catchment using an automated process. This process, supported by field investigation, identified numerous new potentially suitable dam sites and confirmed the relative potential of some previously proposed dam locations, such as Green Hills. The most notable of these was Dagworth, a previously undocumented potential site on the lower Einasleigh River that had a larger yield and was closer to suitable soil than previously identified dam sites on the Einasleigh River. Three dam sites were short-listed for further analysis. These entailed the existing Kidston Dam, and the construction of dams at Dagworth station and immediately downstream of Green Hills station. The construction of dams at these locations is estimated to cost between $1500 and $2000 per ML of water supplied in 85% of years. These dams have an equivalent annual unit cost per ML of water supplied in 85% of years of between $100 and $140, which is considerably less than the equivalent annual unit cost per ML of effective offstream storage (i.e. after accounting for evaporation and seepage losses from the offstream storage) of at least $140 and $240, storing water for 4 and 12 months of the year respectively. The Gilbert River does not have many locations suitable for offstream storages due to its highly permeable soils and substrata. In select locations the soils adjacent to the Einasleigh River may be suitable for offstream storages.

Overview

Section 5.1 examines two types of water storages: (i) large dams, which supply water to multiple properties; and (ii) on-farm dams, which supply water to a single property. The former is typically used to supply water to broad-scale irrigation schemes such as those common in southern Australia, while the latter is typically used to supply water for stock and domestic purposes or for mosaics of small scale irrigation.

Both large dams and on-farm dams can be further classified as instream or offstream water storages. In the Assessment instream water storages are defined as structures that intercept a drainage line (creek or river) and are not supplemented with water from another drainage line. Offstream water storages are defined as structures that (i) do not intercept a drainage line; or (ii) intercept a drainage line and are supplemented with water from another drainage line. Re-regulating structures are also discussed. Ring tanks and turkey nest tanks are examples of offstream storages with a continuous embankment.

The performance of a dam is often assessed in terms of water yield or demand. This is the amount of water that can be supplied for consumptive use at a given reliability. An increase in water yield results in a decrease in reliability.

This section is structured as follows.

Section 5.2.1 examines large dams in the Gilbert catchment. It starts with an introduction to large dams, examines the potential for large dams across the Gilbert catchment discusses ecological, sedimentation and cultural considerations and provides summary information for seven potential dam sites in the Gilbert catchment. An assessment of the cost and cumulative water yield from multiple dams in the Gilbert catchment is then presented. Finally the three short-listed dams are discussed in more detail.

Section 5.2.2 presents information on weirs and re-regulating structures.

Finally Section 5.2.3 examines on-farm dams in the Gilbert catchment. This section contains information on the reliability at which different quantities of water can be extracted from selected rivers of the Gilbert catchment, presents information on the likely suitability of the soils of the Gilbert catchment for offstream storages, and discusses evaporative and seepage losses and possible capital, operation and maintenance costs of offstream storages in the Gilbert catchment.

Unless otherwise stated, the material in Section 5.2 originates from the companion technical report about water storage options (Petheram et al., 2013).

5.2.1 LARGE DAMS

Types of large dams

Dams are usually constructed from earth, rock or concrete materials as a barrier wall across a river, designed to store water in the reservoir so created. They need to be able to safely discharge the largest flood flows likely to enter the reservoir and the structure needs to be designed so that the dam meets its purpose, generally for at least 100 years. Large dams are sometimes referred to as carry-over storages. That is, they are large enough relative to the demands on the dam (i.e. water supplied for consumptive use, evaporation and seepage) so that, when full, water can last two or more years. This has the advantage of militating against years with low inflows to the dam. Large dams also better enable year round use of irrigation developments (e.g. two crops can be planted in a year instead of one) resulting in higher returns per hectare, making it more likely the investor will break even on land development costs.

While there are many different types of dam, the two types of dams most relevant to the Gilbert catchment are embankment dams and concrete gravity dams, of which roller compacted concrete dams are a subset.

Embankment dams

Embankment dams (EB) are usually the most economical (provided that suitable construction materials can be found locally) and are best suited to smaller catchment areas where the spillway capacity requirement is small, such as at the Belmore Creek Dam in the nearby Norman catchment and Corella Dam in the Flinders catchment. In the case of Belmore Creek Dam, a central earth core within the embankment is the watertight barrier that prevents water percolating through the rock fill, whereas at Corella Dam, the seepage barrier is a thin reinforced concrete slab placed on the upstream face of the rock fill. Figure 5.2 shows a schematic diagram of a typical embankment dam.

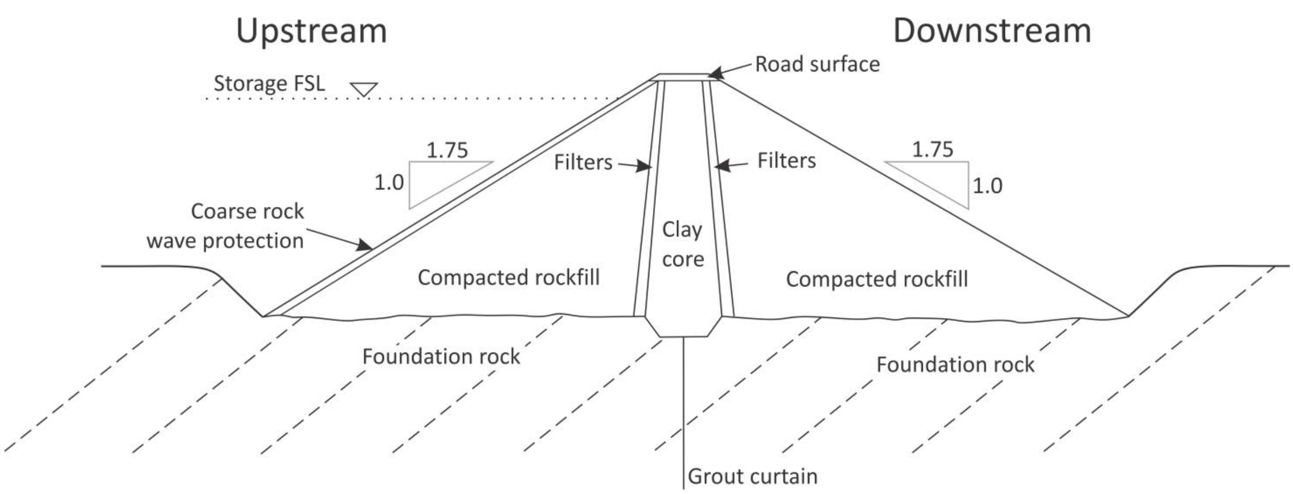

Figure 5.2 Schematic diagram of an embankment dam
Storage full supply level (FSL) is the water level when the storage is full (i.e. this is the level of the dam spillway).

Where sound foundation rock is not available at reasonable depth, an embankment dam can be founded on a ‘soft’ foundation provided that any permeable layers in the foundation can be cut off effectively and water pressures within the foundation limited, for example by pressure relief wells. Many offstream storage embankment dams are founded on soil foundations where spillway requirements are generally minimal.

Concrete gravity dams and roller compacted concrete dams

Where a large capacity spillway is needed to discharge flood inflows from a large catchment, a concrete gravity dam with a central overflow spillway is generally the most suitable type. Traditionally, concrete gravity dams were constructed by placing conventional concrete (CC) in formed ‘lifts’. Roller compacted concrete (RCC) dams are a type of concrete gravity dam and are best used for higher dams where a larger scale plant can provide significant economies of scale. These types of dam are now the favoured type of construction in Australia whenever foundation rock is available within reasonable depth and where a large capacity spillway is required. Kidston Dam (officially known as Copperfield River Gorge Dam) in the Gilbert catchment was the first dam in Australia where roller compacted concrete was used, with low cement concrete placed in continuous thin layers from bank to bank and compacted with vibrating rollers. This approach allows quite large dams to be constructed in a far shorter time frame than required for conventional concrete construction.

Potential dam sites in the Gilbert catchment

A prospective dam site requires inflows of sufficient volume and frequency, topography that provides a physiographic constriction of the river channel, and critically, favourable foundation geology. Favourable foundation conditions include a relatively shallow layer of unconsolidated materials such as alluvium, and rock which is relatively strong, resistant to erosion, non-permeable or capable of being grouted. Geological features that make dam construction challenging include the presence of faults, weak geological units, landslides and deeply weathered zones.

Potential dam sites in the Gilbert catchment occur in erosion resistant units of the Etheridge Province (a province is an area in which geological history has been the same), the Kennedy Province, and where resistant granite intrusions occur (Figure 3.2).

Rock in the Etheridge Province mostly consists of meta-sedimentary types. Generally the topography in this province is not favourable for dam construction except where there are erosion resistant units or where there are resistant granitic intrusions. Rocks of the Kennedy Province include both granite and ignimbrite. Ignimbrite is a strong rock formed from the welding and later consolidation of an ash flow tuff. The best sites occur where the rivers have eroded through ignimbrite. It is resistant to weathering and erosion, and river valleys tend to be relatively narrow and the depth of unconsolidated alluvium relatively shallow.

There are two major basalt provinces in the Gilbert catchment, the Chudleigh Basalt Province and the McBride Basalt Province. Lava flows from the Chudleigh Basalt Province have affected the upper reaches of the Copperfield and Einasleigh rivers. Basalt has flowed down the former river valleys and floodplains forming lava fields and, in some cases, blocking former river channels. The most northern part of the flow is about 24 km north of Einasleigh. The Undara basalt flow of the McBride province has affected the middle reaches of the Einasleigh River downstream of its confluence with Junction Creek to their confluence with Parallel Creek – a distance of about 60 km. Basalt flows cause problems for dam foundations as they can overlie alluvial material which can act as leakage paths underneath or around the dam. Remedial measures are generally expensive and can require extensive excavation of basalt and alluvial material, and cement grouting.

Six potential locations were identified from published and unpublished literature accessed from the Queensland Government and SunWater archives. The extent of prior investigations ranged from a single reference of potential locations (e.g. Mount Alder and Mount Noble) to moderately detailed hydrological and geotechnical investigations (e.g. Green Hills). A difficultly in comparing the outcomes of these studies was that they were undertaken by a range of organisations, at different points in time, using different methods and to varying degrees of rigour. The studies were reviewed and all locations were reassessed using a consistent set of methods, using updated data where available.

To ensure that no potential dam options had been overlooked, the DamSite model was used to undertake a preliminary assessment of over 100,000 potential dam sites in the Gilbert catchment. This model uses a series of algorithms that automatically locate and assess favourable topographic and hydrological locations in the landscape as sites for intermediate to large water storages. The DamSite model identified numerous locations for siting dams in the Gilbert catchment. The better sites are shown in Figure 5.3.

The only new potential dam sites that were investigated further were those identified by the DamSite model that had higher water yields, were situated in geologically favourable formations, and were more favourably located than known potential dam sites. The most notable of these was Dagworth, a previously undocumented potential site on the lower Einasleigh River. In many cases, the DamSite model confirmed the relative potential of known potential dam locations, such as Green Hills and Mount Noble. In other cases it demonstrated that known dam site locations were topographically and hydrologically inferior to other nearby locations (e.g. North Head). The most favourable sites at seven potential dam locations in the Gilbert are summarised in Table 5.1 and a short comment provided in Table 5.2. Three potential dam sites in the Gilbert catchment were selected for further analysis because they were deemed to be the most likely site to proceed in three distinct geographical areas. The assessment of the three most promising sites was based on expert knowledge and primarily took into consideration topography of the dam axis, geological conditions, proximity to suitable soils, and water yield. The short-listed sites entailed raising the existing Kidston Dam, and potential dams at Dagworth and Green Hills. The Dagworth site had not been previously identified. As part of the Assessment, the majority of sites were visited by an experienced infrastructure planner and engineering geologist.

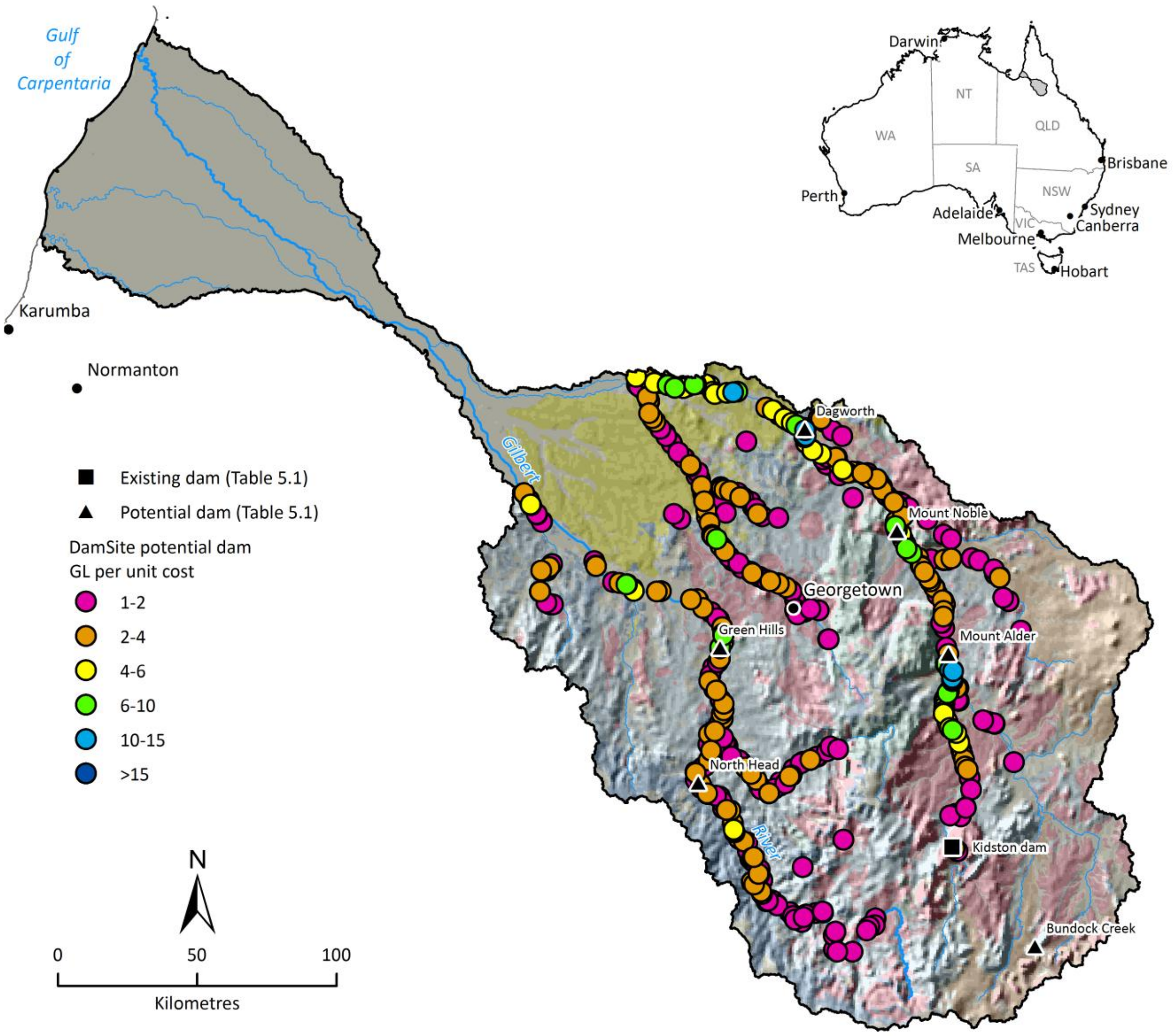

Figure 5.3 DamSite model results for the Gilbert catchment overlain on transparent geology and shaded relief map
Only those potential dam sites with greater than 1 GL per unit cost are shown.

Ecological considerations

For instream ecology, dam walls acts as a barrier to movements of plants, animals and energy, potentially disrupting connectivity of populations and ecological processes. Some of the potential dam sites in the Gilbert catchment (e.g. Green Hills, Dagworth and Mount Noble) are likely to obstruct the movement of barramundi and freshwater sawfish.

The water impounded by a dam inundates an area of land, drowning not only instream habitat but surrounding flora and fauna communities. Despite the majority of the Gilbert catchment containing regional ecosystems that are 'not of concern' (~74%) (Figure 4.6), the majority of potential dam sites in the catchment inundate some regional ecosystems considered to be either 'endangered' or 'of concern'. This is in part because riparian vegetation is limited to drainage lines and consequently is often classed as being endangered.

The inundation areas for the majority of potential dam sites in the Gilbert catchment contain some regional ecosystems considered to be either 'endangered' or 'of concern'.

There are thousands of studies linking water flow with nearly all the various elements of instream ecology in freshwater systems (e.g. Robins et al., 2005). Dams also create a large, deep lake, a habitat in stark contrast to the usually shallow and often flowing habitats it replaces. This lake-like environment favours some species over others and will function completely differently to natural rivers and streams. The lake-like environment of an impoundment is often used by sports anglers to augment natural fish populations, through artificial stocking. Whether fish stocking is a benefit of dam construction is a matter of debate and point-of-view. Stocked fisheries provide a welcome source of recreation and food for fishers, and no doubt an economic benefit to local businesses, but they have also created a variety of ecological issues. Numerous reports of disruption of river ecosystems (e.g. Drinkwater and Frank, 1994; Gillanders and Kingsford, 2002) highlight the need for careful study and regulatory management. Impounded waters may be subject to unauthorised stocking of native fish and releases of exotic flora and fauna.

About 42 fish species are known from the Gilbert catchment (see companion technical report about waterhole ecology (Waltham et al., 2013)). The gradient of declining numbers of fish species with increasing distance from the ocean, so widely recognised in other catchments, is not clear here due to a lack of survey effort and data availability in the lower reaches, where the greatest diversity is to be expected. Available records for barramundi, freshwater sawfish and the freshwater whipray are scant, although both barramundi and sawfish are likely to occur further upstream than the currently available records suggest, and thus intersect with some potential dam sites. In the Gilbert catchment, freshwater sawfish are likely to be able to penetrate upstream of the Green Hills site on the Gilbert River and possibly as far as, or at least near to, the Mount Noble site on the Einasleigh River.

If any potential dam site were to be considered for further investigation, the vegetation and fauna communities present would need to be investigated with a thorough field investigation.

Sedimentation

Rivers carry fine and coarse sediment eroded from hill slopes, gullies, banks and sediment stored within the channel. Sediment delivery to dams can be a major problem for water storage capacity since infilling progressively reduces the volume available for active water storage.

There is a strong relationship between the capacity of the dams and sediment infilling rates. Of the seven potential dams examined in the Gilbert catchment, 71% are estimated to have between 1.2% and 6.3% sediment infilling after 30 years and between 4% and 21% sediment infilling after 100 years. These are predicted to be the most likely percentages, although infilling under the worst case could be as high as 2.5% to 17% after 30 years and 8% to 56% after 100 years for 71% of dams. For the remaining dams, Mt Noble is estimated to have greater than 50% sediment infilling after 100 years (most likely), and Mt Adler is estimated to have completely filled (100%) within 100 years. Under the worst case scenario, both dams are estimated to have completely infilled within 100 years.

There is good agreement in the scientific literature on the key processes that generate sediment in northern Australian catchments (see companion technical report about sediment infilling rates, Tomkins, 2013).

Alluvial gully erosion has been identified as a major source of fine sediment in some rivers draining into the Gulf of Carpentaria (Brooks et al., 2007). Alluvial gullies have been shown to affect only a small area of the Gulf region (less than 1%), but their high connectivity with major river channels enables direct transfer of significant quantities of fine sediment to downstream (Brooks et al., 2009).

On hill slopes, colluvial gully erosion has been shown to be locally important, especially in the headwaters of some of the eastern draining catchments such as the Fitzroy (Hughes et al., 2009) and Burdekin (Bartley et al., 2007). Colluvial gully erosion appears to be less widespread in the Gulf region, potentially due to different geology and/or lower land use pressure. However, the rates and distribution of alluvial and colluvial gully erosion have been found to have increased through post-European disturbance. Overgrazing and other poor land management in a catchment can result in seriously high erosion and sediment loss.

Often deposition of coarser grained sediments occurs in the backwater (upstream) areas of reservoirs, which can cause back-flooding beyond the flood limit originally determined for the reservoir. Downstream impacts can occur as well, including sediment starvation, which can trigger channel bed incision and bank erosion.

Based on a desktop assessment of ten sediment yield studies from across northern Australia (Tomkins, 2013), sediment yield to catchment area relationships for northern Australia were developed and found to predict slightly lower sediment yield values than global relationships. This was not unexpected given the antiquity of the landscape (i.e. it is flat and slowly eroding under ‘natural’ conditions).

Reliable estimation of sediment infill rates requires analysis of specific dam proposals. These would need to be completed if any of the potential dams examined in the Gilbert catchment were considered further.

Cultural heritage considerations

Indigenous people traditionally situated their campsites and subsistence activities along major watercourses and drainage lines. Consequently dams are more likely to impact on areas of high cultural significance than most other infrastructure developments (e.g. irrigation schemes, roads). As a result the cost of cultural heritage investigations associated with dam sites is high relative to other development activities.

Certainly the Gilbert catchment will contain a large number of Indigenous cultural sites, including archaeological pre-colonial sites, some of which are likely to be of national scientific significance. Archaeological sites in parts of the catchment potentially date to the Pleistocene (see geological timeline in Appendix B). The cultural heritage value of these landforms and their immediate surrounds is therefore assumed to be moderate to very high. There is insufficient information relating to the cultural heritage values of the short-listed sites to allow full understanding or quantification of the likely impacts of water storages on Indigenous cultural heritage.

If any potential dam sites in the Gilbert catchment were investigated further an archaeological survey would be required to assess the potential Indigenous archaeological impact of the dam and reservoir. Any such investigation should be undertaken in consultation with the Indigenous parties. Should works proceed in this area, it is recommended that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding contemporary use of water sources in the area.

Dam cost estimates

Cost estimates for Green Hills dam undertaken as part of the Assessment are comparable to cost estimates undertaken by past studies (i.e. within 5%). However, previous cost estimates for Green Hills dam did not account for the additional saddle dam requirement identified by the Assessment. Cost estimates for other potential dam sites in the Gilbert catchment were not undertaken prior to the Assessment.

Preliminary cost estimates were prepared for the three short-listed dam sites based on current construction costs (Petheram et al., 2013). For the remaining potential dam sites, costs were estimated relative to the short-listed dams in the Flinders and Gilbert catchments. This subjective assessment included the following parameters: dam height, width, capacity, catchment area and geological uncertainty. Preliminary cost estimates of potential dams in the Gilbert catchment are provided in Table 5.1.

Summary of potential dams assessed in the Gilbert catchment

Table 5.1 and Table 5.2 provide summaries of potential dams assessed in the Gilbert catchment. In presenting this information it should be noted, however, the geological structure at a particular dam site can be very complex, is always unique and requires thorough investigation because of the high financial risks involved. The investigation of a potential dam site generally involves an iterative process of increasingly detailed studies over a period of years, occasionally over as few as two or three years but often over ten or more years. For any of the options listed in this report to advance to construction, far more comprehensive studies would be needed. Studies at that level of detail are beyond the scope of this regional scale resource assessment.

Table 5.1 Potential dams assessed in the Gilbert catchment

At some locations, up to three alternative sites were assessed. For these locations, the most suitable alternative site is reported.

DAM ID	DAM NAME	DAM TYPE*	CATCH-MENT AREA (km²)	SPILLWAY HEIGHT** (m)	FULL SUPPLY LEVEL (mEGM96)	CAPACITY (GL)	ANNUAL WATER YIELD*** (GL)	CAPITAL COST# ($ million)	UNIT COST## ($/ML)	EQUIVALENT ANNUAL UNIT COST### ($ per year per ML)
1	Bundock Creek	EB/RCC	205	14	659	30	8.8	$225 ☐	$25,590	$ 1794
2	Dagworth	RCC	15,351	30	227	498	326	$474 ◘	$1450	$102
3	Green Hills	RCC	8,310	20	253	227	172	$335 ◘	$1950	$137
4	Raising Kidston Dam	CC	1,244	40	588	25^	17^	$34 ■	$1990	$139
5	Mount Alder	RCC	8,641	20	425	31	37	$275 ☐	$7510	$526
6	Mount Noble	RCC	12,383	20	337	103	113	$375 ☐	$3322	$233
7	North Head	EB/RCC	4,680	30	344	136	108	$325 ☐	$3013	$211

* Conventional concrete (CC), embankment dam (EB), roller compacted concrete dam (RCC). The existing Kidston Dam is a RCC dam but it would be raised using CC.
** The height of the dam abutments will be higher than the spillway height.
*** Water yield is based on 85% annual time-based reliability using a perennial demand pattern for the baseline river model under Scenario A. This is yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These yield values do not take into account downstream existing entitlement holders or environmental considerations.
# ■ cost estimate based on schedule of quantities estimated by McIntyre and Associates (1998). This includes raising of the dam and diversion infrastructure. ◘ indicates preliminary cost estimate is likely to be –10% to +30%. ☐ indicates preliminary cost estimate is likely to be –10% to +50%. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher. Operation and maintenance costs are typically about 0.4% of the capital cost.
This is the unit cost of annual water supply and is calculated as the capital cost divided by the water yield at 85% annual time reliability.
Assuming a 7% real discount rate and a dam life of 100 years. Capital cost only. Does not include operation and maintenance costs.
^ Existing Kidston Dam capacity is 20 GL and annual water yield at 85% time reliability is 15 GL.

Table 5.2 Summary comments for potential dams in the Gilbert catchment
The companion technical report about water storage options (Petheram et al., 2013) provides a comprehensive review of each of the below potential dams.

DAM NAME	COMMENTS
Bundock Creek	Very remote and low water yield. To increase the water yield water could be diverted from the upper Einasleigh River. This would be a very expensive option.
Dagworth	Large catchment and highest water yield of potential dam sites assessed in Gilbert catchment. The right bank saddle dam embankment adopted crest level was set to contain the 1:1000 Annual Exceedance Probability (AEP) flood event. Best potential dam site on Einasleigh River, but is still a moderate distance upstream of moderately suitable soils.
Green Hills	Large catchment and highest water yield of potential dam site on Gilbert River. Close to moderately suitable soils. Crest level of saddle dam No. 2 on the left bank would be set to contain the 1:1000 AEP food event and crest level of saddle dam No. 3 set 0.5 m higher. In the event of larger flood events, the saddle dams would erode out increasing the total discharge capacity.
Raising Kidston Dam	Raising existing dam by 2 m. One of the more potentially viable options in the Gilbert catchment. Small water yield and moderate distance upstream of moderately suitable land.
Mt Alder	Low storage capacity. Relatively high risk of sediment infill. Long distance upstream of moderately suitable land.
Mt Noble	Effected by basalt flows which limits dam height and may act as leakage path under the dam. Long distance upstream of moderately suitable soils (Figure 5.4).
North Head	Remote. Long distance upstream of large areas of moderately suitable soils.

Figure 5.4 Mount Noble range looking upstream along Einasleigh River
Photo: CSIRO.

The total divertible yield in the Gilbert catchment

The total divertible yield, before losses, from six of the most promising dam sites in the Gilbert catchment is about 630 GL in 85% of years. Divertible yield is the amount of water than can be released annually from one or more storages in a controlled manner.

To undertake this analysis the number of dams simulated in the Gilbert River model was incrementally increased, starting with the most viable dam and finishing with the worst combination of the six most promising dams. Cost estimates were obtained from Table 5.1 and do not include the cost of irrigation water distribution infrastructure.

In Figure 5.5a the water yield from each dam was calculated at 85% annual time reliability at the dam wall. In Figure 5.5b the water yield from each dam was calculated at 85% annual time reliability and a 30% loss was applied to the water yield to approximate the loss of water that occurs during conveyance between the dam wall and the farm gate (Section 5.3). Given the distance between many of the dams in the Gilbert catchment and suitable soil, a 30% loss is likely to be conservative. It is important to note that these estimates of divertible yield take into consideration evaporation losses, and seasonality and inter-annual variability in streamflow. They do not, however, take into account environmental, social, cultural or economic factors or existing water users.

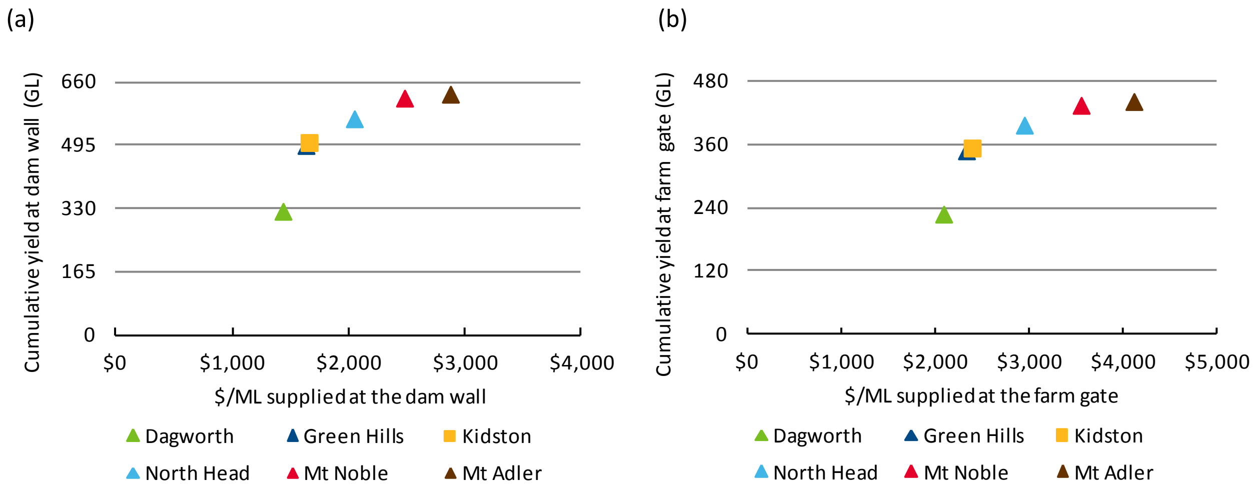

Figure 5.5 Cost of water in $/ML versus cumulative divertible yield at 85% annual time reliability
(a) At dam wall. (b) At farm gate. Cost based on capital cost of dam only, does not include cost of diversion or irrigation scheme infrastructure. A 30% loss between dam wall and farm gate is assumed. Dots indicate combined water yield at 85% annual time reliability of one or more dams, with the colour of the dot indicating the most recently included dam in the cumulative yield calculation. For example, Dagworth has a yield at the dam wall of 326 GL; Dagworth and Green Hills have a cumulative yield of 498 GL. Dam locations are shown in Figure 5.3. Squares indicate existing dams, triangles indicate potential dams.

Figure 5.5 illustrates that with the addition of more dam sites, the construction cost per ML of yield increases considerably with the third and subsequent dams. This is in part because i) each subsequent potential dam site is less favourable than its predecessor; and ii) in those instances where a dam is constructed upstream of an existing dam, their combined yield is less than the sum of their individual yields because the upstream dam reduces inflows to the downstream dam. An example of this is provided with the addition of Mount Alder on the Einasleigh River in addition to dams at Kidston, Mount Noble and Dagworth. The effect of adding a dam at Mount Alder reduces the inflows to Mt Noble and Dagworth dams downstream such that their combined yield (at 85% reliability) is reduced by 25 GL, yet the Mount Alder dam only contributes an additional yield of 35 GL to the system.

It should be noted that the purpose of this analysis is to broadly illustrate the viability of incrementally constructing additional dams in the Gilbert catchment. In an operational environment (e.g. the day to day supply of water to a large city or series of irrigation districts) numerous dams in parallel and in series would be operated in combination, to achieve an optimum yield across the entire system. Consequently the yield of the system (i.e. the combined yield from multiple dams) would be slightly higher than the yield values presented here. For the purposes of the Assessment this level of detail of analysis was not warranted.

Three short-listed potential dam sites in the Gilbert catchment

The three short-listed sites are provided in alphabetical order. These sites are deliberately situated in three distinct geographic areas. This decision was based on cost of construction, yield and proximity to moderately suitable soil. The short-listed dams are presented in alphabetical order.

Raising Kidston Dam

Kidston Dam is an existing dam located in the upper reaches of the Gilbert catchment (Figure 5.6). There is currently potential to release 15 GL of water from the dam in 85% of years. Raising the dam wall by 2 m could supply 17 GL at the dam wall in 85% of years. A limitation of the dam is that it is about 70 km upstream from the town of Einasleigh, the nearest large area of moderately suitable soils. This is likely to result in large transmission losses between the dam and Einasleigh. As this is an existing reservoir, raising the dam wall carries low risk because the geology is known and there would be minimal additional ecological or social impacts.

The Kidston Dam was the first RCC structure built in Australia. It is 40 m in height above its lowest foundation level and a 13 m high fuse plug embankment secondary spillway is set to discharge to an unlined gully through the right abutment when headwater levels reach 0.5 m of the dam abutments. The dam was designed to be constructed to a very tight time frame and to provide a water supply to a mine whose operational life was expected to be only 15 to 20 years. However, SunWater (2005) concluded that the dam foundations and the main dam wall are of an adequate standard to ensure the dam's stability over the long term and are suitable to support a 2 m raising of the wall.

The potential to raise the existing Kidston Dam by 2 m was selected as an option for further investigation, on the basis that it is an existing reservoir and hence likely to be one of the more economically viable water supply options. The most appropriate form of raising is considered to be by placing conventional mass concrete on the downstream face of the dam to raise the spillway crest by 2 m and the abutment sections by a similar amount. In addition to the major works, a number of deficiencies in the existing works (resulting from the low cost approach adopted by the original developers) would need to be addressed. Unfortunately, raising the main dam wall would still result in a relatively small total storage volume.

The capital cost for a 2 m raising of the dam and diversion infrastructure is estimated to be $34 million, based on a schedule of quantities estimated by McIntrye and Associates (1998). Annual operating and maintenance costs for the dam should be relatively low given the type of raising suggested. No allowance has been made in the dam estimate for the cost of a fish transfer facility on the basis that the existing barrier has been in place for nearly 30 years and as a result there has been no movement of native fish from downstream of the dam into the reservoir during that time. If a fish transfer facility were required, the capital cost would increase by at least $5 million.

Figure 5.7a shows a cross-section of the ground surface along the dam axis and Figure 5.7b illustrates the relationship between dam height, reservoir volume and reservoir surface area.

Figure 5.8 illustrates the extent of inundation of the reservoir created by raising Kidston Dam by 2 m. The potentially enlarged reservoir does not inundate adjacent properties.

Figure 5.6 Kidston Dam looking upstream
Photo: CSIRO.

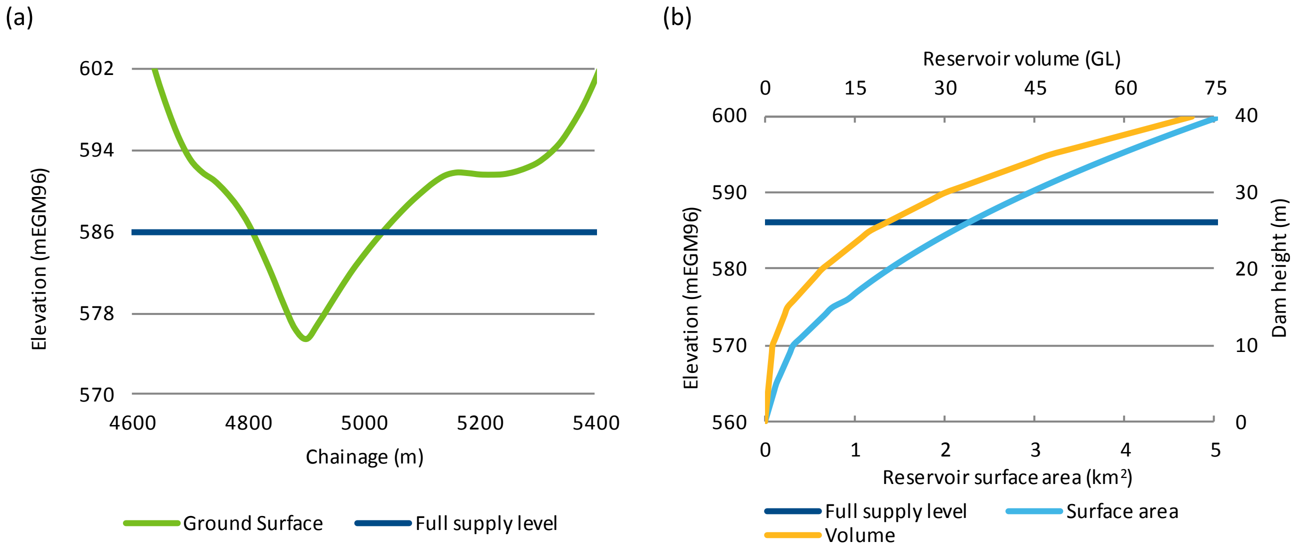

Figure 5.7 Dam cross-section, height, volume and reservoir surface area for Kidston Dam
(a) Cross-section of ground surface along dam axis, looking downstream. (b) Relationship between dam height, reservoir volume and reservoir surface area.

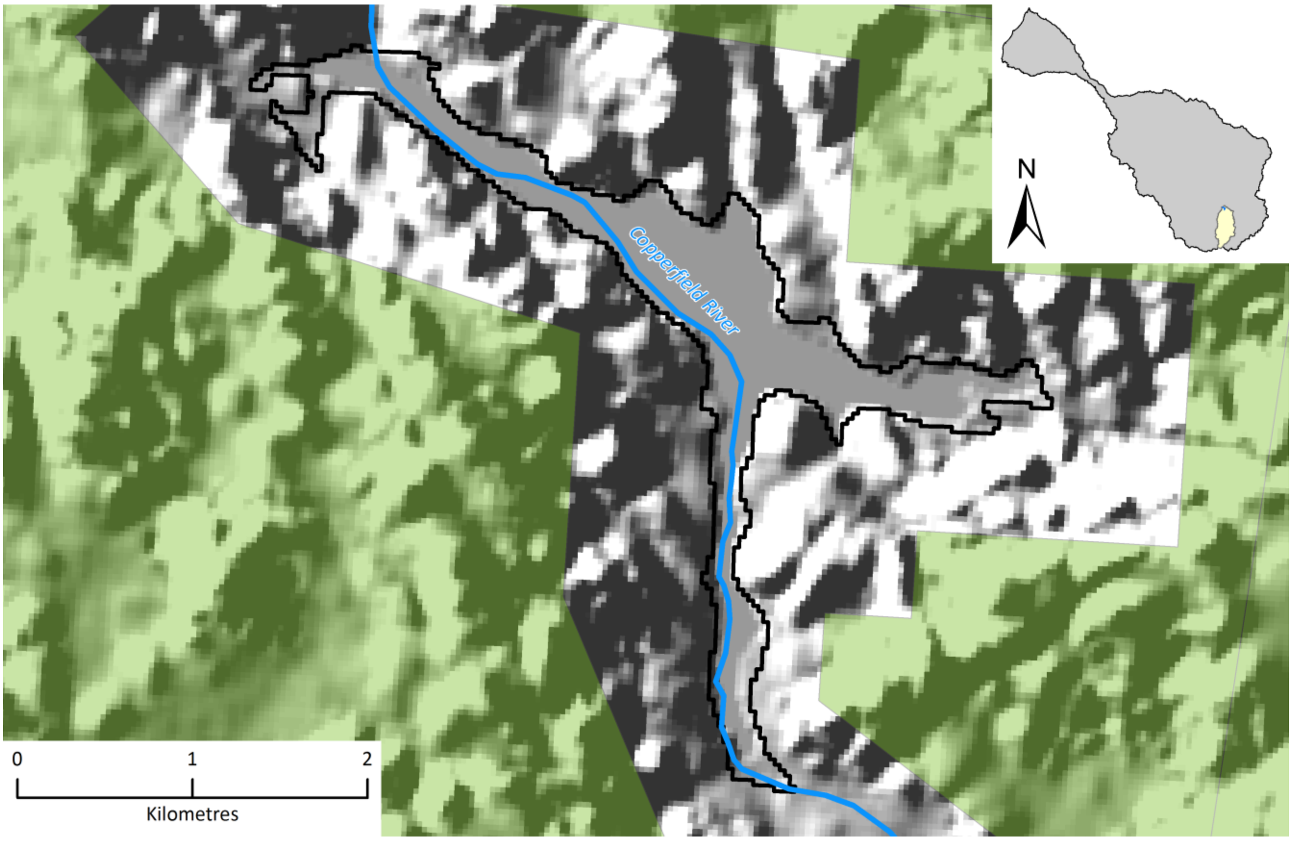

Figure 5.8 Raised Kidston Dam extent of inundation and property boundaries (indicated by coloured shading)

Figure 5.9a shows the annual time reliability (the percentage of years that a given demand could be supplied by the reservoir) and the volumetric reliability (the total volume of water supplied expressed as a percentage of total volumetric demand) of the reservoir created by raising the Kidston Dam. Under Scenario A (historical climate) for the baseline model the yield of the reservoir is approximately 17 GL at 85% annual time reliability. The ensemble of models had a 95% range of 15.7 to 19.5 GL at 85% annual time reliability. The ensemble of models estimates the uncertainty in the water yield estimate as a result of uncertainty in the measurement of streamflow.

The relatively incised landscape within which the Kidston Dam reservoir is situated constrains the reservoir volume (Figure 5.7b). However, it also results in a relatively small evaporative loss, with the ratio of evaporation to water supplied approximately 0.1 (at 85% annual time reliability).

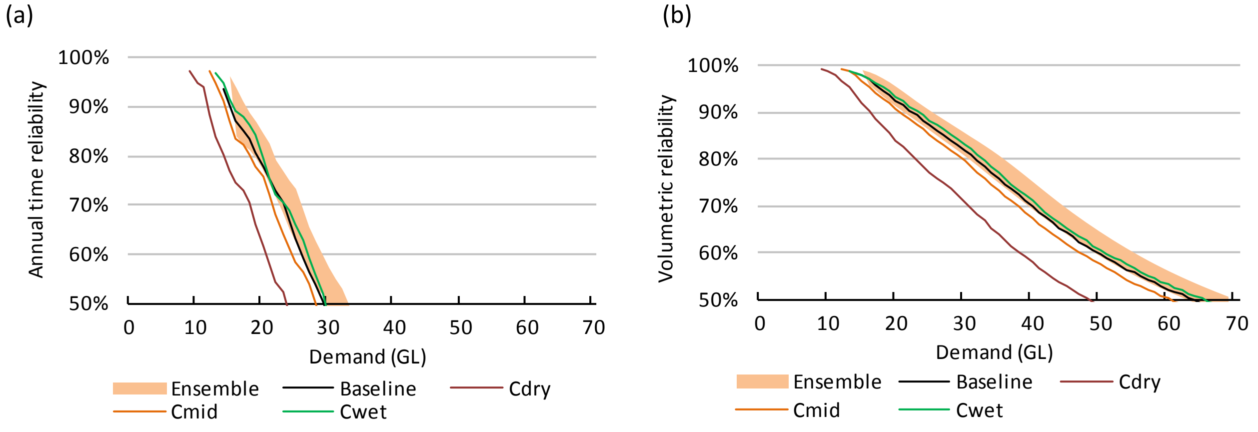

Figure 5.9 Annual time reliability and volumetric reliability for Kidston Dam under scenarios A and C
(a) Annual time reliability. (b) Volumetric reliability. The baseline (i.e. original) model under Scenario A is shown by the black line. The wet future climate (Cwet), mid future climate (Cmid) and dry future climate (Cdry) yield estimates were generated using the baseline model and future climate data. The orange shading indicates the 95% range of the 50 model ensembles under Scenario A. Yields are at the dam wall (i.e. they do not account for distribution losses).

Figure 5.10 illustrates the difference in coastal floodplain area simulated as being inundated with the Kidston Dam and with the raised Kidston Dam empty prior to the 2001 and 2009 flood events. Raising the Kidston Dam wall by 2 m will not result in a noticeable reduction in inundated area on the Gilbert coastal floodplain during small or large flood events.

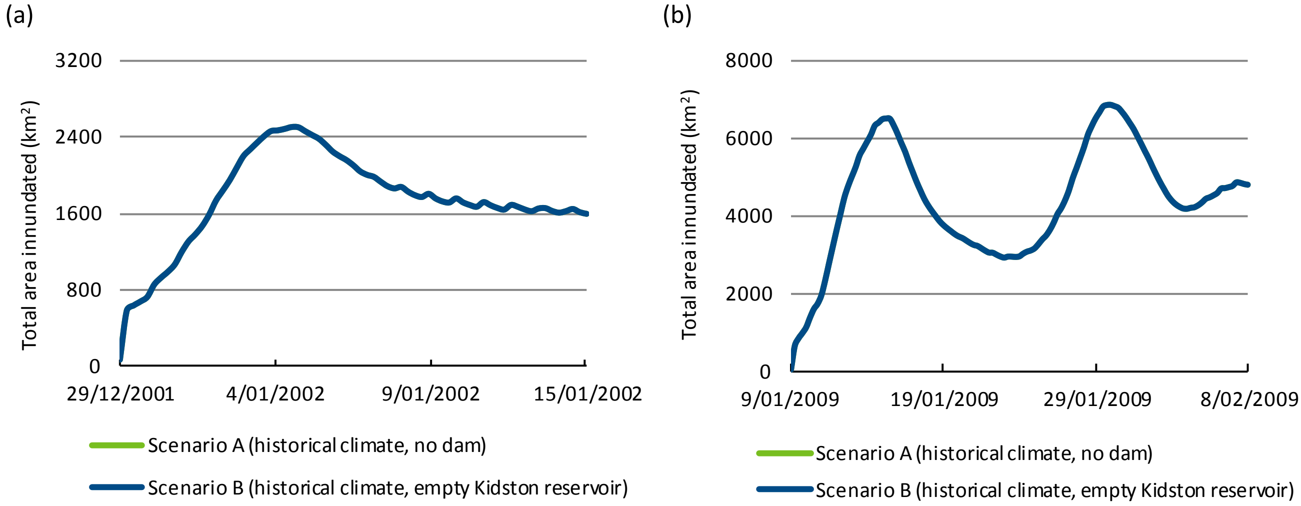

Figure 5.10 Comparisons of inundated area with and without the raising of Kidston Dam under Scenario A
(a) For an event in 2001 (equivalent to 1-in-4-year event at gauging station 917009A). (b) For an event in 2009 (equivalent to 1-in-32-year event at gauging station 917009A). Gauging station locations are shown in Figure 3.29. In this graph Scenario A (green line) underlies Scenario B (blue line).

A fish survey of this dam by the Queensland Department of Primary Industries in 1987 found seven fish species (Barlow, 1987), though several more are likely to be present. This dam was also surveyed by Vallance et al. (2000) but the fish species found were not specified. Raising the dam would trigger the need to assess the requirement for a fish transfer facility.

Figure 5.11 indicates that increasing the area of inundation of this impoundment is not likely to flood any regional ecosystems of concern. However, Tait (1998) identified a number of vine-thickets in the proposed inundation area, which may be too small to appear on existing vegetation mapping.

A desktop assessment of Indigenous cultural heritage considerations in the area surrounding the Kidston Dam area was undertaken by Northern Archaeology Consultancies in 1998 (NAC, 1998). This study found that the most common recorded site types in the locality are artefact scatters, and that stone arrangements, quarries, axe-grinding grooves, scarred trees and rock shelters with art are also present. Sites are frequently located close to water and/or prominent natural features.

NAC (1998) concluded that the area has high archaeological potential and is likely to contain a range of sites. The region is known to have a large number of sites, and the available information indicates that major watercourses, such as the Einasleigh and Copperfield rivers, were a focus of occupation. Further investigation, including archaeological survey, would be required to assess the potential Aboriginal archaeological impact of works in this area. Any such investigation should be undertaken in consultation with relevant Indigenous parties. Should works proceed in this area, it is recommended that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding contemporary use of water sources in the area.

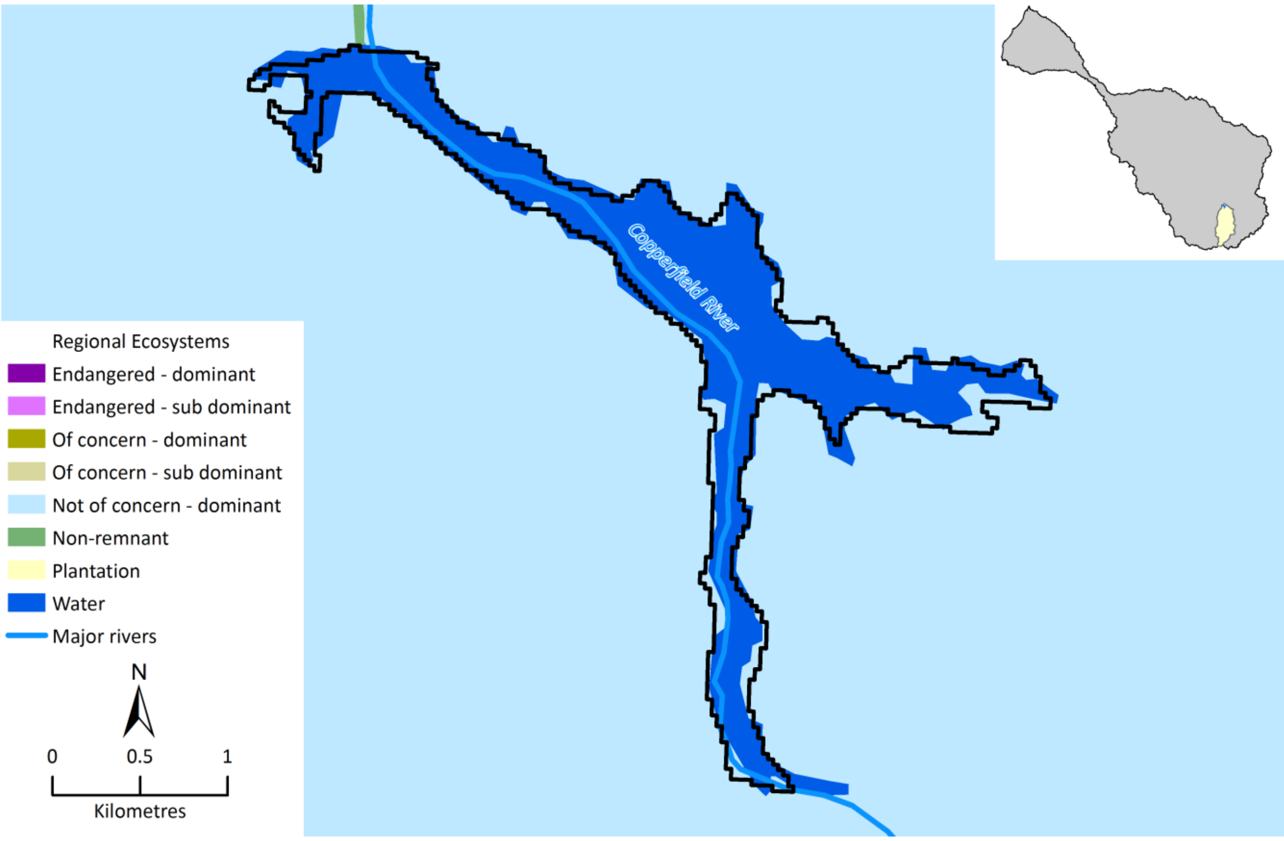

Figure 5.11 Regional ecosystems inundated by the raised Kidston Dam reservoir at full supply level

Dagworth

The Dagworth dam site appears to be geologically favourable and has the largest storage volume and yield of all the potential dam sites investigated in the Gilbert catchment. Despite being the most downstream of the potential dam sites on the Einasleigh River, the site is still approximately 70 km upstream of large areas of moderately suitable soil. The reservoir created by the dam would inundate a large area of regional ecosystems 'of concern' and the dam wall would most likely impede the movement of barramundi and freshwater sawfish.

Two potential dam sites situated in similar geological conditions were identified using the DamSite model on the Dagworth property along the Einasleigh River. Following a site inspection and a preliminary assessment of both sites, the upstream Dagworth dam site was short-listed because it had smaller saddle dam requirements. The potential dam site commands a large catchment area (about 15,000 km^2) and the geology of the site is favourable, being located in extremely high-strength dacitic ignimbrite. A concrete gravity dam with central overflow spillway 30 m above the river bed would be possible, with the main dam wall of RCC construction. On the right bank, an earth and rock fill embankment saddle dam approximately

650 m long and 22 m maximum height would be required (Figure 5.12). The crest level of the saddle dam embankment would be set to contain the 1 in 1000 year AEP flood and, in the event of more extreme flood events, erode away to form an auxiliary spillway. If this proposal were to be considered further, the impact of erosion of the large volume of fill from the saddle dam in the event of floods of high magnitude would need to be assessed in detail, as would the potential impact of the increase in flood discharge from the dam in such an event. The capital cost of the dam is estimated to be $474 million, not including the cost of any downstream distribution works. Annual operating and maintenance costs are likely to be relatively low for the type of dam suggested, although remoteness from service centres may increase some costs.

Figure 5.13a illustrates a cross-section of the ground surface along the dam axis and Figure 5.13b illustrates the relationship between the dam height, reservoir volume and reservoir surface area.

Figure 5.12 Dagworth potential dam site, looking upstream
Photo: CSIRO.

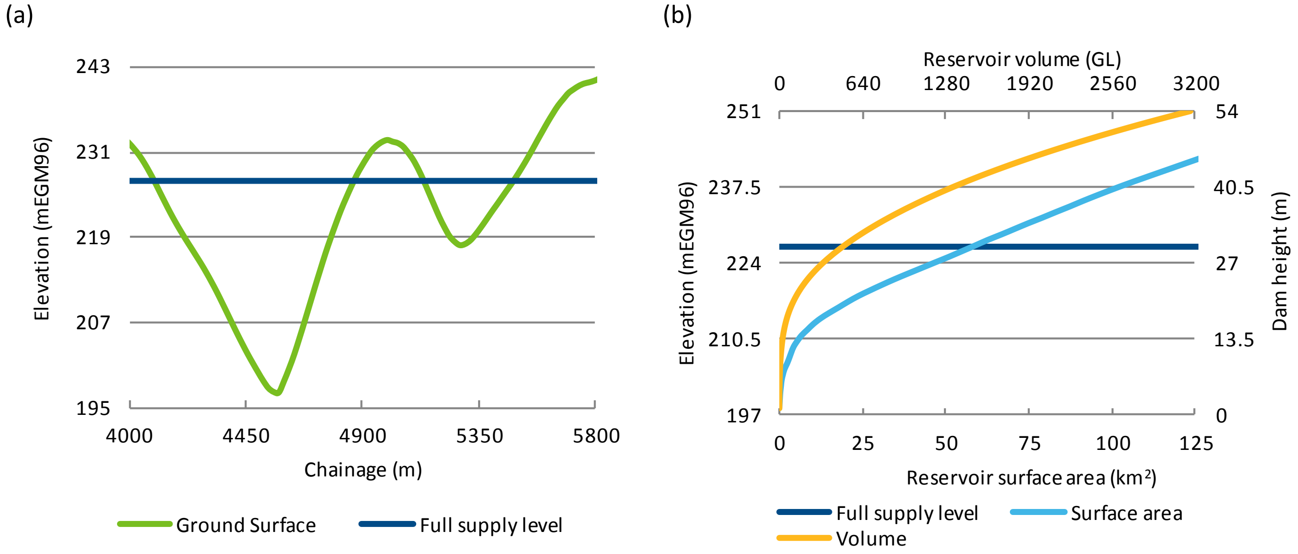

Figure 5.13 Dam cross-section, height, volume and reservoir surface area for Dagworth dam site
(a) Cross-section of ground surface along dam axis; looking downstream. (b) Relationship between dam height, reservoir volume and reservoir surface area.

A large proportion of the reservoir created by the potential Dagworth dam would be greater than 10 m in depth at FSL (Figure 5.14). In this figure a dam wall and saddle dams are required to contain the reservoir at FSL where the reservoir touches the catchment boundary. A spillway notch 280 m wide and 11.5 m deep was assumed having a capacity to discharge a flood in excess of the 1:1000 AEP event. For larger flood events, the right bank saddle dam would progressively erode away, creating additional spillway capacity.

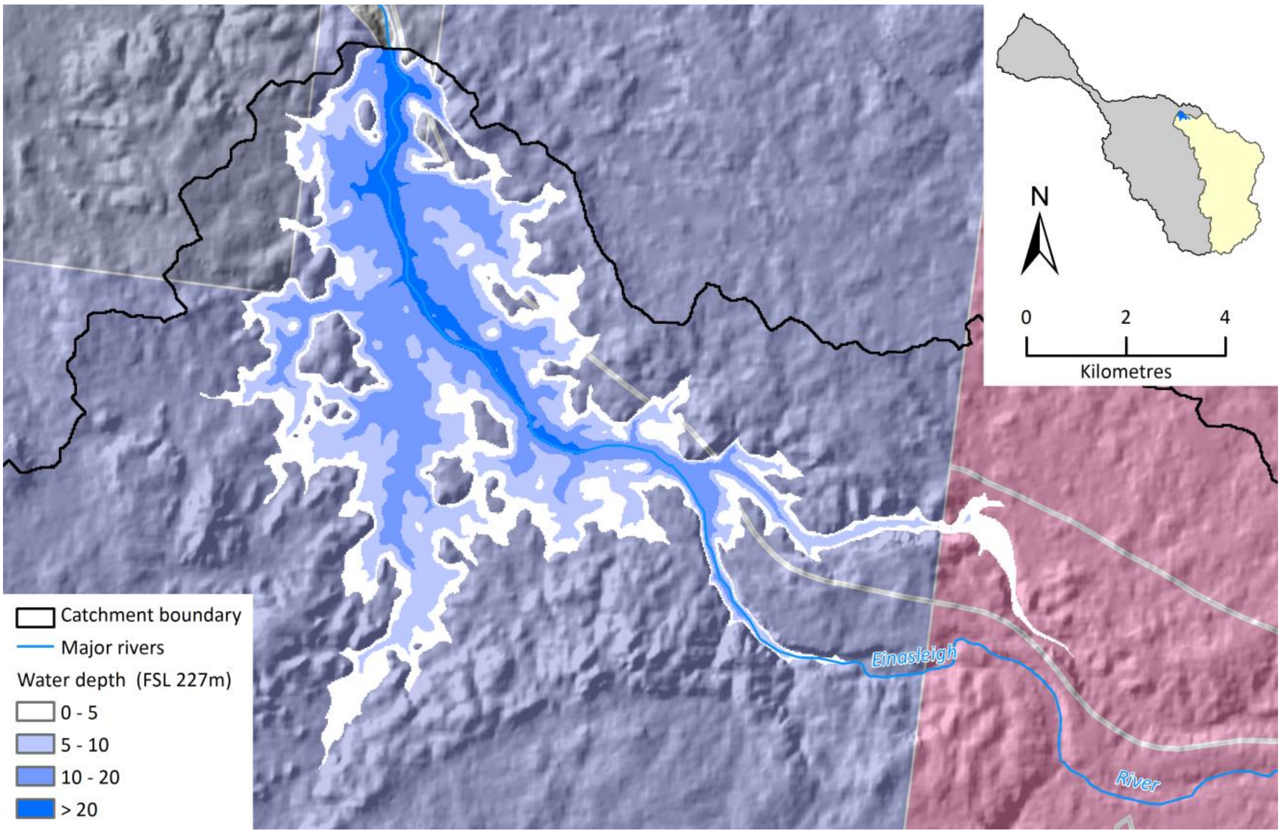

Figure 5.14 Dagworth dam depth of inundation and property boundaries (indicated by coloured shading)

Figure 5.15a shows the annual time reliability (the percentage of years that a given demand could be supplied by the reservoir) and the volumetric reliability (the total volume of water supplied expressed as a percentage of the total volumetric demand) of the reservoir created by a dam at the Dagworth upstream site. Under Scenario A for the baseline model, the yield of the reservoir is approximately 326 GL at 85% annual time reliability. The ensemble of models had a 95% range of 310 to 340 GL at 85% annual time reliability. The ensemble of models provides an estimate of the uncertainty in the water yield as a result of uncertainty in the streamflow data.

The favourable physiographic constriction of the river channel at the Dagworth site, the high dam wall and broad valley upstream of the potential dam site enable a reservoir with a large volume (Figure 5.13b), and a relatively small evaporative loss, i.e. ratio of evaporation to water supplied is approximately 0.15 (at 85% annual time reliability). Evaporation is approximately 13% of the regulated flow.

Figure 5.16 illustrates the difference in the total lower floodplain area simulated as being inundated without Dagworth dam and with Dagworth dam empty prior to the 2001 and 2009 flood events. The construction of Dagworth dam would result in a reduction in inundated area on the Gilbert floodplain for small flood events (Figure 5.16a). However, there would be no noticeable difference for large flood events (Figure 5.16b).

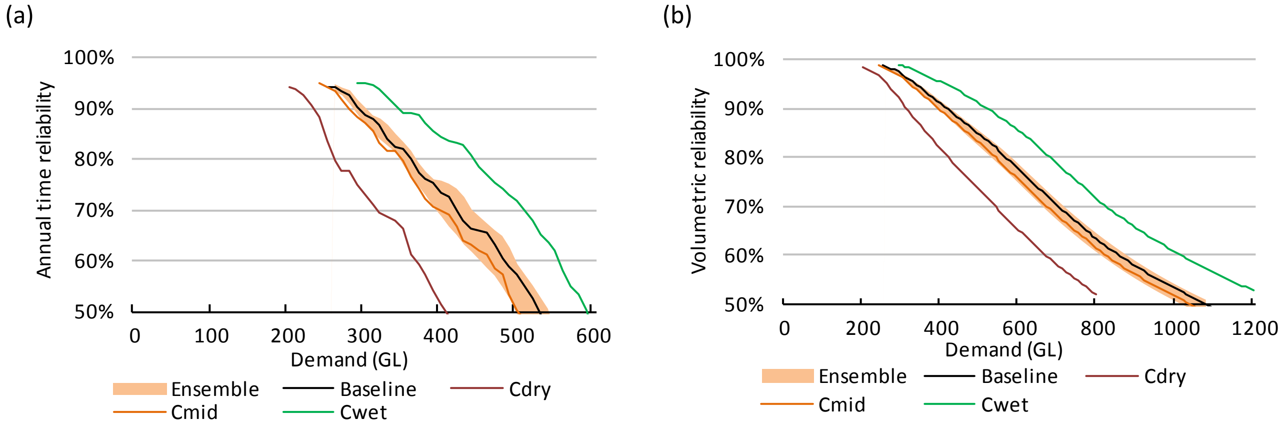

Figure 5.15 Annual time reliability and volumetric reliability for Dagworth dam under scenarios A and C
(a) Annual time reliability. (b) Volumetric reliability. The baseline (i.e. original) model under Scenario A is shown by the black line. The wet future climate (Cwet), mid future climate (Cmid) and dry future climate (Cdry) yield estimates were generated using the baseline model and future climate data. The orange shading indicates the 95% range of the 50 model ensembles under Scenario A. Yields are at the dam wall (i.e. they do not account for distribution losses).

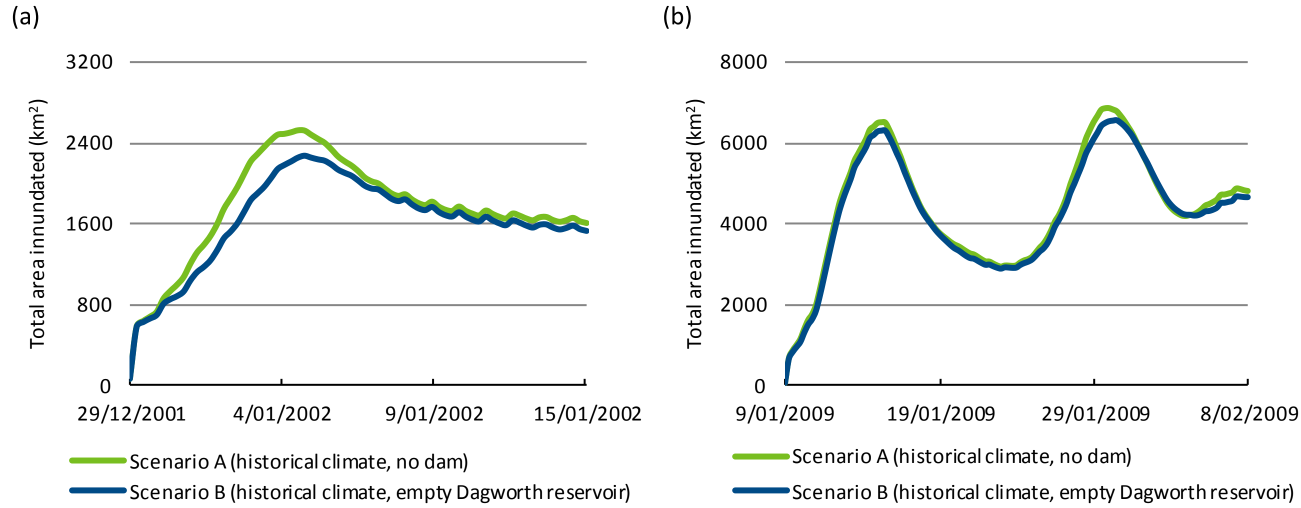

Figure 5.16 Comparisons of inundated area with and without the construction of Dagworth dam under Scenario A
(a) For an event in 2001 (equivalent to 1-in-4-year event at gauging station 917009A). (b) For an event in 2009 (equivalent to 1-in-32-year event at gauging station 917009A). Gauging station locations are shown in Figure 3.29.

The reservoir created by a 30 m high dam at the Dagworth site is predicted to experience persistent thermal stratification with a consistent top-to-bottom temperature difference of 6 to 10 °C (Petheram et al., 2013). The risk of blue-green algal blooms is high and the water column is predicted to mix on only a few occasions. The very long duration of stratification and weak mixing behaviour suggests this potential reservoir would be susceptible to experiencing profound anoxic conditions and associated water quality issues.

Downstream of this potential dam site there are numerous large permanent waterholes (Figure 3.41). Anecdotal evidence suggests this location is within the distribution of barramundi and freshwater sawfish. A dam at this location would provide a barrier to the upstream and downstream migration of numerous fish species and would therefore require a fish transfer facility.

Figure 5.17 indicates that the potential reservoir would inundate a mixture of dominant ‘of concern’, ‘not of concern’ and ‘non-remnant’ regional ecosystems.

No previous archaeological studies at this site have been located. However, results of investigations in the Gilbert catchment more generally indicate that the inundated area is likely to have high archaeological potential.

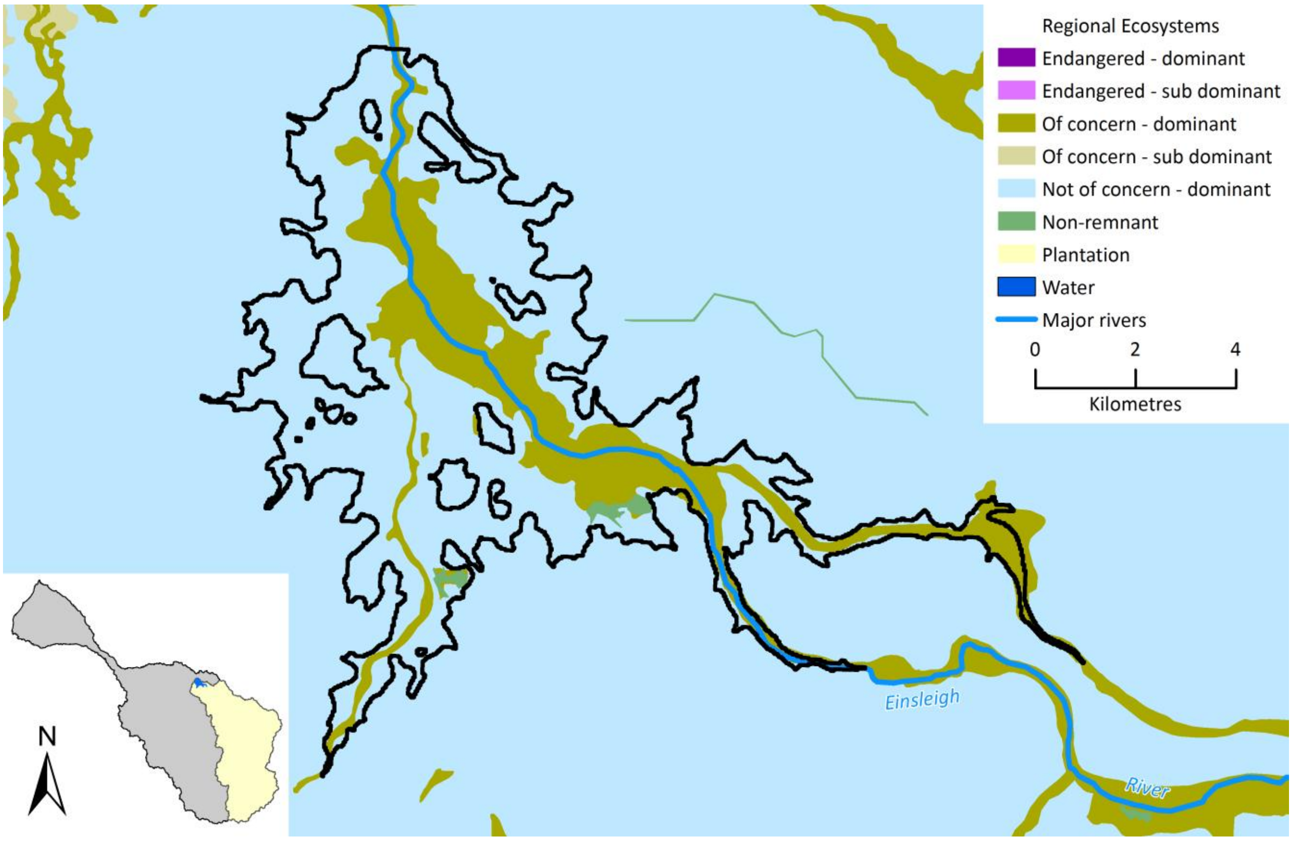

Figure 5.17 Regional ecosystems inundated by the potential Dagworth dam reservoir at full supply level

Green Hills

The Green Hills upstream site is the most suitable dam site on the Gilbert River. The site is geologically favourable and the dam has a relatively high yield (172 GL). The site is also close to moderately suitable soil. The reservoir created by the dam would inundate a large area of regional ecosystem ‘of concern’ and the dam wall would most likely impede the movement of barramundi and freshwater sawfish.

Two sites approximately 5 km apart had previously been identified on the Gilbert River near the Green Hills station, though the downstream site had received most attention. Following a site inspection and an assessment of both sites, the upstream site was selected for further investigation because of the large, previously unidentified saddle dam requirements at the downstream site.

The potential Green Hills upstream dam site commands a large catchment (about 8300 km^2) and it is close to moderately suitable alluvial soils adjacent to the Gilbert River. Limited surface mapping and seismic traverses of the upstream (and downstream) site had previously been undertaken. The site geology is favourable, with slightly weathered high-strength ignimbrite outcropping on both abutments. The dam would consist of a concrete gravity dam of roller compacted concrete construction with a central overflow spillway 20 m above the river bed. Four saddle dams would be required to contain the storage, particularly during flood events (flood design of the Green Hills dam sites was not undertaken in previous studies). The crest level of saddle dam number two would be set at a level to contain the 1 in 1000 year AEP peak flood level and would be expected to fail in the event of more extreme floods to create an auxiliary spillway. Crest level of saddle dam number three would be 0.5 m higher and would also be expected to fail in the event of a more extreme flood event, again to increase the auxiliary spillway discharge capacity. The viability of this arrangement will need to be confirmed by further analyses should this proposal be advanced further. A dam wall higher than 20 m would result in excessively large saddle dams.

The capital cost of the dam is estimated to be $335 million, not including the cost of any downstream distribution works. Annual operating and maintenance costs are likely to be relatively low for the type of dam proposed, although the site is remote from major service centres.

Figure 5.19a presents a cross-section of the ground surface along the dam axis and Figure 5.19b illustrates the relationship between the dam height, reservoir volume and reservoir surface area.

Figure 5.20 shows that a large proportion of the reservoir created by the potential Green Hills dam would be greater than 5 m in depth at FSL. In this figure a dam wall and saddle dams would be required to contain the reservoir at FSL where the reservoir touches the catchment boundary.

Figure 5.18 Green Hills upstream potential dam site, looking upstream
Photo: CSIRO.

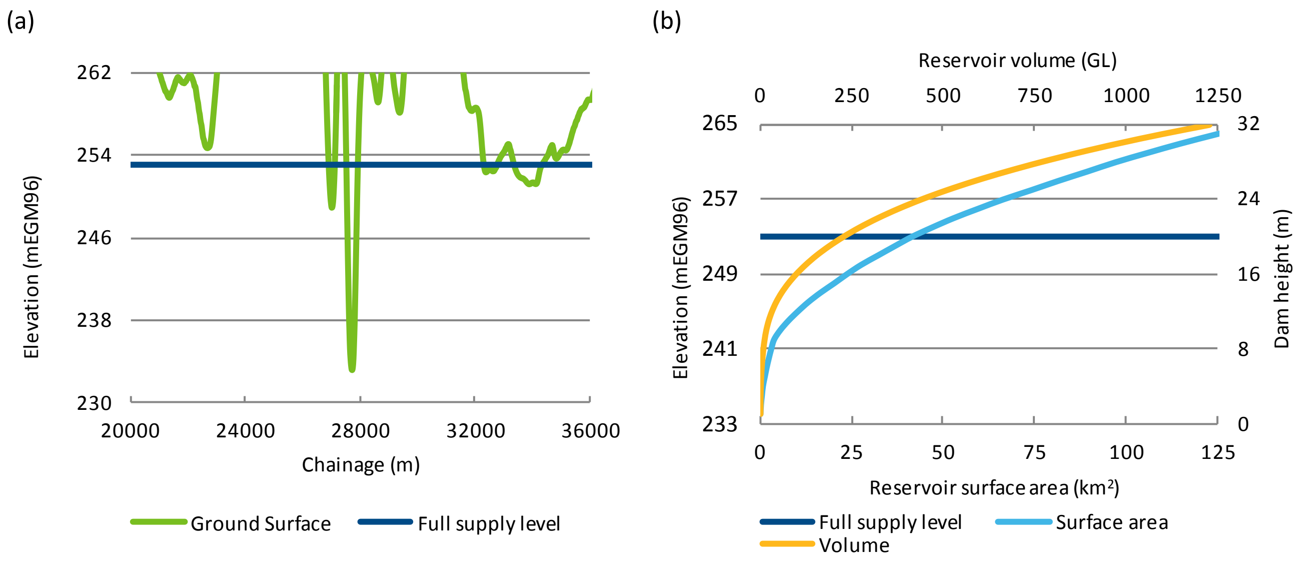

Figure 5.19 Dam cross-section, height, volume and reservoir surface area for Green Hills potential dam site
a) Cross-section of ground surface along dam axis; looking downstream. (b) Relationship between dam height, reservoir volume and reservoir surface area.

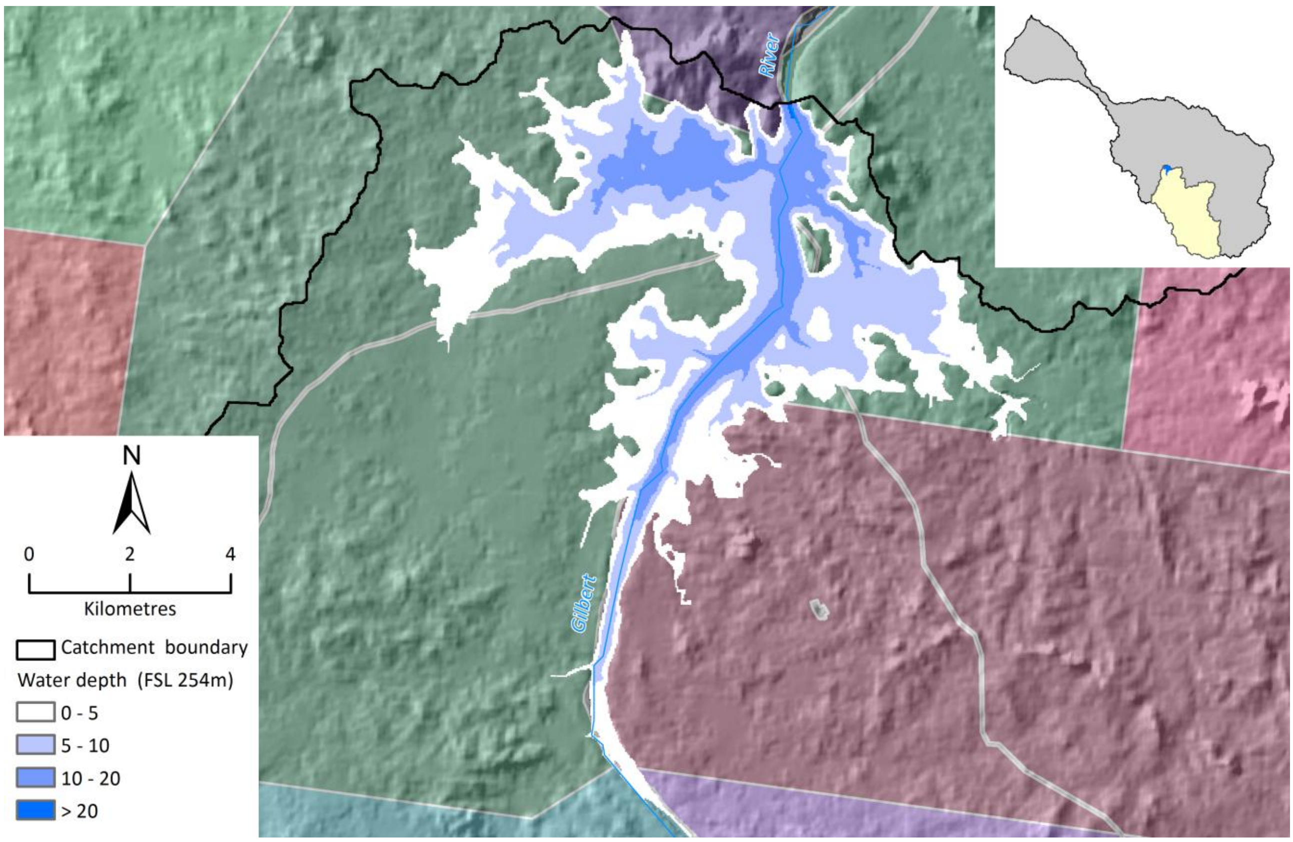

Figure 5.20 Green Hills upstream potential dam depth of inundation and property boundaries (indicated by coloured shading)

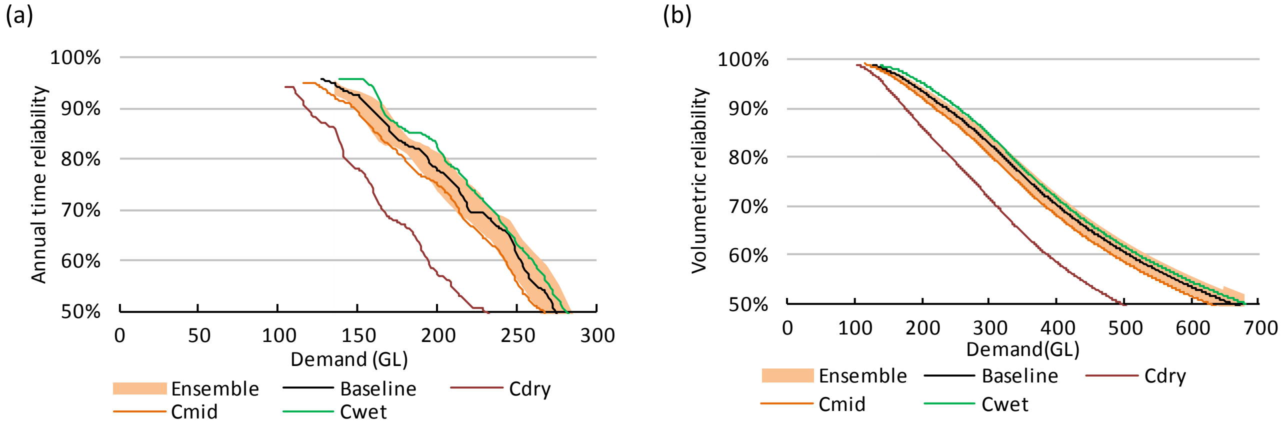

Figure 5.21 Annual time reliability and volumetric reliability for Green Hills dam under scenarios A and C
(a) Annual time reliability. (b) Volumetric reliability. The baseline (i.e. original) model under Scenario A is shown by the black line. The wet future climate (Cwet), mid future climate (Cmid) and dry future climate (Cdry) yield estimates were generated using the baseline model and future climate data. The orange shading indicates the 95% range of the 50 model ensembles under Scenario A. Yields are at the dam wall (i.e. they do not account for distribution losses).

Figure 5.21a shows the annual time reliability (the percentage of years that a given demand could be supplied by the reservoir) and the volumetric reliability (the total volume of water supplied expressed as a percentage of the total volumetric demand) of the reservoir created by a dam at the Green Hill site. Under Scenario A for the baseline model, the yield of the reservoir was approximately 172 GL at 85% annual time reliability. The ensemble of models had a 95% range of 160 GL to 180 GL at 85% annual time reliability. The ensemble of models provides an estimate of the uncertainty in the water yield as a result of uncertainty in the streamflow data.

The favourable physiographic constriction of the river channel at the Green Hills site, the high dam wall and broad valley upstream of the potential dam site enable a reservoir with a large volume and a relatively small evaporative loss – that is, ratio of evaporation to water supplied is approximately 0.2 (at 85% annual time reliability) or evaporation is approximately 18% of the regulated flow (regulated flow is the sum of the evaporation losses and water supplied).

Figure 5.22 illustrates the difference in the coastal floodplain area simulated as being inundated without Green Hills dam and with Green Hills dam empty prior to the 2001 and 2009 flood events. The construction of Green Hills dam could result in a small reduction in inundated area on the Gilbert floodplain during small flood events (Figure 5.22a). There would be no noticeable difference during large flood events (Figure 5.22b).

The reservoir created by a 20-m-high dam at the Green Hills site is likely to experience persistent thermal stratification with a top-to-bottom temperature difference of about 5 °C during most of the year from mid-September to mid-May (Petheram et al., 2013). However, summer inflow events during the months of February appear to cause short-term deep mixing of the water column. The risk of blue-green algal blooms is moderate to high. The water column is predicted to be poorly mixed during periods of stratification each year when dissolved oxygen concentrations fall. Inflow-induced deep mixing during summer inflows is expected to resupply oxygen to the deeper waters and low dissolved oxygen with associated nutrient and metal releases from the sediments is less likely to be experienced in most years in Green Hills reservoir than in reservoirs not experiencing summer mixing events.

The Green Hills potential dam site hosts much less instream habitat than similarly-located dam options on the Einasleigh River (Figure 3.41). Anecdotal evidence suggests this location is within the distribution of barramundi and possibly freshwater sawfish. A dam in this location may therefore require a fish transfer facility. Figure 5.23 indicates that the potential reservoir would inundate a mixture of dominant 'of concern' and 'not of concern' regional ecosystems.

No previous archaeological studies at this site have been located. However, results of investigations in the catchment more generally indicate that the area is likely to have high archaeological potential.

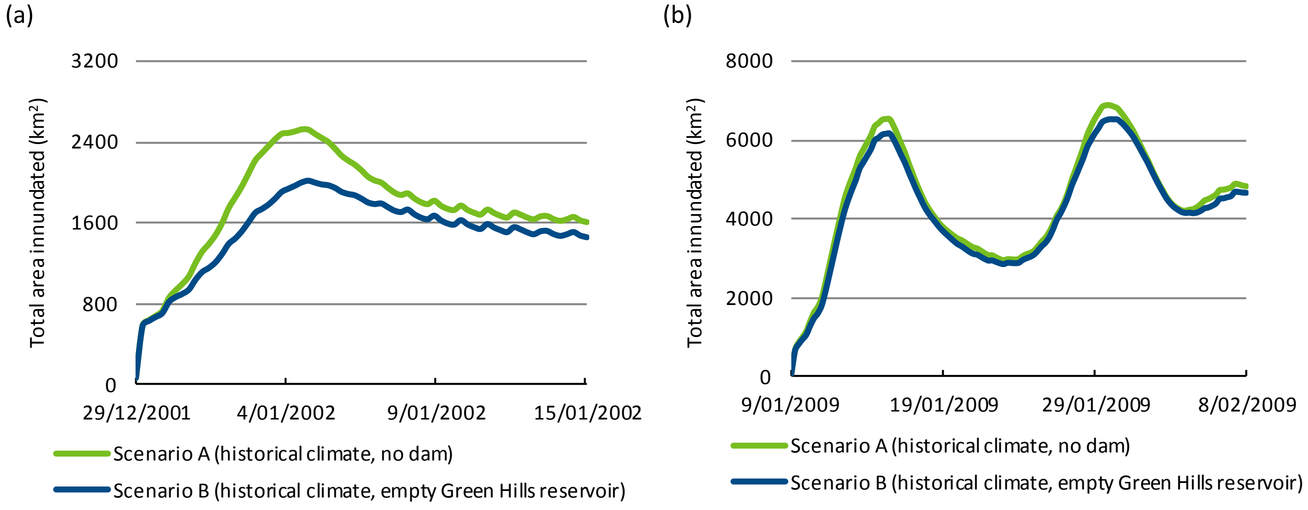

Figure 5.22 Comparisons of inundated area with and without construction of Green Hills dam under Scenario A
(a) For an event in 2001 (equivalent to 1-in-4 year event at gauging station 917009A). (b) For an event in 2009 (equivalent to 1-in-32 year event at gauging station 917009A). Gauging station locations are shown in Figure 3.29.

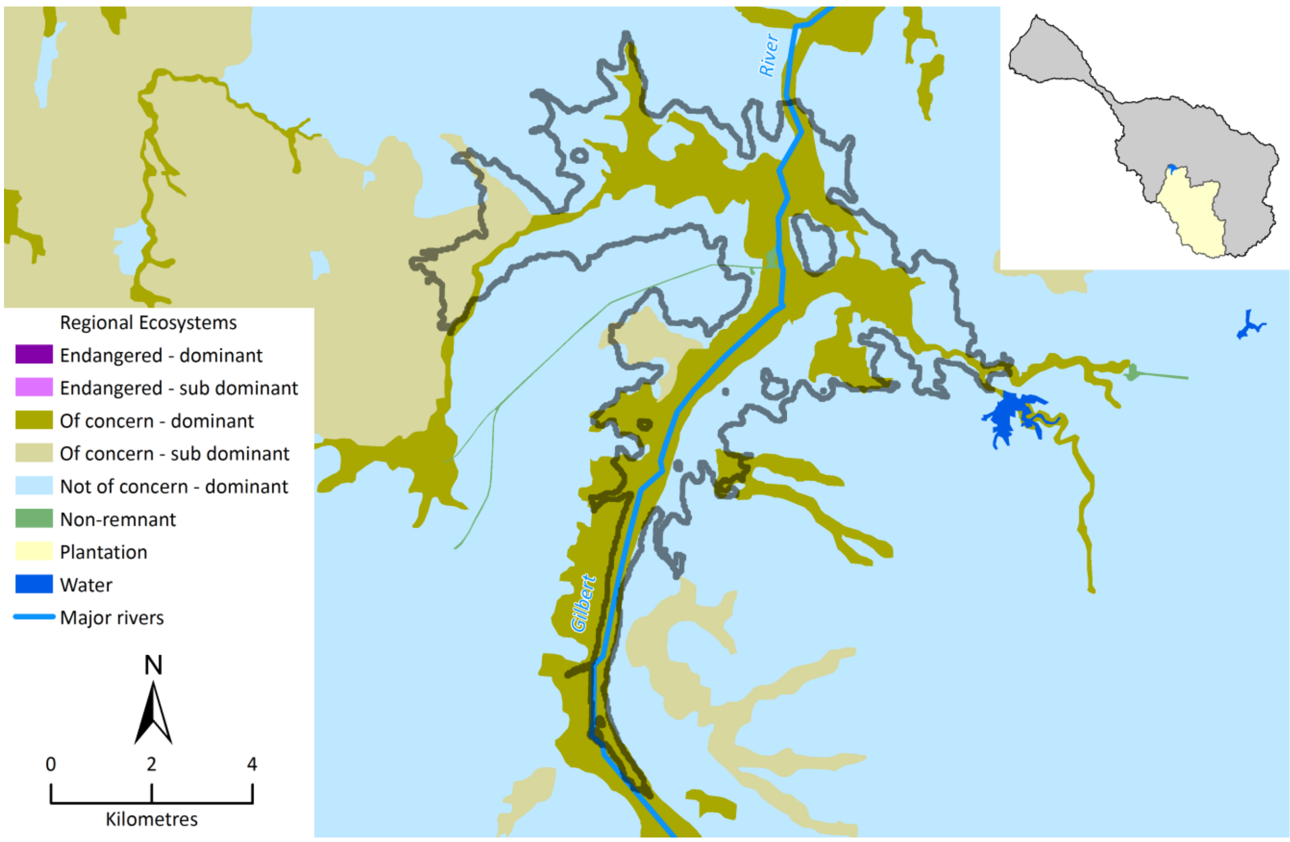

Figure 5.23 Regional ecosystem inundated by the potential Green Hills dam reservoir at full supply level

5.2.2 WEIRS AND RE-REGULATING STRUCTURES

Weirs differ from dams in that they are lower barriers located entirely within stream banks and are totally overtopped during flood events. No specific investigations of possible regulating weir sites have been undertaken in the Gilbert catchment. As a rule of thumb, however, weirs are constructed to half the bank height.

Downstream regulating weirs allow for more efficient releases from the storages and for some additional yield from the weir storage itself, thereby reducing the transmission losses normally involved in supplemented river systems.

Broadly speaking there are two types of weir structures, concrete gravity type weirs and sheet piling weirs. These are discussed below. For each type of weir, rock filled mattresses are often used on the stream banks extending downstream of the weir to protect erodible areas from flood erosion.

The Gilbert River below Green Hills dam is typically between 250 m and 500 m in width. The Einasleigh River below the confluence of the Einasleigh and Etheridge rivers is typically between 500 m and 1500 m in width. The bridges that span the Copperfield and Einasleigh rivers adjacent to the town of Einasleigh are approximately 120 m long. Hence a weir constructed in the lower reaches of the Gilbert and Einasleigh rivers would be the longest in Queensland. For this reason a brief discussion on 'sand dams' is also provided.

Weirs, sand dams and diversion structures obstruct the movement of fish in a similar way to dams.

Concrete gravity weirs

Where rock bars are exposed at bed level across the stream, concrete gravity type weirs have been founded on the rock at numerous locations across Queensland. This type of construction is less vulnerable to flood erosion damage, both during construction and while in service.

Sheet piling weirs

Where rock foundations are not available, stepped steel sheet piling weirs have been successfully used in many locations. These weirs consist of parallel rows of steel sheet piling, generally about six metres apart, with a step of about 1.5 to 1.8 m high between each row (Figure 5.24). Reinforced concrete slabs placed between each row of piling absorb much of the energy as flood flows cascade over each step. The upstream row of piling is the longest being driven to a sufficient depth to cut off the flow of water through the most permeable material.

Table 5.3 provides a preliminary cost estimate for sheet piling weirs, which, is the most likely weir option in the narrower parts of the mid to lower Gilbert and Einasleigh rivers.

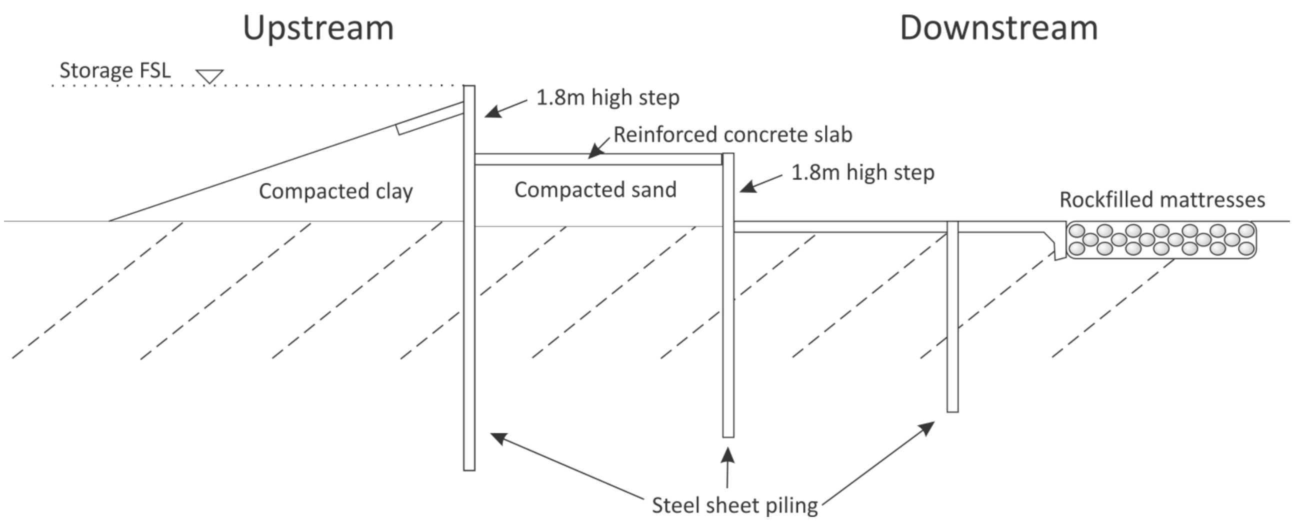

Figure 5.24 Schematic diagram of sheet piling weir
Storage full supply level (FSL) is the water level when the storage is full.

Table 5.3 Estimated construction cost of 3-m-high sheet piling weir

For a full list of assumptions, see the companion technical report about water storage options (Petheram et al., 2013).

WEIR CREST LENGTH (m)	ESTIMATED CAPITAL COST ($ million)
100	$24
150	$31
200	$37

These construction costs are sensitive to a number of factors, including:

- remoteness of location, which can result in higher freight and travel times
- piling costs, because piles are imported into Australia and therefore subject to currency exchange rates
- subsurface material – the presence of rock at shallow depth, for example, would require a different weir arrangement and could result in higher costs.

A full list of assumptions upon which these costs are based is provided in the companion technical report on water storage options (Petheram et al., 2013).

Annual operating costs are likely to be low depending on location. However, depending on the frequency and magnitude of flood events, significant costs could be involved from time to time in the repair of scour damage (e.g. replacement of mattresses). Weirs would also be at risk of infilling with sediment. Annual operating costs could average between 1 and 2% of capital costs.

Sand dams

Sand dams are low embankments built of river bed sands. They are constructed to form a pool sufficiently deep from which to pump water (i.e. typically greater than 4 m depth required) and are widely used in the Burdekin River near Ayr, where the river is too wide to construct a weir. Sand dams are constructed at the start of each dry season during periods of low or no flow when heavy earth moving machinery can access the bed of the river. Typically sand dams take three to four large excavators about two to three weeks to construct and no further maintenance is required until they need to be reconstructed again after the wet season. Bulldozers can construct a sand dam quicker than excavators but have greater access difficulties. Because sand dams only need to form a pool of sufficient size and depth from which to pump water, they usually only partially span a river and are typically constructed immediately downstream of large, naturally formed waterholes.

The cost of 12 weeks of hire for a 20 tonne excavator and float (i.e. transportation) is approximately $75,000. Although sand dams are cheap to construct relative to a concrete or sheet piling weir, they require annual rebuilding and have much larger seepage losses beneath and through the dam wall. No studies have been located that quantify losses from sand dams.

5.2.3 ON-FARM DAMS

On-farm dams are constructed on a single farm using earth embankments, and can take a number of forms, including gully dams, hillside dams, ring tanks, turkey nest tanks and excavated tanks (described in more detail in Table 5.4). The most suitable type of on-farm dam depends on various factors, including topography, the availability of suitable soils, excavation costs and source of water (i.e. groundwater or surface water pumping, flood harvesting).

Earth embankment on-farm dams are best located only in smaller drainage lines because they are highly susceptible to failure during large floods where spillway capacity could be exceeded.

Table 5.4 Types of on-farm water storages
Adapted from Lewis (2002).

TYPE OF ON-FARM DAM	DESCRIPTION	STORAGE TO EXCAVATION RATIO
Excavated tanks	Restricted to flat sites and comprise excavations below the natural surface. Excavated material is wasted. Generally limited to stock and domestic use and irrigation of high-value crops	Low
Gully dam	Gully dams consist of an earth embankment built across a drainage line. Dams are normally built from material located in the storage area upstream of dam site. Gully dams can also be used in conjunction with offstream water storages, where the weir is used to raise the upstream water level to allow diversion into an offstream storage or the creation of a pumping pool	10:1 (favourable conditions)
Hillside dam	An earth dam located on a hillside or slope and not in a defined depression or drainage line	5:1 (on flatter terrain) 1:1 (on steeper slopes)
Ring tank	A storage confined entirely within a continuous embankment built from material obtained within the storage basin	1.5:1 (small tank) 4.5:1 (large tank)
Turkey nest tanks	A storage confined entirely within a continuous embankment but built from material borrowed from outside the storage area. All water is therefore held above ground level	Usually smaller than ring tanks and lower storage to excavation ratio

Offstream storages, such as ring tanks (Figure 5.25), require water to be diverted or pumped from the river into the storage. Diverting water is advantageous because the pumping requirements and hence operating costs are typically lower than a storage that requires water to be pumped directly from the river. Maintenance of diversion infrastructure can be high, however, where considerable quantities of sediment and debris need to be removed. Diverting water requires a unique set of topographic circumstances and although some opportunities to divert water in the Gilbert catchment exist, in many instances water will need to be pumped directly from the river into the storage.

This section discusses the following aspects of offstream water storages:

- suitability for siting storages in the Gilbert catchment
- reliability of supply of water for water harvesting
- evaporative and seepage losses
- construction, operation and maintenance costs of offstream storages.

The Assessment does not seek to provide instruction on the design and construction of farm-scale water storages. Numerous books and online tools provide detailed information on nearly all facets of farm-scale water storage. For instructional information the reader is directed in the first instance to Lewis (2002) and IAA (2007). Siting, design and construction of farm-scale offstream storage should always be undertaken in conjunction with a suitably qualified professional and tailored to the nuances that occur at every site.

Figure 5.25 Ring tank in the Flinders catchment
Photo: CSIRO.

Reliability of supply of water for water harvesting

The exact nature and form of water harvesting licences is subject to policy decisions which are outside the scope of the Assessment. However, to guide potential water users on the reliability of supply from various water harvesting locations in the Gilbert catchment the Assessment explored a range of potential options based on four locations in the Gilbert catchment (917107A, 917102A, 917001D and 917111A) four commence to pump thresholds (i.e. the streamflow value above which pumping can commence) and five pump capacities (i.e. the maximum volume of water that can be extracted by a pump in a day). Commence to pump thresholds of 100 and 2000 ML/day are presented together with a range of pump capacities i.e. 500, 1000, 2000 and 3000 ML/day. Figure 5.26 and Figure 5.27 present results from downstream gauging stations on the Gilbert and Einasleigh rivers (Figure 3.29) and the results from streamflow gauging stations located in two headwater catchments are presented in Figure 5.28 and Figure 5.29.

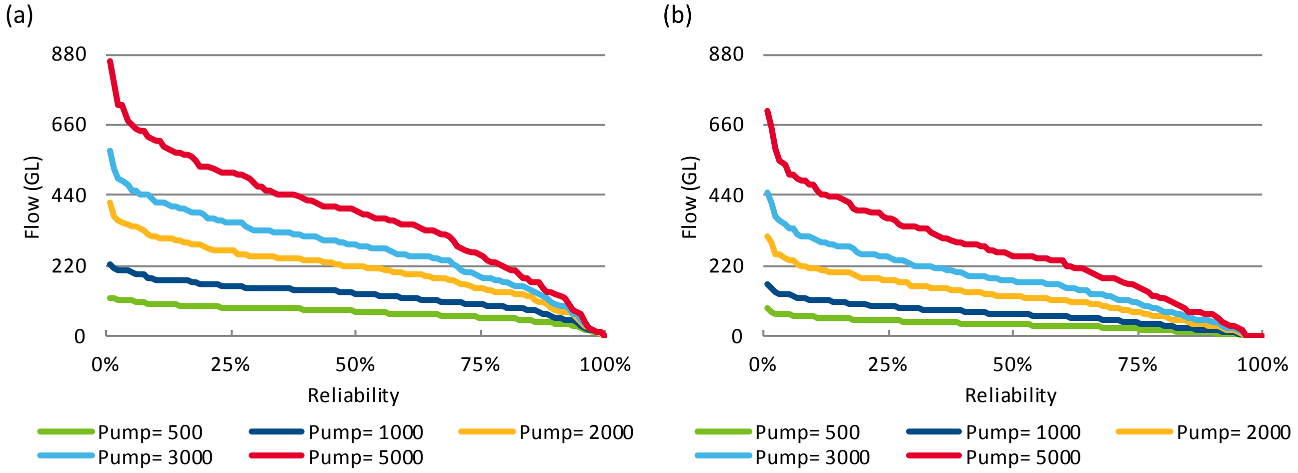

Figure 5.26 Annual volume of streamflow extracted versus annual time reliability for streamflow gauge 917111A
(a) Commence to pump threshold of 100 ML/day. (b) Commence to pump threshold of 2000 ML/day. Pump capacities are in ML/day.

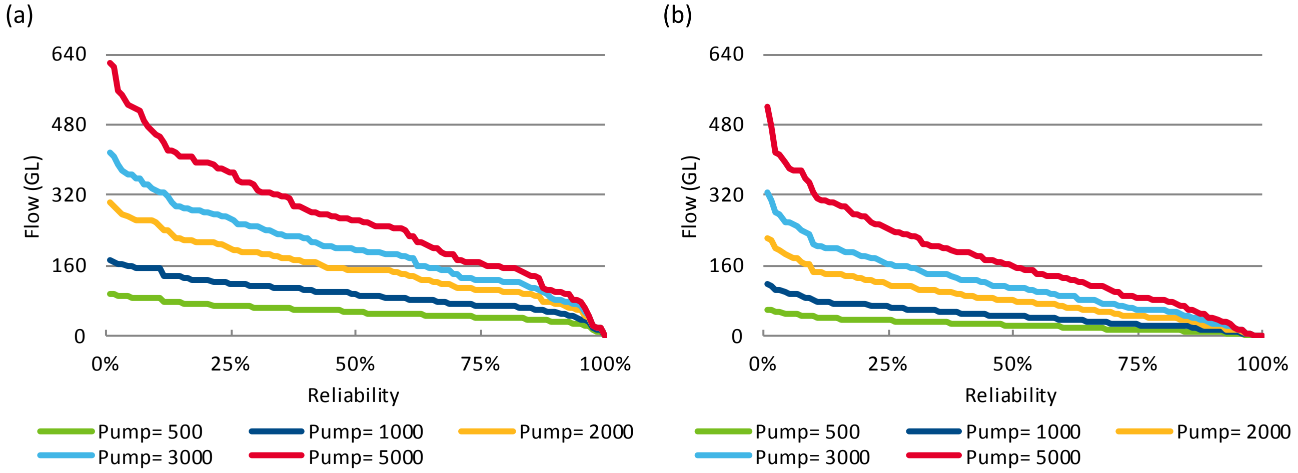

Figure 5.27 Annual volume of streamflow extracted versus annual time reliability for streamflow gauge 917001D
(a) Commence to pump threshold of 100 ML/day. (b) Commence to pump threshold of 2000 ML/day. Pump capacities are in ML/day.

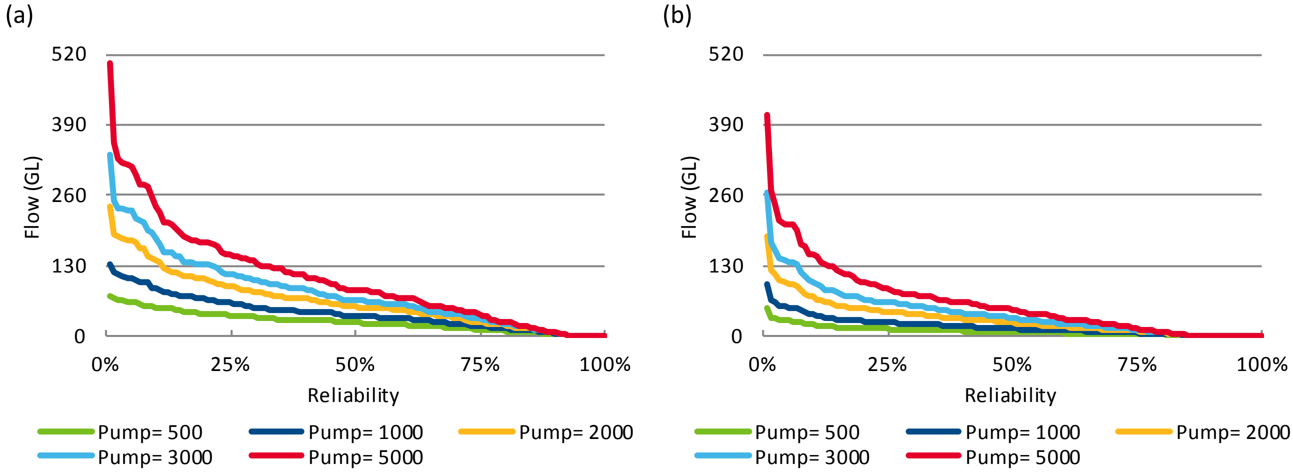

Figure 5.28 Annual volume of streamflow extracted versus annual time reliability for streamflow gauge 917102A
(a) Commence to pump threshold of 100 ML/day. (b) Commence to pump threshold of 2000 ML/day. Pump capacities are in ML/day.

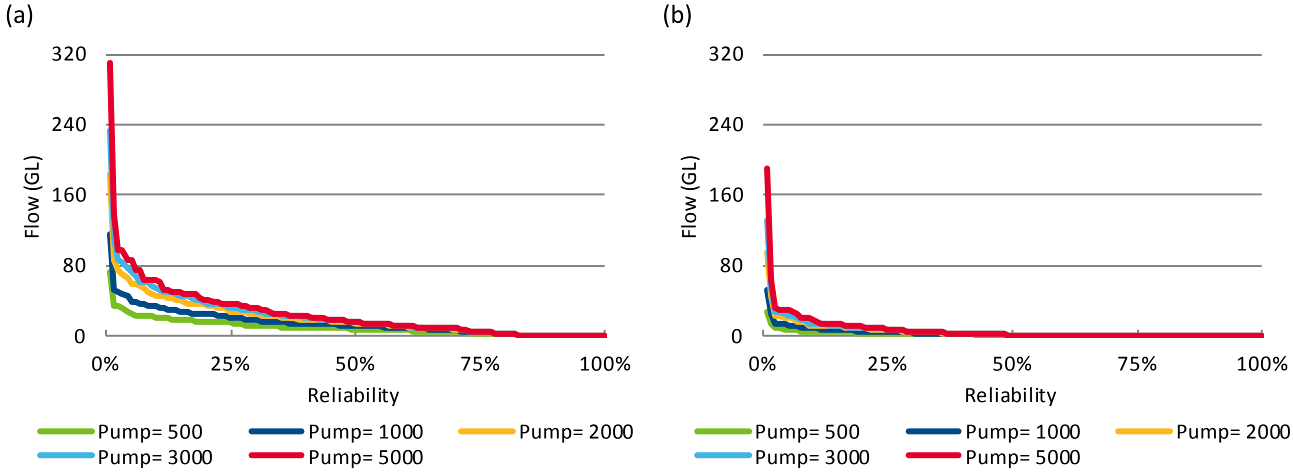

Figure 5.29 Annual volume of streamflow extracted versus annual time reliability for streamflow gauge 917107A
(a) Commence to pump threshold of 100 ML/day. (b) Commence to pump threshold of 2000 ML/day. Pump capacities are in ML/day.

The water harvesting figures show the reliability of extracting water at two thresholds for a range of pump capacities. The reliability is derived by choosing an annual water extraction on the y-axis and following that line across to the desired pump capacity, then following a vertical line to the x-axis. This gives the reliability of annual extraction. For example in Figure 5.26a, a 5000 ML/day pump can extract about 400 GL of water in 50% of years.

Collectively these water harvesting curves show some interesting behaviours:

- The pump curves converge on the x-axis. This represents the years when there is no flow to extract. For example in Figure 5.29a in about 30% of years there is no water to extract.
- The years where water cannot be extracted are strongly dependent on the commence to pump threshold. Comparing Figure 5.26a and Figure 5.26b shows that increasing the commence to pump threshold from 100 ML/day to 2000 ML/day does not significantly change the number of years where no water can be extracted.
- In some cases the increase in pump capacity does not increase the amount of water that can be extracted. This is because all of the water has been taken and consequently there is no more to take with a larger pump.

- The relationship between the commence to pump threshold and pump capacity is reasonably planar, i.e. for a higher commence to pump threshold the same reliability can be achieved by using a larger pump. However, the larger the pump the larger the capital cost of the pump.
- At lower percentage exceedance the volume of water extracted is directly related to pump capacity. At the lower percentage exceedance the streamflow events are extremely large and consequently the volume that can be taken is only limited by the size of the pump. At these low exceedance levels the streamflow events are large and water levels rise and fall quickly, i.e. the duration of the streamflow events is short.
- The reliability increases with catchment area, i.e. more downstream gauges are more reliable.

In using the water reliability curves presented in Figure 5.26 to Figure 5.29, the reader needs to recognise that these curves do not provide any indication of the sequencing of dry spells or events. Successive years without any water extraction will have a significant impact on the viability of a water user. The curves do not indicate when or how often water is extracted in a year. For example the volume of extraction does not distinguish between taking all of the water from a single event or from several events across a year. This may have implications on the cost of infrastructure required to store the water to obtain a sufficiently reliable supply.

Suitability assessment of offstream dams in the Gilbert catchment

Above the confluence of the Gilbert and Einasleigh rivers a minority of the soils along the Einasleigh River may be suitable for siting offstream storages. The soils adjacent to the Gilbert River are highly permeable and are not likely to be suitable for offstream storages.

Figure 5.30 shows a desktop assessment of the suitability of offstream storages in the Gilbert catchment, based on available data from the top 1.5 m of the soil profile (Bartley et al., 2013). This assessment was based on soil depth, drainage, slope and regional geology mapping (see Petheram et al., 2013). It does not give consideration to the nature of subsurface material below 1.5 m, with the exception of general information from broad-scale geological mapping. Nor does the suitability assessment consider the impacts of flooding or proximity to rivers.

On-farm offstream storages require consideration at a scale finer than is possible to assess in a regional scale resource assessment. Hence the results presented here are only indicative of where suitable locations may occur. The design and construction of offstream water storages should be undertaken following a site investigation by a suitability qualified professional.

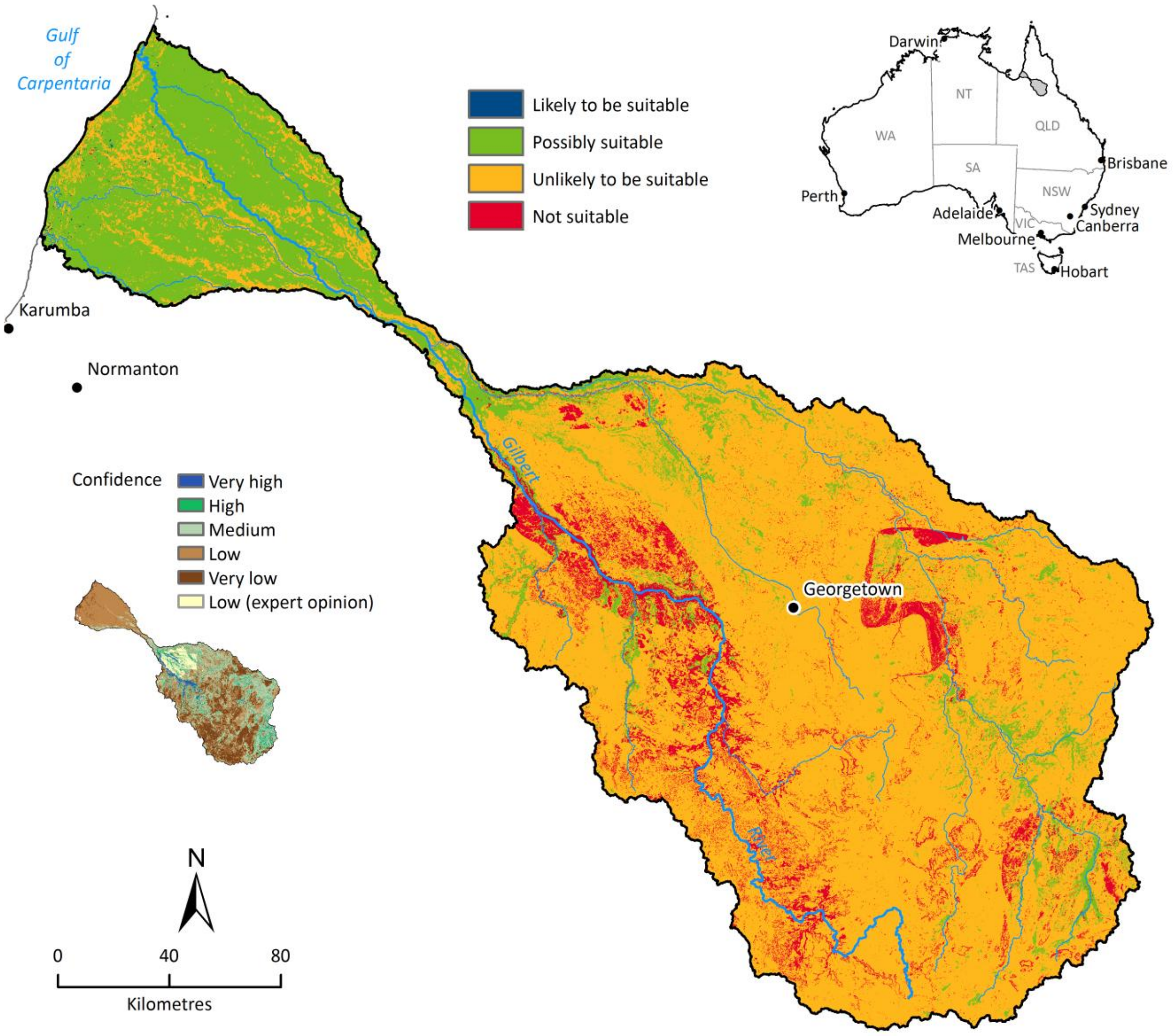

Figure 5.30 Land suitability map for offstream water storages in the Gilbert catchment
Information below 1.5 m is not available, thus the nature of subsurface material below that depth is not considered, with the exception of general information from broad-scale geological mapping. Flood risk is not considered.

Evaporative and seepage losses

Losses from an on-farm dam occur through evaporation and seepage. Mean daily evaporation losses from open water in the Gilbert catchment have been modelled to be between 4.5 and 6 mm (Petheram et al., 2013). When computing evaporative losses from a storage it is important to compute net evaporation (i.e. evaporation minus rainfall) rather than just evaporation. Strategies to minimise evaporation include liquid and solid barriers, but these are typically expensive per unit of inundated area (e.g. $10/m^2 to $26/m^2).

A reservoir constructed on suitable soils will have seepage losses equal to or less than 1 to 2 mm/day and losses will be greater than 5 mm/day if sited on less suitable (i.e. permeable) soils (IAA, 2007). The effect of evaporation and seepage loss on offstream storages is explored in Table 5.5.

Capital, operation and maintenance costs of offstream storages

The cost of an offstream storage scheme needs to include the cost of the water storage, pumping infrastructure, supply channels, levee banks and operation and maintenance of the scheme.

For a given storage capacity, the construction costs (and opportunity cost of land used in the construction) vary considerably, depending on the way the storage is built. For example, circular storages have a better storage volume to cost ratio than rectangular or square storages. It is also considerably more expensive to double the height of an embankment wall than double its length. Effective volume refers to the actual volume of water that could be used for consumptive purposes after losses due to evaporation and seepage. For example, if water is stored for 12 months and there is only 1 mm/day seepage loss, nearly half the stored volume would be lost to evaporation and seepage.

In the Gilbert catchment, the majority of streamflow has occurred by the end of March. Assuming the storage is full at this time, one strategy is to sow suitable crops during the late wet season (i.e. March) to minimise evaporative and seepage losses and enable crops to utilise existing soil water. Hence the configurations provided in Table 5.5 refer to a crop sown in March. Sorghum planted for hay is an example of a crop grown for about four months, sorghum planted for grazing an example of a crop grown for about six months and Rhodes grass, an example of a perennial crop. See Section 5.5 for sowing and growing dates for different crops in the Gilbert catchment.

Data in Table 5.5 are based on costs of $4/m^3 for earthworks. Recent estimates of costs for earthworks from companies in the Assessment area ranged from $3 to $5/m^3 (B Cornfoot and W Lillyman, 2013, pers. comm.) depending on the site. Ring tank construction costs in the Flinders were also reported at $4/m^3 by Mason and Larard (2011). Petheram et al. (2013) computed the cost of an 8000-ML storage, based on the design of SunWater (2009), to be $10 million.

Table 5.5 Construction costs for a 1000-ML storage based on costs of $4/m^3 for earthworks near Georgetown
Assumes a 4:1 storage to excavation ratio. Effective volume refers to the actual volume of water that could be used for consumptive purposes as a result of losses due to evaporation and seepage. Does not include cost of supply channels, levees or pumping infrastructure.

BANK HEIGHT (m)	AREA (ha)	CON-STRUCTION COST ($)	UNIT COST ($/ML)	SEEPAGE LOSS (mm/day)	EFFECTIVE VOLUME (ML)	EFFECTIVE UNIT COST ($/ML)	EFFECTIVE VOLUME (ML)	COST ($/ML)	EFFECTIVE VOLUME (ML)	EFFECTIVE UNIT COST ($/ML)
					4 months (March to June)		6 months (March to August)		12 months	
5	25	$1,000,000	$1000	1	866	$1155	791	$1264	607	$1648
5	25	$1,000,000	$1000	2	836	$1197	745	$1342	516	$1940
5	25	$1,000,000	$1000	5	744	$1344	607	$1647	242	$4136

In Table 5.6 the cost of an offstream storage includes the cost and operation of pumping infrastructure, but ignores the cost of supply channels and levee banks, which will vary from one station to the next.

This analysis makes the following assumptions (see Brennan McKellar et al. (2013) for more details).

- Pumping infrastructure costs $850/ML per day and to fill the storage in most years the pumps have to extract the required water in only five days (see Holz et al. (2013)).
- The cost of pumping is $16/ML (or $11/ML after a fuel rebate of $0.38/L) (assumes about a 10-m head is required; see Section 5.3.5).
- The water storage has a life span of 40 years and operation and maintenance costs are 1% of the capital costs.
- The pumping infrastructure has a life span of 15 years and an operation and maintenance cost of 2% of capital costs.
- A discount rate of 7%.
- Residual value calculated using straight line depreciation approach.
- 15-year investment time frame.

Table 5.6 Equivalent annual cost of the construction and operation of a 1000-ML ring tank and 100 ML/day pumping infrastructure assuming a real discount rate of 7%

ITEM	CAPITAL COST ($)	LIFESPAN (y)	EQUIVALENT ANNUAL CAPITAL COST ($)	ANNUAL OPERATION AND MAINTENANCE COST ($)
Offstream storage (ring tank)	$1,000,000	40	$75,000	$10,000
Pumping infrastructure	$170,000	15	$18,650	$3,400
Pumping cost (diesel)	NA	NA	NA	$16,000

Table 5.7 Equivalent annual cost per ML for storages with different seepage rates near Georgetown
Annual cost is the sum of the equivalent annual capital cost and operation and maintenance cost in Table 5.6. Effective volume refers to the actual volume of water that could be used for consumptive purposes after losses due to evaporation and seepage (Table 5.5). Annual unit cost is the annual cost per ML of effective volume of stored water.

BANK HEIGHT (m)	AREA (ha)	ANNUAL COST* ($)	SEEPAGE LOSS (mm/day)	EFFECTIVE VOLUME (ML)	ANNUAL UNIT COST ($/ML)	EFFECTIVE VOLUME (ML)	ANNUAL UNIT COST ($/ML)	EFFECTIVE VOLUME (ML)	ANNUAL UNIT COST ($/ML)
				4 months (March to June)		6 months (March to August)		12 months	
5	25	$123,000	1	866	$142	791	$155	607	$203
5	25	$123,000	2	836	$147	745	$165	516	$238
5	25	$123,000	5	744	$165	607	$203	242	$508

The total equivalent annual costs for the construction and operation of a 1000-ML ring tank and 200 ML/day pumping infrastructure is about $123,000 or $123 per ML of storage. In Table 5.7 the equivalent annual cost of the water yield from the offstream storage takes into consideration evaporation and seepage from the storage, which increase with the length of the crop growing season (i.e. time required to store water). In this table results are presented for the equivalent annual cost of water yield from an offstream storage for different seepage rates and lengths of time for storing water. See Section 5.5 for information on crop growing seasons in the Gilbert catchment.

For the large instream dams presented in Table 5.1, the lowest equivalent annual capital costs are for Dagworth and Green Hills dams, $102 per ML and $137 per ML, respectively, both at 85% annual time reliability. Including operation and maintenance costs – and assuming a 60% and 80% conveyance efficiency from Dagworth and Green Hills dam to the farm gate – results in an equivalent annual cost of about $160 per ML for each dam. This is considerably cheaper than the equivalent annual cost per ML of storing water in an offstream storage for 12 months, particularly considering the soils adjacent to the Gilbert River and many of the soils adjacent to the Einasleigh River are highly permeable and likely to have seepage losses greater than 5 mm/day (Figure 5.30).

5.3 Water distribution systems – conveyance of water from storage to the crop

In all irrigation systems, water needs to be diverted from rivers or dams through artificial and/or natural water distribution systems before ultimately being used on-field for irrigation. Some water diverted for irrigation is lost during conveyance to the field, before it can be used by a crop. These losses need to be taken into account when planning irrigation systems and developing likely irrigated areas. The amount of water that is lost during conveyance depends on the:

- river conveyance efficiency, from the water storage to the irrigation scheme
- channel distribution efficiency (within an irrigation scheme), from the river offtake to the farm gate
- on-farm distribution efficiency, in getting water from the farm gate to the field
- field application efficiency, which is the efficiency to which water can be delivered from the edge of the field and applied to the crop.

No irrigation system research has previously been undertaken in the Gilbert catchment and the time frame of the Assessment did not permit on-ground research into irrigation systems. Consequently, a brief discussion of the above items is provided based on relevant literature from elsewhere in Australia and overseas. Table 5.8 summarises the broad range of efficiencies associated with each of the above components. These components are examined in more detail in sections 5.3.1 to 5.3.4.

The total conveyance and application efficiency of the delivery of water from the water storage to the crop is dependent upon the product of the four components listed in Table 5.8. For example, if an irrigation development has a river conveyance efficiency of 80%, a channel distribution efficiency of 90%, an on-farm distribution efficiency of 90% and a field application efficiency of 85%, the overall efficiency is 55% (i.e. 80% * 90% * 90% * 85%). This means only 55% of all water released from the dam will be used by the crop.

Section 5.3.1 to Section 5.3.4 provide further detail on each of the efficiency terms listed in Table 5.8.

Table 5.8 Summary of conveyance and application efficiencies

COMPONENT	TYPICAL EFFICIENCY (%)
River conveyance efficiency	50 to 90%*
Channel distribution efficiency	50 to 95%
On-farm distribution efficiency	80 to 95%
Field application efficiency	60 to 90%

* River conveyance efficiency varies with a range of factors (including distance) and may be lower than the range quoted here. Under such circumstances, it is unlikely that irrigation would proceed. It is also possible for efficiency to be 100% in 'gaining' rivers. There are few gaining rivers in the Gilbert catchment.
** Achieving higher efficiencies requires a re-regulating structure (see Section 5.2.2).

5.3.1 RIVER CONVEYANCE EFFICIENCY

The conveyance efficiency of rivers is difficult to measure and even more difficult to predict. Although there are many methods for estimating groundwater discharge to surface water, there are few suitable methods for estimating the loss of surface water to groundwater. In the absence of existing studies for northern Australia, conveyance efficiency as nominated in Water Resource Plans and Resource Operation Plans for four irrigation water supply schemes in Queensland was examined collectively. The results are summarised in Table 5.9.

Water resource plans and resource operations plans prepared under the provisions of the Queensland *Water Act 2000* define the allocation volumes and priority of supplies provided from each water supply scheme in a catchment. Additionally, the plans detail water sharing rules which determine the allocation to be provided in those years when the available supply is insufficient to provide the full volume of allocation. The determination in each case takes into account the volume of storage at the particular time and losses such as evaporation from storages and distribution and operational losses.

It should be noted that the conveyance efficiencies listed in Table 5.9 are from the water storage to the farm gate and that these are nominated efficiencies, based on experience delivering water in these supply schemes. These data can be used to estimate conveyance efficiency of rivers.

Table 5.9 Water distribution and operational efficiency as nominated in water resource plans for four irrigation water supply schemes in Queensland

WATER SUPPLY SCHEME IN QUEENSLAND	TOTAL ALLOCATION VOLUME (ML)	RIVER AND CHANNEL CONVEYENCE EFFICIENCY* (%)	COMMENT
Burdekin Haughton	928,579	78%	The primary storage is the Burdekin Falls Dam (1860 GL), approximately 100 km upstream of Clare Weir, the major extraction point. The Bowen River, a major unregulated tributary of the Burdekin River, joins the Burdekin River downstream of Burdekin Falls Dam. This may assist in reducing transmission losses between the dam and Clare Weir.
Lower Mary	34,462	93.8%**	The Lower Mary irrigation area is supplied from two storages, a barrage on the Mary River and a barrage on Tinana Creek. Water is drawn directly from the barrage storages to irrigate land riparian to the streams. Water distribution is predominantly via pipelines.
Proserpine River	87,040	72%	The scheme has a single source of supply, Peter Faust Dam (491 GL). At various distances downstream of the dam, water is extracted from the river bed sands and is distributed to urban communities, several irrigation water supply boards and individual irrigators.
Upper Burnett	26,870	68%	The Upper Burnett is a long run of river scheme with one major storage (Wuruma Dam (165 GL)) and four weir storages. The total river length supplied by the scheme is 165 km.

* Ignores differences in efficiency between high and medium priority users and variations across the scheme zone areas.
** Channel conveyance efficiency only.

An analysis of streamflow data from across northern Australia as part of the Assessment did not identify any relationships that could be used to predict river conveyance efficiency. An analysis of a number of river reaches confirmed that the percentage loss of streamflow is higher for low streamflow values. Inflow from ungauged tributaries is one of the major confounding factors in trying to compute river conveyance efficiency between upstream and downstream gauging stations.

5.3.2 CHANNEL DISTRIBUTION EFFICIENCY

Across Australia, the average water conveyance efficiency from the river to the farm gate has been estimated to be 71% (Marsden Jacobs Associates, 2003). On the permeable soils and substrata of the Gilbert catchment (Section 3.3) achieving high conveyance efficiencies may be challenging without lined channels.

In the absence of larger scheme-scale irrigation systems in the Gilbert catchment, it is useful to look at the conveyance efficiency of existing irrigation developments in order to estimate the conveyance efficiency of irrigation developments in the Gilbert catchment. Australian conveyance efficiencies are generally higher than those found in similarly sized overseas irrigation schemes (Bos and Nugteren, 1990). Therefore, Australian data should be used in preference.

The most extensive review of conveyance efficiency in Australia was undertaken by the Australian National Commission on Irrigation and Drainage, which tabulated system efficiencies across irrigation developments in Australia (ANCID, 2001). Conveyance losses were reported as the difference between the volume of water supplied to irrigation customers and the water delivered to the irrigation system. For example, if 10,000 ML of water is diverted to an irrigation district and 8,000 ML is delivered to irrigators, then the conveyance efficiency is 80% and the conveyance losses are 20%.

Figure 5.31 shows reported conveyance losses across irrigation areas of Australia between 1999 and 2000, along with the supply method used for conveying irrigation water and associated irrigation deliveries. There is a wide spread of conveyance losses both between years and across the various irrigation schemes. Factors identified by Marsden Jacob Associates (2003) which affect the variation include delivery infrastructure, soil types, distance that water is conveyed, type of agriculture, operating practices, infrastructure age, maintenance standards, operating systems, in-line storage, type of metering used and third-party impacts such as recreational, amenity and environmental demands. Differences across irrigation seasons are due to variations in water availability, operational methods, climate and customer demands.

Based on these industry data, Marsden Jacob Associates (2003) concluded that on average 29% of water diverted into irrigation schemes is lost in conveyance to the farm gate. However, some of this 'perceived' conveyance loss may be due to meter underestimation (about 5% of water delivered to provider (Marsden Jacob Associates, 2003)). Other losses were from leakage, seepage, evaporation, outfalls, unrecorded usage and system filling.

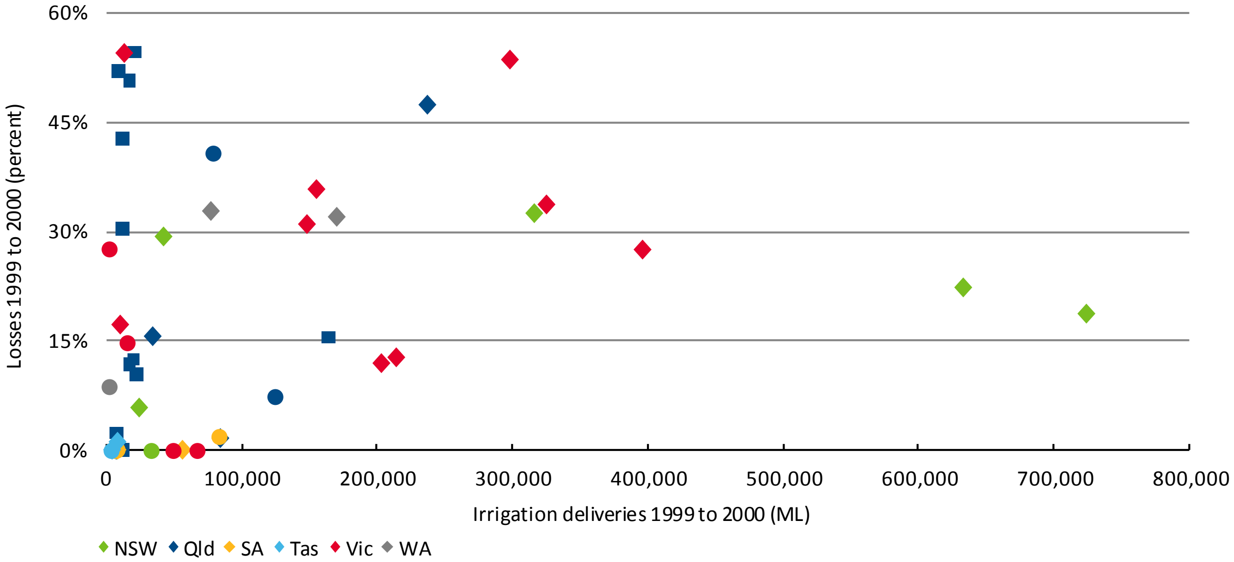

Figure 5.31 Reported conveyance losses from irrigation systems across Australia (ANCID, 2001)
The shape of the marker indicates the supply method for the irrigation scheme: square (▪) indicates natural carrier, circle (•) indicates pipe, and diamond (♦) indicates channel. The colour of the marker indicates the location of the irrigation system (by state), as shown in the legend.

5.3.3 ON-FARM DISTRIBUTION EFFICIENCY

On-farm losses are losses that occur between the farm gate and delivery to the field. These losses usually take the form of evaporation and seepage from on-farm storages and delivery systems. Even in irrigation developments where water is delivered to the farm gate via a channel, many farms have small on-farm storages (i.e. less than 250 ML for a 500 ha farm). These on-farm storages enable the farmer to have a reliable supply of irrigation water with a higher flow rate, and also enable recycling of tailwater. Several studies have been undertaken in Australia on on-farm distribution losses. Meyer (2005) estimated an on-farm distribution efficiency of 78% in the Murray and Murrumbidgee regions, while Pratt Water (2004) estimated on-farm efficiency to be 94% and 88% in the Coleambally Irrigation and Murrumbidgee Irrigation areas respectively. On nine farms in these two irrigation regions, however, Akbar (2000) measured channel seepage to be less than 5%.

5.3.4 FIELD APPLICATION EFFICIENCY

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

There are three types of irrigation systems that can potentially be applied in the Gilbert catchment: surface irrigation, spray irrigation and micro irrigation (Figure 5.32). Irrigation systems applied in the Gilbert catchment need to be tailored to the soil, climate and crops that may be grown in the catchment and matched to the availability of water for irrigation. This is taken into consideration in the land suitability assessment figures presented in Section 5.5. 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 (e.g. the cost of energy). Generally speaking the permeable soils of the Gilbert catchment are better suited to spray and micro irrigation systems than surface systems.

Irrigation systems have a trade-off between efficiency and cost. Table 5.10 summarises the different types of irrigation systems, including their application efficiency, indicative cost and their limitations. Across Australia the ratio of areas irrigated using surface, spray and micro is 83:10:7, respectively. Irrigation systems that allow water to be applied with greater control, such as micro, cost more (Table 5.10) and as a result are typically used for irrigating higher value crops such as horticulture and vegetables. For example, although only 7% of Australia's irrigated area uses micro irrigation, it generates about 40% of the total value of produce produced by irrigation (Meyer, 2005). Further detail on the three types of irrigation systems follows Table 5.10.

(a) (b) (c)

Figure 5.32 Efficiency of different types of irrigation systems
(a) In bankless channel surface irrigation systems, application efficiencies range from 60 to 85%. (b) In spray irrigation systems, application efficiencies range from 75 to 90%. (c) For pressurised drip irrigation system on polymer-covered beds, application efficiencies range from 80 to 90%. Photos: CSIRO.

Table 5.10 Application efficiencies for surface, spray and micro irrigation systems
Application efficiency is the efficiency with which water can be delivered from the edge of the field to the crop.

IRRIGATION SYSTEM	TYPE	APPLICATION EFFICIENCY (%)	CAPITAL COST ($/ha)*	LIMITATIONS
Surface	Basin	60 to 85%	$3400	Suitable for most crops; topography and surface levelling costs may be limiting factor
	Border	60 to 85%	$3400	Suitable for most crops; topography and surface levelling costs may be limiting factor
	Furrow	60 to 85%	$3400	Suitable for most crops; topography and surface levelling costs may be limiting factor
Spray	Centre pivot	75 to 90%	$2500 to $5500	Not suitable for tree crops; high energy requirements for operation
	Lateral move	75 to 90%	$2500 to $5000	Not suitable for tree crops; high energy requirements for operation
Micro	Drip	80 to 90%	$6000 to $9000	High energy requirement for operation; high level of skill needed for successful operation

Adopted from Hoffman et al. (2007), Raine and Bakker (1996) and Wood et al. (2007).
* Source: DEEDI (2011a, b, c).

Surface irrigation systems

Surface irrigation systems are not ideally suited to the permeable soils found in the Gilbert catchment. They are discussed here largely for completeness. Surface irrigation encompasses basin, border strip and furrow irrigation, as well as variations on these themes such as bankless channel systems. In surface irrigation, water is applied directly to the soil surface with check structures (banks or furrows) used to direct water across a field. Control of applied water is dictated by the soil properties, soil uniformity and the design characteristics of the surface system. Generally, fields are prepared by laser levelling to increase the uniformity of applied water and allow ease of management of water and adequate surface drainage from the field. The uniformity and efficiency of surface systems are highly dependent on the system design and soil properties, timing of the irrigation water, and the skill of the individual irrigator in operating the system. Mismanagement can severely degrade system performance and lead to systems which operate at poor efficiencies.

Surface irrigation has the benefit that it can generally be adapted to almost any crop and usually has a lower capital cost compared with alternative systems. Surface irrigation systems perform better when soils are of uniform texture as infiltration characteristics of the soil play an important part in the efficiency of these systems. Therefore, surface irrigation systems should be designed into uniform soil management units and layouts (run lengths, basin sizes) tailored to match soil characteristics and water supply volumes.

High application efficiencies are possible with surface irrigation systems, provided soil characteristic limitations, system layout, water flow volumes and high levels of management are applied. On ideal soil types and with systems capable of high flow rates, efficiencies can be higher than 85%. On poorly designed and managed systems on soil types with high variability, efficiencies can be below 60% (Table 5.10).

The major cost in setting up a surface irrigation system is generally land grading and levelling, with costs directly associated with the volume of soil that must be moved. Typical earth moving volumes are in the order of 800 m^3/ha but can exceeded 2500 m^3/ha. Volumes greater than 1500 m^3/ha are generally considered excessive due to costs (Hoffman et al., 2007).

Surface irrigation systems are the dominant form 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 5.11).

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 and -managed systems can approach efficiencies found with alternative irrigation systems in ideal conditions.

Surface irrigation systems are less suited to the permeable soils found in the Gilbert catchment.

Spray irrigation systems

Spray irrigation is well suited to the permeable soils of the Gilbert catchment. In the context of the Gilbert catchment, spray irrigation refers specifically to lateral move and centre pivot irrigation systems. Centre pivot systems consist of a single sprinkler, laterally supported by a series of towers. The towers are self-propelled and rotate around a central pivot point, forming an irrigation circle. Time taken for the pivot to complete a full circle can range from as little as half a day to multiple days depending on crop water demands and application rate of the system. Generally, lateral spans are less than 500 m.

Lateral or linear move systems are similar to centre pivot systems in construction but rather than move around a pivot point the entire line moves down the field in a direction perpendicular to the lateral. Water is supplied by a lateral channel running the length of the field. Lateral lengths are generally in the range of 800 to 1000 m. They offer the advantage over surface systems that they can be utilised on rolling topography and generally require less land forming.

Both centre pivot and lateral move irrigation systems have been extensively used for irrigating a range of annual broadacre crops and are capable of irrigating most field crops. They are generally not suitable for tree crops or vine crops or for saline irrigation water applications in arid environments which can create foliage damage. Centre pivot and lateral move systems usually have higher capital costs but are capable of very high efficiencies of water application. Generally, application efficiencies for these systems range from 75 to 90% (Table 5.10). They are used extensively for broadacre irrigated cropping situations in high evaporative environments in northern New South Wales and south-west Queensland. These irrigation developments have high irrigation crop water demand requirements similar to those found in the Gilbert catchment. A key factor in the suitable use of spray systems is sourcing the energy needed to operate these systems, which are usually powered by electricity or diesel depending on costs and infrastructure available. Where available, electricity is considerably cheaper than diesel at powering spray systems (Table 5.11).

In moving to pressurised systems such as spray or micro systems, the water can be more easily controlled, and potential benefits of the system through fertigation (application of crop nutrients through the irrigation system, i.e. liquid fertiliser) are also available to the irrigator.

Micro irrigation systems

For high-value crops in the Gilbert, such as horticultural crops, where yield and quality parameters dictate profitability, drip irrigation systems should be considered suitable across the range of soil types and climate conditions found in the Gilbert.

Micro (drip) irrigation systems use thin-walled polyethylene pipe to apply water to the root zone of plants via small emitters spaced along the drip tube. These systems are capable of precisely applying water to the plant root zone, thereby maintaining a high level of irrigation control and water use efficiency. Historically, drip 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. Drip irrigation is suitable for most soil types and can be practised on steep slopes. Drip irrigation systems are generally of two varieties: above ground and below ground (where the drip tape is buried beneath the soil surface). Below-ground drip 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 drip irrigation systems are capable of very high application efficiencies, with field efficiencies of 80 to 90% (Table 5.10). In some situations, drip systems offer water and labour savings and improved crop quality (i.e. more marketable fruit through better water control). Management of drip irrigation systems, however, is critical. To achieve these benefits requires a much greater level of expertise than other traditional systems such as surface irrigation systems which generally have higher margins of error associated with irrigation decisions. Drip 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.

5.3.5 IRRIGATION SYSTEM COSTS

The capital costs for surface irrigation reported in Table 5.10 include earthworks for a supply channel, head ditch, field land forming, and drainage (including tailwater return), as well as pumps and structures. Mason and Larard (2011) reported capital costs for surface (furrow) irrigation in the Flinders catchment to be $1482/ha. This is considerably less than the $3400/ha reported for surface irrigation in Table 5.10; however, the calculation of Mason and Larard (2011) omitted expensive items such as laser levelling (which costs between $300 and $650/ha (DEEDI, 2011a)) and tailwater return ($580/ha (DEEDI, 2011a)). These items significantly increase the capital cost of surface irrigation.

The capital costs associated with the purchase of a centre pivot or lateral move in Table 5.10 include the purchase of the machine and installation costs, such as earthworks. In addition to the cost of the machine, Table 5.10 includes the cost of other items such as pipe work, pumping equipment and the power plant (either diesel or electric). The unit cost ($/ha) of both centre pivots and lateral moves is generally less for machines servicing a larger area. The most significant influence on machine price is the pipe diameter of spans (DEEDI, 2011b). As for surface irrigation, other site-specific capital costs could include power lines (and connection), supply channels, laser levelling, land clearing and road construction. Laser levelling and land forming are often limited to cut to drain as opposed to cut to grade. These additional items can add up to 50% of the system cost (DEEDI, 2011b). Mason and Larard (2011), in a report conducted in the Gilbert catchment, estimated capital costs of pivot irrigation at approximately $4470/ha (which is in the range provided in Table 5.10), with $3800/ha for the centre pivot systems, and earthworks averaging around $670/ha.

Ongoing operational costs for all systems include pumping costs and general maintenance. Operation and maintenance of irrigation equipment is often costed at about 2% of the capital cost (Neil MacLeod, pers. comm.). These irrigation systems have various trade-offs between capital, operating and labour requirements. An important consideration in selecting an irrigation system is energy requirements, and this may become a more important consideration in the future if energy prices rise. Table 5.11 shows the variation in pumping costs for diesel and electricity for different irrigation systems. In addition, there are trade-offs between these costs and efficiency factors. Surface irrigation systems, for example, tend to have lower capital and annual operating costs, but are less efficient with higher water losses (Table 5.10).

Table 5.11 Pumping costs by irrigation type

	UNITS	FLOOD HARVESTING	SURFACE IRRIGATION	TAILWATER RETURN	CENTRE PIVOTS	LATERAL MOVES	SUBSURFACE DRIP
Flow rate	ML/day	120	120	50	8.6	24.2	16.6
Total dynamic head	m	7	6	5.5	50	35	50
Pumping plant efficiency	%	50%	50%	50%	66%	66%	75%
Power required	kWh/ML	38.9	33.3	30.6	210.4	147.3	185.2
Specific fuel consumption	L/kWh	0.25	0.25	0.25	0.25	0.25	0.25
Equivalent diesel requirement	L/ML	9.7	8.3	7.6	52.6	36.8	46.3
Pumping cost, electricity	$/ML	$7.0	$6.0	$5.5	$37.9	$26.5	$33.4
Pumping cost, diesel	$/ML	$10.9	$9.3	$8.5	$58.9	$41.2	$51.9

Adapted from Culpitt (2011), with costs based on assumption of $1.12/L for diesel ($1.50/L less $0.38/L rebate) and $0.18/kWh for electricity.

5.3.6 IRRIGATION SUPPLY WATER QUALITY CONSIDERATIONS

Water quality for irrigation will need to be carefully considered in any potential development and has an effect on irrigation system suitability and also potentially on water demands. Increased leaching fractions are needed if water quality is extremely poor, i.e. high levels of soluble salts are applied through irrigation water. Water quality data is sparse for the Gilbert catchment so it is difficult to draw conclusions on likely water quality from proposed developments. From the limited data available <http://watermonitoring.dnrm.qld.gov.au/host.htm> it would appear that existing water salinity measurements at gauging stations in the Gilbert catchment are generally below 0.75 dS/m and would be classified as a 'non to low' problem severity, see Table 5.12.

Table 5.12 lists other potential issues related to water quality and specifically to micro irrigation systems that will need to be considered when selecting appropriate irrigation systems for the Gilbert catchment. Without further detailed measurements of water quality parameters it is difficult to draw conclusions on the potential for clogging and specific ion toxicity problems within the catchment. However, potential irrigation developments will need to be aware of potential irrigation supply water quality issues that could limit irrigation system suitability in specific cases.

Table 5.12 Water quality limitations for micro irrigation systems (from Ayers and Westcott, 1985)

PROBLEM	RELATED CONSTITUENTS	UNIT	PROBLEM SEVERITY		
			NON TO LOW	SLIGHT TO MODERATE	HIGH
Clogging	pH		<7.0	7.0–8.0	>8.0
	Manganese	ppm	<0.1	0.1–1.5	>1.5
	Iron	ppm	<0.2	0.2–1.5	>1.5
	Hydrogen sulphide	ppm	<0.2	0.2–2.0	>2.0
	Suspended solids	ppm	50	50–100	>100
	Bacterial population	Count per mL	<10,000	10,000–50,000	>50,000
Crop sensitivity	Electrical conductivity*	dS/m or mmho/cm	<0.75	0.75–3.0	>3.0
	Nitrate-Nitrogen	ppm	<5	5–30	>30
Specific ion toxicity	Boron	ppm	<0.7	0.7–3.0	>3.0
	Chloride	meq/L	<4	4–10	>10
	Chloride	ppm	<142	142–355	>355
	Sodium	Adjusted sodium adsorption ratio**	<3.0	3.0–9.0	>9.0
Infiltration***	Adjusted sodium adsorption ratio**		Electrical conductivity of irrigation water		
	0–3		≥0.7	0.7– 0.2	<0.2
	3–6		≥1.2	1.2– 0.3	<0.3
	6–12		≥1.9	1.9– 0.5	<0.5
	12–20		≥2.9	2.9– 1.3	<1.3
	20–40		≥5.0	5.0– 2.9	<2.9

* Total dissolved solids in ppm (approximately) = 640 x EC (dS/m or mmho/cm).
** Adjusted sodium adsorption ratio: calculated based on concentrations of sodium, calcium, magnesium and bicarbonate to account for dissolution of calcium carbonate from the soil or precipitation of calcium carbonate from the water.
*** Affects infiltration rate of water into the soil. Evaluate using ECiw and Adj SAR together.

5.3.7 BEST MANAGEMENT PRACTICES FOR IRRIGATION SYSTEMS

Best management practices for the use of irrigation water can assist in increasing the efficiency and productivity of irrigation systems and help reduce or minimise off-site environmental impacts associated with irrigation systems. Generally, individual farms are unique in their biophysical characteristics and irrigation systems must be developed that are suitable for specific irrigation operations matching the soil, climate, water availability and crop needs. Irrigation best management practices include consideration of irrigation systems, irrigation scheduling, equipment operation, land levelling, tailwater and runoff recovery, tillage and residue management, and pesticide use, management and safety. Within the Gilbert catchment, water availability will be the limiting factor in irrigation development; hence efforts to adopt best practice irrigation management and focus on achieving high water use productivity will have the greatest benefit to the catchment. The supply and use of water for irrigation farming purposes is a complex activity that requires high levels of knowledge and expertise to achieve successful outcomes in terms of both farm profitability and minimising non-beneficial effects on surrounding environments. As such, with any irrigation development on greenfield sites, research, development and extension support networks should be developed. The community can use these networks to address potential issues as they arise and also ensure best management practices are being applied to maximise profitability for irrigators and minimise any off-site environmental impacts.

5.4 Land development for irrigation

Construction costs for an irrigation scheme comprise those associated with channels, drains, roads, siphons, regulating points, road and culvert crossings, road and rail boring, metered outlets, drainage inlets, and overflow and drainage structures. On-farm developments are excluded from scheme costs. Costs will be driven by the length of channels, drains and roads, and depend on the location and catchment size, and design capacity of the channel.

Costs for a notional scheme layout for the O’Connell Creek were reported by SunWater (2009). The development, which assumed broad-scale gravity irrigation for about 7000 ha of development, estimated the construction at $14,168/ha (adjusted to 2012 values) with approximately half of the cost represented by direct costs (earthworks, structures and roads for the supply channel and area works), and the remaining half made up of contractor and project overhead costs, which are calculated as a percentage of direct costs. Taking out the costs of the supply channel (20% of total costs), the development is approximately $8000/ha (adjusted to 2012 values) which was reported as being consistent with similar developments.

5.5 Cropping and other agricultural opportunities

5.5.1 THE OPPORTUNITY FOR CROPPING IN NORTHERN AUSTRALIA

The current value of irrigated agriculture in the northern draining catchments of Australia is in the order of $160 million annual production, which represents around 0.8% of the regional total economic activity. Employment currently generated by irrigated agriculture, directly and indirectly, is estimated to be approximately 1700 full-time equivalents. This represents around 1.3% of the region's total labour force. Environmental impacts, conflicts and synergies with a wide range of interests (Indigenous, tourism, recreation, conservation, mining and fishing) are all small because the irrigated area is also small (about 34,000 ha; <0.03% of northern Australia). Total agricultural water use in northern Australia is only 2% of Australia's agricultural total (Webster et al., 2009). From this small base, there are opportunities to increase the contribution of irrigated agriculture to the nation's food production potential.

There are also opportunities for irrigated agriculture to contribute significantly to regional development objectives. It has been estimated that the addition of each 10,000 ha of irrigated agriculture could, over 20 years, create over 450 full-time jobs and increase regional population by over 700 people, thereby adding over $61 million to gross regional product (Webster et al., 2009).

Irrigated agriculture also provides for economically intensive use of agricultural land; irrigated production accounts for about half the area devoted to cropping in northern Australia, yet it provides over 75% of the value of agricultural production. Of course, dryland agriculture also offers opportunities, either where or when irrigation is not possible or where cost structures favour dryland over irrigated production.

The opportunity presented by irrigated agriculture in northern Australia in general, and the Gilbert catchment in particular, is not new. There is currently around 360 ha of irrigated cropping (field and fodder crops) and horticulture in the catchment. Beyond the Gilbert catchment there have been, since the end of World War II, six large-scale agricultural developments in northern Australia. Many did not meet the unrealistic expectations of the time. The reasons for their inability to meet expectations included poor agronomic practices; poor administration; severe climatic hazards; poor agronomic knowledge of the soils and crop responses to the environment; unreasonable production targets; inefficient labour use; poor site selection; lack of sufficient water; poor water control leading to erosion; soil nutrient deficiencies; high costs due to isolation; excessive capital expenditure; use of unsuitable soils; and unrealistic expectations for market price (Fischer et al., 1977).

Further analysis of the six major attempts at irrigated agriculture in northern Australia suggested that success required expansion through smaller developments, coupled with a research program focused on the potential broad-scale (i.e. whole of system) agriculture challenges, allowing operators to use adaptive management to learn-as-they-go, use resources efficiently and minimise economic and climate risk (Fischer et al., 1977). The Assessment addresses many of these issues, and this section focuses on consideration of cropping opportunity and risk in the Gilbert catchment.

5.5.2 QUANTIFYING OPPORTUNITIES FOR CROPPING IN THE GILBERT CATCHMENT

There is currently limited dryland or irrigated cropping in the Gilbert catchment and consequently there is limited experiential knowledge of crop growing seasons, yields or water usage. The agricultural landscape is currently dominated by the cattle industry, which uses extensive natural pasture grazing to supply beef cattle predominantly to export markets (see Section 4.6.2).

Fortunately, direct experience of cropping in the area is not a prerequisite for understanding yield potential or risk. Each can be estimated using the Agricultural Production Systems Simulator (APSIM) crop model (Keating et al., 2003 and described in the companion technical report about agricultural production (Webster et al., 2013)). APSIM is structured around plant, soil and management modules and provides accurate predictions of crop production potential in relation to climate, genotype, soil and management factors while addressing long-term resource management issues.

While APSIM has provided highly accurate estimates of crop and pasture yield potential for a wide range of environments around the world, it is important to note that it estimates potential rather than actual yields. Potential yields are often, but not always, higher than actual yields, for a range of reasons:

- potential yields assume optimum agronomic management; that is, no impact of pests, diseases or any abiotic stress
- major episodic events such as cyclones and flooding are not accounted for
- for irrigated crops, crop yields are ‘produced’ under unlimited water, with no periods of water stress during crop establishment or growth. Dryland crops are ‘produced’ using available rainfall data and estimates of stored soil water.

It is very important to recognise that actual yields are highly dependent on the critically important yet difficult to define trait of ‘management skill’, the process by which the best decisions and actions occur at the best time. This grows with experience and, until it reaches a high level, the challenges associated with the relative lack of cropping experience in the Gilbert catchment should not be underestimated. Until a pool of expertise develops, built over several years and able to anticipate challenges that in the first instance 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’, usually closes slowly over time, and this needs to be factored into individual enterprise plans.

The companion technical report about agricultural productivity (Webster et al., 2013) provides more detailed information on factors that make actual yields lower than potential yields. Further discussion of these challenges can be found in sections 5.5.6 to 5.5.15 of this chapter.

5.5.3 THE CROPPING ENVIRONMENT IN THE GILBERT CATCHMENT

The Gilbert catchment offers a challenging agricultural environment. A brief overview is provided here, with detailed data and analyses available in the companion technical reports about climate (Petheram and Yang, 2013) and land suitability (Bartley et al., 2013).

Rainfall varies from 650 mm in the south-east of the catchment to 1050 mm at the coast, with a mean annual spatial average of 775 mm. Most of the rainfall (93%) occurs in the wet season and 84% of that evaporates, so that only 13% of the rainfall makes its way to streamflow. Potential evaporation averages 1868 mm each year, which is 2.4 times the average rainfall. While potential evaporation varies little from year to year, rainfall has a very high inter-annual variability. For a region with 775 mm average rainfall, the Gilbert catchment has among the most variable rainfall in the world (coefficient of variation = 0.4). This becomes manifest in the occurrence of dry runs (years with significantly below average rainfall, or drought). Dry runs are not significantly more common or longer in the Gilbert catchment than in most of Australia’s other cropping regions but they are significantly more intense. This is further exacerbated by high potential evaporation. The Gilbert catchment is, for crops, a water limited environment in which water stored in dams and soils is at a premium.

The soils of the Gilbert catchment are largely sandy loams, which have only moderate water holding capacity. The better soils in the Gilbert catchment hold between 100 and 150 mm of soil water. This means that frequent irrigation is required to prevent soil drying out, and that dryland crops require in-season rainfall to survive. The sandiness of most soils in the Gilbert catchment renders them largely unsuitable for flood irrigation because of high soil permeability. Deeper soils tend to occur along river frontages. Towards the coast, the soils include large areas of seasonally wet soils that are unsuitable for cropping. Further detail on the soils of the Gilbert catchment can be found in the companion technical report by Bartley et al. (2013).

Section 5.5.4 discusses the potential for dryland cropping in the Gilbert catchment. Dryland cropping may be pursued either as a stand-alone enterprise or in combination with irrigated agriculture. Irrigated agriculture in the Gilbert catchment is discussed from sections 5.5.5.

Unless otherwise stated, the material in Section 5.5 originates from companion technical report about agricultural productivity (Webster et al., 2013).

5.5.4 POTENTIAL FOR DRYLAND AGRICULTURE IN THE GILBERT CATCHMENT

Dryland production (farming without irrigation) comprises virtually all of the agriculture currently practised in the Gilbert catchment. Primarily, rainfall is used to grow extensive pastures for cattle. Some cattle producers also plant forage crops which are either fed directly to cattle, or are cut and baled as hay to be fed to cattle at a later date. There is almost no dryland cropping for human food or fibre production in the Gilbert catchment.

Dryland farming is wholly dependent on water stored in the soil and rainfall occurring during crop growth. The high variability of rainfall, combined with the relatively small water storage provided by its soils, means that continuous year-on-year dryland cropping is unlikely to be possible in the Gilbert catchment. Opportunistic cropping, pursued when conditions are favourable, is likely to provide the most profitable and sustainable approach to dryland cropping. Fortunately, the highly seasonal rainfall of the Gilbert catchment should make it possible to readily identify years in which conditions are favourable.

The annual cropping calendar in Table 5.16 shows that, for many crops, the sowing window includes the month of February. For relatively short-season crops such as sorghum and mungbean, this coincides with both the sowing time that provides for maximum yield (e.g. Figure 5.38) and the time at which the season's water supply can be most reliably assessed. In February, the contribution of previous rainfall to stored soil water is readily apparent. The prospects of future rainfall can be assessed with a high degree of confidence in February. On average, significant rainfall is expected in February and March (approximately 200 and 100 mm, median, respectively, spatially averaged across the catchment), and the rainfall likely in a given year can be assessed using seasonal rainfall outlooks, which have high levels of 'skill' (reliability) in the Gilbert catchment at this time of year. Data for the Gilbert catchment suggest that rainfall received is consistent with predictions (above or below median) approximately 75% of the time. This is the highest degree of forecasting skill found in Australia (BoM, 2013).

Table 5.13 shows how soil water content at sowing and rainfall in the 90 days after sowing are likely to vary for three different sowing dates. The soil water content is generally high by the end of January increasing to the end of February and decreasing again to the end of March. The amount of rainfall that can be expected after sowing is highest for the end of January, and decreases for the end of February and March sowing dates. 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 is sufficient to grow a good short-season crop. For 'drier than average years' (80th percentile exceedance), the soil water stored at sowing and the expected rainfall in the ensuing 90 days will result in water stress and comparatively reduced yields. Table 5.13 highlights 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.

As outlined above, opportunistic dryland cropping in the Gilbert catchment is favoured by the fact that the information required to make decisions about cropping opportunity and risk becomes most reliable at precisely the time when decisions about planting most need to be made. For many crops that are well adapted to the Gilbert catchment (e.g. maize, sorghum, mungbean, millet, capsicum, melon, sweet corn, peanut, and others) the scale of cropping opportunity is clearly distinguishable at the key 'to sow or not to sow' decision point. This is a major enabler of cropping in a highly variable environment, as it permits growers to distinguish the years in which they are most likely to make a profit from the years in which they are least likely to make a profit. Observing the discipline of not planting in less favourable years is likely to be a critical determinant of the economic viability of dryland cropping in the Gilbert catchment.

Table 5.13 Soil water content at sowing and rainfall for the 90-day period following sowing for three sowing dates (Georgetown)

The 20th percentile, 50th percentile (median) and 80th percentile exceedance values are reported, for the 121 years from 1890 to 2011.

SOWING DATE	SOIL WATER CONTENT AT SOWING DATE (mm)			RAINFALL IN 90 DAYS FOLLOWING SOWING DATE (mm)		
	20th	50th	80th	20th	50th	80th
31 January	179	143	94	500	361	219
28 February	183	150	138	259	126	43
31 March	153	138	136	76	26	4

The actual seasons in which growers will find cropping most or least profitable will vary among farms, which vary in physical attributes, management style and cost structures. As a guide, analysis of gross margins for dryland crops grown at Georgetown indicates that break-even crop yields could be expected more than 9 years in 10 for dryland mungbean, approximately 3 years in 10 for dryland sorghum (grain) and fewer than 2 years in 10 for dryland cotton (Table 5.14).

These data are based on crop yields modelled over a 121-year period (1890–2011, as per the companion technical report about agricultural productivity (Webster et al., 2013)). Figure 5.33 to Figure 5.35 show the yield of selected dryland crops grown at Georgetown and how they compare with fully irrigated crops modelled in the same climate on the same soil.

Figure 5.33 shows that, in the Gilbert catchment, fully irrigated crops of mungbean significantly and consistently outperform those of dryland crops, most often by a factor of two. Second, it shows that in 50% of years, dryland mungbean crops would be expected to yield more than 0.7 t/ha and that potential crop yields of at least 0.5 t/ha could be achieved in almost every year. The break-even crop yield for dryland mungbean grown in Georgetown is estimated to be approximately 0.4 t/ha (Table 5.14); this could be expected to be met or exceeded in approximately 97% of years.

Figure 5.34 shows that, in the Gilbert catchment, fully irrigated crops of sorghum (grain) outperform those of dryland crops, most often by a factor of two to three. Second, it shows that in 50% of years dryland sorghum (grain) crops would be expected to yield more than 3.8 t/ha and that potential crop yields of at least 2.0 t/ha could be achieved in almost every year. The break-even crop yield for dryland sorghum (grain) grown in Georgetown is estimated to be approximately 4.9 t/ha (Table 5.14); this could be expected to be met or exceeded in approximately 25% of years.

Figure 5.35 shows that, in the Gilbert catchment, fully irrigated crops of cotton significantly and consistently outperform those of dryland crops, most often by a factor of three to four. Second, it shows that in 50% of years dryland cotton crops would be expected to yield more than 1.8 bales/ha and that potential crop yields of at least 1 bale/ha could be achieved in almost every year. The break-even crop yield for dryland cotton grown in Georgetown and delivered to the Emerald gin is estimated to be approximately 7.3 bales/ha; this could be expected to be met or exceeded in approximately 5% of years. The break-even crop yield for cotton delivered to a local gin is estimated to be 3.1 bales/ha; this could be expected to be met or exceeded in approximately 30% of years.

This data indicate the variability in crop yield that could be expected from each of these and other crops. Median crop yield data for a wide range of crops can be found in the descriptions of specific crops that follow in sections 5.5.6 to 5.5.15, and in Table 5.14.

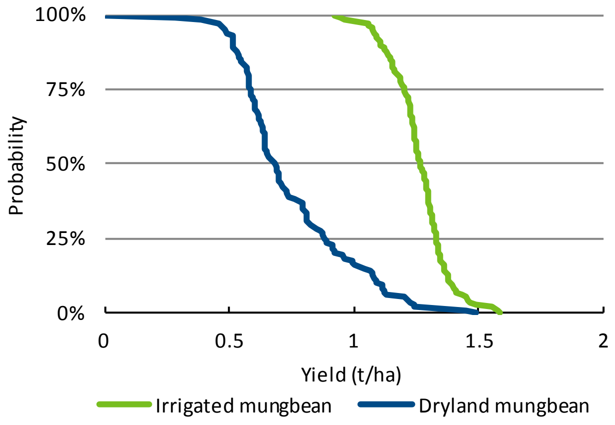

Figure 5.33 Probability of crop yield potential for dryland and fully irrigated mungbean sown in Georgetown climate on 15 February

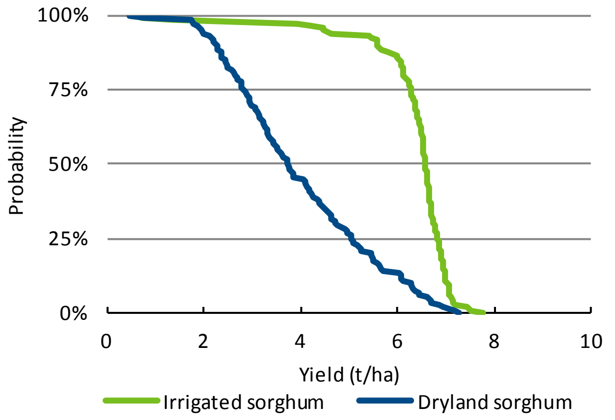

Figure 5.34 Probability of crop yield potential for dryland and fully irrigated sorghum (grain) sown in Georgetown climate on 15 January

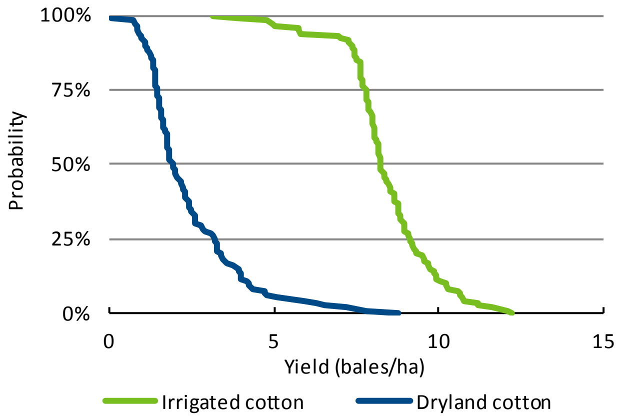

Figure 5.35 Probability of crop yield potential for dryland and fully irrigated cotton sown in Georgetown climate on 15 January

Table 5.14 Sowing date, crop yield, price, variable cost, gross margin and break-even crop yield for dryland crops in the Gilbert catchment

These are modelled results from the (APSIM) crop model. The 20th percentile, 50th percentile (median) and 80th percentile exceedance values are reported for the 121 years from 1890 to 2011. Gross margins for the 20th, 50th and 80th percentile are calculated using the median variable cost in the table, and the 20th, 50th and 80th percentile yields, respectively. Note that cotton yield data are given as bales/ha rather than t/ha. Gross margins for industrial crops (cotton, sugarcane) assume delivery to a (currently non-existent) processing plant.

CROP	SOWING DATE	CROP YIELD (t/ha)			PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)			BREAK-EVEN CROP YIELD (t/ha)
		20th	50th	80th		50th	20th	50th	80th	
Bambatsi	Perennial				$150/t					
Chickpea	1 April	0.8	0.6	0.4	$500/t	$603	–$234	–$283	–$310	1.3
Cotton (bales/ha)	15 January	3.1	1.8	1.3	$450/bale	$1,317	$9	–$524	–$729	3.1 (local gin) 7.3 (Emerald gin)
Guar					$625/t					
Lablab	1 February	7.9	6.2	5.1	$160/t	$285	$976	$714	$528	1.8
Maize	15 January	4.5	3.1	2.1	$280/t	$1,152	$19	–$298	–$520	4.4
Mungbean	15 February	0.9	0.7	0.6	$1000/t	$464	$429	$226	$133	0.4
Peanut	15 February	1.9	1.2	0.8	$850/t	$2,069	–$691	–$1,157	–$2,289	3.0
Sorghum (forage)	15 January	5.7	4.7	3.6						
Sorghum (grain)	15 Jan	5.5	3.8	2.7	$230/t	$1,094	$106	–$232	–$447	4.9
Soybean	15 January	1.4	1.0	0.8	$500/t	$728	–$49	–$218	–$338	1.5
Sugarcane	15 May	41.4	31.0	18.1	$409/t	$993	$382	$126	–$194	26

5.5.5 INTRODUCTION TO IRRIGATED AGRICULTURE IN THE GILBERT CATCHMENT

The extent to which irrigation can increase yields over dryland cropping will in many circumstances depend on the amount of irrigation water available. Crops can be fully (meeting all water requirements) or partially (meeting a fraction of total water requirements) irrigated depending on the water available and the crop area planted. Individual growers will make decisions each season on the mix of irrigated and dryland crop types, and their areas, that comprise their annual cropping program depending on their personal attitude towards risk.

It has already been demonstrated that full irrigation can more than double crop yields in the Gilbert catchment. Figure 5.36 shows how crop yield responds to increasing irrigation application for sorghum (grain) and sugarcane, by way of example. In essence, more irrigation equals more yield up to the point that the full water needs of the crop are satisfied. The slope of the rising part of the curve provides an insight into the relative response of crops to irrigation and could be used to help guide decisions about which crops and which areas of crop should preferentially receive irrigation water in the event that water is limiting.

(a) (b)

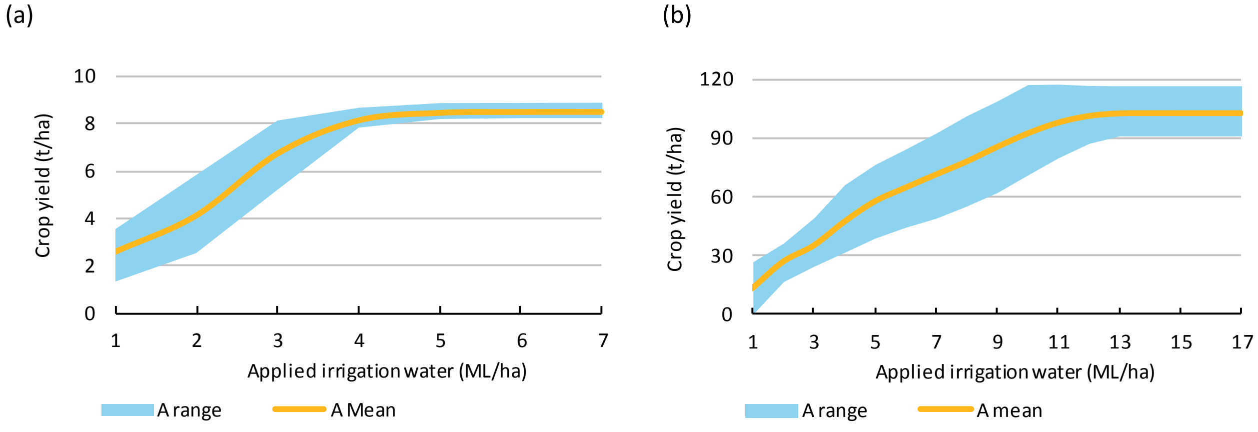

Figure 5.36 Crop yield plotted against applied irrigation water in Georgetown climate
Scenario A is the historical climate (1890 to 2011) A range is the 20th to 80th percentile exceedance and A mean crop yields for (a) sorghum (grain) and (b) sugarcane. Assumes perfect timing of irrigation (i.e. no losses).

Whether or not water is limiting in a particular situation will depend on rainfall, the availability of water storage, the degree and reliability with which that storage is filled with water, and the area and time for which irrigation water is required. These complex interactions are viewed within an economic framework in Chapter 6.

Despite these complex interactions, it is a simple matter to assert that there is more soil suited to irrigated agriculture in the Gilbert catchment than there is water to irrigate it:

- The Gilbert catchment comprises over 1 million hectares of soil that is moderately to highly suited to irrigated agriculture. For some crop and irrigation method combinations (e.g. trickle irrigated capsicum) there are more than 2 million ha of moderately to highly suitable soils.
- Even if all the runoff in the catchment (4620 GL) could be captured and delivered to crops (and that is not physically possible), it would be sufficient to support approximately 462,000 ha of fully irrigated crop, or less than 25% of total suitable soils.
- Assuming that crops are fully irrigated (e.g. at a rate of 10 ML/ha/year), it is not possible that more than 10% of the moderate to highly suitable soil of the Gilbert catchment could be irrigated.

Water storage options are discussed in detail in Section 5.2 but, suffice to say, because there is more suitable soil in the Gilbert catchment than there is water to irrigate it, decisions about the most efficient and cost-effective use of limited irrigation water will need to be made at combinations of regional, farm and paddock scale. At the farm and paddock scale, these decisions may need to be made each cropping season.

A mix of dryland and irrigated crops is likely to make the best use of the available land and water and, given the complexity of these factors, analysis is required on a case by case basis. Further information on the trade-offs between water volume available and crop area is provided in the Assessment's case studies (chapters 8 to 10).

Thirteen categories of irrigated crop were derived by the Assessment agronomists and soil scientists based on knowledge of the crops that have grown well in similar tropical regions, combined with an understanding of the commercial aspirations of local landholders in the Assessment area. The 13 land use categories, and the crops that comprise them, are shown in Table 5.15.

Table 5.15 Land use categories and crops evaluated in the Assessment

LAND USE CATEGORY	CROP EXAMPLES
Cereal crop	Maize/corn, millet, oats, rice, sorghum (grain), wheat
Citrus	Lemon, lime, citrus
Food legume (pulse crop)	Chickpea, mungbean (black), navy bean, soybean
Forage grazing, hay, silage	Rhodes grass, sorghum (forage), millet, maize (forage), bambatsi
Forage legume	Lablab, lucerne, cavalcade
Industrial	Coffee, cotton, sugarcane, guar
Intensive horticulture (vegetables)	Capsicum/chilli, cucurbit, eggplant, sweet corn, tomato, melons, pineapple, strawberry
Oilseed crop	Sunflower
Root crop	Cassava, peanut, sweet potato
Silviculture (plantation)	African mahogany, Caribbean pine, Indian sandalwood, spotted gum, teak
Tree crop/horticulture (fruit)	Avocado, banana, carambola, custard apple, lychee, mango, pineapple
Tree crop (nuts)	Cashew, macadamia
Vine	Grape

The approximately 40 crop examples listed in Table 5.15 were subsequently analysed in much more detail, to identify critical environmental requirements and management considerations. First among the management considerations is sowing time, which determines the conditions in which the crop grows and, consequently, critical factors such as water requirements and yield potential.

Cropping calendar

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

The time during which a crop can be reliably and profitably sown is called the sowing window. Sowing windows vary in both timing and length among crops and regions. Table 5.16 provides a cropping calendar for approximately 40 crops, most of which are likely to be broadly adapted to the Gilbert catchment. Perennial crops are grown throughout the year, and consequently have a less well defined growing season or planting window. Generally, perennial crops are transplanted as small plants (not seeds), and in the tropical north this is usually timed towards the beginning of the wet season to take advantage of wet season rainfall.

The cropping calendar in Table 5.16 was developed based on knowledge of these crops derived from elsewhere in the tropics combined with an understanding of plant physiology, which enables crop responses to differences in local climate to be anticipated. The optimum planting window and growing season were further refined through local experience and through use of the APSIM crop model (detailed in the companion technical report about agricultural productivity (Webster et al., 2013)).

The sowing windows identified in Table 5.16 correspond with the times of sowing that are likely to maximise potential crop yield in the Gilbert catchment. Sometimes, crops can be successfully sown outside of the identified sowing windows and only a small yield penalty would apply. In this analysis, sowing dates between August and November have generally been avoided because high evaporative demand and low water availability are not conducive to seedling establishment; it is, however, possible to sow at this time for many crops. It should be noted that sowing to achieve maximum potential crop yield may not always be possible. Wet season difficulties in access and trafficability may prevent sowing at optimum times.

Table 5.16 Annual cropping calendar for potential agricultural options

Calendar assumes best agronomic management in establishment, weed and insect control, as well as best nutrient management in minimising stress during crop and grain development. Crops are fully irrigated on a deficit with 100% irrigation application efficiency in delivering water to the crop.

LAND USE CATEGORY	CROP	IRRIGATION MANAGEMENT	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	NOTES
Cereal crop	Maize	Rainfed, Supplementary, Fully	Sowing	Sowing	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Fallow	Fallow	Fallow	
	Rice	Supplementary, Fully	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Permeable soils unsuitable for flooded rice
	Sorghum (grain)	Rainfed, Supplementary, Fully	Sowing	Sowing	Sowing	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Growing	
	Wheat	Fully	Growing	Growing	Growing	Growing	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Outside climatic zone
Citrus	Lemon	Fully	Perennial sowing	Perennial sowing	Perennial sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	
	Lime	Fully	Perennial sowing	Perennial sowing	Perennial sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	
	Orange	Fully	Perennial sowing	Perennial sowing	Perennial sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	
Food legume	Chickpea	Fully	Fallow	Fallow	Fallow	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Fallow	Potentially outside climatic zone
	Mungbean	Rainfed, Supplementary, Fully	Fallow	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Growing	Fallow	Fallow	
	Soybean	Rainfed, Supplementary, Fully	Sowing	Sowing	Sowing	Sowing	Growing	Growing	Growing	Fallow	Fallow	Fallow	Fallow	Fallow	
Forage, hay, silage	Bambatsi	Rainfed, Supplementary	Growing	Growing	Perennial sowing	Perennial sowing	Perennial sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	
	Maize	Rainfed, Supplementary	Fallow	Fallow	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Fallow	Fallow	Fallow	
	Millet (forage)	Rainfed, Supplementary, Fully	Sowing	Sowing	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	
	Rhodes grass	Rainfed, Supplementary	Growing	Growing	Perennial sowing	Perennial sowing	Perennial sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	
	Sorghum (forage)	Rainfed, Supplementary, Fully	Growing	Sowing	Sowing	Sowing	Sowing	Growing	Growing	Growing	Growing	Growing	Growing	Growing	
Forage legume	Cavalcade	Rainfed, Supplementary	Perennial sowing	Perennial sowing	Perennial sowing	Perennial sowing	Growing	Growing	Growing	Fallow	Fallow	Growing	Growing	Growing	
	Lablab	Rainfed, Supplementary	Perennial sowing	Perennial sowing	Perennial sowing	Perennial sowing	Growing	Growing	Growing	Fallow	Fallow	Fallow	Growing	Growing	
	Lucerne	Rainfed, Supplementary	Growing	Growing	Growing	Growing	Growing	Perennial sowing	Perennial sowing	Perennial sowing	Perennial sowing	Growing	Growing	Growing	

Sowing window | Growing period | Fallow | Sowing window for perennial crops

Rainfed (dryland) | Supplementary irrigated | Fully irrigated

Table 5.16 Annual cropping calendar for potential agricultural options (continued)

LAND USE CATEGORY	CROP	IRRIGATION MANAGEMENT	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	NOTES
Industrial	Coffee	◒●													Outside recommended climatic zone
	Cotton	💧◒													
	Guar	💧◒													Early summer planting requires irrigation.
	Sugarcane	◒●													
Intensive horticulture	Capsicum, chilli, tomato	●													
	Melon	●													
	Pineapple	●													
	Strawberry	●													
	Sweet corn	●													
Oilseed	Sunflower	💧◒●													
Root crop	Cassava	💧◒													
	Peanut	💧◒													
Silviculture (plantation)	African mahogany	●													
	Indian sandalwood	●													
Tree crop (fruit)	Avocado	●													
	Banana	●													
	Lychee	●													
	Mango	●													
Tree crop (nuts)	Cashew	●													
	Macadamia	●													Outside recommended climatic zone
Vine	Grape	●													

Irrigated crop yields and crop management

As discussed previously, the limited cropping in the Gilbert catchment means that there is a paucity of recorded crop yields from which an assessment of irrigation potential can be based. This deficiency is readily overcome by the use of reliable simulation tools such as APSIM, which have been calibrated for use in the Assessment area (detailed in the companion technical report about agricultural productivity (Webster et al., 2013)).

Table 5.17 details estimates of potential irrigated crop yields at the 20th, 50th and 80th percentile exceedance averaged over all modelled years (1890 to 2011). The use of 121 seasons of data provides for robust assessments of both median yield and the variability that can be expected about the median. The crops outlined are often those that are prospective for growth in the Gilbert catchment. The 20th percentile exceedance values represent the yield that is exceeded in 20% of all years (i.e. in 80% of years, the yield will be lower). Similarly, the 80th percentile exceedance values represent the yield that is exceeded in 80% of years (i.e. in 20% of years the yield will be lower).

As shown in Table 5.17 and Figure 5.33 to Figure 5.35, the yield of irrigated crops is much less variable than that of dryland crops. It is notable that under irrigation the yield of the worst 20% of crop years is generally only about 15% lower than that of the best 20% of crop years. Irrigation provides not only for higher, but also more reliable production compared with dryland crops, for which the difference in yield between the top and bottom 20% of crop years was closer to 50%.

In the Gilbert catchment, as elsewhere, it is largely differences in water availability that determine differences in crop yield. The irrigation water required to fully irrigate a crop varies significantly from year to year; much more than the yield of fully irrigated crops themselves. Analysis of the ‘applied irrigation water’ exceedance values in Table 5.17 shows that the difference in the volume of water required to fully irrigate a crop in the wettest and driest 20% of years was in the order of 35%. This highlights the impact of inter-annual variability on irrigation requirements. Figure 5.37 illustrates the way in which crop water requirement also changes with management factors, such as sowing time.

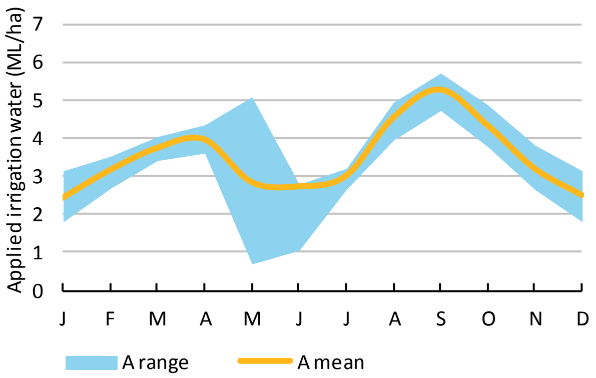

Figure 5.37 Applied irrigation water for planting on the 15th day of each month for sorghum (grain) at Georgetown
Scenario A is the historical climate (1890 to 2011). A range is the 20th to 80th percentile exceedance and A mean is the 50th percentile exceedance. Assumes perfect timing of irrigation (i.e. no losses) and optimum management (and no stress).

The large 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, and streams generally have the least flow, and water storages are also likely to be least full, highlighting an additive risk attached to irrigation. The area of crop that can be reliably irrigated must be carefully assessed each year, with reference to the available stored soil water, the likelihood of future in-season rainfall, and the volume and availability of stored (dammed) water. These factors are analysed in more detail in the Asssesment’s case studies. In addition to its impact on irrigation requirements, sowing date has a major impact on crop yield, as illustrated in Figure 5.38.

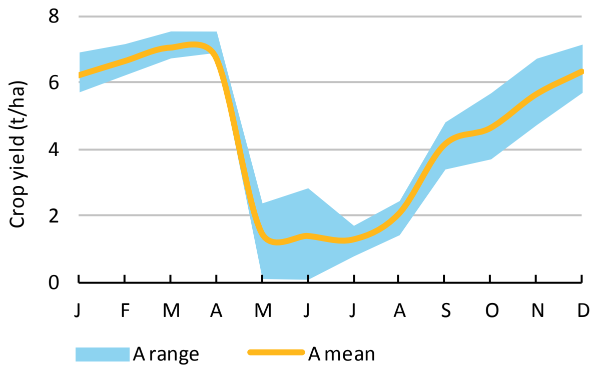

Figure 5.38 Crop yield for planting on the 15th day of each month for sorghum (grain) at Georgetown
Scenario A is the historical climate (1890 to 2011). A range is the 20th to 80th percentile exceedance and A mean is the 50th percentile exceedance. Assumes perfect timing of irrigation (i.e. no losses) and optimum management (and no stress).

As outlined previously, the yields detailed in the discussion above are potential rather than actual yields. Actual yields would be expected to be lower for a range of reasons, including the incidence of pests and diseases.

Pests and diseases

The warm, moist and high-nutrition conditions favoured by crops are, unfortunately, very much the conditions that favour the multiplication of agricultural pests and diseases. These are not usually identified as present before a crop has been introduced to an area but, once a considerable food source has been created (i.e. a crop) the various pathogens and insects that generally infest crops make their presence felt. The consistently warm climate of northern Australia enables insects and pathogens to multiply rapidly and also to evolve resistance to treatment more quickly than occurs in cooler climes. It was through this means that insect pests caused the collapse of the Ord's cotton industry in the 1970s (Chapman et al., 1996). Furthermore, if irrigated production extends through the full duration of the dry season, the ability to kill off pathogens by depriving them of food is diminished which, for many pests and diseases, creates a reservoir for disease in the next season. northern Australia's climate naturally favours the growth of insects and diseases, and 'solutions' such as genetically modified crops are not a panacea so much as an additional tool for dealing with them.

The introduction of food into a landscape also seems to attract macro-pests, such as pigs, cockatoos, bats and magpie geese (the latter are often blamed for the failure of the Adelaide River rice industry in the 1950s). Control measures against these and other pests are not always effective and are, depending on the species, not legal. Bird pests are likely to be more common in northern Australia than the southern cropping regions, at least in part because the more intact northern landscape supports a greater number of birds and bird species.

Pigs are a major problem in Queensland, and some 75% of their estimated population of 4 to 6 million is found in tropical north Queensland. Pigs carry weed seed such as parthenium (*Parthenium hysterophorus*) from watercourses to open country and cause direct and major damage to a wide range of crops and even to cultivated ground. Their daily water requirement 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 crops are most prospective. Pig control is expensive (it can cost more than $25 per pig) and is rarely more than 75% effective (Mitchell and Kanowski, 2003). Pig control is likely to be an important component of irrigated cropping management in the Gilbert catchment.

Table 5.17 Sowing date, applied irrigation water, crop yield, irrigation type, price, variable cost, gross margin and break-even crop yield for irrigated crops in the Gilbert catchment

These are modelled results from the (APSIM) crop model. The 20th percentile, 50th percentile (median) and 80th percentile exceedance values are reported, for the 121 years from 1890 to 2011. Irrigation types include surface (F), spray (S) and micro (M). Variable costs reflect those for the 50th percentile crop yield and applied irrigation water values. Gross margins for the 20th, 50th and 80th percentile are calculated using variable costs in the table, and the 20th, 50th and 80th percentile crop yields, respectively. Gross margins for process crops (cotton, sugarcane) assume delivery to a (currently non-existent) processing plant. Applied irrigation water assumes perfect timing of irrigation (i.e. no losses).

CROP	SOWING DATE	APPLIED IRRIGATION WATER (ML/ha)			CROP YIELD (t/ha)*			IRRIGATION TYPE	PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)			BREAK-EVEN CROP YIELD (t/ha)*
		20th	50th	80th	20th	50th	80th			50th	20th	50th	80th	
Bambatsi	Perennial	13.1	11.8	10.6	13.5	12.6	11.6	S	$150/t	$1,268	$757	$622	$472	8.5
Capsicum, chilli, tomato								M	$130/t	$5,514		$2,286		
Chickpea	1 May	2.7	2.3	1.9	2.3	2.2	2.0	S	$500/t	$844	$300	$256	$167	1.6
Cotton (bales/ha)	1 January	3.7**	3.2**	2.6**	9.6	8.5	8.0	F	$450/bale	$1,317	$2,791	$2,321	$2,108	3.2 (local gin) 7.5 (Emerald gin)
Guar			1.9			2.0			$625/t	$423				
Lablab	1 March	5.0	4.5	3.9	9.7	9.1	8.6	S	$160/t	$590	$757	$622	$472	3.7
Maize	15 March	5.1	3.8	1.0	11.8	10.6	9.4	S	$280/t	$1,836	$1,400	$1,132	$864	5.5
Mango								M	$2.71/kg	$23,201		$3,672		
Melon								M	$0.93/kg	$34,080		$5,445		
Mungbean	15 March	2.0	1.2	0.8	1.3	1.3	1.2	S	$1000/t	$639	$661	$661	$576	0.5
Peanut	15 March	5.2	4.9	4.5	5.1	4.8	4.5	S	$850/t	$3,195	$1,076	$885	$693	3.4
Sorghum (forage)	15 August	5.5	4.9	4.3	17.2	16.4	15.2	S						
Sorghum (grain)	15 March	4.6	3.5	2.8	8.4	8.0	6.8	S	$230/t	$1,469	$450	$371	$134	6.1
Soybean	1 January	2.4	1.9	1.3	2.5	2.3	2.1	S	$500/t	$927	$312	$223	$134	1.8
Sugarcane	15 May	15	12	10	153	128	113	F	$409/t	$1,927	$3,033	$2,415	$2,043	30
Sweet corn								M	$0.6/kg	$12,845		$10,805		

* Cotton crop yields are given as bales/ha rather than t/ha.

** The water balance component of the APSIM cotton model has not been validated for northern Australia.

Crop gross margins

Indicative crop gross margins are provided in Table 5.17; for several reasons, great care needs to be taken with their use.

Gross margins are sensitive to variation in yield and price of outputs, and levels and costs of inputs. These vary from farm to farm, paddock to paddock and year to year.

Perhaps more importantly, gross margins provide no insight into the cost of establishing new enterprises. This requires the use of whole or partial farm budgets which, because of their enterprise specificity, is beyond the scope of this chapter. Returns to capital investment are explored in the Assessment's case studies (chapters 8 to 10).

The gross margins are provided merely as an indication of the cash flow that might be generated by established irrigated cropping enterprises in the Gilbert catchment. Gross incomes were calculated using the modelled 20th, 50th and 80th percentile exceedance crop yield values. These modelled crop yield values were used to calculate tonnage-related variable costs (e.g. cartage, levies, harvesting) which were converted to a dollar per hectare cost and added to other variable costs of production. Pumping costs were calculated using the modelled median applied irrigation water (ML/ha). Costs and prices were sourced from a range of sources (DPI, 2013; Queensland Government, 2013; ABARES, 2013 a, b; Queensland Department of Agriculture, Fisheries and Forestry staff, 2013, pers. comm.; Mason and Larard, 2011; Mason, 2009). Full details are provided in the companion technical report about the costs and benefits of irrigation (Brennan McKellar et al., 2013).

Land suitability assessment

The land suitability assessment method (see the companion technical report about land suitability (Bartley et al., 2013)), allows a range of soil properties to be scored for suitability to support different combinations of crop and irrigation type (e.g. trickle irrigated capsicum; microspray irrigated mango; flood-irrigated sugarcane).

Land receives a score of 1 (most suited) to 5 (least suited) based on their ability to cost-effectively support a given agricultural enterprise. The scoring system is outlined below. Note that a large proportion of Australia's agricultural soils are classified as class 3.

Table 5.18 Land suitability classification used in the Assessment

CLASS	DESCRIPTION
Class 1	**(Highly) Suitable land with negligible limitations**. This is highly productive land requiring only simple management practices to maintain economic production.
Class 2	**Suitable land with minor limitations** which either reduce production or require more than the simple management practices of class 1 land to maintain economic production.
Class 3	**Moderately suitable land with considerable limitations** which either further lower production or require more than those management practices of class 2 land to maintain economic production.
Class 4	**Marginal land which is presently considered unsuitable due to severe limitations**. The long-term significance of these limitations on the proposed land use is unknown. The use of this land depends on undertaking additional studies to determine whether the effects of the limitation(s) can be reduced to achieve sustained economic production.
Class 5	**Unsuitable land with extreme limitations that preclude its use**. Class 5 is considered unsuitable, having limitations that in aggregate are so severe that the benefits would not justify the inputs required to initiate and maintain production in the long-term. It would require a major change in economics, technology or management expertise before the land could be considered suitable for that land use.

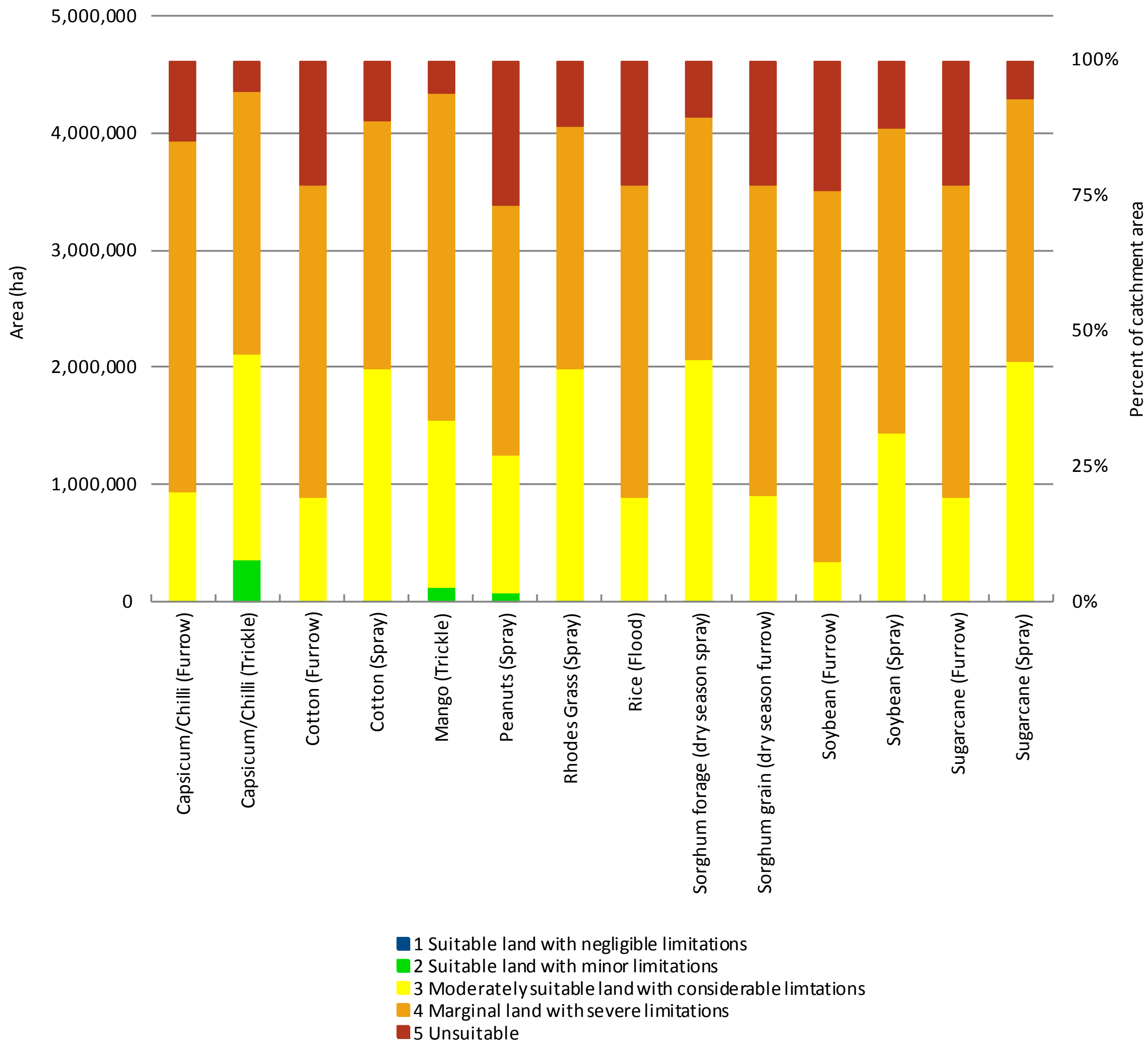

Figure 5.39 The area associated with each land suitability class for a selection of 14 crops in the Gilbert catchment
The land suitability classes are defined in Table 5.18. Land suitability assessment does not take into consideration flooding, secondary salinisation risk or availability or water. Model confidence is not considered in data presented in this figure. Data relating to 76 combinations of crop and irrigation type can be found in the companion technical report about land suitability (Bartley et al., 2013).

These suitability scores were used for several purposes. They were applied across the whole catchment to give an indication of the total area of soil suited to a range of purposes. The results of this analysis indicate that very large areas of the Gilbert catchment (1 to 2 million ha) are moderately suitable (class 3) for a wide range of crops and irrigation methods (Figure 5.39). For selected crops, a smaller proportion of the catchment, though still up to 300,000 ha, comprises class 2 soils. It should be noted the land suitability assessment does not take into consideration flooding, risk of secondary salinisation or availability of water. As outlined previously, the volume of water available for irrigation places a greater limit on irrigated agriculture than the area of suitable soils.

Land suitability and its implications for crop management are discussed in more detail for a wide range of crops in the section that follows. There, the location of soils best suited to a given crop and irrigation combination are mapped, along with information critical to the consideration of the crop in an irrigated farm enterprise.

Section 5.5.6 to 5.5.15 provides an overview of key land uses listed in Table 5.15, using one crop from each land use category as an example. Each land suitability map presented in these sections is accompanied by a map indicating the reliability of the mapping for a given crop-irrigation combination. This reliability map should be consulted when interpreting the land suitability maps.

The companion technical report about land suitability (Bartley et al., 2013) provides a complete description of the land suitability assessment method and results for all crops listed in Table 5.15.

5.5.6 CEREAL CROPS

Dryland and irrigated cereal production are well established in Australia. Around 20 million ha of land is devoted to grain (wheat, barley, grain, sorghum, oats, triticale, maize, etc.) production each year, yielding an average of approximately 35 Mt/year. Domestic markets demand all cereals. Significant export markets exist for wheat, barley and sorghum (grain) and there are niche export markets for grains such as maize and oats.

Among the cereals, the 'summer crops' such as sorghum (grain) and maize are the most promising for the Gilbert catchment. As outlined previously, these could be grown opportunistically using dryland production or more continuously using irrigation. About 2 million ha of the Gilbert catchment is moderately suited (class 3) to spray irrigated cereal cropping (Figure 5.39 and Figure 5.40). Flood-irrigated cereal cropping is considered less promising for the Gilbert catchment because the soils are not conducive to long flood irrigation furrows. The area suited to flood irrigation of cereal crops is around 0.9 million ha. While flood irrigation is possible it is not the most water-efficient method of irrigation, a potentially important consideration in a strongly water limited environment such as the Gilbert catchment.

It may be useful to explore the theoretical upper limits of cereal production in the Gilbert catchment, using sorghum (grain) as an exemplar:

- If the approximately 2 million ha of suitable arable soil in the Gilbert catchment were devoted to dryland sorghum (grain), median potential regional production of around 7.6 Mt is theoretically possible. At a price of $230/t, this would have a gross value of $1,748 million. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.
- Assuming that the most promising instream water storages in the Gilbert catchment could deliver approximately 250 GL to crops (i.e. after conveyance and field application losses): based on a median irrigation requirement of 3.5 ML/ha and a median potential yield of 8 t/ha, this would enable a potential regional sorghum (grain) yield of approximately 570,000 t, grown on more than 71,000 ha. At current prices ($230/t) this would have a gross value of approximately $130 million. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.

The 'winter cereals' such as wheat and barley are not well adapted to the environment of the Gilbert catchment. If grown during winter, they would require full irrigation.

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

Table 5.19 provides summary information relevant to the cultivation of cereals, using sorghum (grain) as an example. The companion technical report about agricultural productivity (Webster et al., 2013) provides greater detail for a wider range of crops.

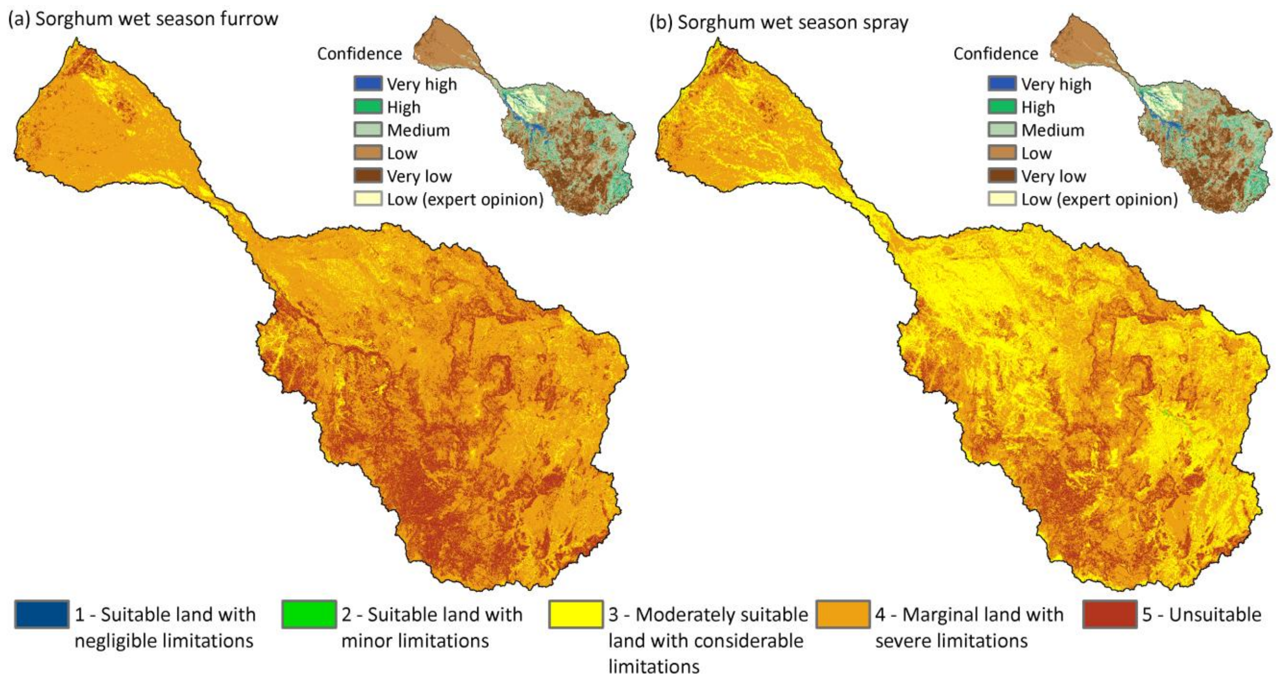

Figure 5.40 Modelled land suitability for sorghum (grain). Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water
(a) Wet season sorghum (grain) using furrow irrigation and (b) wet season sorghum (grain) using spray irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.41 Sorghum (grain)
Photo: CSIRO.

Table 5.19 Sorghum (grain) (*Sorghum bicolor*)

PARAMETER	DESCRIPTION
Summary	Major summer rainfed (dryland) grain crop grown mainly for stock feed. Currently grown extensively in southern and central Queensland (600,000 to 700,000 ha). Sorghum has been a major grain crop in the Northern Territory, grown in rotation with pasture legumes such as cavalcade. It potentially can supply an increasing intensification of the northern Australian cattle industry.
Growing season	Planting window December to July. 120 to 180 day duration of growth. Ranges of sorghum cultivars are available to suit different sowing times and geographic locations.
Land suitability assessment	A large part of the Gilbert catchment is marginal (class 4) or unsuitable (class 5) for cereal cropping. These limitations are caused by rockiness, potential erosion (slope) and soil water storage capacity (due to shallow and/or lightly textured soils). More land is moderately suitable to spray irrigation than furrow primarily due to the lightly textured soils being unsuitable to furrow irrigation. The Gilbert delta soils are seasonally wet and/or poorly drained and generally unsuited for cereal production.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	3.5 ML/ha (March sowing). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Dryland: 3.8 t/ha (March sowing). Break-even crop yield 4.9 t/ha Irrigated: 8.0 t/ha (March sowing). Break-even crop yield 6.1 t/ha
Salinity tolerance	Moderately tolerant – EC_e threshold for yield decline 6.8 dS/m
Downstream processing	Available for direct delivery to end user
By-products	Biomass for stock feed, bio-processing?
Production risks	Frost, heat stress at flower, minimum soil temperature for germination
Rotations	High potential for annual rotation
Management considerations	Header, row crop planter, spray rig (pest control), fertiliser
Complexity of management practices	Medium
Legislative constraints	None
Markets and emerging markets	In Australia sorghum grain is used mostly for stock feed in the cattle, pig and poultry industries. A large amount of grain is exported. Potential emerging market for feedlots supplying local abattoir
Prices	Generally $150/t to $300/t
Opportunities and risks under a changing climate	More tolerant of drought and temperature stress than maize
Further reading	DAFF (2011a)

5.5.7 FOOD LEGUME (PULSE CROPS)

Pulse production is well established in Australia. Approximately 2 million hectares of pulse crops are grown annually, producing 2 to 2.5 million tonnes of mainly chickpea, lupin and field pea with a value greater than $600 million (ABARES, 2012). Pulses produced in the Gilbert catchment would most likely be exported.

The pulses, many of which have a short growing season, are often well suited to opportunistic dryland production or more continuous irrigated production, probably in rotation with cereals or other non-legume crops. Approximately 1.5 million ha of the Gilbert catchment is moderately suited (class 3) to spray irrigated pulse production (Figure 5.39 and Figure 5.42). Flood-irrigated pulse cropping is considered less promising for the Gilbert catchment because the soils are not conducive to long flood irrigation furrows. The area moderately suitable to flood irrigation of pulse crops is around 0.3 million ha. While flood irrigation is possible it is not the most water-efficient method of irrigation, a potentially important consideration in a strongly water limited environment such as the Gilbert catchment.

It may be useful to explore the theoretical upper limits of pulse production in the Gilbert catchment, using mungbean as an exemplar:

- If the approximately 1.5 million ha of suitable arable soil in the Gilbert catchment were devoted to dryland mungbean, a median potential regional yield of around 1 Mt is theoretically possible. At current prices, this would have a gross value of almost $1000 million. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.
- Assuming that the most promising instream water storages in the Gilbert catchment could deliver approximately 250 GL to crops (i.e. after conveyance and field application losses): based on a median irrigation requirement of 1.2 ML/ha and a median potential yield of 1.3 t/ha, this would enable potential regional mungbean production of approximately 271,000 t, grown on more than 208,000 ha. At current prices ($1000/t) this would have a gross value of approximately $270 million. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.

Not all pulse crops are likely to be suited to the Gilbert catchment. Those that are 'tender' such as field peas and beans may not be well suited to the highly desiccating environment and periodically high temperatures. Direct field experimentation in the catchment is required to confirm this, for these and other species. Until this occurs, all crop yield estimates should be treated with caution.

Pulses are often advantageous in rotation with other crops because they provide a disease break and, being legumes, often provide nitrogen for subsequent crops. Even where this is not the case, their ability to meet their own nitrogen needs can be beneficial. This may be a distinct advantage in areas such as the Gilbert catchment where freight costs (for fertiliser, etc.) pose a considerable cost burden on potential growers.

To grow pulse crops, farmers will require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is generally a contract operation, and in larger growing regions other activities can also be performed under contract. The equipment required for pulse crops is the same as is required for cereal crops, so farmers intending on a pulse and cereal rotation would not need to purchase extra 'pulse-specific' equipment.

Table 5.20 provides summary information relevant to the cultivation of many pulses, using mungbean as an example. The companion technical report about agricultural productivity (Webster et al., 2013) provides greater detail for a wider range of crops.

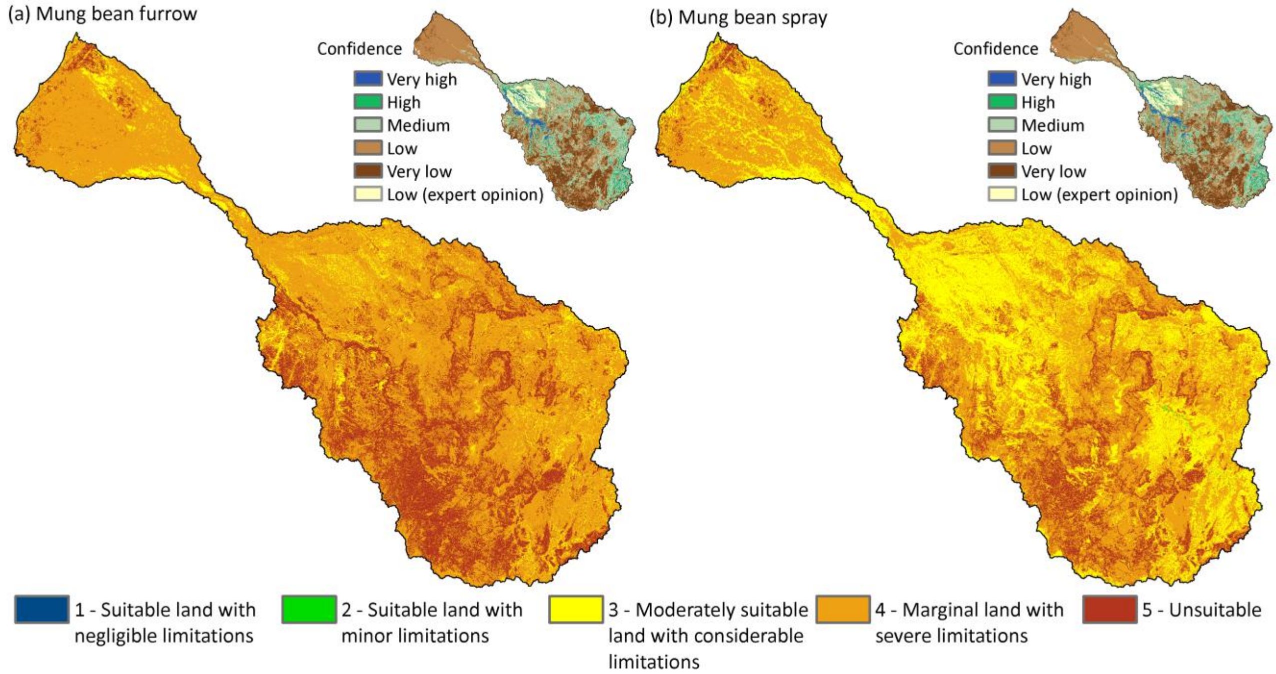

Figure 5.42 Modelled land suitability for mungbean. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water
(a) Mungbean using furrow irrigation and (b) mungbean using spray irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.43 Mungbean
Photo: CSIRO.

Table 5.20 Mungbean *(Vigna radiata)*

PARAMETER	DESCRIPTION
Summary	Mungbean is a relatively quickly maturing (90 days) grain legume that can be sown in early spring or late summer as part of a planned rotation or as an opportunity crop. Mainly used for human consumption (sprouting and processing) but can be used as green manure and livestock forage. In the northern grains region of Queensland and New South Wales, 66,000 ha were grown in 2011. Generally reliable production for spring and summer plantings for both rainfed (dryland) and irrigation. Market-driven demand for high-quality product for sprouting.
Growing season	Planting window February to May
Land suitability assessment	The same limitations that make much of the Gilbert catchment marginal (class 4) or unsuitable (class 5) for cereal cropping apply to wet season cropping of food legumes as well: rockiness, potential erosion (slope) and soil water storage capacity (due to shallow and/or lightly textured soils). More land is suitable for spray irrigation because less critical slope limits apply and spray systems are more suited to lightly textured soils. The Gilbert delta soils are seasonally wet and/or poorly drained for mungbeans as they are susceptible to wet soil conditions (hence are class 4).
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	1.2 ML/ha (March sowing). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Dryland: 0.7 t/ha (March sowing). Break-even crop yield 0.4 t/ha Irrigated: 1.3 t/ha (March sowing). Break-even crop yield 0.5 t/ha
Salinity tolerance	Sensitive – ECe Threshold for yield decline 1.8 dS/m
Downstream processing	Available for direct delivery to end user
By-products	Biomass for stock feed
Production risks	Rain periods during late grain fill for spring-sown mungbean. Insect damage resulting in quality downgrades
Rotations	Opportunity crop, annual rotation
Management considerations	Header, row crop planter, spray rig (pest control)
Complexity of management practices	Medium
Legislative constraints	None
Markets and emerging markets	Increasing demand for high-quality grain to supply the domestic market. Nearly all (95%) of the Australian mungbean crop is exported (DEEDI, 2010).
Prices	World mungbean prices are largely determined by both the volume and quality of the crops in China and Burma. Price trends usually become obvious in December when the harvest of the Chinese crop nears completion and both the volume and quality of production become apparent. Mungbeans are classified into five grades and price varies accordingly.
Opportunities and risks under a changing climate	Short-season opportunity crop, lower fertiliser requirements, potential for increased insect pest pressure as a result of increased temperatures
Further reading	DEEDI (2010), DAFF (2012c)

5.5.8 NON-LEGUMINOUS FORAGE, HAY, SILAGE

Forage, hay and silage are crops that are grown for consumption by animals. Forage is consumed in the paddock in which it is grown. Hay is cut, dried, baled and stored before being fed to animals at a time when natural pasture production is low (generally towards the end of the dry season). Silage use resembles that for hay, but crops are stored wet, in anaerobic conditions where fermentation occurs to preserve the feed's nutritional value.

Dryland and irrigated production of fodder is well established 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. Approximately 85% of production is consumed domestically. The largest consumers are the horse, dairy and beef feedlot industries. Fodder is also widely used in horticulture for mulches and for erosion control (RIRDC, 2013). There is a significant fodder trade in support of the northern beef industry, though there is room for expansion as fodder costs currently comprise less than 5% of beef production costs (Gleeson et al., 2012).

The Gilbert catchment is well suited for dryland or irrigated production of non-leguminous forage, hay and silage. Potential markets exist in the extensive cattle industry of northern Australia, which may comprise among the most promising opportunities for dryland and irrigated agriculture in the Gilbert catchment. There is potential for farmers primarily engaged in extensive cattle production to use irrigated forage, hay and silage to increase the carrying capacity of their enterprise.

More than 2 million ha of the Gilbert catchment is moderately suited (class 3) to spray irrigated forage production (e.g. Rhodes grass or sorghum) (Figure 5.39 and Figure 5.44). Flood-irrigated fodder production is considered less promising for the Gilbert catchment because the soils are not conducive to long flood irrigation furrows. The area moderately suitable to flood irrigation of fodder crops is around 0.9 million ha. While flood irrigation is possible it is not the most water-efficient method of irrigation, a potentially important consideration in a strongly water limited environment such as the Gilbert catchment.

It may be useful to explore the theoretical upper limits of fodder production in the Gilbert catchment, using forage sorghum as an exemplar:

- If the approximately 2 million ha of suitable arable soil in the Gilbert catchment were devoted to dryland forage sorghum, a median potential regional yield of nearly 10 Mt is theoretically possible. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.
- Assuming that the most promising instream water storages in the Gilbert catchment could deliver approximately 250 GL to crops (i.e. after conveyance and field application losses): based on a median irrigation requirement of 4.9 ML/ha and a median potential yield of 16.4 t/ha, this would enable potential regional sorghum (grain) production of approximately 836,000 t, grown on more than 51,000 ha. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.

Forage crops (i.e. for grazing) include sorghum and maize, with particular cultivars specific for forage. A potential advantage of forage sorghum and maize over sorghum (grain) and maize is that the crop is grazed prior to setting seed and growing a grain 'head'. Therefore the growing season of forage crops is much shorter than for a grain crop and approximately 30% less water is required.

Hay crops are often annual or perennial grasses. Perennial grasses are generally grown for several years. Grass is grown, cut for hay, and will regrow again with adequate water. Dryland hay production from perennials gives producers the option of irrigation when required or, if water becomes limiting, allowing the pasture to remain dormant before water again becomes available.

Silage can be made from a number of crops, such as grasses, maize and sorghum.

Apart from irrigation infrastructure, the equipment needed for forage production is machinery for planting. Fertilising and spraying equipment is also desirable but not necessary. Cutting crops for hay or silage requires more specialised harvesting, cutting, baling and storage equipment.

Table 5.21 describes bambatsi production for hay over a one-year cycle. Bambatsi was chosen primarily because of the ability to model its production over 120 years. Rhodes grass will respond in a very similar way to bambatsi. The application of irrigation water described for bambatsi for hay would be much higher than that required for a (grazed) forage crop, which is grown quite differently to hay crops. Information similar to that in Table 5.21 for grazed forage crops is presented in the companion technical report about agricultural productivity (Webster et al., 2013).

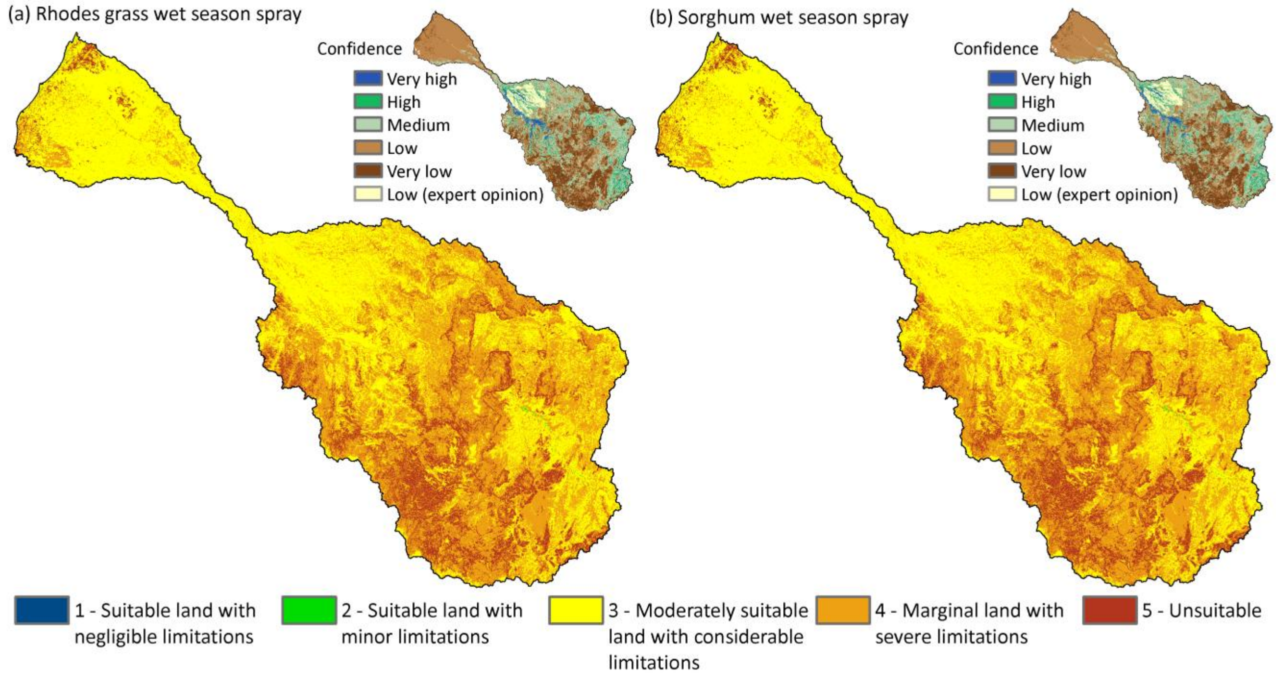

Figure 5.44 Modelled land suitability for Rhodes grass and sorghum (forage). Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water
(a) Wet season Rhodes grass using spray irrigation and (b) wet season sorghum (forage) using spray irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.45 Bambatsi
Photo: CSIRO.

Table 5.21 Bambatsi *(Panicum coloratum var. makarikariense)*

PARAMETER	DESCRIPTION
Summary	Bambatsi (makarikari grass; *Panicum coloratum*) is a drought tolerant perennial grass growing to 1.5 m at flowering and producing high-quality forage during the spring and summer months. Bambatsi can be grazed or cut for hay production. Well adapted to heavier clay soils. Lower productivity on less fertile sandy soils. Able to tolerate moderate levels of flooding and soil salinity. Used in mixed cropping and livestock systems in northern Australia.
Growing season	Under irrigation planting from early spring (September) through to autumn
Land suitability assessment	The same limitations that make much of the Gilbert catchment marginal (class 4) or unsuitable (class 5) for most cropping groups apply to the forage grasses: rockiness, potential erosion (slope) and soil water storage capacity (due to shallow and/or lightly textured soils). There is much variability in the class 3 soils with the river alluvium and delta having clay subsoils with good soil water storage capacity while the soils between the Einasleigh and Gilbert rivers are sandier and more freely drained, requiring more frequent irrigation applications. All soils with hardsetting surfaces require specific management to improve water infiltration.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	11.8 ML/ha (March sowing). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Irrigated: 12.6 t/ha (March sowing). Break-even crop yield 8.5 t/ha
Salinity tolerance	Moderately tolerant
Downstream processing	Available for direct delivery to end user
By-products	Biomass for stock feed, potential use in biofuels
Production risks	Slow to establish without adequate water post sowing. Low frost tolerance
Rotations	Perennial pasture. Potentially a component of a ley farming system, where crops are grown in rotation with grass pastures or legumes to disrupt carryover pest and disease and improve soil fertility and structure.
Management considerations	Baler, forage cutter. Nitrogen fertiliser may be required to maintain productivity if not sown with legumes. No significant pests or diseases
Complexity of management practices	Low
Legislative constraints	None
Markets and emerging markets	Growing demand from northern Australian livestock industry for good-quality forages
Prices	Primarily for use on-farm. Price received will depend on drought conditions, with higher prices during dry periods
Opportunities and risks under a changing climate	Drought tolerant, with some tolerance of moderate soil salinity (when established)
Further reading	DAFF (2013a)

5.5.9 FORAGE LEGUME

The use of forage legumes is similar to that of forage grasses, described in Section 5.5.8. They are generally grazed by animals, but can also be cut for silage or hay. Some forage legumes are very well suited to the Gilbert catchment, and would be considered among the more promising opportunities for irrigated agriculture (Figure 5.39 and Figure 5.46).

Forage legumes are desirable because of their high protein content and their ability to fix atmospheric nitrogen. The nitrogen fixed during a forage legume phase is often in excess of that crop's requirements, and leaves the soil with additional nitrogen. Forage legumes could be used by the northern cattle industry, and farmers primarily engaged in extensive cattle production could use irrigated forage legumes to increase the capacity of their enterprise, turning out more cattle from the same area. Cavalcade and lablab are currently grown in northern Australia, and would be well suited to the Gilbert catchment.

It may be useful to explore the theoretical upper limits of forage legume production in the Gilbert catchment, using lablab as an exemplar:

- If the approximately 2 million ha of suitable arable soil in the Gilbert catchment were devoted to dryland lablab production, a median potential regional yield of around 12.4 Mt is theoretically possible. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.
- Assuming that the most promising instream water storages in the Gilbert catchment could deliver approximately 250 GL to crops (i.e. after conveyance and field application losses): based on a median irrigation requirement of 4.5 ML/ha and a median potential yield of 9.1 t/ha, this would enable potential regional lablab production of approximately 500,000 t, grown on more than 55,000 ha. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.

The equipment needed for grazed forage legume production is similar to that for forage grasses, that is, a planting method, with fertilising and spraying equipment being desirable but not essential. Cutting crops for hay or silage requires more specialised harvesting, cutting, baling and storage equipment.

Table 5.22 describes lablab production over a one-year cycle. The comments could be applied equally to cavalcade production.

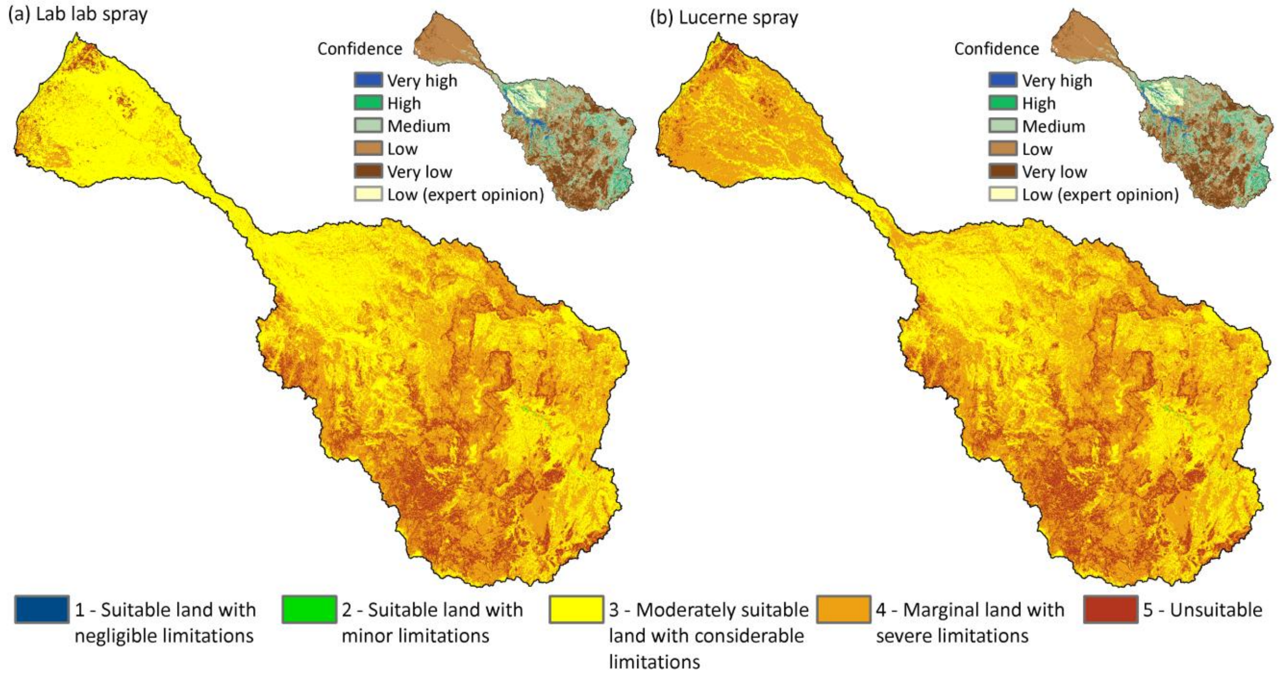

Figure 5.46 Modelled land suitability for lablab and lucerne. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water
(a) Lablab using spray irrigation and (b) lucerne using spray irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.47 Lablab
Photo: CSIRO.

Table 5.22 Lablab (*Lablab purpureus*)

PARAMETER	DESCRIPTION
Summary	Lablab is a widely adapted forage legume sown for grazing, hay production and green manure. It is used in mixed cropping and livestock systems and sometimes as a legume ley in cropping systems to address soil fertility. It can be grown on the majority of arable soils, from deep sands to heavy clays with adequate drainage. Used in mixed cropping and livestock systems in northern Australia.
Growing season	Under irrigation planting from early spring (September) through to autumn
Land suitability assessment	The same limitations that make much of the Gilbert catchment marginal (class 4) or unsuitable (class 5) for most cropping groups apply to the forage legumes: rockiness, potential erosion (slope) and soil water storage capacity (due to shallow and/or lightly textured soils). There is much variability in the moderately suitable (class 3) soils, with the river alluvium and delta having clay subsoils with good soil water storage capacity, while the soils between the Einasleigh and Gilbert rivers are sandier and more freely drained, requiring more frequent irrigation applications. All soils with hardsetting surfaces require specific management to improve water infiltration. The Gilbert delta soils are seasonally wet and/or poorly drained, being class 4 for lucerne as it is susceptible to wet soil conditions.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	4.5 ML/ha (March sowing). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Dryland: 6.2 t/ha (March sowing). Break-even crop yield 1.8 t/ha Irrigated: 9.1 t/ha (March sowing). Break-even crop yield 3.7 t/ha
Salinity tolerance	Moderately sensitive
Downstream processing	Available for direct delivery to end user
By-products	Biomass for stock feed, potential use in biofuels
Production risks	Timing of crop establishment to avoid high temperature stress at flowering and to maximise harvesting outside of major rainfall periods. Does not tolerate heavy grazing.
Rotations	Annual rotation, break crop in cotton or sugar rotation
Management considerations	Baler, forage cutter
Complexity of management practices	Low
Legislative constraints	None
Markets and emerging markets	Growing demand from northern Australian livestock industry for good-quality forages
Prices	Primarily used on-farm
Opportunities and risks under a changing climate	Drought tolerant (when established). Provides additional soil nitrogen in crop rotation
Further reading	Cook et al. (2005), Brown and Pengelly (2007)

5.5.10 INDUSTRIAL (COTTON)

Dryland and irrigated cotton production are well established in Australia. The area of land devoted to cotton production varies widely from year to year, largely in response to availability of water. An average of approximately 320,000 ha is planted each year, though this has varied from about 70,000 to almost 600,000 ha over the last 20 years. On average Australia produces approximately 550,000 t of cotton each year though, as with the area planted, this figure is volatile. Average lint yields are 1.8 tonnes (7.9 bales) per hectare (ABARES, 2012).

Commercial cotton has had a long but discontinuous history of production in northern Australia, including in Broome, the Fitzroy River and the Ord River Irrigation Area in Western Australia; in Katherine and Douglas-Daly in the Northern Territory; and near Richmond and Bowen in northern Queensland. An extensive study undertaken by the Australian Cotton Cooperative Research Centre in 2001 (Yeates, 2001) noted that past ventures suffered from:

- a lack of capital investment
- too rapid movement to commercial production
- a failure to adopt a systems approach to development
- climatic variability.

Mistakes in pest control were also a major issue in early projects. Since the introduction of genetically modified (GM) cotton in 1996, yields and incomes from cotton crops have increased in most regions of Australia. The key benefits of GM cotton (compared to conventional cotton) are savings in insecticide and herbicide use, and improved tillage management. In addition, farmers are now able to forward-sell their crop as part of a risk management strategy.

The Australian Cotton Cooperative Research Centre (Yeates, 2001) analysis of the climate of northern Australia concluded that in Queensland, cotton could be grown in the far northern region of the Cape during the winter period, with summer planting in coastal and inland regions of north Queensland.

Climatic constraints will continue to limit production potential of northern cotton crops when compared to cotton grown in more favourable climatic regions of northern New South Wales and southern Queensland. On the other hand, the low risk of rainfall occurring during late crop development favours production in the north, as it minimises the likelihood of late season rainfall that can downgrade fibre quality and price. Demand for Australian cotton exhibiting long and fine attributes is expected to increase by 10 to 20% during the next decade and presents local producers with an opportunity in targeting production of high-quality fibre.

Almost 2 million ha of the Gilbert catchment is moderately suited (class 3) to spray irrigated cotton cropping (Figure 5.39 and Figure 5.48). The area suited to flood irrigation of cotton crops is around 0.9 million ha. While flood irrigation is possible it is not the most water-efficient method of irrigation, a potentially important consideration in a strongly water limited environment such as the Gilbert catchment. It may be useful to explore the theoretical upper limits of cotton production in the Gilbert catchment:

- If the approximately 2 million ha of suitable arable soil in the Gilbert catchment were devoted to dryland cotton, median potential regional production of around 3.6 million bales is theoretically possible. At current prices, this would have a gross value of $1620 million. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.
- Assuming that the most promising instream water storages in the Gilbert catchment could deliver approximately 250 GL to crops (i.e. after conveyance and field application losses): based on a median irrigation requirement of 3.2 ML/ha and a median potential yield of 8.5 bales/ha, this would enable a potential regional cotton yield of approximately 665,000 bales, grown on more than 78,000 ha. At current prices ($450/bale) this would have a gross value of approximately $300 million. Actual production would be lower and more variable. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.

In addition to a normal row planter and spray rig equipment used in cereal production, cotton requires access to suitable picking and module or baling equipment as well as transport to processing facilities.

Initial development costs and scale of establishing cotton production in the region would need to consider sourcing of external contractors and could provide an opportunity to develop local contract services to support a growing industry.

Cotton production is also highly dependent on access to processing plants (cotton gins). There are no processing facilities in the Gilbert catchment, and the nearest gin is in Emerald, approximately 900 km by road. The economics of establishing a cotton gin is discussed in the Green Hills dam and irrigated three-crop rotation case study (Chapter 8). The absence of a nearby cotton gin is likely to decrease the attractiveness of cotton production in the Gilbert catchment, compared with other cropping options, particularly those that can service a local regional market. Break-even crop yields for irrigated cotton produced in the Gilbert catchment are 3.2 bales/ha for a local gin (50 km transport) and rise to 7.5 bales/ha for transport to Emerald (900 km).

The high oil and protein content of seed cotton, a co-product of the ginning process, is a profitable source of oil for domestic and export markets and local stock feed. Cottonseed contains about 20% crude protein and is a major component in drought feeding when mixed with molasses or grain. Regional processing of cotton could supply local cattle producers with a cost-effective high-quality feed supplement.

Other industrial crops such as tea and coffee are unlikely to yield well in the Gilbert catchment climate, and tobacco and hemp are not currently allowed to be grown in Australia. Niche industrial crops, such as guar and chia, may be feasible for the Gilbert catchment, but there is only limited verified agronomic and market data on these crops. Past research on guar has been conducted in the Northern Territory and current trials are underway. These could prove future feasibility.

The companion technical report about agricultural productivity (Webster et al., 2013) provides greater detail for a wider range of industrial crops.

Table 5.23 describes some key considerations relating to cotton production.

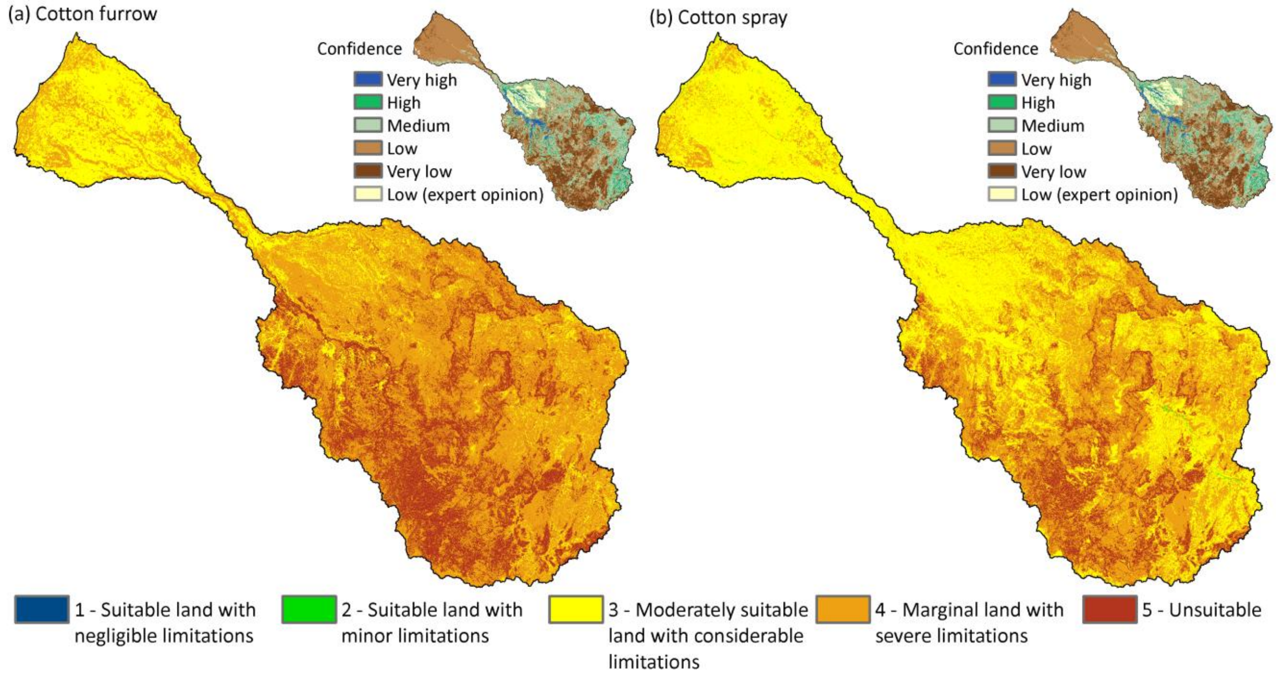

Figure 5.48 Modelled land suitability for cotton. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water

(a) Cotton using furrow irrigation and (b) cotton using spray irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.49 Cotton

Photo: CSIRO.

Table 5.23 Cotton (*Gossypium spp.*)

PARAMETER	DESCRIPTION
Summary	Cotton is a shrub native to some tropical and sub-tropical regions, producing 32% (in 2009) of the world's fibre production. Australian cotton production is small compared with production in the USA and Israel. However, due to favourable climatic conditions during the growing season, Australia is recognised (along with Egypt) as currently producing the world's best cotton. A high proportion of Australian cotton (84% in 2005–06) is produced under irrigation with rainfed (dryland) crops sown into stored soil water resulting from traditional fallowing processes. Cotton is marketed on qualities of grade, colour and fibre length. Cotton can be grown on the majority of deep arable soils with adequate rainfall or supplementary irrigation. CSIRO genetically modified (GM) cotton has been successfully grown in both the Flinders and Gilbert catchments and is currently grown commercially in the Burdekin.
Growing season	Planting window December to February, maturity May to July
Land suitability assessment	Similar to sugarcane, the same limitations that make much of the Gilbert catchment marginal (class 4) or unsuitable (class 5) also apply to cotton production: rockiness, potential erosion (slope) and soil water storage capacity (due to shallow and/or lightly textured soils). Like sugarcane, cotton is more tolerant of wet soil conditions making the Gilbert delta area moderately suitable (class 3). The moderately suitable (class 3) soils between the Einasleigh and Gilbert rivers are sandier and more freely draining, thus requiring more frequent irrigation applications. Furrow-irrigated cotton is less suited to the more permeable and better drained (sandier) soils due to low irrigation efficiency and soil water storage capacity. More land is suitable for spray irrigation because less critical slope limits apply and spray systems are more suited to lightly textured soils. Other management considerations are hardsetting surface soils and soils where ESP > 6 contributes to poor water infiltration.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	3.2 ML/ha (January sowing). Assumes perfect timing of irrigation (i.e. no losses). The water balance component of the APSIM cotton model has not been validated for northern Australia. More work is required for validating the cotton model in the tropics.
Crop yield (median)	Dryland: 1.8 bales/ha (January sowing). Break-even crop yield 3.1 bales/ha (local gin);7.3 bales/ha for Emerald gin Irrigated: 8.5 bales/ha (January sowing). Break-even crop yield 3.2 bales/ha (local gin), 7.5 bales/ha for Emerald gin
Salinity tolerance	Tolerant – EC_e Threshold for yield decline 7.7 dS/m
Downstream processing	Cotton gin
By-products	Cottonseed for stock feed
Production risks	Early frost, prolonged water logging, reduced radiation due to cloud cover
Rotations	High potential for annual rotation
Management considerations	Picker, row crop planter, spray rig (pest control), fertiliser
Complexity of management practices	High
Legislative constraints	None
Markets and emerging markets	Price is influenced by international commodity markets. Australia is one of the world's largest exporters of raw cotton, with more than 90% of production exported, mainly to Asian spinning mill customers. China, Indonesia, Thailand, South Korea, Japan, Taiwan, Pakistan and Italy are the main buyers. Cotton growers have the option of delivering their cotton directly to a processor or having it marketed by an independent merchant. There are several pricing options available, including forward contracts.

Table 5.23 Cotton (*Gossypium spp.*)
(continued)

PARAMETER	DESCRIPTION
Prices	Currently approx. $450/bale
Opportunities and risks under a changing climate	Seasonal climate variability, water availability for irrigation
Further reading	DAFF (2012a)

5.5.11 INDUSTRIAL (SUGARCANE)

Sugar production is well established in Queensland, which produces approximately 95% of the Australian crop. Sugarcane was grown in the Ord River Irrigation Area until 2007. There is approximately 380,000 ha of cane grown annually, supplying 24 mills that produce approximately 4.4 Mt of sugar. The gross value of production is approximately $1400 million.

Sugarcane is classified as an industrial crop in the Assessment because it requires a local processing facility. It is estimated that at least 12,000 ha are required for a sugar mill to be economically viable. As a consequence, sugarcane is considered to be a promising crop only where large areas of suitable irrigable land are available.

More than 2 million hectares of the Gilbert catchment is moderately suited (class 3) to spray irrigated sugarcane production (Figure 5.39 and Figure 5.50). Flood-irrigated sugarcane cropping is considered less promising for the Gilbert catchment because the soils are not conducive to long flood irrigation furrows.. While flood irrigation may be possible on the less permeable soils in the Gilbert catchment it is not the most water-efficient method of irrigation, a potentially important consideration in strongly water limited environments.

It may be useful to explore the theoretical upper limits of sugarcane production in the Gilbert catchment. Dryland sugarcane production is not feasible. Economic production would require continuous irrigation throughout the dry season.

- Assuming that the most promising instream water storages in the Gilbert catchment could deliver approximately 250 GL to crops (i.e. after conveyance and field application losses): based on a median irrigation requirement of 12 ML/ha and a median potential yield of 128 t/ha, this would enable potential regional sugarcane production of approximately 2.67 Mt, grown on more than 25,000 ha (including the land needed for fallow between ploughing out the final ratoon and harvesting the plant cane). At a cane price of $35/t, that equates to more than $93 million gross value of production. Actual values would be lower than this potential upper limit. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2, 5.5.4 and 5.5.5.

The relatively large diurnal temperature variation in the Gilbert catchment through the May to September months, and lack of rainfall during this time, could render sugar content of cane grown in the Gilbert catchment among the highest in the Australian industry. Lack of strong cyclonic winds would confer on the Gilbert catchment an advantage over coastal sugarcane growing regions.

While sugarcane may be well adapted to the Gilbert catchment under optimal management and with a reliable supply of water, the large distance to existing sugar processing and marketing facilities (350 km by road to the Mareeba mill) would in the short term preclude sugarcane as a likely crop for the catchment.

Equipment required for growing sugarcane is mostly industry-specific, with only tillage, spraying and some fertiliser equipment, such as used on other crops. Specialised planting, row formation, and harvesting equipment is required, but most farmers use contract harvesting, and many also use contract planters. At least 10 to 12 contract harvesters would be needed to service the minimum 12,000 ha of sugarcane required to support a viable sugar mill.
Table 5.24 describes some key considerations relating to sugarcane production.

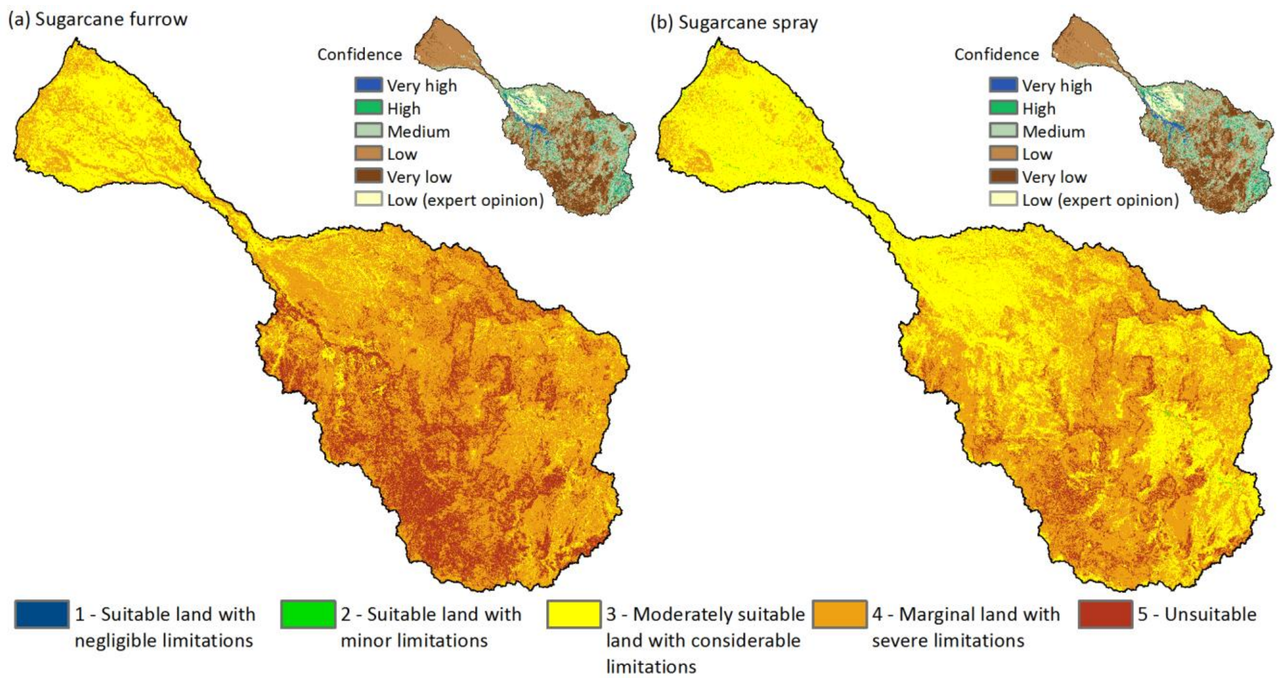

Figure 5.50 Modelled land suitability for sugarcane. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water
(a) Sugarcane using furrow irrigation and (b) sugarcane using spray irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.51 Sugarcane
Photo: CSIRO.

Table 5.24 Sugarcane (*Saccharum*)

PARAMETER	DESCRIPTION
Summary	Sugarcane is a tall tropical and sub-tropical perennial grass supplying 80% of the world's sugar production. Australia is the 3rd largest raw sugar producer, milling about 4 to 4.5 Mt raw sugar annually. Depending on the local conditions, sugar is usually harvested between July and November and allowed to regrow (ratoon) for a further 3 to 4 years. Sugarcane can be grown on the majority of well-structured arable soils, with a preference for free-draining soils. Acid sulfate soils can present management problems.
Growing season	Sugarcane is grown from 12 to 16 months before harvesting. A plant crop of 15 to 16 months is followed by four ratoon crops of 12 months. Harvesting occurs between June and December.
Land suitability assessment	Sugarcane is a high water use crop and tolerates flooding and wet soil conditions. It is therefore suited to a wide range of soil types. The moderately suitable (class 3) soils of the river alluvium and delta have clay subsoils with good soil water storage capacity but may require more management input when these coincide with hardsetting surface soils and soils where ESP > 6 results in poor water infiltration. The moderately suitable (class 3) soils between the Einasleigh and Gilbert rivers are sandier and freely draining, thus requiring more frequent irrigation applications. Furrow-irrigated sugarcane is less suited to the more permeable and better drained (sandier) soils, reducing irrigation efficiency and soil water storage capacity. The large areas of undulating to rolling hilly country in the upper catchment make a large proportion of the catchment marginal (class 4) and unsuitable (class 5) for irrigated sugarcane due to shallow or rocky soils, low soil water storage capacity and potential for erosion largely driven by slope.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (median)	12 ML/ha (May sowing, September harvest). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Dryland: 31 t/ha. Break-even crop yield 26 t/ha. Note that break-even crop yield does not occur with sufficient frequency to make local processing of dryland sugarcane viable. Irrigated: 128 t/ha (May planting, September harvest). Break-even crop yield 30 t/ha, assuming local processing.
Salinity tolerance	Moderately sensitive – EC_e threshold for yield decline 1.7 dS/m
Downstream processing	Requires local processing soon after harvest
By-products	Molasses, bagasse, ethanol. Ash and filter mud as a source of fertiliser
Production risks	Significant production losses occur if sugarcane is flooded for prolonged periods when less than 1 m tall. Productivity can be affected by rats, pigs, canegrubs and insects. Exotic pests and diseases present a significant threat to the sugarcane industry.
Rotations	Five-year rotation (one seed and four ratoon crops). Can be sown in rotation with a legume crop, such as soybean
Management considerations	Header, row crop planter, spray rig (pest control). Permits may be required for burning.
Complexity of management practices	Medium
Legislative constraints	None
Markets and emerging markets	Sugarcane is one of Australia's most important industries, worth $1.7 to $2.0 billion. Increasing demand from developing nations in South East and southern Asia. More than 80% of all sugar produced in Australia is exported as bulk raw sugar, with key export markets including South Korea, Indonesia, Japan and Malaysia. Returns to producers are determined primarily by the world futures price for sugar but are also influenced by the level of the Australian dollar, regional sugar premiums, and the costs for marketing and transporting the product.
Prices	Currently approximately $400 per tonne of sugar, which converts to a price of around $35 per tonne of sugarcane

Table 5.24 Sugarcane (*Saccharum*)
(continued)

PARAMETER	DESCRIPTION
Opportunities and risks under a changing climate	Reduced water availability in a drier climate will reduce yields.
Further reading	Canegrowers (2013), DAFF (2012b)

5.5.12 INTENSIVE HORTICULTURE

Intensive horticulture is an important and widespread Australian industry, occurring in every state, particularly close to capital city markets. It is something of a ‘sleeping giant’ of Australian agriculture, employing approximately one-third of all people employed in agriculture, and having a farm gate value of approximately $9 billion (of a total of about $22 billion for all Australian crops) (ABARES, 2012).

Production is highly seasonal and typically involves the growth on a particular farm of a wide range of crops. The importance of freshness in many horticultural products means seasonality of supply is important in the market. The Gilbert catchment may have advantages in that it could supply southern markets ‘out of season’. This requires a heightened understanding of risks, markets, transport and supply chain issues.

The total value of Australian exports of fresh and processed fruit, nuts and vegetables was $1.23 billion in 2010–11, compared with a total value of imports of these products of $1.81 billion (DAFF, 2012).

The Assessment provides details on a subset of the horticultural crops possible in the catchment.

There are approximately 0.3 million ha of soil that are classified as suitable (with minor limitations; Class 2) for the production of trickle irrigated horticultural crops such as capsicum, curcurbits and sweet corn (Figure 5.39 and Figure 5.52). The area at least moderately suited to trickle irrigated production of horticulture crops is considerably greater; about 2 million ha. As with all other crops, water is more limiting than land. Potential yields for horticultural crops are not modelled as there are no simulation models that have been calibrated for the Gilbert catchment, or similar environments. Dryland production of horticultural crops is unlikely to be viable.

Horticulture typically requires specialised equipment and a large labour force. Therefore, a system for attracting, managing and retaining sufficient staff is also required. Harvesting is often by hand, but packing equipment is highly specialised. Irrigation is with micro equipment, but overhead spray is also feasible. Leaf fungal diseases need to be more carefully managed with spray irrigation. Micro spray equipment has the advantage of also being a nutrient delivery (fertigation) mechanism, as fertiliser can be delivered via the irrigation water.

Table 5.25 describes some key considerations relating to sweet corn production, as an exemplar of those relating to horticultural production more broadly.

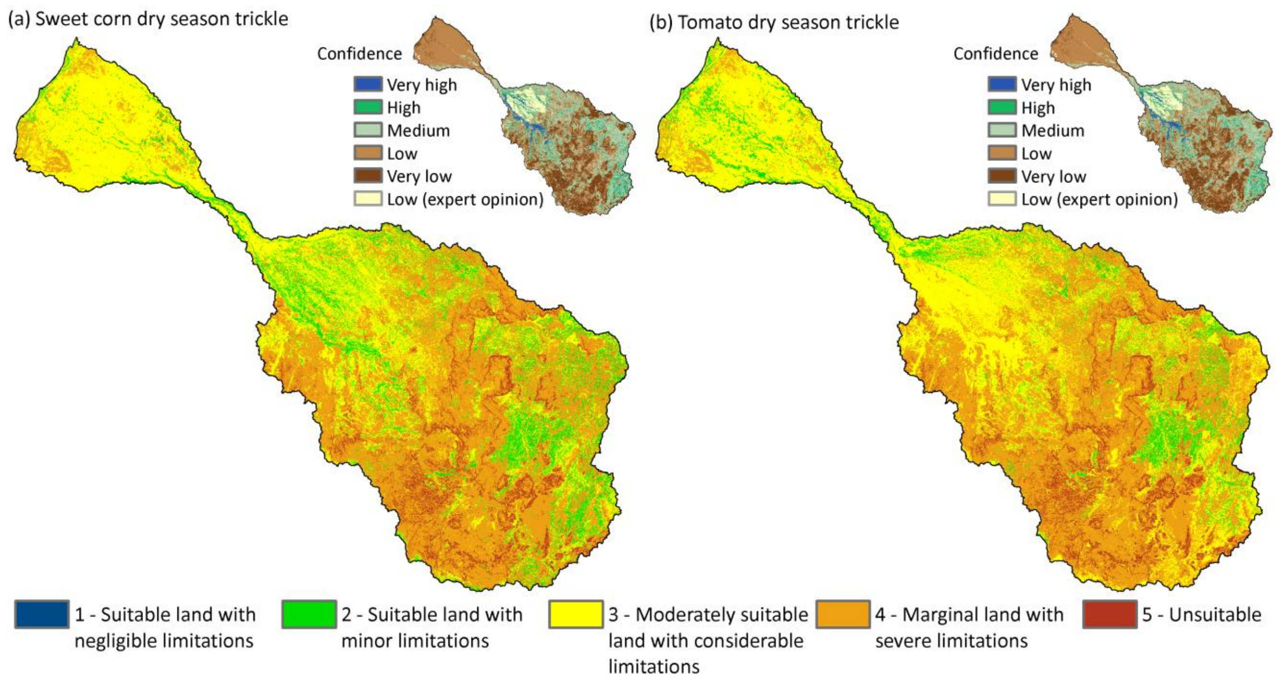

Figure 5.52 Modelled land suitability for sweet corn and tomato. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water
(a) Dry season sweet corn using trickle irrigation and (b) dry season tomato using trickle irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.53 Sweet corn
Photo: CSIRO.

Table 5.25 Sweet corn (*Zea mays var. saccharata*)

PARAMETER	DESCRIPTION
Summary	Sweet corn is a warm season, frost-sensitive crop with a preferred growing season temperature of 15 to 32 °C. Sweet corn can be produced for the fresh or processed market, and is sold both locally and overseas. Sweet corn is currently grown under irrigation in the Burdekin.
Growing season	Sweet corn can be sown between March and August with harvesting from May to October. It matures in 75 to 105 days.
Land suitability assessment	Horticultural crops are more intensively managed than other crop groups, reflecting their ability to be grown across a wide range of soil types and conditions. They have shallower rooting depths, hence soil water needs to be managed for optimum production. The suitable (class 2) areas require fewer inputs for production than the moderately suitable (class 3) soils. Large areas of marginal (class 4) and unsuitable (class 5) land are dominated by undulating to rolling hilly country. This makes a large portion of the catchment unsuitable for trickle irrigation due to the slope, rockiness, shallow soils and low soil water storage capacity.
Irrigation system requirements	Micro
Applied irrigation water (median)	3.8 ML/ha, based on maize. Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Irrigated: 8.5 t/ha (fresh weight) based on DPI Agrilink
Salinity tolerance	Moderately sensitive – EC_e threshold for yield decline 1.7 dS/m
Downstream processing	Requires local processing soon after harvest. Rapid transport and cooling of fresh market crops is important to maintain quality. 80% of sweet corn goes to the processing sector rather than the fresh food market.
By-products	Stubble can be grazed by livestock.
Production risks	Late sowings risk high temperature stress during flowering. Sweet corn is very prone to pest damage. Complete crop losses do occur.
Rotations	The plant grows quickly and is considered a valuable rotation crop, and is suitable for rotation with peanuts.
Management considerations	Row crop planter, harvester, spray rig, fertiliser, insect pest control (chemical resistance). There is a high labour requirement for grading and packing.
Complexity of management practices	Medium
Legislative constraints	None
Markets and emerging markets	Most sweet corn is sold on the domestic market, which is dominated by the processing sector. Australia exports frozen or canned kernel, frozen cob, long-life vacuum sealed cobs and fresh cobs. The important markets are Japan, South East Asia and Europe. Any growth in production will depend on access to export markets. Some increase in production for the domestic market is possible, though overproduction will rapidly occur.
Prices	Prices vary greatly depending on current supply and demand. Processing crops are generally grown under contract at a set price, depending on quality.
Opportunities and risks under a changing climate	Warmer climates allow multiple crops per year. Sweet corn is highly perishable in hot weather. Hot, dry, windy conditions at flowering time can stress plants and disrupt pollination and seed set. Sweet corn is more sensitive to heat stress than field maize.
Further reading	NSW Department of Primary Industries (2007), DAFF (2013b)

5.5.13 ROOT CROPS

Root crops – such as peanut, sweet potatoes and cassava – are potentially well suited to the light soils found in the alluvial stretches of the Gilbert catchment.

Approximately 1.2 million ha of the Gilbert catchment is moderately suited (class 3) to spray irrigated root crops, with a smaller subset (about 50,000 ha) comprising class 2 soils (suitable with minor limitations) (Figure 5.39 and Figure 5.54).

Peanuts are a crop that has been well established in Queensland. They can be planted in summer or winter. Peanuts grown in the Gilbert would probably be summer-grown, with supplementary irrigation required as the crop entered the dry season.

It may be useful to explore the theoretical upper limits of peanut production in the Gilbert catchment.

Assuming that the most promising instream water storages in the Gilbert catchment could deliver approximately 250 GL to crops (i.e. after conveyance and field application losses): based on a median irrigation requirement of 4.9 ML/ha and a median potential yield of 4.8 t/ha, this would enable potential regional peanut production of approximately 245,000 t, grown on more than 50,000 ha. At a peanut price of $850/t, that equates to more than $200 million gross value of production. Actual values would be lower than this potential upper limit. Actual yields would be lower and would vary significantly from year to year, as outlined in sections 5.5.2 and 5.5.4.

As a legume crop, peanuts require little or no nitrogen fertiliser, and are very well suited to growing in rotation with cereal crops because the atmospheric nitrogen fixed is frequently available to following crops. In addition, the stubble remaining after peanut harvest could be used as a high-quality supplementary feed for cattle. Most of the equipment suitable for cereal production (planter, fertiliser spreader, spraying and harvesting) can be used for peanut production, but a specialised digger is required to remove the nut 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.

Table 5.26 describes considerations relevant to peanut production in the Gilbert catchment. Many of these considerations are relevant to other root crops, such as cassava.

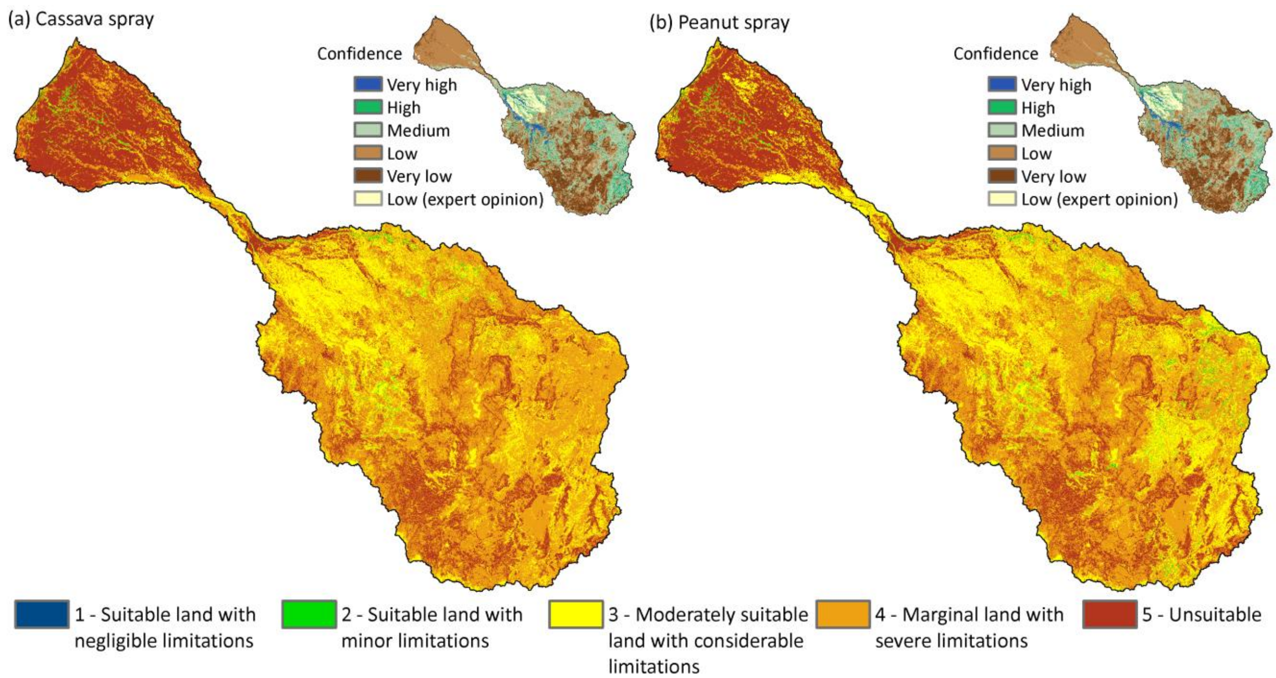

Figure 5.54 Modelled land suitability for cassava and peanuts. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water
(a) Cassava using spray irrigation and (b) peanut using spray irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.55 Peanuts
Photo: CSIRO.

Table 5.26 Peanuts

PARAMETER	DESCRIPTION
Summary	Peanuts are a tropical and sub-tropical annual legume grown as a wet season crop (when rainfed (dryland)) or dry season under irrigation. Peanuts can be sold for human consumption, while the remaining foliage can be used for stockfeed. Peanuts are currently grown in northern Queensland and the Northern Territory.
Growing season	Peanuts can be grown at any time of year in northern Australia, but to produce a consistently high-quality crop, peanuts should be harvested during the dry season. Sowing window from December to February (wet season, rainfed (dryland)) and March to April (dry season, irrigated). Peanuts take approximately 160 to 180 days to mature.
Land suitability assessment	Only small portions of the Gilbert catchment have soil characteristics suitable for root crops. Most of the catchment is marginal (class 4) and unsuitable (class 5) due to shallow soil depth, rockiness, low soil water storage capacity or waterlogging. The physical properties of the surface layers of the soil affect the suitability of root crops, requiring friable soils for root development. Suitable (class 2) and moderately suitable (class 3) soils have sandy and loamy surfaces. These lighter textured soils also require extra water management as root crops have shallower rooting depths than other crop groups.
Irrigation system requirements	Spray, surface, micro
Irrigation demand (median)	4.9 ML (March sowing). Assumes perfect timing of irrigation (i.e. no losses).
Crop yield (median)	Dryland: 1.2 t/ha (March sowing). Break-even crop yield 3.0 t/ha Irrigated: 4.8 t/ha (March sowing). Break-even crop yield 3.4 t/ha
Salinity tolerance	Moderately sensitive – EC_e threshold for yield decline 3.2 dS/m
Downstream processing	Sheller and processor required (Atherton Tableland)
By-products	Garden mulch from shells. Crop residues are a good-quality cattle feed.
Production risks	Poor crop establishment when soil surface temperatures exceed 40 °C. High temperatures and water increase the risk of aflatoxin.
Rotations	Rotations are important for weed and disease management. Good rotation crops include corn, sugarcane, sorghum and Rhodes grass. Potatoes, soybeans and navy beans are not good for rotations with peanuts because they tend to host many of the same pests and diseases. Peanuts should only be grown once every 2 to 3 years in a single paddock.
Management considerations	Digger, row crop planter, spray rig (pest control). Pesticide residues and heavy metals can contaminate peanuts. Seeds need to be inoculated.
Complexity of management practices	Medium
Legislative constraints	None
Markets and emerging markets	There is a very strong demand for peanuts. Australian growers supply a fraction of the local domestic peanut market.
Prices	Growers are paid according to peanut quality. Payment is determined on the basis of grading and clean dry weight of the load.
Opportunities and risks under a changing climate	Soil nitrogen benefit in crop rotations. Early maturing varieties can be used to avoid end-of-season droughts. Peanut growth is favoured by warm temperatures in excess of 25 °C.
Further reading	DAFF (2011b), Wright et al. (2013)

5.5.14 SILVICULTURE (PLANTATION)

Of all the potential plantation tree species available to be grown in the Gilbert catchment, African mahogany and Indian sandalwood are the only two that would be considered economically feasible. Many other plantation species could be grown; however, returns are much lower than for these two crops.

Large areas of the Gilbert catchment are considered suitable (class 2 and 3) for Indian sandalwood (Figure 5.39 and Figure 5.56).

Plantation timber species require over 15 years to grow, but once established can tolerate prolonged dry periods. Irrigation water is critical in the establishment and first two years of a plantation.

Table 5.27 describes Indian sandalwood production.

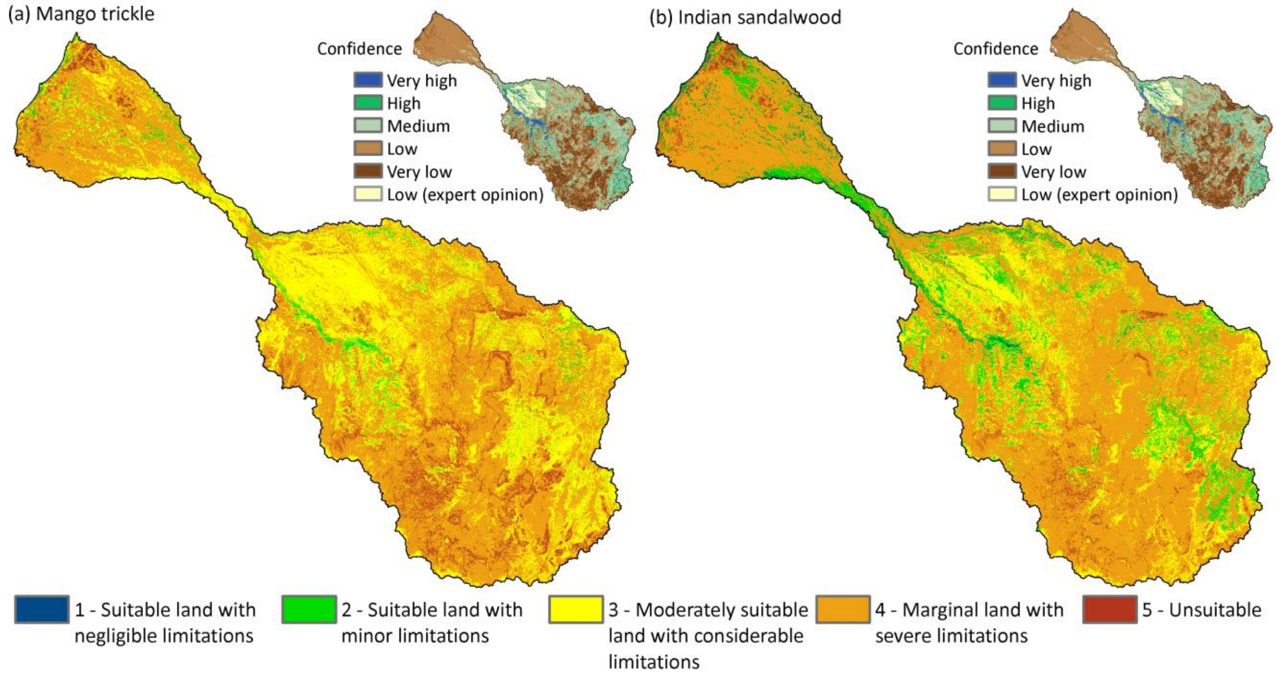

Figure 5.56 Modelled land suitability for mango and Indian sandalwood. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water
(a) Mango using trickle irrigation and (b) Indian sandalwood using trickle irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.57 Indian sandalwood
Photo: Tony Page, James Cook University. Used with permission.

Table 5.27 Indian sandalwood (*Santalum album*)

PARAMETER	DESCRIPTION
Summary	Sandalwood is a medium-sized, hemiparasitic tree grown for its aromatic wood and essential oils. The key product of value from sandalwood trees is the heartwood, which contains most of the oil and scented wood. Heartwood starts to develop when the tree is about 10 years old, with the proportion of heartwood (and value of the plantation) increasing with age after that time. Commercially viable sandalwood can take at least 15 years to reach harvestable maturity, but many plantations are not harvested for 20 to 35 years. Large areas of Indian sandalwood have been planted in the Ord River Irrigation Area, with some plantations reaching maturity in 2013. Production risks are mostly associated with the long period of time from planting to harvest, and uncertainty about the market for sandalwood in 20 years.
Land suitability assessment	Plantation species require greater soil depth than other crop groups. The moderately suitable (class 3) areas have sandy and loamy deep soils that need to be managed for soil water storage capacity for optimum production. Soils with loamy textures have better soil water storage capacity (class 2). Oversupply of water needs to be avoided to prevent soil water logging, as Indian sandalwood is susceptible to wet soil conditions mainly in the lower part of the landscape, the delta and other poorly drained soils. The marginal (class 4) and unsuitable (class 5) areas are generally on shallow or rocky soils.
Irrigation system requirements	Surface
Applied irrigation water (median)	5–6 ML/ha
Crop yield (median)	Heartwood 8 t/ha at 15 years, with oil 2 to 7 % of heartwood
Salinity tolerance	Unknown
Downstream processing	Sandalwood can be processed in Australia or exported overseas for oil extraction.
By-products	Spent pulp after oil extraction is available for production of incense. Sandalwood nuts are edible, but there may also be potential markets in the cosmetics industry. The host plants may be harvested for timber or biofuels.
Production risks	Long length of time between planting and harvest.Termites can significantly reduce the yields of plantations. Synthetic and biosynthetic sandalwood oil is the greatest threat to the Australian sandalwood industry.
Rotations	Perennial tree crop not suited for rotation with other species. Sandalwood requires a host plant to supply water and nutrients.
Management considerations	Harvesting is usually done by contractors. May require several hosts during the lifespan of the tree. The first host is usually a herbaceous plant (e.g. *Alternanthera*) introduced to the container-grown sandalwood one month prior to planting. The second short-term host aims to produce rapid sandalwood growth and will die 2 to 4 years after establishment (e.g. *Sesbania formosa)*. A long-term host (e.g. *Cathormion umbellatum*) supports the sandalwood over its production life. These hosts are planted at the same time as the sandalwood. Host species also need to be suited to local soil type and climate. Two to three host trees are required per sandalwood tree. Using several species of host plants will minimise risks from pests and diseases. Weed control is important and must use methods that do not negatively impact the sandalwood or host plant.
Complexity of management practices	Medium
Legislative constraints	NA

Table 5.27 Indian sandalwood (*Santalum album*)
(continued)

PARAMETER	DESCRIPTION
Markets and emerging markets	Globally, sandalwood is highly valued due to the presence of unique aromatic substances in the heartwood, and it is important to certain cultures and religions. The incense industry is the largest consumer of sandalwood material. High prices are paid for good-quality timber suitable for carving, but the proportion of such material is low. The next most valuable product is the oil, which is the main driver of international trade and is sought after for high value end uses such as perfumery. The traditional markets of Taiwan, Hong Kong and China are the biggest consumers of sandalwood.
Prices	Prices have increased over the past decade in response to a steady decline in worldwide supply.
Opportunities and risks under a changing climate	Can take advantage of water at any time of year. Planting several species of sandalwood and host plants together makes the plantation more resilient to changes in climate. Sandalwood trees are not fire tolerant.
Further reading	Forest Products Commission Western Australia (2008), Clarke (2006)

5.5.15 TREE CROPS (FRUIT)

Some fruit tree crops – such as mango and cashew – are demonstrably well suited to the climate of the Gilbert catchment. Other species – such as avocado, citrus, macadamia and lychee – are not likely to be well adapted to the climate and are less promising.

Fruit production shares many of the marketing and risk features of intensive horticulture. The importance of freshness in many fruit products means seasonality of supply is important in the market. The Gilbert catchment may have advantages in that it could supply southern markets 'out of season'. This requires a heightened understanding of risks, markets, transport and supply chain issues.

The perenniality of tree crops makes a reliable year-round supply of water essential. However, some varieties, such as mango, can survive well under mild water stress until flowering (generally August to October for most fruit trees). It is critical for optimum fruit production that fruit trees are not water stressed from flowering through to harvest. This is the period up to November through to February, depending on the species.

The Assessment provides details on a subset of the tree crops possible in the Gilbert catchment.

There are approximately 0.1 million ha of soil that are classified as suitable (with minor limitations) for the production of trickle irrigated fruit tree crops such as mangoes (Figure 5.39 and Figure 5.58). The area at least moderately suited to trickle irrigated production of fruit tree crops is considerably greater; over 1.5 million ha. As with all other crops, water is more limiting than land. Potential yields for horticultural crops are not modelled as there are no simulation models that have been calibrated for the Gilbert catchment, or similar environments. Existing production data is commercial-in-confidence. Dryland production of horticultural tree crops is unlikely to be viable.

Specialised equipment for fruit 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 being able to deliver fertiliser directly to the trees through fertigation.

Table 5.28 describes some key considerations relating to mango production in the Gilbert catchment, as an exemplar of those relating to tree crop production more broadly. Similar information for other fruit tree crops is described in the companion technical report about agricultural productivity (Webster et al., 2013).

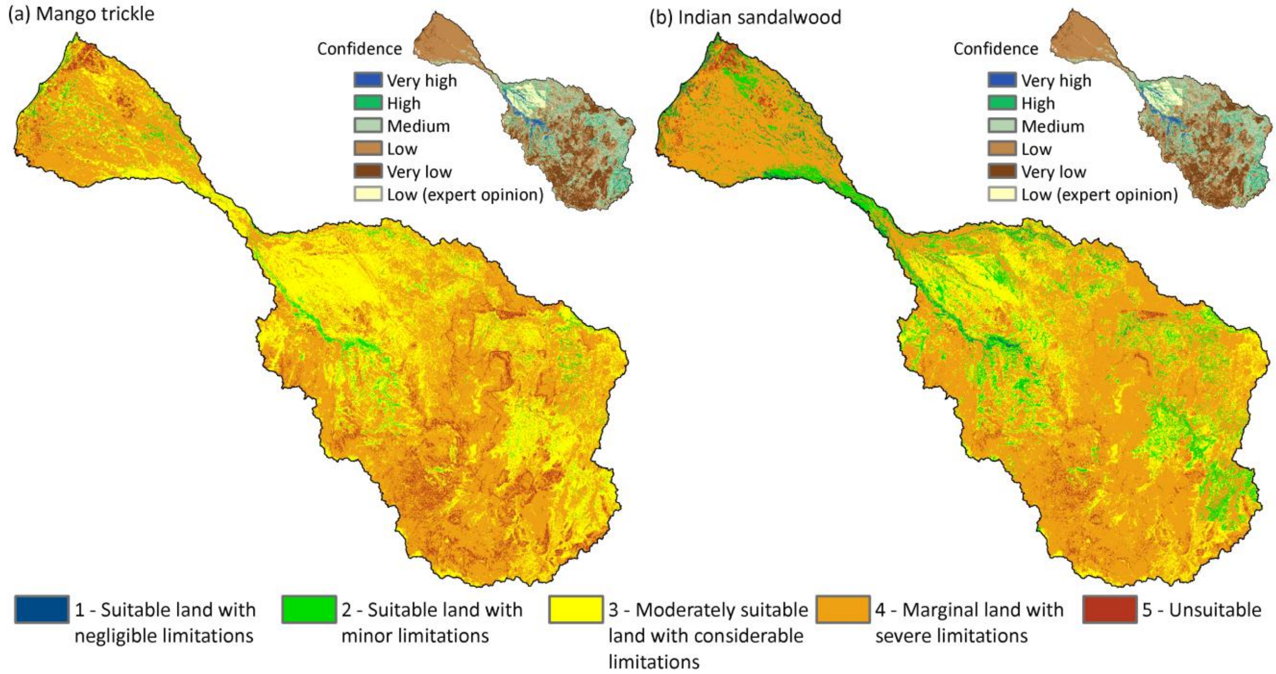

Figure 5.58 Modelled land suitability for mango and Indian sandalwood. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water
(a) Mango using trickle irrigation and (b) Indian sandalwood using trickle irrigation. The methods used to derive the confidence data in the inset map are outlined in Section 3.6 of Bartley et al. (2013).

Figure 5.59 Mangoes
Photo: Ian Bally, Agri-Science Queensland. Used with permission.

Table 5.28 Mango *(Mangifera indica)*

PARAMETER	DESCRIPTION
Summary	Mangoes are one of the major horticultural crops grown in Australia and around 7000 ha are currently grown in Queensland. The main production areas are the Burdekin, Bundaberg and Mareeba regions.
Growing season	Mango harvests start in late October in Gilbert catchment and extend to January – depending on variety.
Suitable soils	All tree crops require greater soil depth than other crop groups. The moderately suitable (class 3) areas have sandy and loamy deep soils that are more freely draining; however, they require more frequent irrigation compared to the suitable (class 2) loamy soils. The suitable (class 2) soils generally have clay at depth with better soil water storage capacity. The marginal (class 4) and unsuitable (class 5) areas largely have shallow or rocky soils. The Gilbert delta has clay soils which are seasonally wet and/or poorly drained (thus class 4).
Irrigation system requirements	Micro, need capacity to apply up to 0.3 ML/ha per week in peak demand
Applied irrigation water (median)	6 ML/ha, based on DPI Agrilink
Crop yield (median)	13 t/ha, based on DPI Agrilink
Salinity tolerance	Sensitive
Downstream processing	Requires local processing soon after harvest. Unripe fruits are used in pickles, chutneys and salads. Ripe fruits can be eaten fresh or frozen, or can be dehydrated, canned or made into products such as jams and juices.
By-products	None
Production risks	Susceptible to cold and frost. Many varieties have irregular yields, with a heavy crop one year followed by several lighter crops.
Rotations	Perennial tree crop not suited for rotation. Could be planted for alley cropping
Management considerations	Packing equipment, harvest aids. A wide range of climatic zones in northern Australia provides opportunities to maintain a sustained period for supplying the domestic market. The two most common varieties grown in Queensland are Kensington Pride and B74, while other varieties are grown on a limited scale to extend seasonal availability or supply niche markets.
Complexity of management practices	Medium
Legislative constraints	None
Markets and emerging markets	The majority of fruit are sold on the domestic market with only 5–10% exported from Queensland. (www.daff.qld.gov.au)
Prices	Highly variable depending on timing
Opportunities and risks under a changing climate	Increasing opportunity to supply processed market for canned mango, juice and flavoured products
Further reading	Johnson and Parr (2006), DAFF (2013c)

5.6 Summary of dam and scheme-scale costs

This section provides an estimate of the dam and scheme-scale capital and operating costs for a potential irrigation development in the Gilbert catchment. It does not include farm-scale costs such as those associated with irrigation system infrastructure or farm machinery nor does it include legal or approval costs. The material reported in this section is drawn largely from Chapter 5 and the case study on Green Hills dam and irrigated three-crop rotation (Chapter 8).

Table 5.29 provides scheme-scale capital and operating costs for a potential irrigation development associated with the Green Hills dam. The capital costs are expressed as a constant equivalent annual cost over the life of capital items based on a real discount rate of 7%. Despite the large cost of land development (i.e. approximately $8000/ha, Section 5.4), Table 5.29 shows that the estimated cost of scheme-scale irrigation development and distribution infrastructure is small (i.e. 30% of the total cost) compared to the cost of the Green Hills dam.

Table 5.30 expresses the total annual cost reported in Table 5.29 in terms of per ML supplied to the farm gate. The ML volume corresponds to that which can be supplied in 85% of years. Based on this analysis, the total annual cost of water for Green Hills dam and scheme-scale infrastructure is $269 per ML supplied in 85% of years. This accounts for the annual capital and operating costs. It should be noted that the Green Hills dam was selected for this analysis because it had the second lowest unit cost (Table 5.1) and is the dam that is closest to land that is moderately suitable for spray irrigation (see Section 5.5). The development of other dams and associated irrigation infrastructure in the Gilbert catchment will result in a larger annual cost of water per ML supplied in 85% of years than that reported in Table 5.30 for Green Hills dam.

Table 5.29 Scheme-scale capital and operating costs for a 10,000-ha potential irrigation development and Green Hills dam

The costs are approximate scheme-scale costs to the farm gate. Farm-scale capital costs such as irrigation system (e.g. Table 5.10) and farm machinery (Chapter 6) are not included in this analysis. The size of the irrigation development is based on an annual water requirement of 15 ML/ha (including losses) and the supply of water to the farm gate in 85% of years. All costs indexed to 2012.

ITEM	CAPITAL COST ($ million)	LIFE SPAN (y)	EQUIVALENT ANNUAL COST# ($ million)	ANNUAL OPERATING COST ($ million)	TOTAL ANNUAL COST## ($ million)
Large dam	$335.00	100	$23.48	$1.34	$24.82
Sheet piling weir *	$55.00	40	$4.13	$0.55	$4.68
Main supply channel *	$11.79	40	$0.88	$0.12	$1.00
River pumping infrastructure *	$2.50	15	$0.27	$0.05	$0.32
Access roads *	$1.58	100	$0.11	$0.02	$0.13
Area works (earthworks and structures)**	$56.53	40	$4.24	$0.57	$4.81
Area works (roads) **	$20.86	100	$1.46	$0.21	$1.67
Total	$483.26		$34.57	$2.85	$37.42

* See case study on Green Hills dam and irrigated three-crop rotation (Chapter 8) for more detail.
** Includes overheads.
# Assumes a 7% real discount rate.
Sum of equivalent annual costs of capital infrastructure and operating costs.

Table 5.30 Summary statistics for a 10,000-ha potential irrigation development and Green Hills dam
The costs are approximate scheme-scale costs to the farm gate. Farm-scale capital costs such as irrigation system (e.g. Table 5.10) and farm machinery (Chapter 6) are not included in this analysis. The size of the irrigation development is based on an annual water requirement of 15 ML/ha (including losses) and the supply of water to the farm gate in 85% of years.

PARAMETER	UNIT	VALUE
Water supply at dam wall in 85% of years	GL	172.0
Conveyance efficiency to farm gate (%) *	%	80.8%
Water supplied to farm gate in 85% of years	GL	138.9
Total annual cost	$ million	$37.4
Total annual cost per ML supplied to the farm gate in 85% of years	$ per ML supplied in 85% of years	$269

* Conveyance efficiency is likely to be generous. See case study on Green Hills and irrigated three-crop rotation (Chapter 8) for more detail.

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6 Overview of economic opportunities and constraints

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The question 'Is irrigated agriculture economically viable?' is addressed in Chapter 6. It is considered at a range of scales and circumstances, starting with an investigation of the benefits of incorporating irrigated fodder crops into existing beef production systems in the catchment, followed by an examination of the costs and benefits of developing land for irrigated agriculture, at both scheme scale and farm scale. Regional and national benefits of investment in irrigated agriculture are also evaluated, taking into account not just irrigated agriculture per se, but the associated economic activity that accompanies such development (e.g. construction activity and processing industries). The factors that facilitate the development of a 'greenfield site' (i.e. one without previous development) are considered. These include infrastructure requirements, agricultural skills and labour, and legislation and regulation.

The key components and concepts of Chapter 6 are shown in Figure 6.1.

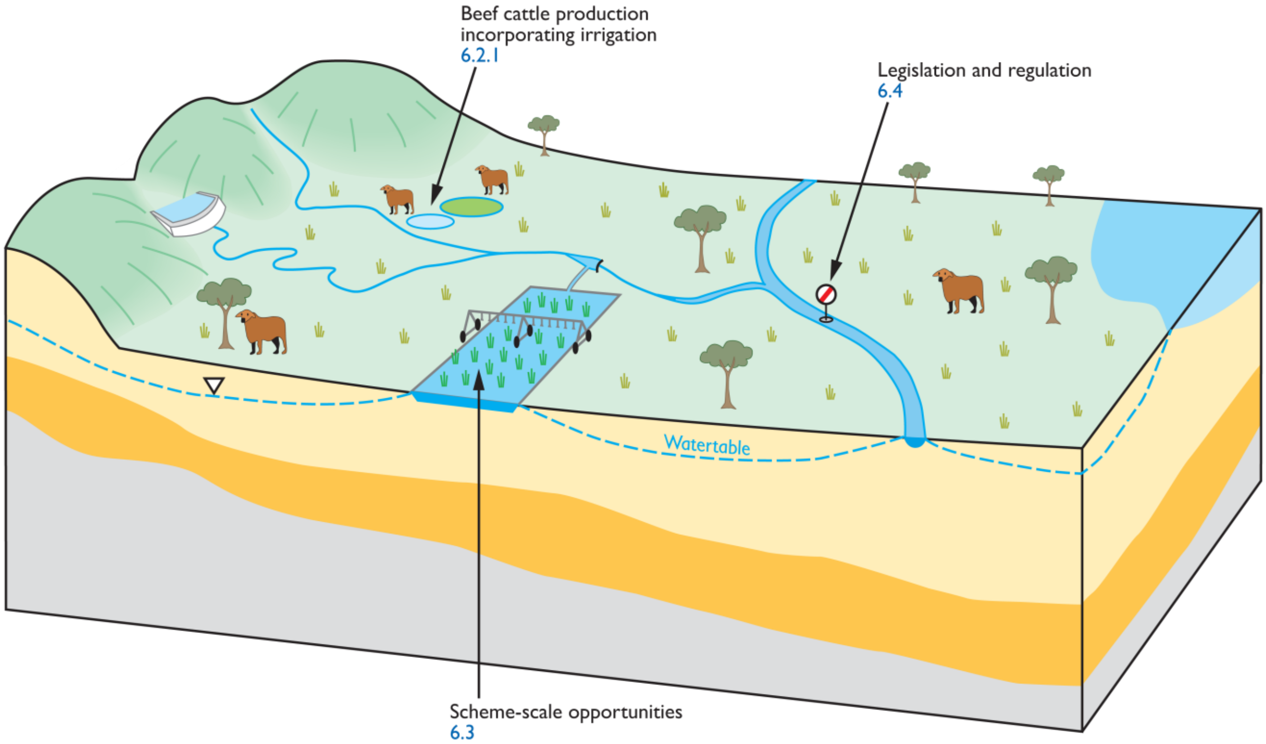

Figure 6.1 Schematic diagram of key components and concepts in the establishment of a greenfield irrigation development

6.1 Summary

6.1.1 FARM-SCALE OPPORTUNITIES FOR IRRIGATION DEVELOPMENT

Cattle enterprises in the Gilbert catchment rely on extensive grazing from unimproved native pastures. During the wet season, feed is plentiful but this is often followed by feed shortages in the dry season. Irrigation could increase dry-season feed and improve the productivity of cattle enterprises. Under the development scenarios examined, the high capital cost of irrigation infrastructure precluded commercial returns on investment in water assets used to grow irrigated forage. Where third-party investment in the 'patient capital' required for water storage and delivery was examined, commercial returns on forage production were possible.

Irrigated agriculture provides profitable opportunities at the farm scale. The capital costs of irrigation development, particularly when combined with an offstream storage, are high and impact substantially on the net returns from irrigated agriculture. Profitable irrigated agriculture investments require gross margins that can be sustained at levels sufficient to cover capital costs. Gross margins, and in turn investment performance, are sensitive to variability in crop yield, commodity and input prices, and water allocation reliabilities.

To deliver 4 ML/ha (after irrigation losses) to a 500-ha crop, a gross margin greater than $1500/ha is required each year to cover the capital and overhead costs of a farm dam and irrigation system. Water allocation reliabilities have a significant impact on net returns. A $2000/ha gross margin generated annually results in $1.4 million in net returns in 15 years, but if the reliability of this gross margin falls such that it is generated in only 80% of years, the gross margins are unable to cover costs and the investment becomes unviable.

6.1.2 SCHEME-SCALE OPPORTUNITIES FOR IRRIGATION DEVELOPMENT

Farm-scale investment performance may be improved where irrigation water is supplied through a larger scale irrigation development in the local area rather than through investing in individual farm dams. In Queensland, new water infrastructure investments require assessment not only of the economic viability of an irrigation development but an estimate of the expected cost recovery of initial infrastructure and related costs. Irrigators are likely to be able to afford to pay a water price to cover the capital and operating costs of a scheme-scale irrigation development only when capital costs are relatively low and gross margins from a cropped area are high. In reality, with expected variability in margins and likely capital costs, irrigators would only be able to pay a water price that covered operating and maintenance costs for scheme-scale irrigation infrastructure, and not under all circumstances.

6.1.3 LEGISLATION AND REGULATION

Legislation and regulation are often viewed as constraints through proscribing and prescribing land uses and management actions and describing when water licences can be taken in full and whether they can be freely traded. A large suite of legislation is applicable to irrigation development, including Acts relating to water, land and vegetation management; tenure; native title; cultural heritage; and environmental protections. Therefore, the implications for irrigation development are most reliably assessed case by case.

Irrigated agriculture requires access to skilled labour to work in irrigated enterprises and in any processing industries that arise from the irrigated enterprises. A current lack of expertise is expected to be a limitation to irrigation development in rangelands or pastoral areas that lack experience of irrigated agriculture. Assistance may be required to attract skilled labour to remote areas.

6.1.4 REGIONAL-SCALE IMPACTS

Irrigation development could bring economic benefits to the region – construction of irrigation infrastructure increases employment and generates additional economic activity. Opportunity costs of capital may be an important regional development consideration.

6.2 Farm-scale opportunities

6.2.1 BEEF CATTLE PRODUCTION INCORPORATING IRRIGATION

Introduction to beef enterprises in the Gilbert catchment

The dominant beef production system that is used across most of northern Australia is centred on a cow–calf breeding operation with several variations in the post-weaning management and marketing of male animals produced by the breeding herds (Gleeson et al., 2012). Some enterprises specialise in breeding and 'turning off' (bringing the animal to the stage for selling) very young stock after weaning (6 to 9 months); some retain and grow young male animals to weights that are suited for the live export trade (300 to 350 kg at 12 to 18 months); and others carry older steers through to heavier weights (360 to 450 kg at 24 months) suited to feedlot 'finishing' (the process of feeding an animal to become slaughter-ready) or weights suited for slaughter for north Asian markets (590 to 620 kg at 30 to 40 months). The final choice for any single holding is largely determined by the interplay of land resource endowments, local climate and market opportunities.

In many instances, these variants of the cow–calf breeding system are conducted across geographically segregated holdings that are integrated under common ownership and management. Most of these production system variants, including the geographic separation of system components, are found on the beef holdings that are located in the Gilbert catchment, but the most common are cow–calf breeding systems that turn off weaners of both sexes or light steers for export or 'backgrounding' (allowing cattle to be grown out to a uniform weight before entering a feedlot). Beef cattle holdings in the region that are an integral component of geographically segregated production enterprises will generally run a specialist breeder herd and transfer young and often newly weaned animals of both sexes to other holdings outside the region for growing out for live export, backgrounding for feedlots or finishing for slaughter. While many holdings retain a proportion of their own-bred heifers to maintain breeding herd numbers after culling or mortalities, others source their replacement breeders from other regions where they have already been grown out to a suitable weight and condition for mating. If suitable conditions prevail – and especially if forage supplies are adequate – many holdings may finish cull breeders and older steers to heavier weight classes for slaughter.

The forage base for cattle enterprises in the Gilbert catchment is largely comprised of unimproved native pastures with only limited areas of sown grasses and legumes. These pastures generally provide a plentiful supply of herbage for grazing in the wet season, although there is considerable year-to-year variation in the total quantity and quality of available pasture due to seasonal rainfall variability. Herbage quality declines rapidly with the onset of the annual dry season during which feed shortages are also prevalent. As a result, annual animal growth patterns typically follow a sequence of seasonal weight gains and weight losses which affects the ability of stock to reach different market weight for age specifications, as well as breeder reproductive performance (Figure 6.2). Dry-season feeding of energy- and protein-enriched supplements (e.g. urea and molasses; cottonseed meal) to some or all stock classes is commonly practised. Some enterprises also feed hay to stock, especially in very dry seasons (Gleeson et al., 2012). This hay may be produced locally by cutting and baling dryland pastures or from sown pasture with limited irrigation, or it may be trucked in from other regions (e.g. sub-coastal regions, Atherton Tablelands).

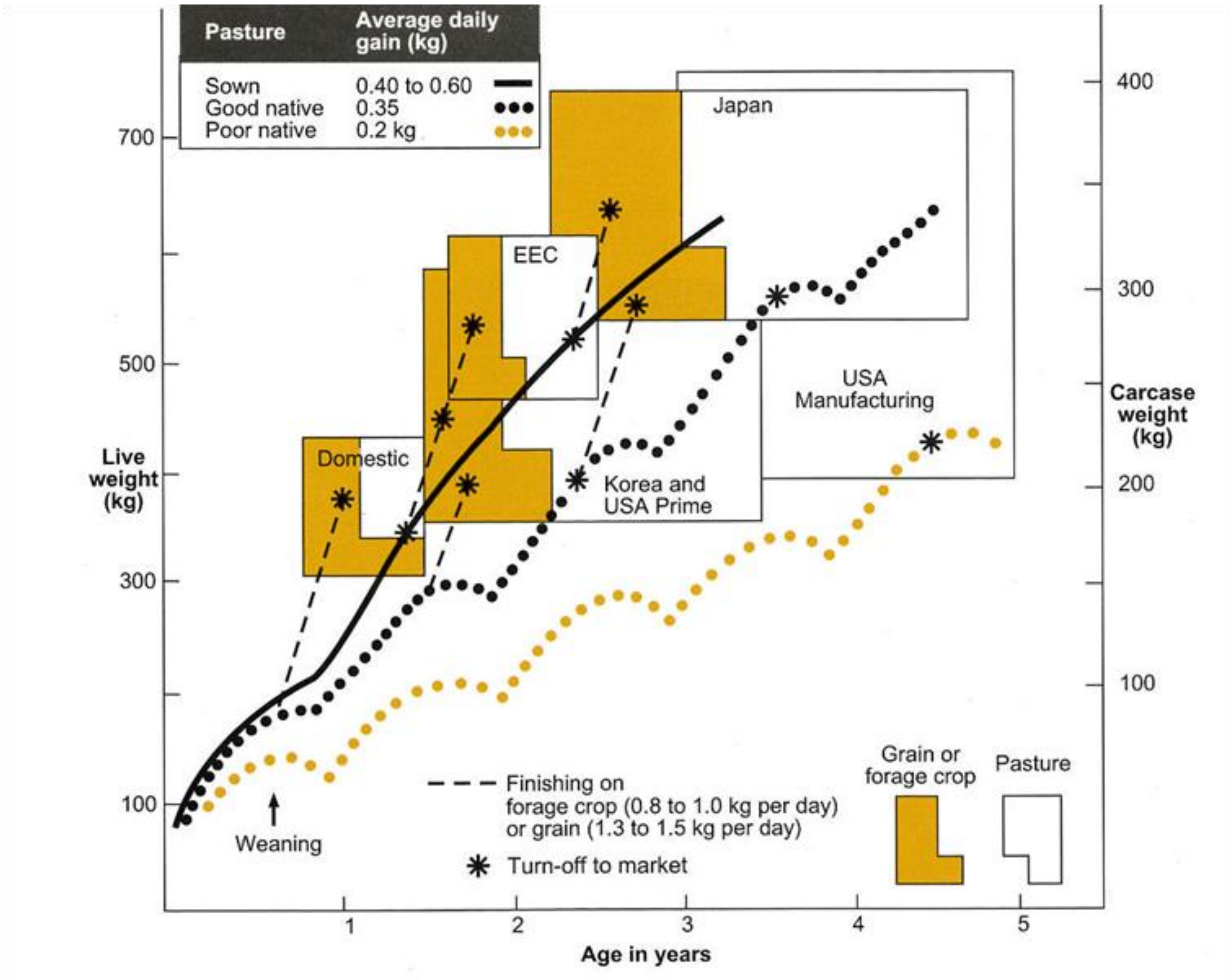

Figure 6.2 Growth patterns of beef cattle in northern Australia

Plot shows the effects of different pastures and the finishing options for various markets. Source: Gramshaw and Lloyd (1993). Reproduced by permission of the State of Queensland (acting through the Department of Agriculture, Fisheries and Forestry) 2013.

Although a range of factors – such as genetic makeup, physiological state, health, ambient temperature, stress, distance to water and general husbandry – affect beef reproductive efficiency and animal growth, a key driver remains the unrestricted availability and intake of digestible dry matter. It is in this regard that the opportunities for irrigation to directly affect the productivity and profitability of existing beef enterprises in the Gilbert catchment are best considered.

The prospective markets that can be accessed for a particular class of cattle in a herd (e.g. weaner steers, three-year-old bullocks, cull breeding cows, etc.) are largely determined by the pattern of growth of those animals relative to their age, which is significantly influenced by the type of pastures on which they are grazed and the extent to which high-quality forages and grain might be employed to supplement their diet (Figure 6.2). The capacity of different types of pastures, forage crops and grain to produce liveweight gain in beef cattle is well understood. Most beef enterprises will use that knowledge and their available pasture resources to develop feeding regimes to produce cattle that meet particular targeted market requirements in terms of weight and age (Gramshaw and Lloyd, 1993).

Figure 6.2 presents general growth patterns of beef cattle grazing on different pasture types in northern Australia and the finishing options for livestock that is targeted at various beef markets. The present beef production and marketing patterns in the Gilbert catchment are due to the interplay of:

- constraints to animal intake from local pasture and forage resources
- opportunities for directing various cattle classes to different markets

- relative returns from those markets.

Irrigation developments may offer contemporary beef enterprises opportunities to alter feeding management strategies to exploit different market categories and to seek price premiums for out-of-season turn off of suitable animals.

Cattle producers' reasons for incorporating irrigation into beef production systems

Four cattle producers and managers were interviewed as part of the Assessment in November 2012. They previously irrigated – or currently irrigate – their properties in the Gilbert catchment or other nearby catchments, or were interested in developing their properties for irrigation for the first time. At the time of the interview, some were seeking additional water through the Queensland Government tender process. There is interest locally in investing in irrigation development for forage production.

The interviewees gave a number of reasons for accessing new irrigation water, including a range of responses relating to beef cattle production, such as to:

- better safeguard their cattle operations during periods of drought through the production of fodder
- produce fodder for off-farm sale and on-farm consumption.

Interviewees also commented on the lack of opportunity for growth and the importance of the irrigation development for the vitality of the regional community.

Irrigation has been identified as one of the critical factors determining growth of the northern Australian beef industry (Gleeson et al., 2012). Improving cattle nutrition through improved pasture or forage crops leads to faster finishing of cattle and increased beef quality. This addresses a key risk factor identified by Gleeson et al. (2012) – that is, export market risk – and allows producers to move from operating 'breeding' enterprises to 'fattening' enterprises necessary to supply meat processors with slaughter-ready cattle. Such a shift would need to be supported by development of irrigation for growing pasture and fodder crops, extending the ability to fatten cattle through the dry season. Finished beef production could occur in areas where stock is now mostly shipped out either in the northern live export trade or to southern feedlots as 'store' (unfinished or not ready for slaughter) stock.

Benefits of incorporating irrigation into beef operations

To examine the impact of irrigated forages on the performance of a beef enterprise in the Gilbert catchment, selected irrigation developments were examined. These are development options for accessing surface water harvesting opportunities. The analysis used North Australia Beef Systems Analysis (NABSA) (McDonald, 2012), a tool that integrates data about animal, pasture and crop production with labour and land requirements; accounts for revenue and costs; and evaluates these against existing land, labour and financial resources.

The analysis was undertaken using a number of different scenarios, which are independent from other scenarios defined elsewhere in the report (e.g. scenarios A to C). As shown in Table 6.1, different assumptions underlie each scenario, including:

- forage crop type and area
- water demand per crop
- irrigation system used
- irrigation efficiencies: storage, 'conveyance' (the way water is moved from one place to another) and application
- storage size and cost
- available feed options
- access to the feed base
- key livestock changes in selling age, weight and timing
- price changes for quality.

Given the predominance of sandy soils in the Gilbert catchment, a spray irrigation system was assumed because a surface irrigation system, while of lower capital cost, would have high water losses. Spray irrigation also has high water pumping costs than surface irrigation.

A cattle breeding enterprise in Georgetown typically relies on grazing of native grass and feed supplements. As a result, in the baseline scenario (Scenario 1, against which all other scenarios are compared), it is assumed that there is an insufficient feed base to sustain the fattening of weaners past the age of 6 to 8 months. The weaners are sold at that age, weighing 180 to 200 kg, and are assumed to be worth $2.00/kg, for a total of $360 to $400/head. In the scenarios, the key assumption is that having a proportion of the property with forage for grazing (scenarios 2 and 3) or hay (scenarios 4 and 5) allows weaner steers out on the property up to approximately 12 to 14 months until they reach approximately 300 kg (live export weight) through extra feeding. These steers sell for an average $1.80/kg, or $540/head. While younger weaners fetch a higher price in the marketplace because they are young and in demand when cattle are scarce, heavier steers get slightly lower value per kilogram, but make up for it in the higher sale weights (38% increase in price per head relative to Scenario 1, Table 6.1). In addition, there is a potential benefit from the sale of hay under scenarios 4 and 5.

Table 6.1 Key features of the five scenarios used in the analysis with the North Australia Beef Systems Analysis tool for Georgetown

FEATURE	UNIT	SCENARIO 1 (BASELINE)	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
Farm irrigated area	ha	0	100	200	500	1000
Irrigated forage type		-	Sorghum (grazing)	Bambatsi (grazing)	Lablab (hay)	Sorghum (hay)
Length of crop growing season	months	-	6	Perennial	3	4
Water allocation *	ML/ha	-	4	10	6	4
Total water demand	ML	-	400	2,000	3,000	4,000
Water storage efficiency **		-	0.58	0.24	0.78	0.72
Water conveyance efficiency #		-	0.86	0.86	0.86	0.86
Water application efficiency ##		-	0.85	0.85	0.85	0.85
Total irrigation efficiency		-	0.42	0.18	0.57	0.52
Effective water volume to meet irrigation demand	ML	-	944	11,381	5,277	7,642
Selected water storage size	ML	-	1,000	12,000	6,000	8,000
Total annual capital and overhead costs of irrigation investment	$/y	-	$341,839	$1,026,253	$806,646	$1,139,973
Available feed options		Native pasture Supplements	Native pasture Grazed fodder Supplements	Native pasture Grazed fodder Supplements	Native pasture Forage hay Supplements	Native pasture Forage hay Supplements
Target herd class		Weaner	Steer	Steer	Steer	Steer
Selling age for class	months	6–8	12–14	12–14	12–14	12–14
Selling weight for class	kg	180–200	300	300	300	300
Selling price for class	$/kg	$2.00	$1.80	$1.80	$1.80	$1.80

* Excludes losses.
** After evaporation and seepage over the growing season.
# Includes river to storage efficiency (0.90) and storage to field efficiency (0.95).
Centre pivot (spray) irrigation system.

Net present value (NPV) is a standard method for using the value of money over time to appraise long-term projects by measuring the differences between costs and revenues in terms of present value. It was used to facilitate comparisons between development options. A series of NPVs were calculated from 15-year streams of net profit sampled, in sequence, from the whole 121-year simulation period of 1890 to 2010. This results in a sequence of 15-year series commencing from 1890, 1891, 1892, etc. through to 1996, which includes the last 15 years to 2010. Of the 107 series (15 years each), the last sequence (from 1996 to 2010) was considered suitable for further analyses because it generates an NPV close to the median and it corresponds to the most recent historical period.

The analysis using the NABSA tool incorporated five steps:

- Standard simulation runs under all five scenarios, assuming 100% reliability of water supply from 1996 to 2010. These simulations provide a reference for more detailed analyses.
- A multi-factorial analysis combining four key commodity and input prices that are subject to uncertainty and/or fluctuation over time (price of beef, price of hay, purchase price of urea fertiliser, and cost of pumping irrigation water via a centre pivot system), under each scenario from 1996 to 2010. This step identifies the range of possible outcomes resulting from different combinations of parameters in the sensitivity analysis for a typical farm in the Gilbert catchment.
- Sensitivity testing on the water-loss efficiency of irrigation storage and conveyance conducted on the scenario with the highest NPV.
- An analysis of reliability of water supply from irrigation (70 to 100%) conducted on the scenario with the highest NPV for each of the 15-year sequences over the whole 121-year period. This analysis allows for a meaningful assessment of the impact on net profit of water reliability.
- A sensitivity analysis conducted on the capital cost of irrigation underlying the scenario with the highest animal turnoff and gross margins overall. The intent of this analysis is to explore how potential incentives or alternative arrangements could help producers, given that this is the most significant cost of irrigation.

Table 6.2 presents results under all five scenarios described in Table 6.1. Table 6.2 shows that the case for investment in on-farm irrigation development is not compelling, with a positive NPV under only one scenario (scenario 1, the baseline scenario with no irrigation). The average total gross margin (per animal) under scenarios 2 and 3 exceeded that under the baseline scenario, but was not high enough to offset the capital costs associated with the irrigation investment.

In summary, under scenarios 2 to 5, irrigation is not more profitable than under the non-irrigated baseline scenario. Capital costs under all irrigation scenarios are significant. The increases in beef turn off attributable to irrigation are modest in comparison and do not generate sufficient income to offset capital costs.

This analysis was based on the assumption that the forage crops are grown with 100% reliability of water supply, which is not likely to occur in reality. Therefore, results that might be obtained for a more likely 80% level of water reliability would be less profitable than those presented in Table 6.2. Full details of the analysis are provided in the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013).

Table 6.2 Modelled results from the analysis using the North Australia Beef Systems Analysis tool, under scenarios 1 to 5 for Georgetown from 1996 to 2010
Key features of the five scenarios are summarised in Table 6.1.

KEY RESULTS	UNIT	SCENARIO 1 (BASELINE)	SCENARIO 2	SCENARIO 3	SCENARIO 4	SCENARIO 5
Total animal equivalents	AE	3,161	3,310	3,685	3,597	3,357
Weaning rate	%	56%	59%	68%	66%	60%
Total head turn off	head	1,349	1,453	1,677	1,649	1,500
Total beef turn off	kg	331,493	413,411	564,037	456,857	400,909
Average total gross margin per animal	$/AE	$111	$136	$161	$78	–$16
Net present value of net profit	$	$1,423,830	–$1,113,592	–$6,897,313	–$8,090,577	–$15,555,503
Difference relative to Scenario 1	$/ha	-	–$72	–$238	–$272	–$485
Payback period	y	-	13	15	15	15

6.2.2 IRRIGATED CROP PRODUCTION

Gleeson et al. (2012) concluded that development of irrigated agriculture in northern Australia would provide opportunities, not only for improved pasture and fodder production, but also for diversifying into other cropping activities. Such diversification would reduce risk by providing varied income sources.

The producers who were interviewed as part of the Assessment also commented on cropping opportunities, and there was interest in reducing the reliance on cattle income as the sole source of income. Some of their comments, previously summarised, are also relevant in the cropping context (e.g. the benefits of irrigation to create opportunities for diversification and supply the market with a reliable product).

A number of agricultural activities were identified by interviewees as potential uses of water, including irrigated fodder crops (for sale, silage or on-farm consumption), grain for sale to feedlotting operations, seed production and curcurbits. No horticultural growers in the Gilbert catchment were interviewed, although locals indicated interest in further development of horticultural operations with additional water. There was clear interest in cropping, but one interviewee noted that graziers lacked the skills and experience to undertake irrigated cropping.

Previous economic analysis of irrigated enterprises

Mason and Larard (2011) analysed potential irrigated fodder and cropping scenarios based on water harvesting along the Flinders River. While not in the Gilbert catchment, the analysis is relevant. They modelled two categories of development options: 50- to 100-ha fodder-based systems (forage crops and silage), designed to complement existing cattle production operations, and 200- to 500-ha cropping developments.

This modelling was based on monoculture cotton growing, with the report noting that cotton was of current interest to local stakeholders. Their analysis assumed that the investor leased the production area. River system reliability was recognised as a key factor, with 65, 75 and 85% reliability assumed in the model of a 500-ha cotton development with furrow irrigation and a ring tank.

With a cotton gross margin of $2400/ha (similar to the $2321 median determined by the Assessment; Table 5.16) and capital costs of approximately $8500/ha, all water reliability scenarios modelled by Mason and Larard (2011) generated positive returns (NPVs) over the 20-year investment periods analysed. Fodder crops also generated positive NPVs under the model parameters used, which included on-farm storages much smaller than those in Table 6.1. Mason and Larard (2011) noted that changes in prices, crop yields, production costs, cattle weight gains and water reliability affect cash flows, and emphasised that a key impact on economic viability is the large capital input required to develop an irrigation block.

Profitability determinants for cropping

Chapter 5 presents the key elements of irrigated cropping: capital expenditure for irrigation infrastructure, ongoing overheads costs and variable costs, and the gross margins for a range of cropping activities. The analysis reported in this section brings these cost components into one framework and investigates the farm-scale benefits of irrigation.

Overview of costs

The farm-scale costs associated with irrigation developments fall in three main categories: capital costs, overhead costs and variable costs.

Capital costs

This refers to money spent on equipment or asset improvements that add to the productive capacity of the business. Costs in this category include:

- irrigation infrastructure and property redevelopment, for example: clearing land, ground preparation, survey, design and construction of the on-farm irrigation infrastructure (water storage, pipes and pumps and delivery systems such as centre pivot irrigators)
- equipment for cropping enterprises for cultivation, planting and spraying
- potential upgrade or acquisition of motor vehicles (including tractors), workshops, sheds, houses and employee accommodation attributable to irrigation development.

Overhead costs

Overhead costs do not change with relatively small changes in the level of a productive activity. For example, changing the cropping area by 20% is typically not likely to lead to a rise in overheads, whereas an increase of 100% would. Additional overhead costs likely to be incurred by the farm business from irrigation development include:

- annual repairs and maintenance to buildings, structures and equipment
- wages, if additional labour is hired
- insurance associated with any additional structures, equipment and employees
- power costs associated with running irrigation developments
- professional services (consultants, legal, etc.)
- registrations
- irrigation administrative charges not directly related to volume of water applied
- land lease costs – directly relevant for managers leasing land. However, for cattle producers converting an area of their property to irrigated activity, the lease price can represent the opportunity cost of irrigation, particularly if the leasing price is tied closely to the agistment value of the property. In other words, budgeting for a lease accounts for the forgone revenue from displaced cattle production.

Variable costs

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

In addition to these variable costs, in analysing a potential irrigation development, a manager should also:

- weigh up the costs of adjusting to new enterprises: information acquisition, skill development, planning
- consider the opportunity cost for forgone returns from existing enterprises (see note on lease costs above)
- evaluate the costs associated with exposure to risk for producers.

The specific costs of on-farm infrastructure development can vary considerably depending on the storage and conveyance system used by the landowner. The way in which water is accessed will determine costs – for example, water accessed directly from a river and delivered through open channels, or piped systems to the crop, or via an on-farm water storage (e.g. ring tank). Costs will also be determined by the options for conveying water from the river or dam onto individual fields (e.g. spray irrigation, surface irrigation). Therefore the analysis reported here is only for the purpose of presenting a framework for on-farm investment analysis, and illustrating some drivers of investment performance.

The assumptions in Table 6.3 are based on the cost components of irrigation that are presented in Chapter 5, and are used in a generic analysis to explore the drivers of profitability for on-farm irrigation investments.

The costs shown in Table 6.3 assume that 500 ha will be developed for cropping. In addition to the irrigation infrastructure summarised in Chapter 5 (water storage infrastructure, irrigation systems), capital items such as tractors and vehicles; cultivation, planting and spraying equipment; and workshops are required to undertake cropping. Expected capital outlays for these items are at least $1000/ha (based on requirements for 500 ha). This could be regarded as a conservative estimate of equipment requirements and assumes that specialised equipment is provided by contractors (e.g. contract harvesters). Cost estimates for these items, refered to as 'other capital' in Table 6.4, were sourced from Mason and Larard (2011) and a detailed summary is provided in the companion technical report on irrigation costs and benefits (Brennan McKellar et al., 2013).

Table 6.3 Assumptions for analysis of irrigation investment

INVESTMENT ASSUMPTIONS	UNIT	VALUES
Cropped area	ha	500
Project life	y	15
Discount rate	%	5%, 7%
Capital costs		
Storage and channels	$ million	$2.8, $3.7, $4.7, $5.6
Irrigation system (surface)	$ million	$1
Other capital (sheds, vehicles, machinery)	$ million	$0.58
Overheads		
Wages	$/y	$200,000
Repair and maintenance	$/y	$100/ha + 0.5% storage capital
Other (including $50/ha land lease)	$/y	$35,000
Gross margin		
Gross margin	$/ha	$500, $1000, $1500, $2000, $2500

Expenditures are associated with additional overhead costs. Wages are the most expensive overhead cost, and for a 500-ha development, it is assumed that one manager, one permanent staff member and two casuals are employed at a total cost of $200,000/year. Overhead and capital costs will increase if staff accommodation is provided on the property. Repairs and maintenance for equipment are assumed to be $70,200/year and insurance, registrations, office expenses and professional services fees are set at $35,000/year.

An analysis was undertaken for an investment in a ring tank (on-farm dam), constructed for water harvesting. Capacities ranging from 952 to 3810 ML and surface irrigation ($2000/ha) were included in the analysis. The four storage capacities (Table 6.4) correspond to effective volumes ranging from an allocation of 500 ML (1ML/ha) to 2000 ML (4ML/ha) after evaporation and seepage losses from the storage (30%) and field application losses (25%) are accounted for. Losses can be either higher or lower, depending on the rate of seepage from the storage, the duration of water storage, and the irrigation system used. For example, to provide an effective volume of 2000 ML, reducing the field application loss from 25 to 15% can reduce the capacity requirement of the storage from 3810 to 3360 ML – a cost reduction of about $450,000. However, the additional capital costs of a more efficient irrigation system to achieve this – such as a centre pivot irrigator ($4500/ha) – would exceed the saving enabled by the smaller dam. The storage construction cost was based on earthworks construction costs of $4/m^3 and a 4:1 ratio of storage to excavation.

The storage was assigned an economic life of 40 years; at year 15, the straight line depreciation method was used to calculate the residual value. Costs and revenue streams were accounted for over a 15-year investment period and discounted at a real discount rate of 5% in order to calculate an NPV.

The impact of capital cost on NPV was explored under an annual crop gross margin of $1500/ha (Table 6.4). It is assumed that this gross margin is generated in every year of the investment period. It is not suggested that this reliability of income is achievable in practice; however, this analysis is intended to only be illustrative of the magnitude of investment net returns for different capital costs.

Table 6.4 Financial performance indicators for selected irrigation investment scenarios
For 500 ha with storages ranging from 952 to 3810 ML capacity under a $1500 crop gross margin and a 5% and 7% discount rate.

INDICATOR	UNIT				
		Storage capacity			
		952 ML	1905 ML	2857 ML	3810 ML
Capital cost	$	$2,760,881	$3,713,262	$4,665,643	$5,618,024
Annual overhead costs	$	$315,917	$320,679	$325,441	$330,203
Annual gross margin	$	$750,000	$750,000	$750,000	$750,000
Net present value (5% discount rate)	$	$2,100,520	$1,385,031	$669,543	-$45,945
Net present value (7% discount rate)	$	$1,460,780	$680,770	–$99,240	–$879,251
Internal rate of return	%	14%	9%	7%	5%

The capital costs of water storage significantly affect the viability of the irrigation investment. For the largest storage (3810 ML), and 5% discount rate, a gross margin of $1509 is required to break even (i.e. return an NPV of zero). Table 5.17 shows that gross margins around this value, which can be achieved with the storage's corresponding allocation of 4 ML/ha, are possible for a limited range of crops (e.g. cotton, maize, lablab (hay)), with varying degrees of reliability each year under the set of price, input cost and yield combinations presented. Investment net returns are higher with smaller, less expensive farm dams – however, over the cropping area assumed (500 ha), this further restricts the set of crops that could be grown to those with a relatively low water use and still able to generate the gross margin assumed in the analysis (e.g. cotton, with a median water water use of 3.2 ML/ha and median gross margin of $2321/ha). This analysis shows that larger storage capacity can increase cropping flexibility by allowing a greater range of crops to be grown, but that the payoffs are not there under the gross margin assumption of $1500/ha.

Crop gross margins are sensitive to commodity price movements and yield variation, which in turn reflects a range of production risks, including water reliability. Likewise, the performance of the overall investment is very sensitive to gross margin (Table 6.5). With gross margins reduced to $1000/ha or lower, none of the investment options are viable. Conversely, a $2000/ha gross margin at least doubles the value of the investment compared with the $1500/ha gross margin.

Table 6.5 Net present values under selected irrigation investment scenarios

For storages ranging from 952 to 3810 ML capacity under crop gross margins ranging from $500 to $2000/ha and a 5% and 7% discount rate.

GROSS MARGIN ($/ha)	NET PRESENT VALUE ($)			
	Storage capacity and capital cost			
	952 ML $2.8 million	1905 ML $3.7 million	2857 ML $4.7 million	3810 ML $5.6 million
	5% discount rate			
$500	−$3,089,309	−$3,804,798	−$4,520,286	−$5,235,774
$1000	−$494,395	−$1,209,883	−$1,925,371	−$2,640,859
$1500	$2,100,520	$1,385,031	$669,543	−$45,945
$2000	$4,695,434	$3,979,946	$3,264,458	$2,548,970
$2500	$7,290,349	$6,574,861	$5,859,372	$ 5,143,884
	7% discount rate			
$500	−$3,093,177	−$3,873,187	−$4,653,197	−$5,433,208
$1000	−$816,198	−$1,596,208	−$2,376,219	−$3,156,229
$1500	$1,460,780	$680,770	−$99,240	−$ 879,251
$2000	$3,737,759	$2,957,749	$2,177,738	$1,397,728
$2500	$6,014,737	$5,234,727	$4,454,717	$3,674,706

To illustrate water reliability impacts in a simple way, for a gross margin of $1500/ha and a storage size of 2857 ML, NPVs were compared assuming full and reliable production each year (100% reliability) and reliability scenarios of 60% and 80% (Table 6.6). In the 80% example, this means that there would be some degree of crop failure 1-in-5 years. A year of crop failure is represented on an alternating basis as ‘no income’ or ‘reduced income’. ‘No income’ is the assumption that the crop is not planted due to insufficient water and therefore does not generate revenue and does not incur variable costs. A reduced income year reduces the gross margin by 50%. All capital costs and annual overhead costs are still incurred.

The timing of this ‘failed year’ is described as either ‘early’, meaning that the failed year occurs in year 1 of 5, or ‘late’, meaning that the failed year occurs at year 5 of the stream of project cash flows (Table 6.6). For the set of assumptions modelled, progressively poorer reliability can turn profitable investments into unviable ones.

The impact of discounting means that the timing of years with lost production influences economic viability. Poor years occurring early in the investment result in a more severe financial penalty, and can be the difference between the investment being viable or not.

This analysis assumes that the cost of the pump required to fill the on-farm storage with water from the river is a component of the capital costs associated with the storage. The capacity of the pump affects the ability of irrigators to fill storages. Investing in a more expensive, but higher capacity pump, can improve the security of water supply. Therefore the reliability analysis presented here would be refined by accounting for the relationship between pump capacity and water reliability.

Table 6.6 Net present value and internal rate of return
Values are for the storage capacity of 3810 ML under a $2000 and a $2500 crop gross margin, a 7% discount rate, and a range of allocation reliabilities (60 to 100%) which vary in timing.

RELIABILITY	NET PRESENT VALUE ($)	INTERNAL RATE OF RETURN (%)	NET PRESENT VALUE ($)	INTERNAL RATE OF RETURN (%)
	$2000/ha gross margin		**$2500/ha gross margin**	
100%	$1,397,728	10%	$3,674,706	15%
80% – early	–$345,115	6%	$1,496,152	10%
80% – late	$68,121	7%	$2,012,698	12%
60% – early	–$1,584,922	3%	–$53,606	7%
60% – late	–$1,207,434	4%	$418,254	8%

In conclusion, the key findings of this farm-scale analysis are:

- Capital costs impact substantially on investment performance. The storage costs presented here represent examples only, and modelling is required to determine the maximum size of a farm dam that can be filled with an acceptable level of reliability.
- Gross margins can vary considerably from year to year, and with large capital investments they may need to be sustained at high levels.
- Reliability and variability are significant issues. Profitable investments under reliable allocation delivery can be made unviable with reduced water reliability. While in reality, reliability impacts may not be expressed in the way presented in this analysis, variability – be it driven by crop yield, commodity price or water availability – can result in years of low or negative annual net margins, even if the investment is profitable over a longer-term period. The timing of variability matters. Poor yield outcomes early in the life of the investment will further disadvantage the investment performance.
- This analysis is an introduction to the costs incurred at the farm scale for irrigated cropping. It also introduces the impacts on net revenues of factors such as changing the discount rate, gross margin, and reliability of water supplies. The analysis is generic only, and is limited to the exploration of net returns arising from a ring tank investment. In Section 6.3, farm-scale investment performance is further explored under a different situation, where irrigation water is supplied through an irrigation development not requiring investment in individual farm dams. Again, this example is generic. In chapters 8 to 10, more detailed analysis is reported for a number of case studies, investigating the net returns from specific irrigation developments for a range of irrigated crops.

6.3 Scheme-scale opportunities

The Assessment defines scheme-scale irrigation developments as being comprised of two or more adjacent irrigated farms with common engineering infrastructure (e.g. roads, channels) serving multiple irrigators.

6.3.1 EVALUATION OF WATER INFRASTRUCTURE INVESTMENTS AND WATER PRICING PRINCIPLES

The *Guidelines for financial and economic evaluation of new water infrastructure in Queensland* (the Guidelines; Queensland Government, 2000) provide a framework for the financial and economic assessment component of new water infrastructure investments in Queensland (including extensions to existing water infrastructure). Importantly, they require a financial and economic assessment be completed for water investment projects so that not only is the economic viability of the project established, but the expected cost recovery of the project is also estimated. This is important in relation to water pricing.

Financial assessment is used to determine the commercial viability (profitability) of a project from a developer's, or fund owner's, perspective, whereas economic assessment determines the net benefits of a project to the economy and society as a whole. Given the purpose and objectives of financial and economic assessment are different, it will not always be the case that a project which proves to be financially viable will be economically viable and vice versa.

Where a project is not financially viable (in other words, the NPV of the project is less than zero), there may be a justification for the government to contribute funds towards new infrastructure in the form of community service (CSOs; Queensland Government, 1999). The CSO specifies that the financial support for new infrastructure will be considered only in exceptional circumstances, for example where water prices are unable to at least cover the costs of assuring the ongoing financial viability of the development (DNRME 2004). To be considered as being eligible for government CSOs, a project (i.e. an irrigation development) should at least be able to cover the direct costs of providing the service (i.e. operational, maintenance and administrative costs, asset consumption (including future asset refurbishment and replacement), externalities, taxes, interest costs associated with the developer and a dividend (if any) (Queensland Government, 2000)).

Water prices convey signals to individual irrigators and other commercial interests about the viability of investment in new water supply. The requirements for water pricing set by the National Water Initiative (National Water Commission, 2009) are that the end price to irrigators should encompass:

- the costs of investing in, operating and maintaining the infrastructure to produce, store and deliver water
- the price or value of the resource itself
- the costs associated with the planning and management of the resource
- the otherwise unpriced costs (externalities) resulting from water production, extraction, use and disposal (such as environmental impacts).

In summary, if water users are unable to fully pay supply costs, then new water infrastructure could be developed only through government support. Queensland Government investment would go through more detailed feasibility studies in accordance with state and national policies intended to govern the provision of water services and infrastructure.

6.3.2 ANALYSIS OF DEVELOPMENT OPTIONS

The Assessment undertook a financial analysis for an irrigation development, initially without the assumption that costs and benefits are incurred by different interests. In other words, the analysis treats the whole development as a project conducted by a single developer who incurs all of the costs and receives all of the benefits. The analysis asked 'Are the projected revenues sufficient to cover all expenditures?'. If the NPV of the stream of net benefits for the life of the investment is zero or higher, the answer is 'yes'. This approach provides an overall view of the feasibility of the development.

Most of the direct costs of providing infrastructure was accounted for in the financial analysis, using a set of direct costs similar to, but less than, those identified by the *Guidelines for testing financial viability of developments* (Queensland Government, 2000). For example, administrative costs and taxes are excluded.

The purpose of the analysis was to initially explore the whole-of-development financial performance under a range of scheme-scale capital costs and sizes of irrigation developments. Various combinations are investigated under different discount rates and water reliability scenarios by comparing NPVs.

The next step in the analysis changes the assumption to that of irrigators as water purchasers from scheme water suppliers who bear the scheme capital and operating costs. The analysis then identifies the minimum water price that irrigators would need to be charged in order to cover the scheme costs, both capital and operating, and operating only, and compares this to the irrigators capacity to pay for water. The analysis is generic in nature, and is designed to explore the ranges of prospectively profitable situations. Context-specific analyses are reported in the case studies contained in chapters 8 to 10.

Cost and revenue assumptions

Revenue is the total gross margin of irrigated agriculture – i.e. revenue from crop product sales less variable crop production costs. The analysis included the following costs: capital expenditures for scheme-scale (off-farm) infrastructure, on-farm capital expenditures for irrigation infrastructure, scheme-scale operating expenditures (operations and maintenance), and on-farm overheads.

Construction costs for an irrigation development comprise those associated with the provision of storages, weirs, channels, drains, roads and structures such as siphons, regulating points, road and culvert crossings, road and rail boring, metered outlets, drainage inlets, overflow and drainage structures. Costs will be driven by the length of channels, drains and roads, and depend on the location and catchment size, and design capacity of the channel.

Cost assumptions are listed in Table 6.7 (scheme-scale capital costs are specific to a $4000 million investment scenario). Scheme-scale capital costs are also set at $250, $500, $1000 and $2000 million, and partitioned between long-life (100-year asset life) infrastructure (dams and roads) and shorter-life infrastructure (e.g. scheme-scale works with an asset life of 40 years) in a 66% to 34% split. This ratio was derived from a specific scheme-scale costing (using the assumptions listed in Table 6.7) and then applied consistently to all capital scenarios.

The farm-scale capital cost assumptions are based on the costs ($/ha) expected for a 500-ha development. Costs are consistent with those reported for the farm-scale analysis in Section 6.2.1, except that this scenario has capital costs based on spray irrigation and no ring tank. In other words, this example has the farm accessing water directly through channels forming part of the irrigation development infrastructure, with no on-farm water storage. This is a different farm-scale scenario to that presented in Section 6.2.1. The farm-scale capital and overhead costs ($/ha) are the same across combinations of irrigation area and capital costs. In reality, larger land development parcels may be favoured, which may allow economic efficiencies to be achieved that reduce the $/ha on-farm capital costs.

Table 6.7 Assumptions for capital and operating costs for irrigation developments

COSTS	ITEM	LIFE SPAN (y)	UNIT COST ($)	UNIT	OPERATING AND MANAGEMENT COST (% capital cost)
Scheme-scale capital costs					
	100-year infrastructure	100	66%		0.5%
	40-year infrastructure	40	34%		1%
	Annual energy pumping cost		$16	ML	
Farm-scale capital costs (500-ha blocks)					
	Irrigation system (spray)	15	$4000	ha	
	Farm equipment (package)	15	$1160	ha	
Farm-scale operating costs					
	Overheads		$660	ha	

Table 6.8 Scheme-scale capital and operating costs

These values were used to derive the scheme-scale ratio of 100-year capital cost to 40-year capital cost in Table 6.7.

ITEM	LIFE SPAN (y)	UNIT COST ($)	NUMBER	UNIT	TOTAL COST ($ million)	OPERATION AND MANAGEMENT COST (% capital cost)
Large dams	100	$249,000,000	1	dam	$249.00	0.5%
Weir	50	$37,000,000	1	weir	$37.00	1%
Supply channels	40	$408	3000	m	$10.20*	1%
Area works (earthworks)	40	$2,171	8000	ha	$17.37	1%
Area works (structures)	40	$919	8000	ha	$7.35	1%
Area works (roads)	100	$1,140	8000	ha	$9.12	1%
Area works and supply channel (overheads)		$3,849	8000	ha	$30.79	NA
Area works (approvals)		$8,000,000	1		$8.00	NA
Area works (survey and legals)		$1,000,000	1		$1.00	NA
Pump from river to channel	16	$250	8000	ha	$2.00	2%

*Price includes structures.

Other assumptions

Median annual water use is set at 6 ML/ha. Channel distribution efficiency and irrigation application efficiency has been set at 86 and 85% respectively. The analysis was conducted over a project period of 30 years with a 7% real discount rate. On-farm asset replacement was accounted for at year 16 and capital residual values at year 30 (using the straight line depreciation method to calculate the residual value).

Break-even gross margins

'Break-even annual gross margins' (the annual gross margins that generate an NPV of zero, in $/ha) were calculated for a range of scheme-scale infrastructure costs, planted areas, allocation reliability scenarios, and discount rates. Table 6.9 below shows the break-even annual gross margins under a range of assumptions for scheme-scale capital costs and irrigated areas (ha), with 100% reliability of water allocation and a 7% discount rate.

Table 6.9 Break-even annual gross margins required under different combinations of scheme-sale capital cost and irrigated area

Assumptions include 100% reliability of water allocation and a 7% discount rate.

SCHEME CAPITAL COST ($ billion)	BREAK-EVEN ANNUAL GROSS MARGIN ($/ha)				
	Irrigated area assuming 100% reliability (ha)				
	5,000	10,000	20,000	40,000	80,000
$0.25	$5,422	$3,385	$2,367	$1,858	$1,603
$0.5	$9,497	$5,423	$3,386	$2,367	$1,858
$1	$17,646	$9,497	$5,423	$3,386	$2,367
$2	$33,945	$17,647	$9,498	$5,423	$3,386
$4	$66,543	$33,946	$17,647	$9,498	$5,423

Smaller irrigated areas produce less revenue, and higher scheme-scale capital costs demand higher returns to cover these costs. The gross margins in these parts of the table are generally not attainable by growing the range of irrigated options described in Chapter 5. Because adequate gross margins are not attainable, the project NPVs under these combinations are negative. Under the constraint of water use of 6 ML/ha, some of the these gross margins are attainable for the crops reported in Table 5.17. Cotton has a gross margin ranging from $1133 to $3224 per ha, corresponding to the 20th to 80th percentile exceedance of modelled crop yields (Table 5.17), with a median water use of 3.2 ML/ha. Other crops which have median water use of 6 ML/ha or less which come close to the lowest gross margin in this table include lablab (hay) and rice, with median gross margins of $1354/ha and $1368/ha, respectively.

The impact of reduced reliability of water allocation is presented in Table 6.10 as the factor by which the break-even annual gross margin is adjusted under four reliability situations, which also reflect the timing of failed years (i.e. no income and reduced income). As for the on-farm analysis, a 'no-income year' is the assumption that the crop is not planted due to insufficient water and therefore does not generate revenue but does not incur variable costs. A 'reduced income year' reduces the gross margin by 50%. All capital costs and annual overhead costs are still incurred. Half of the failed years are 'no income' and half are 'reduced income'.

In the early situation, the failed years are incurred at the start of the stream of project cash flows, and the late situation has failed years occurring at the end of the project stream of cash flows. The impact of discounting means that failed years incurred early in the project require a higher break-even gross margin to realise a positive NPV. The practical implication is that timing matters in the performance of an investment – unprofitable years occurring early in the life of an investment penalise the overall investment performance.

Table 6.10 Scaling factors for gross margins accounting for changed reliability (60 to 90%) and timing of failed years (early and late in the cash flow)

90% RELIABILITY		80% RELIABILITY		70% RELIABILITY		60% RELIABILITY	
Early	Late	Early	Late	Early	Late	Early	Late
1.14	1.09	1.28	1.22	1.47	1.39	1.72	1.61

Break-even water prices

The water price that would need to be charged to recover the overall irrigation development area capital and operating costs was calculated for a range of capital infrastructure cost and area combinations (Table 6.11), assuming 100% reliability of water allocation and a discount rate of 7%. Note that this excludes on-farm costs and revenues.

Additionally, the water price that would need to be charged to cover only the scheme-scale operating costs was calculated (Table 6.12).

Table 6.11 Minimum water price charged by supplier to cover capital and operating costs under different combinations of scheme-sale capital cost and irrigated area

Assumptions include 100% reliability of water allocation and a 7% discount rate.

SCHEME-SCALE CAPITAL COST ($ billion)	MINIMUM WATER PRICE TO COVER CAPITAL AND OPERATING COSTS ($/ML)				
	Irrigated area assuming 100% reliability (ha)				
	5,000	10,000	20,000	40,000	80,000
$0.25	$509	$263	$139	$78	$47
$0.5	$1,003	$509	$263	$139	$78
$1	$1,990	$1,003	$510	$263	$139
$2	$3,964	$1,990	$1,003	$510	$263
$4	$7,913	$3,964	$1,990	$1,003	$510

Table 6.12 Minimum water price charged by supplier to cover operating costs under different combinations of scheme-sale capital cost and irrigated area

Assumptions include 100% reliability of water allocation and a 7% discount rate.

SCHEME-SCALE CAPITAL COST ($ billion)	MINIMUM WATER PRICE TO COVER OPERATING COSTS ($/ML)				
	Irrigation area assuming 100% reliability (ha)				
	5,000	10,000	20,000	40,000	80,000
$0.25	$55	$35	$26	$21	$18
$0.5	$96	$56	$36	$26	$21
$1	$177	$96	$56	$36	$26
$2	$339	$177	$97	$56	$36
$4	$664	$340	$178	$97	$56

These prices were compared to the capacity of irrigators to pay for water. In other words, the water price that resulted in a NPV of zero, taking into account on-farm costs and benefits only. As the capacity to pay for water depends on the crop gross margin (given the assumption that the on-farm capital and operating costs remain the same on a per hectare basis), it was calculated for four gross margins ($500, $1000, $1500 and $2000/ha) which cover most of the range of gross margin presented in Table 5.17. Table 6.13 presents the break-even water prices for gross margins ranging from $1250 to $2000/ha. In addition to the 6 ML/ha assumption used throughout the irrigation development-area-scale analysis, other irrigation rates were also explored (4, 8 and 12 ML/ha). At all rates, irrigators were unable to pay for water at $1000/ha gross margin.

Table 6.13 Capacity of irrigators to pay for water (break-even water price) under different combinations of gross margin and irrigation use

GROSS MARGIN ($/ha)	BREAK-EVEN WATER PRICE ($/ML)			
	Irrigation use (ML/ha)			
	4	6	9	12
$1000	$0	$0	$0	$0
$1250	$8	$6	$4	$3
$1500	$71	$47	$35	$24
$2000	$196	$131	$98	$65

With gross margins of $1500 and $2000, irrigators are able to pay for operating and maintenance costs under several circumstances, favouring large irrigation areas and small scheme-scale costs. Under a much more limited set of conditions, irrigators can also afford to pay for capital costs as well and the investment remains viable, again favouring large irrigation areas and small overall irrigation development area costs. This is consistent with the break-even gross margins in Table 6.9 which shows gross margins that are expected to be attainable.

In summary, should irrigators have responsibility for on-farm costs only and receive revenues for irrigated agriculture for the generic configurations in this analysis, they have the capacity to contribute to irrigation development area capital, operating and maintenance costs under some circumstances. Again it should be noted that this is a generic analysis. In chapters 8 to 10 specific irrigation developments and crops are investigated.

6.3.3 ACCESS TO AGRICULTURAL SKILLS AND SERVICES

Skills requirements for irrigated agriculture

Particular skills are required to operate an irrigated agriculture enterprise. Limitations to irrigation development arising from insufficient expertise are expected to be particularly evident in rangelands or pastoral areas that have a limited tradition of agricultural knowledge and irrigation.

Irrigators require expertise and advice regarding regulatory and legal matters and specialist technical irrigation knowledge. Irrigation implementation requires access to agronomy services, equipment suppliers and repairers, and input suppliers (e.g. chemicals, fertilisers). Local knowledge and ready access (for time-sensitive or contingency operations) are important considerations.

The Gilbert catchment-based producers interviewed as part of the Assessment indicated that confidence in their skills was variable, and it was remarked that cropping and grazing are distinct operations, requiring different skill sets, just as irrigation requires particular skills.

Agronomy services are typically not locally based but it was noted that they could be accessed from other areas (e.g. the Atherton Tablelands). Human skills, experience and farming practices, however, cannot always be transferred from other areas. The pool of service providers with accumulated and interpreted locally-relevant experience is limited.

In remote and regional areas, appropriately skilled staff with technical expertise to assist in setting up and running irrigation may be difficult to attract. Attracting skilled labour to remote localities may need to be accompanied by additional incentives such as social activities and community services. For example, the mining industry has succeeded in this area because it is able to provide accommodation, facilities and high wages (Gleeson et al., 2012).

Adoption considerations

The analysis reported in Section 6.2.2 assumes a 500-ha developed area for irrigated cropping, which could be considered consistent with the investment of a private investor. However, if development in the region is entered into by corporate investors, much larger development areas could be expected. Development conducted at large scale can bring further economic efficiencies and specialist skills (e.g. through improved utilisation of on-farm capital). Another potential efficiency may arise through integration of supply chain compents (e.g. developers owning processing facilities as well as running irrigated operations).

Where irrigation development is expected to be in reach of private investors, who are able to make choices about the scale, type and management of an irrigation investment, it is relevant to consider the factors that may influence the rate and extent of irrigation adoption by individuals. The perceived profitability of development is a key driver of investment but factors, such as the degree to which the development is compatible with existing and ongoing personal and business goals and operations, also matter. The ability to trial irrigation is an important adoption determinant, as is the observability of irrigated development – in other words, the degree to which results of innovation are visible to others.

While irrigated crops and forages are likely to be well suited to trialling on a limited basis, the investment in a water storage and irrigation systems for example, cannot be done on a similarly small scale. Interviewees reported that trialling is costly. Mistakes due to inexperience can be extremely costly in the early years of new enterprise evaluation, often a time when costs can be absorbed least easily and the risk of failure is large. This is also why the experience of near peers in an agricultural community can be highly influential in investment decisions.

An implication is that the provision of planned and facilitated interactions between producers can influence uptake.

Gleeson et al. (2012), reporting in the context of the growth of the northern Australian beef industry, cited as critical that the government and industry work to coordinate research, development and extension support of northern Australian beef productivity drivers, including irrigation, and ensure that learning from current irrigation research be well-communicated to producers; and that policy incentives to encourage adoption of new practices or increase technical efficiency are well-aligned.

Labour requirements

Irrigated agriculture requires access to farm labour to work in irrigated enterprises and in any processing industries that arise from the irrigated enterprise. In addition, irrigated agriculture development creates demand for specialist services and suppliers of inputs, farm machinery and equipment.

The dominant land use in the Gilbert catchment is beef cattle production, which is not labour intensive. Most are family-run operations, with some hired labour. To illustrate, from 2008 to 2011, beef production in northern Australia (the categorisation referring to the beef industry in three states, north of the Tropic of Capricorn) used 77,800 ha of land per farm on average and the wages for hired labour per farm was $50,200/year on average (Gleeson et al., 2012). Specialist beef properties in the Queensland Central north region (as categorised by Meat and Livestock Australia for Australian broadacre regions that includes most of the Gilbert catchment) employed 31 weeks of hired labour which is weeks worked by hired permanents and casuals in the 2010–12 financial year and 37 weeks in the 2011–12 financial year. This is less than one person working full time over a year (ABARES, 2013).

Irrigated agriculture is a much more labour intensive activity. Changes to on-farm labour requirements are dependent on the scale and nature of the irrigated development. Adding an irrigation development of 40 to 50 ha under pivot irrigation is estimated to increase the labour demand by the equivalent of one person working half time.

Shadur (2012) estimated employment from cotton of six FTEs (full-time equivalents) per 1000 ha, which could be further split into 4.6 FTEs per 1000 ha of year-round labour and 1.5s FTE per 1000 ha of seasonal staff (e.g. harvesting). This would translate to, for example, 75 FTEs in direct employment arising from 12,500 ha of cotton. Additional indirect employment would also be expected.

Processing facilities have significant labour demands, often with a significant seasonal component. A typical sugar mill could employ, on average, 70 permanent workers and 30 extra seasonal workers for the crushing season (Table 6.14) which lasts approximately 20 weeks (estimates only; derived from Sucrogen fact sheet (Burdekin Shire Council, 2012)). Sugarcane harvesting is a seasonal activity running over a crushing period. A harvesting crew of one harvester driver and two to three cane hauling vehicles with a harvest contract of 70,000 tonne would have a labour requirement of three to four persons per 600 ha (approximately) for the crushing season (assuming an average cane yield of 120 t/ha).

Based on estimates provided by Cubbie Ag (ABC, 2013) which announced in 2013 intentions to build a four-stand cotton gin, the gin will employ 30 people (including 20 permanent staff) when it is processing cotton. Shadur (2012) reported that direct employment from a cotton gin processing cotton from 12,500 ha was 15 persons.

Table 6.14 Summary of labour requirements

ACTIVITY	LABOUR
Abattoir	175 to 220 persons
Cotton	6 FTEs per 1000 ha
Cotton gin	15 to 20 total (permanent and casual staff)
Sugarcane mill	70 permanent and 30 extra for crushing season
Sugarcane harvesting	3 to 4 persons per 600 ha for crushing season

Sources of labour

The Gilbert catchment is accessible from major east coast population centres (the largest is Cairns) which are potential sources of labour. Cairns' population is 224,436 (Cairns Statistical Area Level 4 2011 census, (ABS, 2013)) and has 7% unemployment which is higher than Queensland and Australian state averages of 6.1 and 5.6% respectively. Unemployment in the Gilbert catchment is low relative to other parts of Queensland (Table 6.15). Availability of farm labour was not reported as a constraint to irrigation development by interviewees in the Gilbert catchment.

Table 6.15 Population for selected statistical local areas

STATISTICAL LOCAL AREA	POPULATION (2011)	UNEMPLOYMENT (%)
Cairns	22,4436	7%
Etheridge	894	3.6%

Source: ABS (2013).

6.4 Legislation and regulation

Legislation and regulation are often viewed as constraints through proscribing and prescribing land uses and management actions and describing when water licences can be taken in full and whether they can be freely traded. Political change, new science and new opportunity may drive change of legislation and regulation. There is a renewed national desire to develop northern Australia and to do it sustainably (economically, socially and environmentally). Also there are state-based initiatives to reduce red tape for development (e.g. 'The Greentape Reduction project') and to overcome bottlenecks to development (such as more flexible temporary skilled worker visas – known as 457 visas). Furthermore, in the Gilbert catchment in 2013, almost all water identified as 'general unallocated water' (*Water Resource (Gulf) Plan 2007*) – a total of 15 GL – was made available through tender for use, thus providing an additional 14.2 GL in water licenses to three enterprises for irrigation development.

A wide set of legislation and regulation is relevant to irrigation development in the Gilbert catchment. Full details are provided in the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013) and are summarised below.

6.4.1 WATER, LAND TENURE AND LAND MANAGEMENT

Queensland's *Water Act 2000* is the authorising law, with subordinate legislation including

- *Water Act 2000 (Qld)* – herewith referred to as Water Act (Qld)
- *Water Resource (Great Artesian Basin) Plan 2006*
  - *Great Artesian Basin Resource Operations Plan 2006*
- *Water Resource (Gulf) Plan 2007* – herewith referred to as Gulf WRP
  - *Gulf Resource Operations Plan 2010*
- *Sustainable Planning Act 2009 (Qld)* – herewith referred to as Sustainable Planning Act (Qld).

The economic and development priorities in the Gilbert catchment are clearly identified in the water planning documents that support the Water Act (Qld). For example, the Gulf WRP (Clause 13) lists 16 outcomes for water development sought under the plan. The outcomes pertain to development that is environmentally sustainable, culturally sensitive, and socially and economically sensible.

Queensland's main enabling legislation related to land tenure and management includes:

- *Land Act 1994* – herewith referred to as Land Act (Qld)
- Sustainable Planning Act (Qld)
- *Vegetation Management Framework Amendment Act 2013*.

Land Act (Qld) and Sustainable Planning Act (Qld)

Approximately 68% of Queensland is Crown land (SDIIC, 2012), much of which is Crown leasehold land of large pastoral leases in the north and west of the state. Figure 6.3 shows the land tenure arrrangements in the Gilbert catchment.

A key difference between leasehold and freehold land tenure is that lessees must comply with the purpose and conditions of the lease and the provisions of the Land Act (Qld) (SDIIC, 2012). Therefore, leaseholders wishing to develop irrigated agriculture on a leasehold property need to consider land tenure regulations and associated permits. Depending on the tenure of an individual's property, the number and type of permits required will vary. Note that development on land, whether the property is freehold or leasehold, must be consistent with the Sustainable Planning Act (Qld). Assessable land development (e.g. reconfiguration of a lot, building works, material change of land use, plumbing and drainage works, etc.) must undergo an integrated development assessment system (IDAS) by local and state governments (McGrath, 2011).

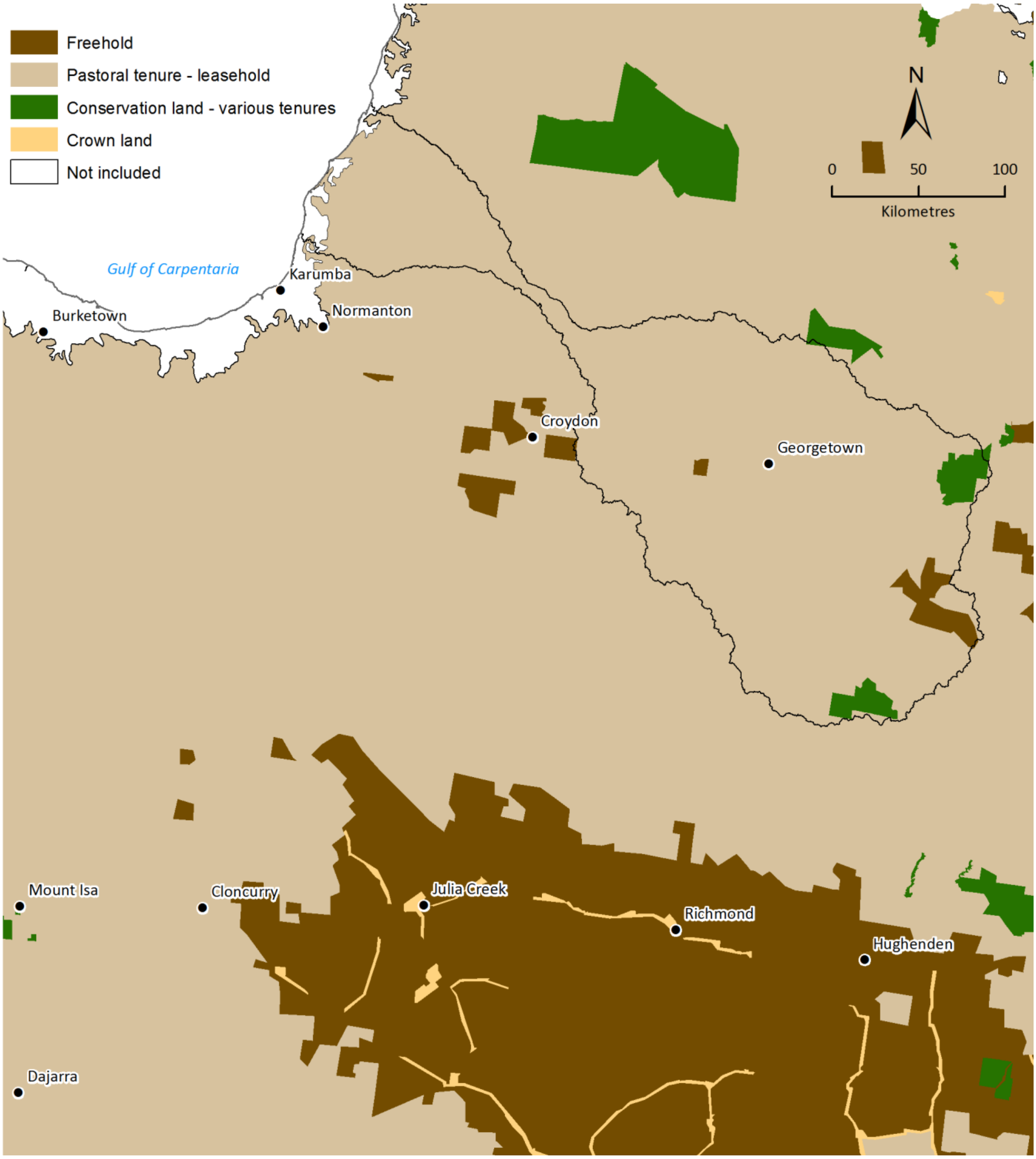

Figure 6.3 Land tenure in the Gilbert catchment

Infrastructure for irrigation development is considered building works and/or operational works and thus subject to IDAS. There are numerous forms to complete as part of this process, for example Form 16 – Referable Dam; this covers all dams which, if it were to fail or collapse, would put people and property at risk (DERM, 2010a). The IDAS process incorporates public notification which provides opportunity for community members to object to the proposal and then be included in a consultation process. Only impact assessable developments require this step (EDO, 2012). Reconfiguration (development and subdivision) of state leasehold land requires IDAS approval and the minister's consent (Queensland Law Society, 2008).

IDAS approval is also required when changing the primary use of the land, for example from cattle grazing to irrigated agriculture. If the applicant does not wish to convert the use, the property would need to be subdivided or subleased and two permits would need to be acquired: one for grazing and one for agriculture, with the practices only occurring on the land that permitted that use (DERM, 2010b).

6.4.2 OTHER

A suite of other legislation may apply to irrigation development in the Gilbert catchment:

- the Commonwealth's *Native Title Act 1993*
- Queensland's *Heritage Act 1992*
- Queensland's *Aboriginal Cultural Heritage Act 2003*
- the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999*
- Queensland's *Environmental Protection Act 1994*
- Queensland's *Wild Rivers Act 2005*
- Queensland's *Coastal Protection and Management Act 1995*
- Queensland's *Fisheries Act 1994*.

6.5 Regional-scale impacts

Earlier sections of Chapter 6 conducted analyses at the scheme scale and the farm scale. Section 6.5 is concerned with irrigation impacts at a larger scale: regional scale and national scale. At this scale, costs and benefits of irrigation are not confined to the immediate irrigation development. For example, construction of irrigation infrastructure increases employment in a region and generates additional economic activity.

Economic analysis was undertaken to determine the importance of the prevailing economic conditions in influencing the economic viability (at a regional and national scale) of investment in irrigated agricultural development in the region. This was done using TERM, a dynamic multi-regional computable general equilibrium model of Australia (Wittwer, 2012).

The regional-scale findings relate to the whole of Queensland's North West statistical division (SD) – an Australian Bureau of Statistics geographical classification that covers 308,098 km^2 and contains the shires of Cloncurry, Flinders, McKinlay, Richmond, Carpentaria, Doomadgee, Mornington and Mount Isa.

The irrigation development modelled was the full set of case studies presented in chapters 8 to 10. All case studies were modelled as if they were implemented simultaneously; thus this modelling does not account for case study developments that are mutually exclusive. While this may not represent irrigation development in reality, the analysis is indicative of the direction of economic impact.

The TERM model used the same data from the case study analyses presented in chapters 8 to 10, including costs of dam construction, scheme-scale water distribution networks, construction of downstream processing facilities, ancillary investments in roads, and agricultural output.

Assuming that the current economic environment prevails until 2027, the model predicted that the economy of Queensland's North West SD will enlarge, notably with an initial boost to employment. However, the long-term impact, over the duration of this period, is predicted to be relatively small.

At the national scale, the short-term economic boosts during the irrigation investment phase, while providing local and national stimuli, are not sufficient to justify investment expenditures, and over the full duration of project the returns do not outweigh costs. As a result, the NPV of benefits is negative. Further detail is reported in the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013).

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7 How can the sustainability of irrigated agriculture be maximised?

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Chapter 7 examines the question 'How can the sustainability of irrigated agriculture be maximised?'. It provides fundamental information about the risk of rise in watertable level, the effects of surface water drainage, and the likely ecological responses to altered flow regimes in the Gilbert catchment. While there are many ecological changes that could occur as a result of irrigation development in the Gilbert catchment, these are three key considerations. Key components and concepts are shown in Figure 7.1.

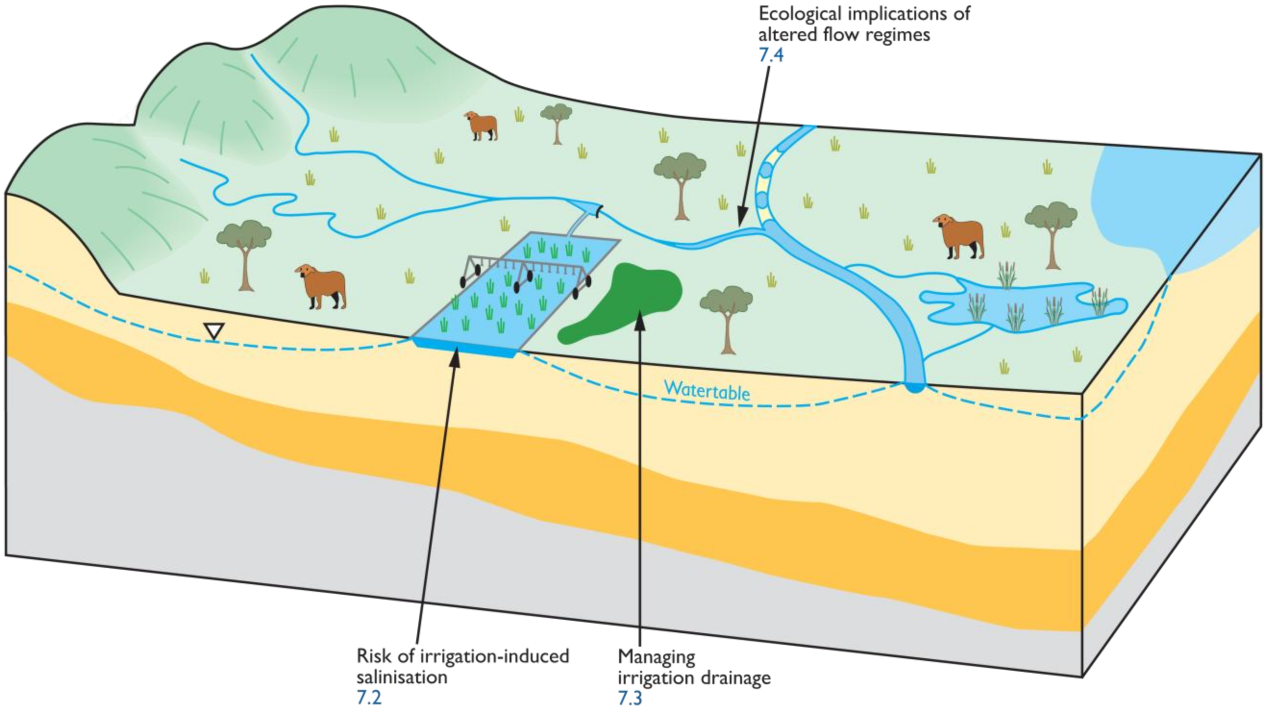

Figure 7.1 Schematic diagram of key components and concepts in the establishment of a greenfield irrigation development

7.1 Summary

The sustainability of agriculture in the Gilbert catchment is in part related to the long-term impact of agricultural development on the natural environment. This chapter explores the scale of ecosystem response that would be expected based on the likely impacts of potential agricultural development.

The complexity of natural systems – and the many factors that impact on ecosystem response – mean that more detailed investigation would be required to inform specific developments. Many environmental changes may not be anticipated at the outset of a development, or could take many years to manifest, so these changes would require adaptive management and a thorough, well-documented understanding of baseline (pre-development) conditions.

7.1.1 RISK OF IRRIGATION-INDUCED SALINISATION

Rising groundwater can mobilise salts in the soils and substrata, bringing them close to the surface and discharging them into nearby rivers. The Gilbert catchment has large areas of cracking clays with subsoils that are high in salt and susceptible to irrigation-induced secondary salinity. The alluvial soils, while smaller in extent, have lower salt levels. The watertable level depends on the initial depth to the watertable, recharge from rain and irrigation, the size of the irrigation area, management practices and distance to the river. The Assessment indicates that watertable levels under small neighbouring irrigation developments (less than 500 ha in area) are not likely to interact in the next 100 years if the developments are placed at least 1 km apart.

The watertable level is most likely to rise with high recharge rates and in soils with low saturated hydraulic conductivity. Proximity to rivers considerably reduces irrigation-induced rise in watertable level by increasing groundwater discharge. It may take many decades for watertable levels to respond fully to irrigation development, especially if the cultivated area is large or far from the river.

7.1.2 MANAGING IRRIGATION DRAINAGE

Surface drainage, or runoff, from irrigated land can arise from irrigation itself and from rain falling on already wet soils. Transport of suspended sediments is unlikely to be significantly increased by continuous irrigated fodder production, but nitrogen and phosphorus accession to waterways could increase by up to 25% and 50%, respectively, depending on the area planted. Predictions for irrigated crops vary depending on how crops are managed, but in sugarcane, for example, sediment loads are likely to increase and nitrogen and phosphorus in runoff could increase by up to 44% and 71%, respectively, if best practices are not used.

Increases in phosphorus in runoff water are likely to have major impacts on downstream ecosystems, including Gulf of Carpentaria fisheries. Sediment runoff is likely to increase the turbidity of persistent waterholes that are refugia for biota adapted to clear water. The clear waterholes of the Gilbert catchment are sensitive to changes in turbidity and nutrient levels, which reduce levels of light and dissolved oxygen and can result in fish kills and species loss.

7.1.3 ECOLOGICAL IMPLICATIONS OF ALTERED FLOW REGIMES

The responses of aquatic ecosystems to irrigation developments are varied and depend not just on the amount of water extracted, but also on the way in which water is extracted, stored and distributed through the landscape; the types of crops grown and irrigation systems used; the management systems in place; and local climate and environmental conditions.

Significant weed and water quality issues can arise from loss of riparian function following irrigation development. These impacts can be minimised through retention of riparian zones and appropriate farm and riparian management.

Irrigation development changes the flow regime of a river system via extraction or diversion of water, instream barriers and return of potentially contaminated irrigation tailwater. Natural flows in the Gilbert catchment are low or non-existent during the dry season and waterholes become essential refugia for biota. They are vulnerable to changes in the dry-season flows that impact on waterhole number, water volume and quality. Changes to flows can reduce the wet-season 'first flush', essential for refreshing water holes after the dry season. Changes to flow regime also affect fish migration and recruitment, as well as the delivery of nutrients to coastal waters, each of which is important in determining commercial and recreational fishing catches.

7.2 Risk of irrigation-induced salinisation

For salt to become an environmental problem there are three basic requirements: (i) a source of salt, (ii) a source of water in which to mobilise the salt, and (iii) mechanisms by which the salt is redistributed to locations in the landscape where it causes damage.

Soil and airborne electromagnetic data and analytical modelling results acquired as part of the Assessment highlight the importance of carefully selecting the location of irrigation development in the landscape and managing potential groundwater impacts.

Soil and airborne electromagnetic data indicate that many of the soils and substrata adjacent to the Gilbert and Einasleigh rivers above their confluence are highly permeable and as a result have low levels of salt. Furthermore the river water is fresh. Consequently this part of the Gilbert catchment is considered to have a low risk of developing irrigation-induced salinisation. However, there are other parts of the Gilbert catchment, such as near the town of Einasleigh, which have elevated salt levels in the soils and substrata and as a result there is a greater risk of developing irrigation-induced salinisation.

Analytical modelling results highlight that increased groundwater accessions from an irrigation development increases the watertable level beneath the development and also potentially increases groundwater discharge to the river system. If the watertable approaches within a couple of metres of the surface and there is a source of salt, irrigation-induced salinisation may occur. Watertable levels within irrigation developments can be managed using engineering approaches such as artificial drainage systems (Christen et al., 2003), used in conjunction with careful management (Hornbuckle et al., 2005). However, these systems are generally expensive and in most cases need a viable disposal method for drainage effluent (Ayars et al., 2006).

The results of this analysis show that irrigation developments close to rivers benefit from the river acting as a natural drainage point for the increase in groundwater accessions. This reduces the potential for land salinisation to occur. This is particularly the case along the Gilbert and Einasleigh rivers above their confluence, where the soils and substrata are highly permeable. However, groundwater discharge to rivers can result in environmental problems. Unlike surface water drainage (Section 7.3), the flow of groundwater accessions to the river system is difficult to control through engineering approaches. Above the confluence of the Gilbert and Einsasleigh rivers groundwater discharge to these rivers following irrigation development is likely to be low in salt, however, the rate of discharge could result in changes to the streamflow regime. Careful consideration of the location of irrigation developments and likely environmental impacts will be needed to minimise potential non-beneficial impacts – i.e. changed flow regimes and saline discharge to the river system.

Controlling and minimising accessions to the groundwater system is critical and efforts to maximise the efficiency of irrigation systems to minimise groundwater accessions should be considered a key priority when developing new irrigation areas in the Gilbert catchment.

Section 7.2 is structured as follows. An introduction to irrigation-induced salinisation is provided in Section 7.2.1. In Section 7.2.2, a new analytical modelling approach is used to evaluate the likely rise in watertable level and changes in groundwater discharge due to irrigation development. Section 7.2.3 uses this modelling approach to explore interactions of groundwater mounds as a result of neighbouring irrigation developments. For irrigation-induced salinisation to occur there needs to be a source of salt. Section 7.2.4 discusses potential salt stores in the Gilbert catchment.

This section presents generalised results. The risk of salinisation at a specific location in the Gilbert catchment can only be properly assessed by undertaking detailed field investigation.

7.2.1 INTRODUCTION

Prior to European settlement, Australia was dotted with naturally-occurring brackish creeks, saltpans and salt marshes (Ghassemi et al., 1995). In these areas of 'primary salinity', ecosystems evolved that were adapted to the high concentrations of salt in the water and soil. Areas where the effects of salinity are now evident as a consequence of European settlement, are referred to as secondary salinity. Secondary salinity manifests itself in two main forms: that which occurs in irrigation regions and salinity occurring in dryland regions. The Assessment is concerned with irrigation-induced (secondary) salinity.

Three basic requirements for salt to become an environmental problem are: (i) a source of salt; (ii) a source of water in which to mobilise the salt; and (iii) mechanisms by which the salt is redistributed to locations in the landscape where it causes damage.

Rainfall contains small quantities of salt. Over many hundreds of years salts from rainfall can become concentrated in the soil, through evaporation. Areas most susceptible typically have relatively low annual rainfall (i.e. less than 800 mm/year) and low soil permeability. An example in the Gilbert catchment is the cracking clay soils formed on the Rolling Downs group. Areas with higher rainfall (i.e. more than 1200 mm/year) and/or highly permeable soils tend to have lower concentrations of salts in the soil profile because the salts are leached down to the watertable and flushed out of the groundwater system. Examples include the sand or loam over friable or earth clay and friable non-cracking clay or clay loam soils on the alluvial soils adjacent to the Gilbert and Einasleigh rivers. Salts can also be concentrated by in-situ weathering of rock and minerals in the soil.

In many irrigation developments around the world, poor-quality irrigation water is the source of salt in salinisation. In the Gilbert catchment, however, the river water is relatively fresh (less than 500 EC), so is unlikely to be a source of salt. This is because the low levels of salt in the river water would be leached through the soil profile before they could accumulate in the root zone to levels that adversely affect crop development.

However, the increase in root zone drainage following applications of irrigation water can provide the source of water to mobilise soluble salts stored in the soil. Root zone drainage rates tend to be higher under coarser-textured soils (Petheram et al., 2002) and poor irrigation practices. In Australia, excessive root zone drainage through poor irrigation practices, together with leakage of water from irrigation distribution networks and drainage channels, has caused watertable levels to rise under many intensive irrigated areas. Significant parts of all major intensive irrigation areas in Australia are currently either in a shallow watertable equilibrium condition or approaching it (Christen and Ayars, 2001). Where shallow watertables containing salts approach the land surface (in the vicinity of 2 to 3 m from the land surface), salts can concentrate in the root zone over time through evaporation. The process by which salts accumulate in the root zone is accelerated if the groundwater also has high salt concentrations. There are few groundwater data for the Gilbert catchment and groundwater quality is highly variable from one location to another. While the quality of groundwater in the alluvial aquifers adjacent to the Gilbert River can be fresh, the groundwater beneath the Einasleigh common was found to exceed the guideline value for drinking water (0.8 dS/m).

The extent to which the watertable level rises close to the surface depends on: (i) the initial depth to the watertable, (ii) the amount of recharge (originating from root zone drainage), (iii) the size of the irrigation area (thus dictating the total volume added to the landscape), (iv) the lateral distance to the river (which acts as a drainage boundary, thus reducing the height of the groundwater mound under irrigation), and (v) aquifer parameters, including the saturated hydraulic conductivity, aquifer thickness and specific yield. The hydraulic conductivity and specific yield are hydraulic properties of a soil's ability to transmit water when submitted to a hydraulic gradient (e.g. difference in watertable level between two locations). The specific yield is the volume of water that could be allowed to drain from an aquifer under the forces of gravity and expressed as a proportion of the total volume of material in the aquifer.

In the Gilbert catchment, there are few groundwater data and aquifer parameters typically need to be estimated from bore log information and generic relationships in the literature. The use of such relationships is made particularly challenging by the fact that saturated hydraulic conductivity is the most variable environmental parameter, its range varying by over 11 orders of magnitude. Typical values of saturated hydraulic conductivity and specific yield are provided in Table 7.1.

Section 7.2.2 provides guidance on the maximum rise of watertable level under different circumstances and the time frame over which the rise in watertable level may occur.

Table 7.1 Typical values of specific yield and saturated hydraulic conductivity

SOIL TEXTURE	SPECIFIC YIELD*	SATURATED HYDRAULIC CONDUCTIVITY** (m/day)
Gravel	0.25	3 to 30,000
Sand	0.20	0.3 to 300
Silt	0.18	0.00003 to 3
Clay	0.02	0.00000003 to 0.00003

* Adapted from Johnson (1967) and Carsel and Parrish (1988).
** Adapted from Freeze and Cherry (1979).

7.2.2 RISE IN WATERTABLE LEVEL AND CHANGES IN GROUNDWATER DISCHARGE DUE TO IRRIGATION DEVELOPMENT

A new analytical modelling approach (Jolly et al., 2013) was developed to evaluate the maximum (steady-state) rise in watertable level likely as a result of introducing new irrigation developments of varying areas situated at various distances from a river. A separate analysis was undertaken to investigate the time it takes the watertable level to rise to its maximum point and how changes in groundwater discharge occur.

To investigate the sensitivity of the results to these parameters, a range of likely values was selected (Table 7.2). Irrigation developments between 100 and 1000 ha in size are representative of irrigation developments on individual properties. Results of these farm-scale areas are presented in this section. Irrigation developments between 1000 and 12,000 ha are representative of the size of scheme-scale irrigation developments and these results are presented in the case study analysis in chapters 8 to 10.

Table 7.2 Likely range of values for parameters in the Gilbert catchment

PARAMETER	SYMBOL	UNIT	VALUES	COMMENT
Distance from centre of irrigation area to river	d	km	0.5, 1.0, 2.0, 5.0, 10.0	River assumed to be straight
Circular irrigation area	A	ha	100, 250, 500, 1000	For radii of 564, 892, 1262 and 1784 m
Recharge rate	R	mm/y	1, 10, 20, 50, 100, 200, 500	Recharge rate is related to the amount of water applied and the permeability of the soil. A recharge rate of 500 mm/y (or more) could occur under a ring tank.
Aquifer transmissivity (saturated hydraulic conductivity multiplied by aquifer thickness)	T	m^2/day	200, 500, 2000	Represents a constant saturated aquifer thickness (h = 10 m), and hydraulic conductivities (K) of 20, 50 and 200 m/day
Specific yield	Sy		0.10 to 0.20	Specific yield does not alter the maximum height of the watertable. It affects the time over which the watertable rise occurs.

Maximum rise in watertable level

The maximum rise in watertable level increases with higher recharge rates and decreases with higher saturated hydraulic conductivity. Figure 7.2a shows that the effects of saturated hydraulic conductivity (and hence aquifer transmissivity) and recharge rates are linear but opposite and perfectly correlated. Hence, to simplify the presentation of results and reduce the number of variables, it is possible to report watertable level against recharge rate divided by the aquifer transmissivity.

Figure 7.2b shows the maximum watertable level expected for an irrigation area of 100 ha. This maximum level decreases as the distance to the river decreases. This is because, with the irrigation development located closer to the river, groundwater can be discharged to the river at a greater rate.

Figure 7.3 shows that the maximum watertable level increases in a non-linear manner as the distance to the river increases.

Figure 7.4a, Figure 7.4b and Figure 7.5a show that the maximum watertable level increases as the irrigation area increases, and also as the recharge rate increases. For the combination of parameters considered for the Gilbert catchment, the highest point on the red line in Figure 7.5a shows the upper bound for a rise in watertable level (h_{max} = 41.8 – 10 = 31.8 m, where 10 m is the initial watertable level), which represents the largest irrigation area (A = 1000 ha) located furthest from the river (d), with an aquifer having the lowest drainage capacity (highest R/T). Figure 7.5b presents the same results in a different way to highlight the effect of increasing the recharge area and distance to the river on watertable level.

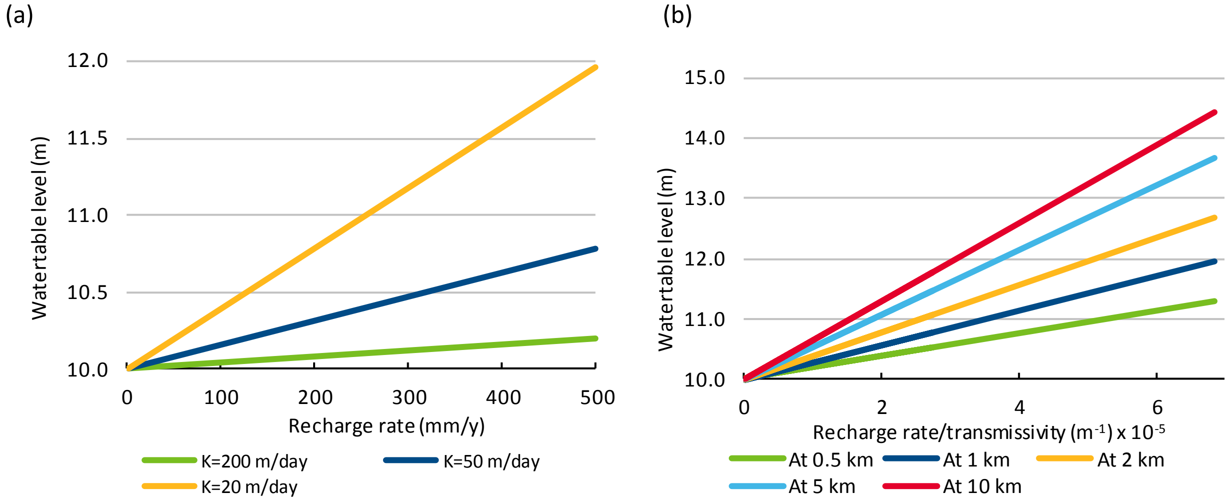

Figure 7.2 Steady-state watertable level for (a) various recharge rates and hydraulic conductivities (K) and (b) an irrigation area of 100 ha, at varying distances to the river

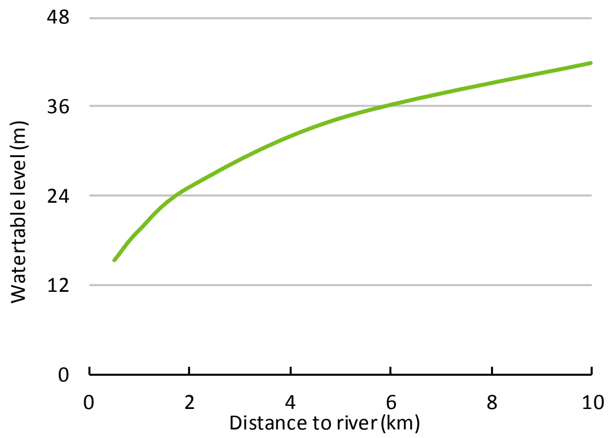

Figure 7.3 Steady-state watertable level for an irrigation area of 1000 ha, plotted against distance to the river

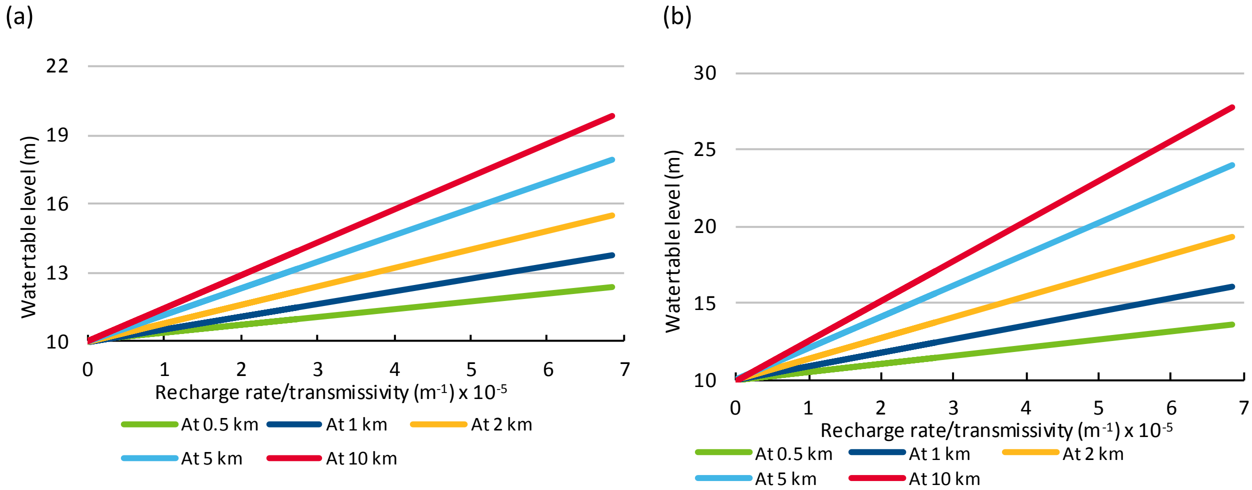

Figure 7.4 Steady-state watertable level at varying distances to the river for an irrigation area of (a) 250 ha and (b) 500 ha

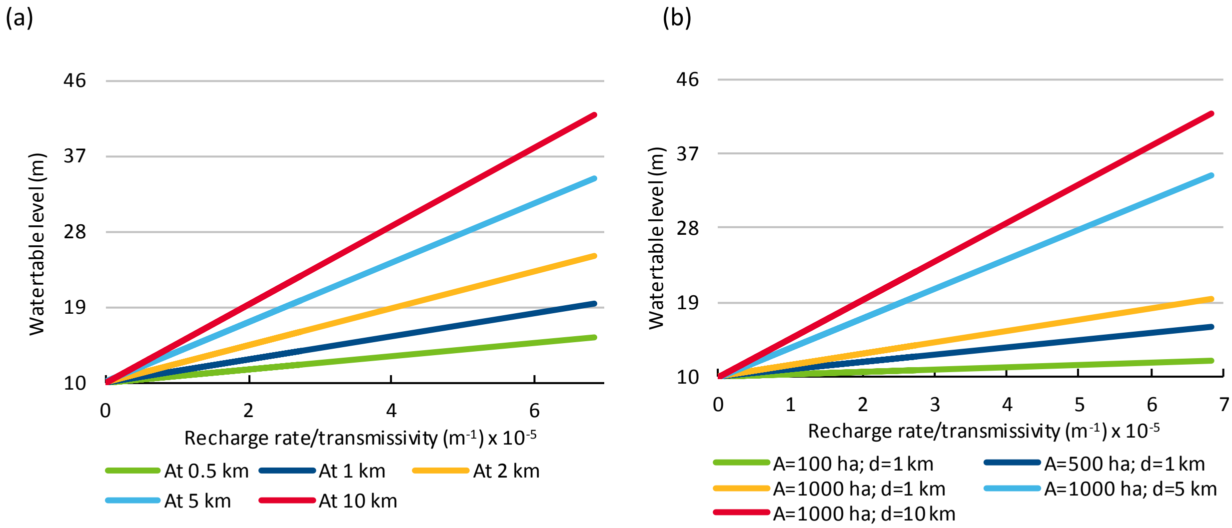

Figure 7.5 Steady-state watertable level at varying distances (d) to the river for (a) an irrigation area of 1000 ha and (b) various irrigation area and distance combinations

Changes in rise in watertable level over time

One of the challenges in managing groundwater is the time lag between a change in management and the response of the groundwater system. This analysis demonstrates how the watertable level rises over time until it achieves its maximum height. A key parameter for undertaking this analysis is the specific yield of the groundwater system. Figure 7.6 provides an example where the irrigation area is 100 ha and the recharge rate is 100 mm/year. For a given aquifer diffusivity (D) (i.e. aquifer transmissivity divided by specific yield), Figure 7.6 shows that after a change in recharge, the initial response of the groundwater system is identical regardless of the distance to the river (d). This is because the groundwater mound under an irrigation development forms before groundwater discharge to the river increases. When the groundwater mound reaches the river, the rate of the rise in watertable level starts to decline until the level reaches its maximum (i.e. under steady-state conditions). The watertable level takes longer to reach its maximum when the irrigation development is further from the river (Figure 7.6).

In Figure 7.6, for an aquifer diffusivity (D) with a high value of 200,000 m^2/day, the maximum watertable level is reached within about 13 years, whereas for the low value of 20,000 m^2/day, the maximum watertable level is reached in 30 to 100 years. The watertable level takes longer to reach its maximum when irrigation areas are larger and are located a greater distance from the river. With the most extreme combination of parameters from Table 7.2 (d = 10 km, A = 1000 ha, R = 500 mm/year, and D = 2000 m^2/day), it takes the watertable level about 270 years to reach approximately 90% of its rise.

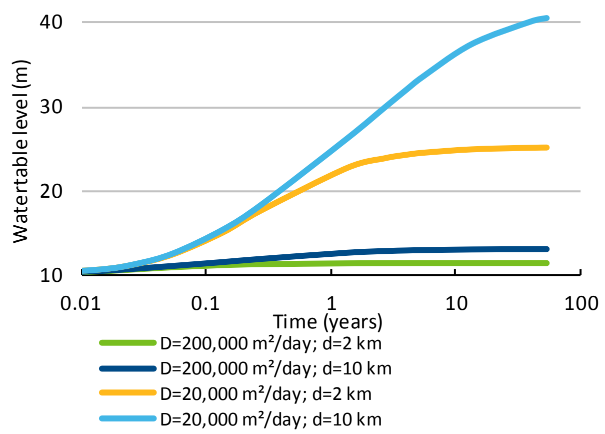

Figure 7.6 Watertable level for various aquifer diffusivities (D) and distances to river (d), for an irrigation area of 100 ha and recharge rate of 100 mm/year

Changes in groundwater discharge over time

Groundwater mounds under irrigation developments can result in increased groundwater discharge to nearby rivers. This can have important ecological implications.

The time taken for a groundwater mound to discharge to a nearby river depends on the aquifer diffusivity and the distance to the river. In Figure 7.7 the groundwater discharge to the river (i.e. flux response) is expressed as a fraction of the recharge. The increase in groundwater discharge to a river following an irrigation development can take many years to occur, particularly where the irrigation development is located a long distance from the river.

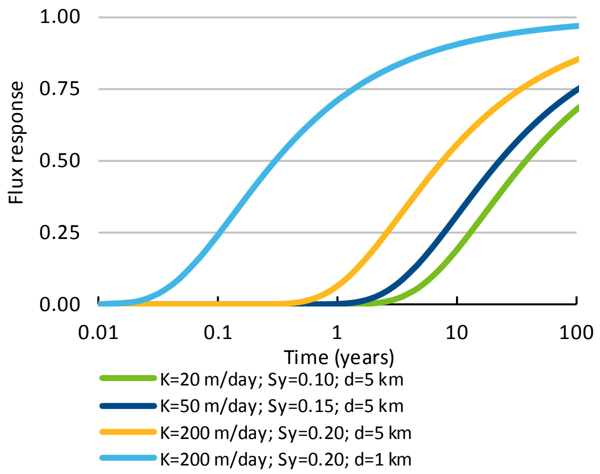

Figure 7.7 Flux response for different aquifer diffusivities, for different hydraulic conductivities (K), specify yields (Sy) and distances to river (d)
The flux response is the groundwater discharge to the river, expressed as a fraction of the recharge. Because it is a fraction, it is unitless.

7.2.3 INTERACTIONS OF GROUNDWATER AS A RESULT OF NEIGHBOURING IRRIGATION DEVELOPMENTS

The groundwater mounds that form under neighbouring irrigation developments have the potential to superimpose upon each other resulting in higher groundwater levels than may otherwise occur. Figure 7.8 illustrates the variation in groundwater level beneath two small (500 ha) neighbouring irrigation developments at different distances of separation. Two sets of parameters are examined. The first assumes a saturated hydraulic conductivity of 1 m/day and a recharge rate of 65 mm/year. The second assumes a saturated hydraulic conductivity of 20 m/day and a recharge rate of 130 mm/year. Both assume the irrigation developments are 1 km from a river. The latter (Figure 7.8b) is considered to be more representative of mosaic irrigation developments associated with offstream storages in the Gilbert catchment. The results indicate that small size irrigation developments (i.e. 500 ha) have little interaction during the first 10 years after development. Considerable interactions may occur within a 100-year time frame (i.e. resulting in an additional 8-m rise in watertable level), but interactions can be avoided when the developments are placed 4 km apart. Placing 500-ha irrigation developments at least 10 km apart excludes any interaction (i.e. under steady-state conditions).

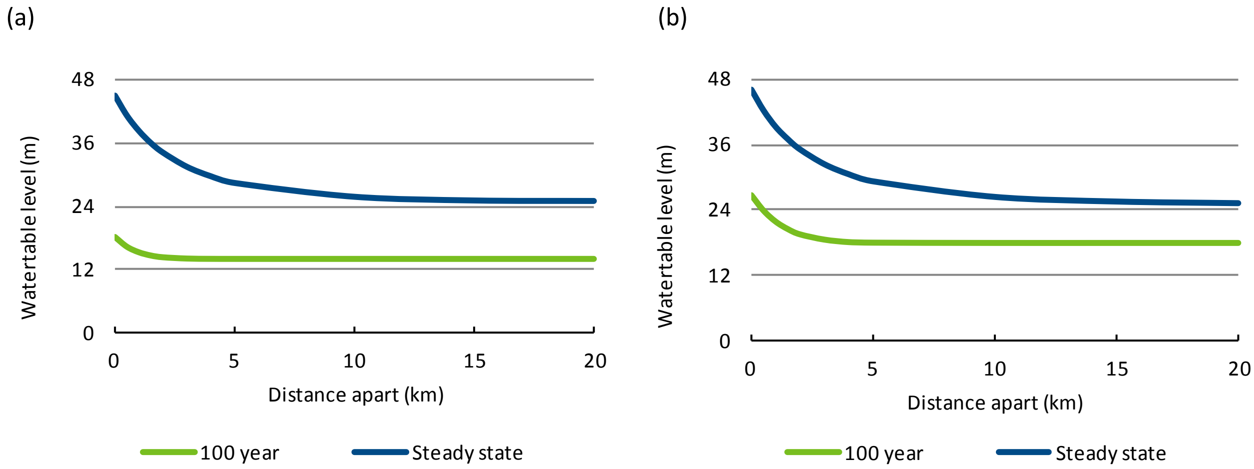

Figure 7.8 Variation in watertable level beneath two neighbouring 500-ha irrigation developments at different distances of separation
(a) Saturated hydraulic conductivity of 1 m/day, recharge of 65 mm/year and 1 km from river. (b) Saturated hydraulic conductivity of 20 m/day, recharge of 130 mm/year and 1 km from river.

7.2.4 SALT STORES IN THE GILBERT CATCHMENT

There is very little information in the Gilbert catchment on salt stores below 1.5 m. The alluvial soils of moderate to high agricultural potential, adjacent to the Gilbert and Einasleigh rivers above their confluence, have high permeability (Figure 3.7) and consequently have low concentrations of stored salt. The substrata underlying these soils are also likely to be highly permeable and are also likely to have low concentrations of stored salt. This is confirmed by conductivity-depth sections derived from electromagnetic data (Figure 7.9), which indicate that this part of the Gilbert catchment has very low conductivity levels. Surface water in the Gilbert and Einasleigh rivers is fresh and therefore it is unlikely that salinisation will occur should watertable levels approach the ground surface.

Near the town of Einasleigh, however, the soils and substrata have relatively high conductivity (Figure 3.26) indicating the presence of salts is likely. Elevated watertable levels in this area may result in secondary salinisation.

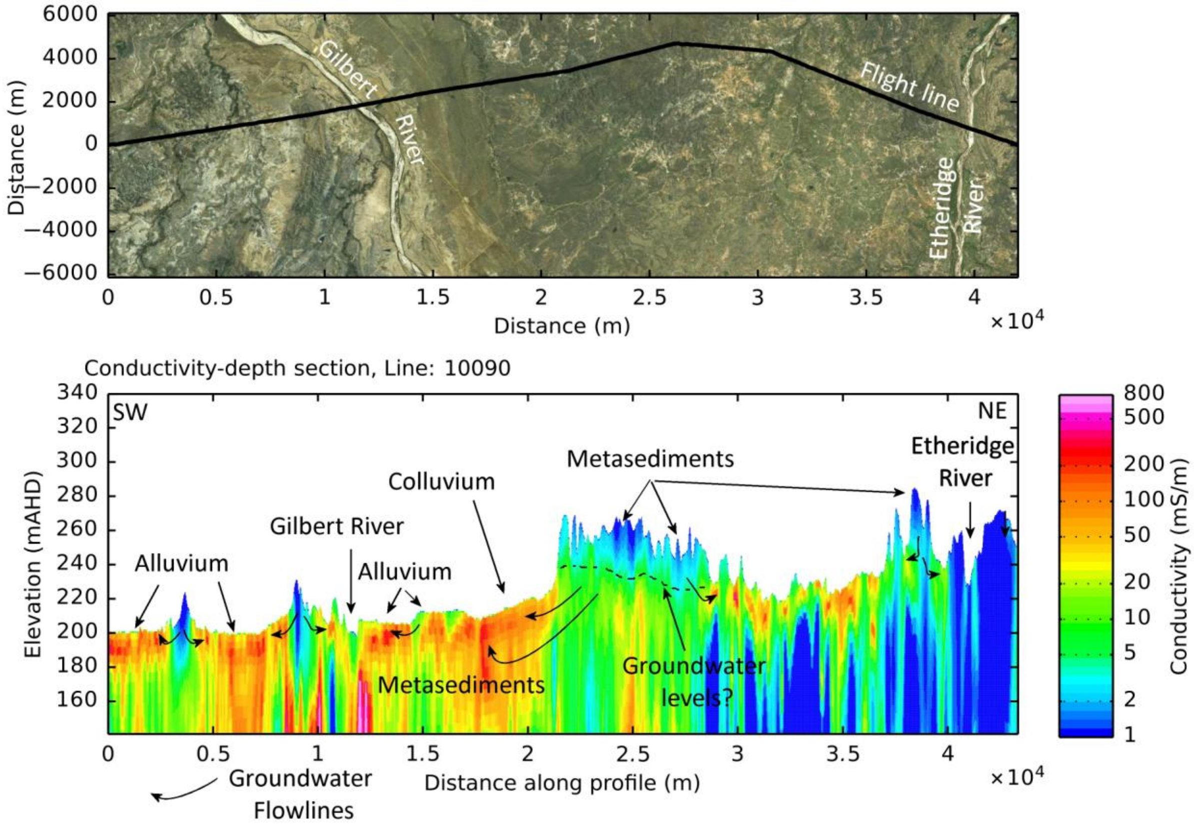

Figure 7.9 Conductivity–depth section (lower panel) for flight line 10090. Location of flight line on a satellite image is shown in upper panel. This flight line transects the Gilbert River and Etheridge River downstream of Georgetown

7.3 Managing irrigation drainage

Surface drainage water is water that runs off irrigation developments as a result of over-irrigation or rainfall.

This excess water can potentially affect the surrounding environment by modifying flow regimes and changing water quality. Hence, management of irrigation or agricultural drainage waters is a key consideration when evaluating and developing new irrigation systems and should be given careful consideration in the planning and design process. Regulatory constraints on the disposal of agricultural drainage water from irrigated lands are being made more stringent as this disposal can potentially have significant off-site environmental effects (Tanji and Kielen, 2002). Hence, minimising drainage water through the use of best practice irrigation design and management should be a priority in any new irrigation development in northern Australia. This involves integrating sound irrigation systems, drainage networks and disposal options so as to minimise off-site impacts.

Surface drainage networks need to be designed to cope with the runoff associated with irrigation, and also the runoff induced by rainfall events occurring on irrigated lands. Drainage must be adequate to remove excess water from irrigated fields in a timely manner, and hence reduce waterlogging and salinisation, which can seriously limit crop yields. In best practice design, surface drainage water is generally re-used through a surface drainage recycling system where runoff tailwater is returned to an on-farm storage or used to irrigate subsequent fields within an irrigation cycle.

The quality of drainage water will vary depending upon a range of factors including water management and method of application, soil properties, method and timing of fertiliser and pesticide application, hydrogeology, climate and drainage system (Tanji and Kielen, 2002). These factors need to be taken into consideration when implementing drainage system water recycling and also when disposing of drainage water to natural environments.

A major concern with tailwater drainage is the agro-pollutants derived from pesticides and fertilisers that are generally associated with intensive cropping, and are found in the tailwater from irrigated fields. Crop chemicals can enter surface drainage water if poor water application practices or significant rainfall events occur, after pesticide or fertiliser application (Tanji and Kielen, 2002). Tailwater runoff from pesticides and fertilisers can contain phosphate, organic nitrogen and pesticides that have the potential to adversely affect flora and fauna and ecosystem health, on land waterways, estuaries or marine environments. Tailwater runoff may also contain elevated levels of salts, particularly if the runoff has been generated on saline surface soils. Training of irrigators in responsible application of both water and agro-chemicals is therefore an essential component of sustainable management of irrigation.

As tailwater runoff is either discharged from the catchment or captured and recycled, it can result in a build-up of agropollutants that may ultimately require disposal from the irrigation fields. In externally draining basins, the highly seasonal nature of flows in northern Australia does offer possibilities to dispose of poor quality tailwater during high-flow events. However, downstream consequences are possible and no scientific evidence is available to recommend such disposal as good practice. Hence, consideration should be given to providing an adequate understanding of downstream consequences of disposing of drainage effluent and options must be provided for managing disposal that minimise impacts on natural systems.

7.3.1 IMPACTS OF SEDIMENT, NUTRIENTS AND AGROPOLLUTANTS TO RECEIVING WATERS OF THE GILBERT CATCHMENT

Little information is available on the current or historical water quality of the Gilbert River, its associated estuaries and coastal areas. Previous agricultural irrigation developments in tropical Australia have been associated with decreased river and offshore water quality (Brodie et al., 2010; Brodie et al., 2013; Lewis et al., 2009). These reductions in water quality are directly related to the removal of pre-existing ground cover and consequent high sediment loads, as well as the application of fertilisers and pesticides. Fertiliser and pesticide applications are in part absorbed and used by crops; but, during rain events, unused nutrients, and other chemicals, sediments eroded from exposed soils, are washed into rivers. These are released as pollutants into natural ecosystems as river flows spread out and slow in downstream reaches of the river, estuary and coastal receiving areas.

Downstream receiving areas effectively collect material carried in agricultural runoff into habitats including wetlands, mangroves and seagrass meadows of ecological, economic and social importance. Some of these habitats can be sensitive to increased levels of sediments, nutrients and pesticides from agricultural runoff.

The Assessment evaluated the potential for water quality change resulting from agricultural development for freshwater, estuarine and marine receiving areas of the Gilbert catchment for five crop types: irrigated fodder, cotton, sorghum, sugarcane and guar (for more details see the companion technical report about waterhole ecology (Waltham et al., 2013). Scenarios were developed to assess the effects of crop type, management practice and total area cropped on suspended sediment, nitrogen, phosphorous, herbicides and pesticides. These scenarios were evaluated using the Export Coefficient Model (Cuddy et al., 1994; Johnes, 1996; Letcher et al., 2002).

The Export Coefficient Model allows broad estimates of the amount of sediment, and the proportion of applied agrochemicals, that wash into rivers in surface runoff. These load estimates can be broadly categorised as small (1 to 10%), moderate (10 to 50%) and large (greater than 50%) relative to baseline estimates, where a 50% increase in loads is equivalent to a 1.5-fold increase. Experience shows that small (1 to 10%) load increases are likely to have minimal ecological impact and moderate (10 to 50%) load increases are likely to have some degree of downstream impact, but without more information accurate prediction of impact is impossible. Large (greater than 50%) increases in loads are considered likely to have major impacts downstream.

Reliable data describing pesticide behaviour under rainfall or irrigation runoff conditions are scarce for northern Australian crops and pastures, consequently not all pesticide loads could be modelled. A reasonable amount of data are available for four pesticides or herbicides of particular environmental concern, three pesticides (2,4D amine, diuron, atrazine) and one insecticide (imidacloprid). The lack of current pesticide data for many crops proposed for the Gilbert catchment means that their effects will first need to be thoroughly investigated before development takes place.

The results suggest that negligible change will occur in suspended sediment loads as a result of irrigated fodder; however, increases in phosphorus loads above baseline range between 25 and 50%, depending on the size of the area planted. Increases in nitrogen loads range from 12 to 25%. These increases are moderate, and so are considered likely to have some impact downstream. Pesticides are not used in great amounts for irrigated fodder, so are unlikely to negatively affect water quality.

Suspended sediment and nitrogen loads in the Gilbert River are not predicted to increase to a large extent under irrigated sorghum, and predicted increases in phosphorus load were moderate (15 to 40%), with little difference between management practices. There is likely to be some downstream impact from increased phosphorus loads. It was not possible to model likely losses of pesticides given the lack of data.

Poorly managed ground cover (including no retention of stubble), combined with intensive tillage, can lead to substantial erosion in intense rainfall events in dry tropics cotton cultivation; as demonstrated in the Fitzroy catchment in Queensland (Silburn and Hunter, 2009). When these practices are used, the model predicts losses of 200,000 to 400,000 t/year (from 10,000 ha to 20,000 ha cropped). In contrast, with minimum or zero tillage, stubble retention and contour bank practices, suspended sediment loads can be reduced to near natural levels. Increases in phosphorus loads above baseline are small except for a moderate (11%) increase predicted for 20,000 ha under the more intensive practices. Predicted increases above baseline for nitrogen range from 10 to 25%. The predicted increases in nitrogen and phosphorus loads are likely to have some impact downstream. It was not possible to model likely losses of pesticides due to lack of data.

Sugarcane cropping is unlikely to substantially increase suspended sediment loads to the Gilbert River. Moderate increases in nitrogen (16 to 44%) are predicted under some practices modelled, and larger cropping areas (50,000 ha).

Moderate to large increases (11 to 71%) were predicted for phosphorus. Australian ecosystems are low in phosphorus – the limiting nutrient for many freshwater ecosystems. Consequently increases of this magnitude are likely to have major impacts downstream (Harris, 2001).

For pesticide loads the difference predicted between management practices is dramatic. Under two modelled practices the loads are large, in the order of hundreds of kilograms per year. This is likely to have significant effects on freshwater and estuarine ecosystems; however, the lack of research into the environmental effects of these chemicals prevents prediction of what these effects may look like.

Note that should agricultural development lead to cropping areas exceeding the 50,000 ha modelled here, the impact from sediment, fertiliser and pesticide loads will be higher

7.4 Ecological implications of altered flow regimes

Irrigation development necessarily alters the flow regime of streams and rivers, via extraction or diversion of water, the construction of levee banks, or return of irrigation tailwater. Each of these can affect the magnitude, frequency, duration, timing, rate of change and predictability of water flow (Poff et al., 1997).

Flow regime is the dominant driver of water quality, biotic community assemblages, aquatic productivity and the physical form of streams (their bank and channel structures, instream sand bars); it is therefore a critical determinant of the physical and ecological character of streams and rivers.

While some ecological responses to changed flow regimes are gradual and cumulative, for others there are often thresholds above which small changes in flow regime can have large and rapid impacts on ecosystem function and process.

The responses of aquatic ecosystems to irrigation developments are varied and depend not just on the amount of water extracted, but also on the way in which water is extracted, stored and distributed through the landscape; the types of crops grown and irrigation systems used; the management systems in place; and local climate and environmental conditions. Where a dam or weir is built across a stream, large areas of aquatic and terrestrial habitat may be inundated, and formerly shallow (even flowing) aquatic habitat is converted to a deep, lake-like environment that favours different species and ecological processes. Major structures – such as dams or weirs – impair or completely halt the critical passage of fish and other aquatic creatures. Such impediments have resulted in the localised extinction of many fish species from many thousands of kilometres of waterways. While such instream structures can be avoided by using water harvesting schemes that pump water directly from the river into offstream storages, these tend to reduce stored water yield.

Generally, where water is extracted from a river, the reduced flow volume results in reduced habitat availability and poorer water quality. This reduction in flow is the change most often associated with irrigation development, and the Assessment has shown that water extraction would affect the number, standing volume and flushing frequency of waterholes in affected streams.

Where a dam or weir is constructed, overall annual flow volume often delines, but where water is released for distribution to downstream irrigators, the river reaches below the dam or weir may receive higher dry-season flow than prior to development – a process known as supplementation. In such situations, whether streamflow decreases or increases depends on the season and the way in which water is extracted and distributed. Given that the character of any stream depends on its flow regime, increases in flow – including seasonal increases – also greatly alter the character of streams, possibly as much as the outcomes of decreasing flow. There are many studies that have examined the ecological impacts of supplementation and, in some cases, considerable management interventions are being enacted to reduce elevated flow volumes. Relevant north Queensland examples include the Barron and Walsh rivers (Brizga et al., 2001a; Butler et al., 2008), the Pioneer River (Brizga et al., 2001b) and the Burdekin River irrigation area (Perna, 2003; Butler, 2006; Burrows et al., 2012).

The range of environmental changes that could potentially occur as a result of irrigation development is as varied as the number of developments that could be proposed. Thus, there are limitations to the specific advice that can be provided in the absence of specific development proposals. Even where a specific proposal is being evaluated, many environmental changes associated with irrigation developments are not easily predicted before or during development, and an adaptive management process is required to deal with each as they arise.

For instance, prior to the construction of the Burdekin Falls Dam, the Burdekin Project Committee (1977) and Burdekin Ecological Study (Fleming et al., 1981) concluded that the dam would improve water quality and clarity in the lower river and that para grass, an invasive weed from Africa, then present at relatively low levels, could become a useful ecological element as a result of increased water delivery to the floodplain. However, the Burdekin Falls Dam has remained persistently turbid since construction in 1987, greatly altering the water quality and ecological processes of the river below the dam, and the many streams and wetlands into which that water is pumped on the floodplain (Burrows and Butler, 2007). Para grass (and more recently hymenachne, an ecologically similar plant from South America) have become serious weeds of the floodplain wetlands, rendering innumerable wetlands unviable as habitat for most aquatic biota that formerly occurred there (Tait and Perna, 2000; Perna, 2003, 2004). Several elements are important in the pervasive impact of weeds within the irrigation area. The flow regime has been greatly altered, with seasonal or ephemeral streams becoming essentially perennial. Dry-season conditions restrict the growth of introduced plants, and favour local native species. Perennial flow, especially where nutrient levels are elevated, enables fast-growing weeds to proliferate. In the Burdekin River irrigation area, these have come to dominate most wetlands and – in many cases – to entirely cover the water surface of deepwater lagoons and the margins of stream channels. Similar, though not as widespread and devastating, effects are seen in the Mareeba-Dimbulah Irrigation Area (Butler et al., 2008).

Apart from the processes for extraction, storage and delivery of irrigation water, the way in which irrigation is practised is very important to environmental outcomes. Flood irrigation is commonly practised, resulting in large losses of water from the paddock to nearby streams and wetlands. More efficient irrigation systems will prevent such losses, but these are very expensive to install and maintain. Use of detention basins to capture runoff from farms is becoming more common. Again, this adds cost to farm establishment and operations. Ironically, as Burrows and Butler (2007) point out, some creek systems within intensive agricultural areas are actually maintained in a healthy, though unnatural, state through receiving supplemented year-round flow, rather than more natural seasonal or ephemeral flow regimes.

For example, Barratta Creek (within the Burdekin River irrigation area) was naturally seasonal but now runs year-round, through a combination of tailwater return from flood-irrigated farms (Burrows and Butler, 2007) and elevated watertable levels (DERM, 2013). The increased runoff contains elevated levels of nutrients and pesticides (Davis et al., 2013), but the persistent flow and the resulting aeration prevents the creek from worse environmental outcomes than would result if it ceased to flow and became stagnant – as has happened in nearby streams and lower downstream on the floodplain of Barratta Creek (Burrows and Butler, 2007; Burrows et al., 2012).

The receiving environments (natural streams) in the Assessment area are often of low volume and with limited opportunities for natural dilution. In the absence of diluting flows, contaminants and elevated nutrients may result in poor ecological health outcomes for these low-volume streams. Ecologically, poor quality stormwater runoff from farms is one of the biggest risks to aquatic health. Typically, runoff from farms drains initially to small creeks rather than larger rivers. This is because most rivers are naturally leveed. Even farms close to major rivers tend to drain away from the river bank into smaller creeks that have lesser dilution capacity and that are more susceptible to the impacts of poor quality runoff or the elevated baseflows it may generate.

Wetlands and streams in intensive irrigation districts of coastal north Queensland are severely compromised by altered flow regimes, poor water quality, invasive weeds, and loss of riparian integrity and fish passage barriers (Burrows, 1998; Tait and Perna, 2000; Perna, 2003; Godfrey and Pearson, 2012). Plant diversity is diminished and most water bodies support a lower abundance and diversity of fish species than they previously did (Hogan and Graham, 1994a, 1994b; Burrows, 1998). Fish kills and other high profile displays of poor health are common, although in some wetlands fish kills are now rare because all the moderately sensitive fish species have already been eliminated, and only the more tolerant species remain (Butler and Crossland, 2003).

Nutrients are commonly implicated in water quality decline in irrigation districts (Tait and Perna, 2000; Perna, 2003, 2004) and more recent sampling, including in several different north Queensland irrigation districts, has shown that pesticides from cropped farms are regularly present in natural waters (Davis et al., 2012). Less commonly recognised, though, is that most wetlands and watercourses examined in these same irrigated districts have dangerously low levels of dissolved oxygen (Pearson et al., 2003; Butler and Burrows, 2007), a critical element for the survival of aquatic fauna. Farm runoff has been conclusively linked to these low dissolved oxygen levels (Butler and Crossland, 2003; Butler et al., 2007; Perna and Burrows, 2005; Veitch et al., 2008), especially in sugarcane farming areas where sugarcane juice itself has a high oxygen demand and can, when washed into adjacent waterways, rapidly consume all the available oxygen (Pearson et al., 2003; Butler and Crossland, 2003).

Another key component is the role of riparian management. Riparian zones in the dry tropics require active management. For graziers, riparian zones are part of their productive landscape and they therefore manage them as best they can. Irrigators do not use riparian zones as part of their productive landscape and thus tend not to actively manage them. In the case of the Burdekin River irrigation area, this lack of management has resulted in significant degradation of riparian zones when the land management changed from grazing to cropping (Tait and Perna, 2000). A visually obvious example is the manner in which para grass has proliferated and dominated riparian zones since cessation of grazing and conversion to cropping. In the Burdekin, this has resulted in recent attempts to reintroduce grazing (and fire management) to riparian zones (Tait and Veitch, 2007). Some of these efforts have successfully rehabilitated wetlands, but often riparian corridors are too small for the reintroduction of grazing, fire, or other forms of active management. In Barratta Creek in the Burdekin River irrigation area, an undeveloped buffer of varying width, but up to 1 km wide, was retained when the area was developed for irrigated sugarcane in the mid-1990s. This has served well for some purposes but is gradually declining due to invasive weeds, poor regeneration of riparian trees, and a general inability to graze and burn key locations along the corridor (Tait and Veitch 2007). Where cattle grazing and/or fire management has been implemented under environmental management funding, it has been successful in controlling weeds and restoring habitat functions. Its wider application, however, is limited by insufficient corridor width to make such operations truly financially viable.

For a variety of reasons, it is preferable to locate farms further from the riparian zones and banks of major streams. The recommended widths vary but for the purposes of maintaining riparian functions, distances of a few hundred metres to 1 km are commonly suggested. However, for viable grazing and/or fire management regimes to be implemented, much greater distances may be required. This may create difficulties as suitable irrigable soils are usually located closer to major streams. Pumping costs from the streams are also a major consideration.

Overall, the condition of wetlands and streams affected by major irrigation development is often poor, especially for those located within the irrigation development itself. The degree to which flow has been reduced is one factor but often smaller streams that have increased flow are also greatly altered. Some of the impacts result from the development itself (e.g. construction of impoundments and fish passage barriers) and are difficult to rectify, but many significant weed and water quality issues are the result of operations and environmental management after the development has begun operation. These issues can, with appropriate effort and willingness, be managed to a degree. Many of the environmental changes may not be predicted at the outset and may take years to manifest. Therefore, adaptive management is required, as well as a thorough, well-documented understanding of baseline pre-development conditions. In the context of a catchment where data and descriptions of existing conditions are very poor, this is a major gap that needs to be redressed.

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Part III Case studies

The Assessment considered three case studies in the Gilbert catchment, as described in chapters 8 to 10 in Part III. These case studies are based on the information in chapters 3 to 7, and use the methods as described in Chapter 2. Their purpose is to help evaluate the type of opportunity for irrigation in selected geographic areas of the catchment. By analysing water storage options and potential crops, they allow the reader to better understand the viability and sustainability of irrigated agriculture.

The geographic areas of the case studies were determined by the location of the more promising water storage options in the Gilbert catchment. The storyline for each case study is a narrative about a hypothetical development and is based on a range of information including consultation with local stakeholders, local knowledge and aspirations, biophysical opportunities, market and infrastructure factors, and transport logistics.

The case studies are illustrative only; the Assessment is not recommending these developments – or types of development – for the Gilbert catchment. No proposals or funding are currently in place to finance these irrigation developments.

The financial analysis for these case studies adopts the common perspective of investigating whether the projected revenues from the sale of the crop is sufficient to cover the costs of irrigation development and crop production. The agricultural opportunities investigated in these case studies may, however, be pursued under a range of investment models, including investments that integrate component parts of the supply chain – for example, growing and processing. These alternatives are beyond the scope of the Assessment, but the analyses presented here can be used in further investigations of such options.

8 Green Hills dam and irrigated three-crop rotation

Authors: Justin Hughes, Perry Poulton, Cuan Petheram, Linda Holz, Stephen Yeates, Shaun Kim, Scott Podger, Michael Kehoe, Daniel Aramini, Peter R Wilson, David McJannet, Arthur Read, , David Rassam, Nathan Waltham, Damien Burrows, Lisa Brennan McKellar, Geoff Podger, John Hornbuckle, Seonaid Philip, Andrew Higgins, Marcus Barber and Rebecca K Schmidt

In this case study, a potential irrigation development adjacent to the Gilbert River was investigated (see Figure 8.1). The development is based on a rotation of cotton, peanuts and an irrigated fodder, with a new cotton gin located in Georgetown. Irrigation water would be supplied from a dam built immediately downstream of Green Hills station.

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

- the physical capacity to create a water storage and water distribution infrastructure, to supply water to agriculturally suitable soils, and to grow irrigated crops
- the capacity of the scheme to generate positive net revenues, based on a consolidated developer–owner–operator model
- the capacity of the farm to generate positive net revenues, when water development and supply costs are borne by off-farm interests.

The financial analysis for this case study investigates whether the projected revenues from the sale of cotton, peanuts and sorghum (forage) are sufficient to cover the costs of irrigation development. This perspective is appropriate to adopt if the investor does not have interests in a cotton gin, for example. It is acknowledged, however, that alternative investment models could be possible – ranging from individual investors with no interests in irrigation supply or ginning (i.e. cotton growers who purchase water from a supplier) through to investors with interests that extend to ginning as well as cotton production. These alternative models are not investigated in this case study.

The analysis of the irrigation development is presented at both the scheme scale and the farm scale, using results under scenarios A and B. Both scenarios use the same 121-year historical climate data (from 1890 to 2011). Scenario A includes historical climate and current development, while Scenario B includes historical climate and future irrigation development (such as the irrigation development specified in this case study). All results in the Assessment are reported over the 'water year', defined as the period 1 July to 30 June. This allows each individual wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons).

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

In undertaking this analysis, the case study assessment included an allowance to avoid impacts on the reliability with which existing entitlement holders could extract water. For more details see Holz et al. (2013).

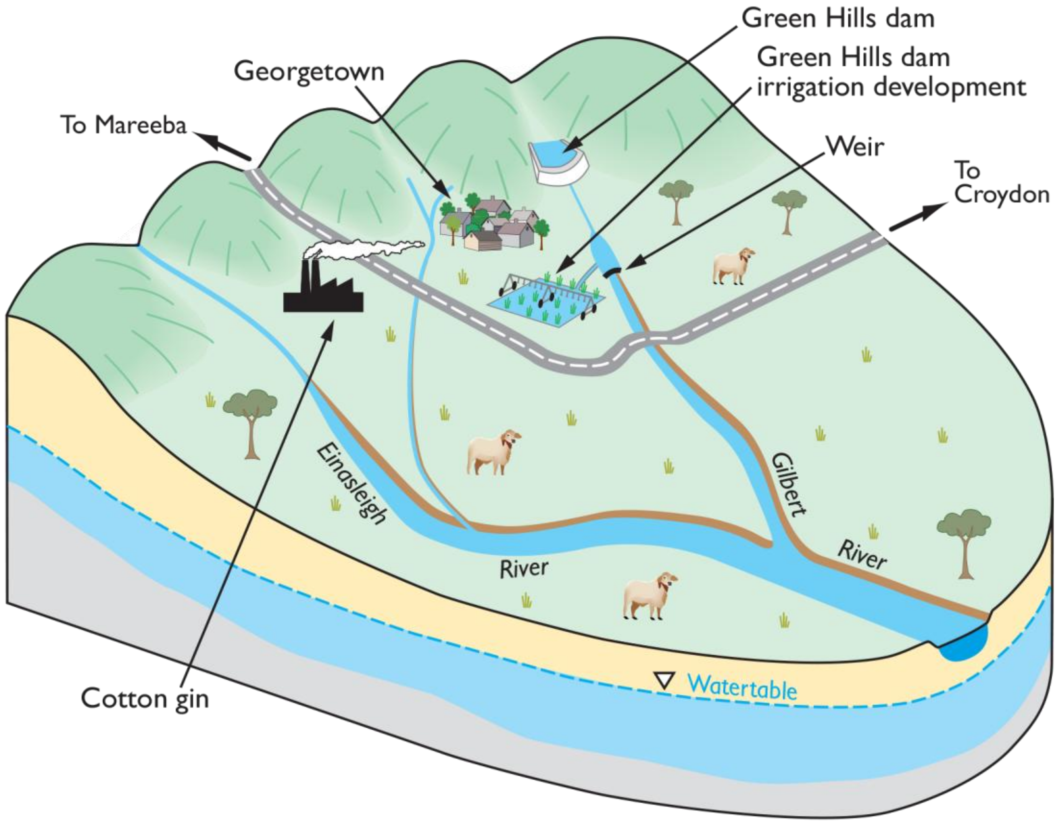


Figure 8.1 Schematic diagram illustrating the components of the case study for a dam and irrigation development near Green Hills station

8.1 Summary

The case study concludes that the physical conditions at the site would enable the development of a dam to supply irrigation water for a 12,000-ha irrigation development of cotton, peanuts and sorghum (forage).

The case study found the following:

- A dam capable of storing 227 GL of water can potentially be located downstream of Green Hills station, west of Georgetown. Because of high evaporative losses, and high inter-annual variability in streamflow its annual water yield would be 172 GL/year (at 85% reliability). The estimated storage cost of $335 million and annual yield of 172 GL results in a unit cost of $1950/ML at the dam wall. Approximately 30% of this water yield at the dam wall would be lost in conveyance and application to the crop.
- More than 25,000 ha of soils moderately suited to spray-irrigated crop production lie downstream of the dam site and upstream of the Gulf Development Road. Given adequate irrigation and crop management, these soils are capable of supporting median crop yields of approximately 8.5 bales/ha for cotton, 5 t/ha of peanuts or 14 t/ha of sorghum (forage) per year.
- Secondary salinity risk is relatively low in this area – large rises in watertable levels are unlikely and there are low levels of accumulated salts.

A dam and irrigation development paid for and operated by the same entity is not, under the conditions examined in this case study, likely to be economically sustained. Examination of 92 separate 30-year investment windows occurring in each of the past 121 years failed to identify any conditions under which a positive net present value (NPV) could be generated from a combined investment in water supply and farm operations. To generate a positive NPV at the specified discount rate the price of cotton, peanuts and sorghum (forage) would need to be double (current prices) over the entire investment period. The recreational amenity of this reservoir is likely to be quite high on the basis that the reservoir will contain a reasonable volume of water for a large proportion of time.

There is potential to generate on-farm profits using water and related capital if this was supplied by and paid for by a third party. With a gin in Georgetown, farmers could pay $263/ML for water and break even. However, at the default cotton price, it is not profitable to transport cotton to Charters Towers or Emerald. This highlights the importance of local processing infrastructure to the profitability of local farming enterprises.

The high reliability of water supply from the Green Hills dam means that it is possible that a 12,000-ha irrigation development (of which 6000 ha would be cotton at any one time), producing a mean of 8.5 bales/ha of cotton, could support a local cotton gin at Georgetown. It is also possible for the Green Hills dam to support a larger irrigation development at lower reliability.

8.2 Storyline for this case study

In this case study, a potential irrigation development along the Gilbert River was investigated. The development is based on a crop rotation of cotton, peanuts and an irrigated fodder, with a new cotton gin located in either Georgetown or Charters Towers. Water for the irrigation district would be supplied from a large dam on the Gilbert River located just downstream of the Green Hills station (Figure 8.2).

Cotton and peanut crops were selected firstly for their market potential, and secondly because the soils and climate (when these crops would be grown) appear suitable. Peanuts are currently grown successfully along the Gilbert River, with March to August being the preferred growing season. Cotton was successfully grown in the 1960s; however, there was insufficient area of production to sustain an industry. The similarity of the Gilbert River climate and soils to those at Katherine, Northern Territory, where peanuts and cotton have been shown to grow well, also supports the selection of these crops. Importantly, the absence of the cotton insect pest Pink Bollworm (*Pectinophora gossypiella)* from the Georgetown area is an advantage with growing cotton in the wet season (January to June) when compared with Katherine.

There is also interest from the cotton industry in establishing cotton growing areas in northern Australia, because this could help the overall Australian industry to meet more reliably their international commitments, particularly in times of drought in southern Australia.

The third rotation crop in the case study, sorghum (forage), could be replaced by any forage crop or pasture. Because extensive grazing is the dominant agricultural industry in the Gulf region, a reliable water supply during the later period of the dry season would provide a major opportunity to produce spring feed (silage or hay) at a time when the demand for animal feed is at its highest. Additional benefits of incorporating a fodder into the rotation include improved weed, pest and disease management in the other crops, and diversification of income source.

Although cotton can be a high-gross margin crop, the raw product requires processing at a cotton gin to separate the fibres (lint) from the cotton seeds. In northern Australia, approximately 38% (range 35 to 40%) of the total unprocessed cotton mass is cotton fibre; about 55% is cotton seed and 5% is plant trash. The closest active cotton growing area to the Gilbert River is about 600 km away in the Lower Burdekin region, where between 400 (2011) and 900 (2008) hectares have been planted each year. The nearest cotton gin, however, is in Emerald, approximately 950 km from the case study area (and 600 km from the Lower Burdekin region). For the Burdekin district, where water supply is very reliable, it has been estimated that a minimum production of about 50,000 bales per season – or 5500 to 7000 ha assuming a yield of 8 bales/ha of cotton – would be required to justify establishing a local gin (about 15,000 ha are fallow in the sugar production system each wet season). However, the recent drought in southern Australia has shown that, for regions with less-reliable production due to variable water supply (e.g. Bourke, Dirranbandi), a capacity to produce closer to 100,000 bales in seasons when water allocations are adequate (perhaps 50% of allocation or more) is probably required.

This case study considers the development of a future cotton gin at Georgetown. However, given the lead time to develop a local industry, an alternative of a new gin constructed at Charters Towers was also investigated. A gin at Charters Towers would be centrally located to cotton growers in the Lower Burdekin and potential cotton growers in the Flinders and Gilbert catchments. These two alternatives are compared to the scenario of transporting unprocessed cotton to the existing gin in Emerald.

The outline of this case study is as follows:

- Section 8.3 describes the soils of the case study area.
- Section 8.4 describes the suitability of the climate for growing cotton, peanuts and sorghum (forage) near Georgetown.
- Section 8.5 describes the configuration of the irrigation developments and cropping systems.
- Section 8.6 describes two financial analyses.
    - The first (in Section 8.6.1) surveys a range of different combinations of (i) the ‘scheme area’ (the area of the irrigation development) and (ii) planted crop area based on a crop area decision. These combinations were assessed with respect to crop yield, financial outcomes, and production and economic risk.
    - The second (in Section 8.6.2), undertakes a more detailed assessment of the profitability at the scheme and farm scale for a single combination of scheme area and crop area decision. Three alternative cotton gin locations are considered.
- Section 8.7 describes some potential on-site and off-site impacts associated with the scheme area selected in Section 8.6.2.

The case study area is shown in Figure 8.2 and Figure 8.3. To provide a sense of scale and an indicative sense of place, a potential irrigation development of 12,000 ha is delineated in these figures. This is referred to in this case study as the Green Hills dam irrigation development. Before irrigation development, the area would require more intensive assessment of usable soils and areas.

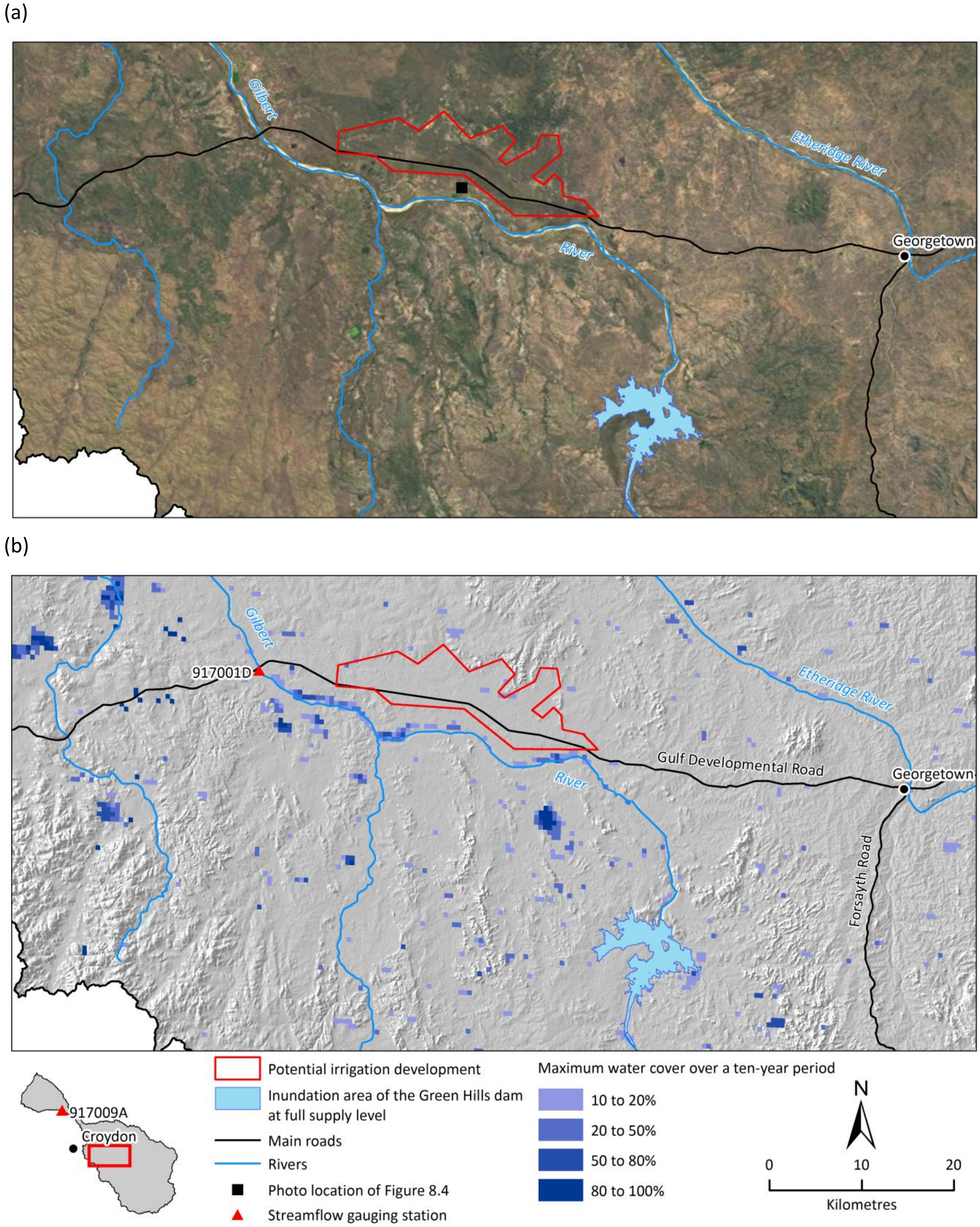


Figure 8.2 (a) Satellite map and (b) relief and flood map of the area surrounding Green Hills dam
The red rectangle on the inset map of the Gilbert catchment indicates the location of the case study area.

8.3 Soils near Green Hills

The Green Hills dam case study area is confined to the alluvial plain along the Gilbert River, upstream of Georgetown to Croydon Road. The area is dominated by alluvial plains that are largely influenced by the diverse range of rock types in the Gilbert catchment, including very old rocks altered by heat and pressure, as well as granites and sedimentary rocks. The shallow rocky soils on undulating to steep low hills and rises adjacent to the alluvial plains have limited development potential. The soils of the case study area are shown in the soil generic group map in Figure 8.3a and are described below. Figure 8.3b shows a land suitability map for cotton under spray irrigation. The landscape near the Green Hills dam irrigation development is shown in Figure 8.4.

Alluvial plains along the Gilbert River

Adjacent to the Gilbert River and upstream of where the Georgetown to Croydon Road crosses the Gilbert River there are 4150 ha of very deep, well-drained, loamy-textured, brown massive and structured soils (corresponding to friable non-cracking clay or clay loam soils, and sand or loam over friable earthy clay). Subsoils may have clay textures. These moderately permeable soils are very deep with a moderate to moderately high water-holding capacity and are well suited to a wide variety of irrigated crops, particularly using spray and micro-irrigation methods. Soils may be inundated by occasional floods. The main restriction in this area is the narrow width of the alluvial soil plains, restricting the area most suited for cropping.

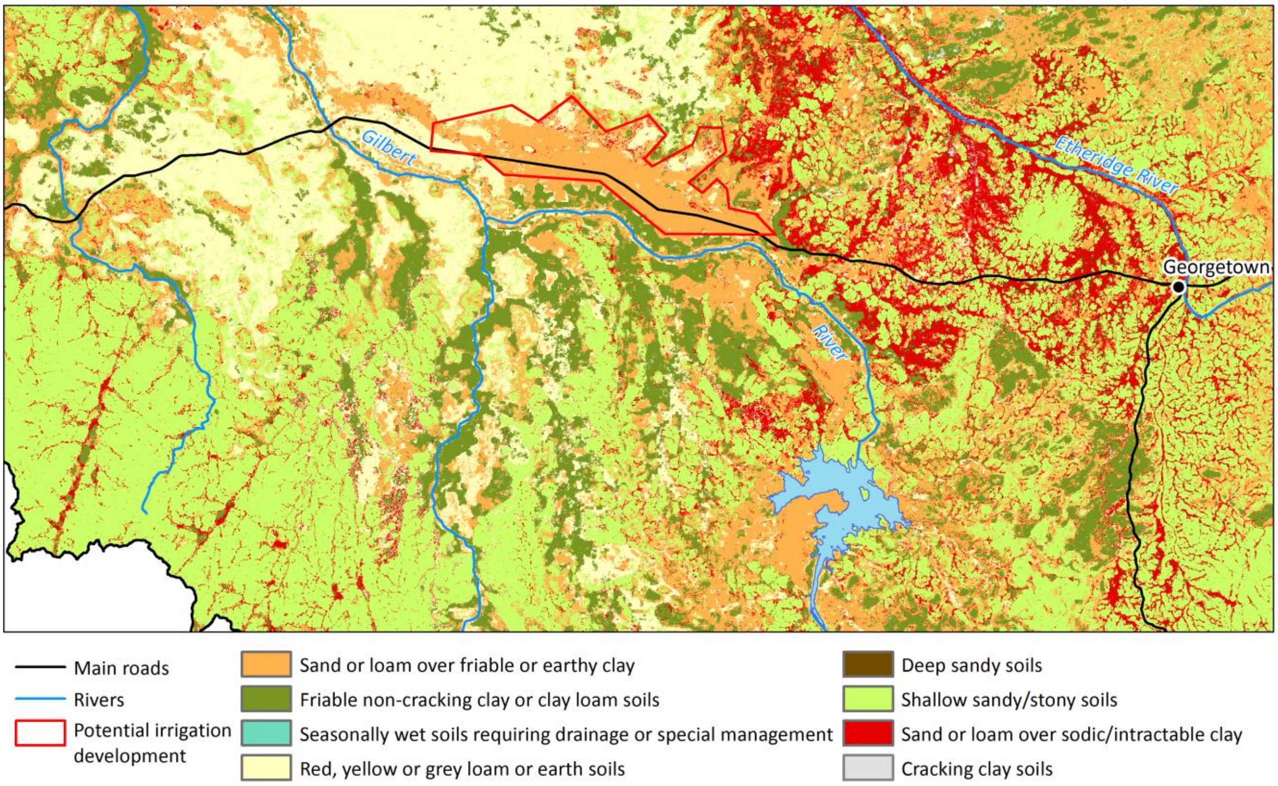
The plains further from the river are dominated by very deep texture contrast and gradational soils (corresponding to loam over sodic/intractable clay soils), with a loamy to silty surface over imperfectly to moderately well-drained slowly permeable dispersible clay subsoils (4050 ha). Soils have moderate water-holding capacity and development potential for furrow-irrigated crops; the main restrictions are surface sealing and difficulty with plant establishment and water infiltration. The relatively narrow areas make cropping of large areas difficult. Areas may be subject to occasional flooding and seasonal waterlogging.

In the low-lying areas, generally occurring as depressions on the alluvial plains, there are 5400 ha of imperfectly to poorly drained, slowly permeable, mottled hard setting, mottled grey gradational soils (corresponding to friable non-cracking clay or clay loam soils, and sand or loam over friable or earthy clay) and minor grey cracking clays. These soils have some limited potential for spray- or furrow-irrigated crops that can withstand regular flooding and seasonal waterlogging. The other restriction is the relatively small size of uniform areas.

Either side of the Gilbert River (but mainly on the eastern side), there are over 15,000 ha of high-level, flood-free, very deep and well-drained to imperfectly drained, moderately permeable, sandy- to loamy-surfaced soils (corresponding to sand or loam over friable or earthy clay soils) on elevated, gently undulating, alluvial plains. Subsoils are massive to structured red and brown clays. Low-lying areas correspond to imperfectly drained, mottled brown subsoils. These soils have a moderate water-holding capacity. Moderately large areas are moderately suitable to spray-irrigated field crops and micro-irrigated horticulture. Seasonal waterlogging may be a restriction on lower slopes.

A potential area of 12,000 ha is delineated in Figure 8.3. It has predominantly sand or loam over friable or earthy clay soils (high-level, flood-free alluvium). These soils are a considerable distance from the river (which means relatively high pumping costs) and soils are only marginally suitable for construction of on-farm storages due to the moderate to high subsoil permeability. Before irrigation development, the area would require more intensive assessment of usable areas. On the high-level, flood-free alluvium, rising watertable levels are unlikely, due to the high permeability of the substrate.

(a)



(b)

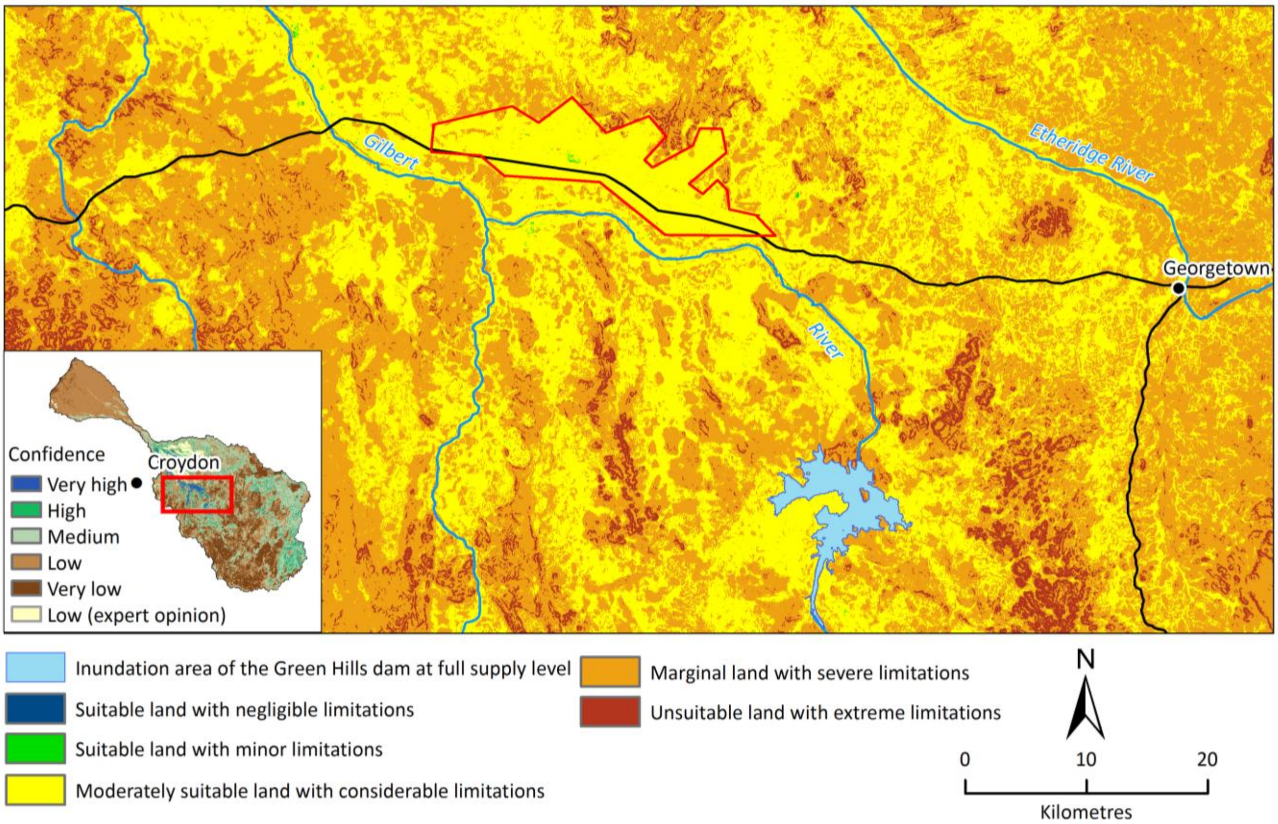


Figure 8.3 (a) Soil generic group map and (b) land suitability map of the area surrounding the Green Hills site for spray-irrigated cotton

The land suitability map does not take into consideration flood risk or the availability of water. The red rectangle on the inset map of the Gilbert catchment indicates the location of the case study area.

Figure 8.4 Landscape near the potential Green Hills dam irrigation development
Site where photograph was taken is shown on Figure 8.2.

8.4 Climate suitability for cotton, peanuts and sorghum (forage) at Green Hills

The climate is described as semi-arid tropical and is similar to other areas of northern Australia that have an annual rainfall of 600 to 1200 mm (e.g. Katherine, Northern Territory, and Kununurra, Western Australia) (Williams et al., 1985). Rainfall at the Green Hills irrigation area, and in the Gilbert catchment more generally, is highly variable among years as well as highly seasonal, with the majority (86%) of rain falling from December to March (Figure 8.5). The minimum temperatures at nearby Georgetown during June to August are at least 1 °C colder on average than at Katherine and are likely to be too low for dry-season production of cotton, although this has not been confirmed by research (Figure 8.6) (Yeates et al., 2013). The variable rainfall combined with the short wet season precludes rain-fed cotton – at least at the level of economic returns acceptable in Australia (Wood and Hearn, 1985). Similarly, peanuts will require irrigation because of the need for a product that meets the market preference for quality (i.e. no aflatoxins) and reliable yield. Cotton needs to be sown in early January so that boll growth can occur early in the dry season when temperatures and solar radiation are most favourable for photosynthesis (i.e. less likelihood of cloud cover and temperatures are mild but not cold); harvest will then occur in the dry months of May to July. Irrigation will be mostly required from April to June and from December to March (for a summer crop) only when rainfall is below average. Local experience suggests that peanuts appear best suited to a March sowing with harvest in August, although sowing in December or January is also feasible.

Forage crops can be grown year-round under irrigation. These crops can provide valuable fodder late in the dry season (July to November) as a grazed crop or as hay used on-farm, or sold to nearby cattle producers. Irrigation water requirement will be very high from September to December. It is also possible to finish cutting hay from these crops earlier (April to August) to save water. The hay can then be fed to cattle in the late dry season. Some fodder species may need resowing in the next wet season (e.g. sorghum (forage)); other species can re-establish from seed produced in the previous season (e.g. *Centrosema pascuorum*, *Urochloa mosambicensis*). A rigorous fertiliser program will be required to replace nutrients removed with intensive-irrigated fodder and crop production.

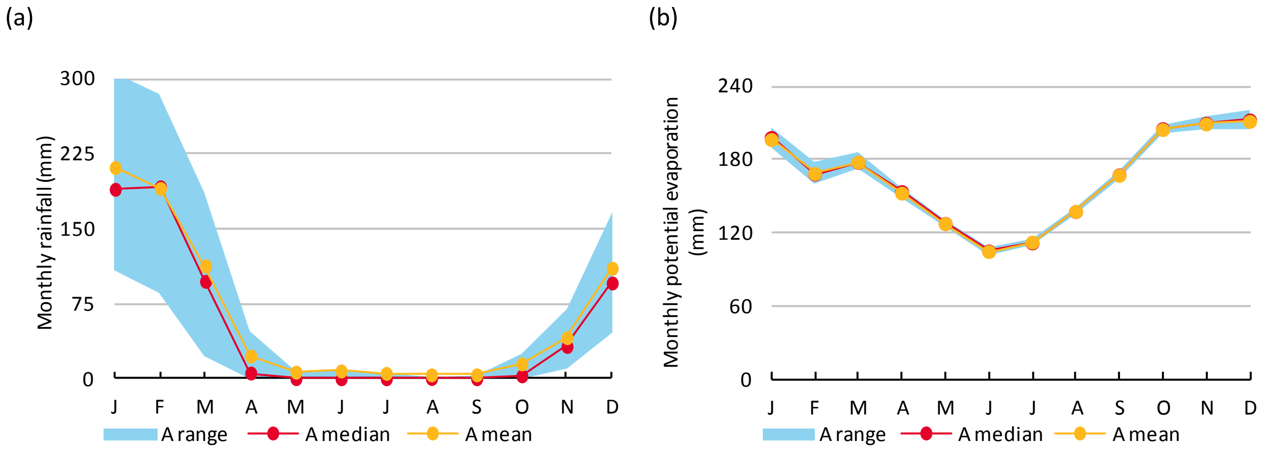


Figure 8.5 (a) Monthly rainfall and (b) monthly potential evaporation under Scenario A at Green Hills
Scenario A is the historical climate (1890 to 2011). The A range is the 20th to 80th percentile exceedance.

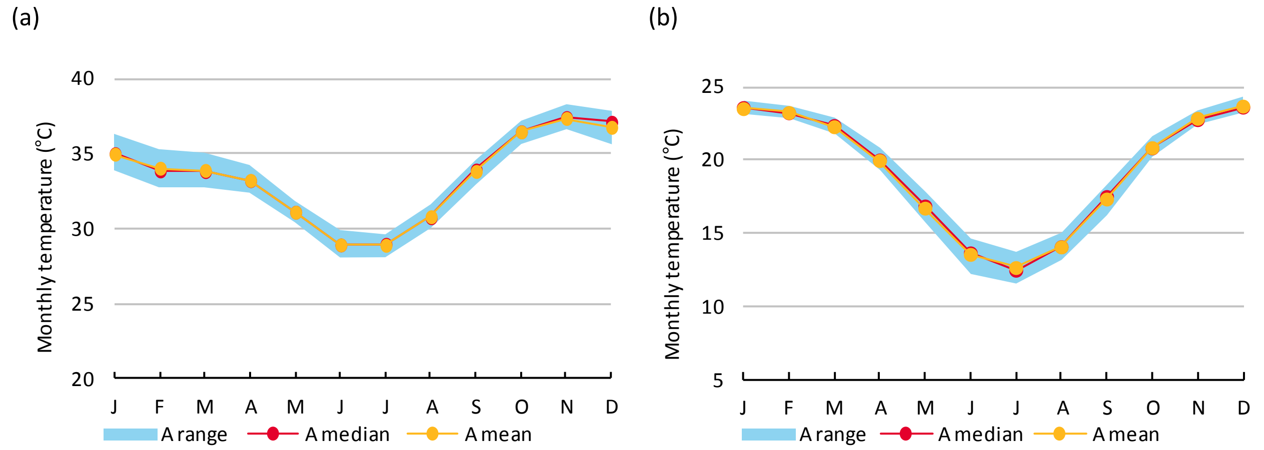


Figure 8.6 (a) Maximum monthly temperature and (b) minimum monthly temperature under Scenario A at Green Hills
Scenario A is the historical climate (1890 to 2011). The A range is the 20th to 80th percentile exceedance.

8.5 Scheme configuration and cropping systems

This section provides a description of the configuration of the irrigation developments and cropping systems associated with the Green Hills dam. It provides information on Green Hills dam, outlines the configuration and costs for water supply and irrigation development, examines the relationship between applied irrigation water and crop yield at production potential and discusses production risks.

8.5.1 GREEN HILLS DAM

There are two potential sites in the vicinity of the Green Hills dam irrigation development – an upstream and a downstream site. The upstream site was selected for this case study because the downstream one was deemed unsuitable due to its requirement for a large saddle dam.

At the upstream dam site, the Gilbert River has a median annual flow of 503 GL (Table 8.1) and streamflow is highly variable among years (Figure 8.7). The Green Hills dam has a relatively large storage capacity (227 GL). More details on the dam can be found in Section 5.1.

Table 8.1 Streamflow on the Gilbert River at the Green Hills dam site under Scenario A

RIVER NAME	MAXIMUM FLOW (GL/y)	20% EXCEEDANCE FLOW (GL/y)	50% EXCEEDANCE FLOW (GL/y)	80% EXCEEDANCE FLOW (GL/y)	MINIMUM FLOW (GL/y)	MEAN FLOW (GL/y)	COEFFICIENT OF VARIATION
Gilbert River	8653	1096	503	201	17	802	1.29

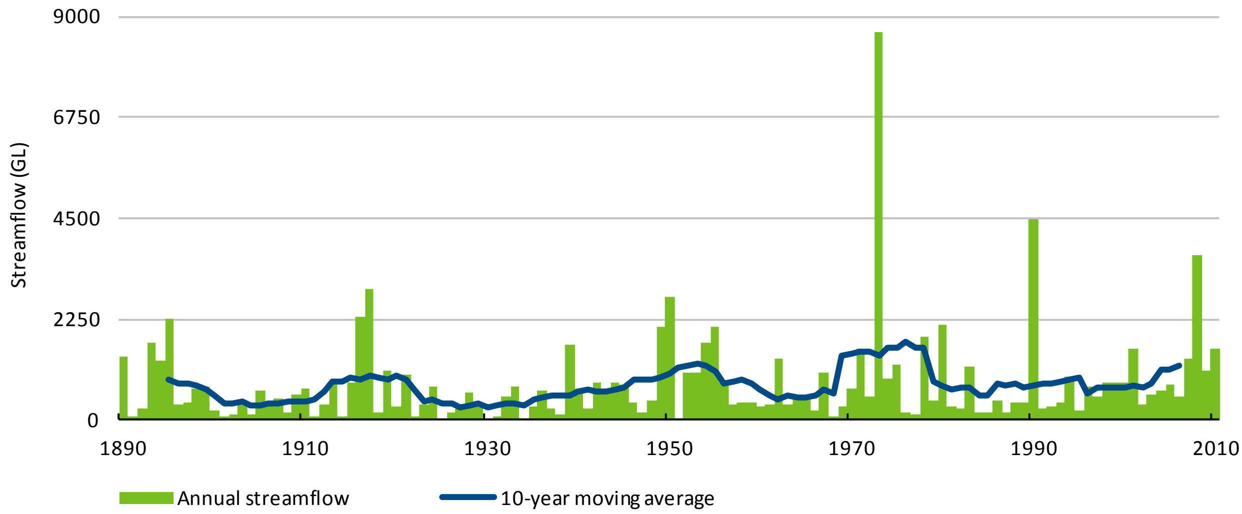


Figure 8.7 Annual streamflow on the Gilbert River at the Green Hills dam site under Scenario A
Blue line indicates the 10-year moving average.

Table 8.2 Parameters for Green Hills dam

DAM TYPE	CATCHMENT AREA (km^2)	SPILLWAY HEIGHT (m)	CAPACITY (GL)	FULL SUPPLY LEVEL (mAHD)	ANNUAL WATER YIELD* (GL)	COST** ($ million)	UNIT COST*** ($/ML)
Roller compacted concrete	8310	20	227	253	172	$335	1950

*85% annual time-based reliability using a perennial demand pattern for the baseline model under Scenario A. This is water yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These water yield values do not take into account downstream existing entitlement holders or environmental considerations.
**Likely cost range is –10 to +30%. Price includes saddle dams. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher.
*** This is the unit cost of annual water yield and is calculated as the capital cost divided by the water yield at 85% annual time reliability.

The spillway height of the dam at the Green Hills upstream site is 20 m, which was deemed to be the optimal height without excessively large saddle dam requirements. The Green Hills dam would comprise a roller compacted concrete (RCC) main dam and four small saddle dams, and would be situated on the Gilbert River about 20 km upstream of the potential irrigation development and 60 km upstream of where the Gulf Development Road crosses the Gilbert River. The Green Hills RCC main dam is likely to cost between $300 million and $435 million (Table 8.2), according to a preliminary desktop estimate (Petheram et al. 2013).

8.5.2 CONFIGURATION AND COSTS FOR WATER SUPPLY AND IRRIGATION

Configuration for water supply irrigation development

Under this potential configuration, water would be released from the Green Hills dam to a re-regulating structure (sheet-piling weir) 20 km downstream of the dam. The re-regulating structure allows for more efficient releases from the dam at key times required by irrigators, thereby reducing the transmission losses normally involved in supplemented river systems. The width of the river adjacent to the irrigation development (~325 m) means that constructing a sheet-piling weir would be challenging and expensive.

Water would be pumped from behind the weir in the river (assuming a 15-m head requirement) into an open distribution channel on the east bank. This channel would need to be lined because of the sandy soils. The potential irrigation development is situated 2 km from the river, due to the presence of marginally suitable land closer to the river. This enables a 2-km wide riparian zone to be maintained between the irrigation development and the river.

It is assumed that irrigation water would be distributed within farm (i.e. from the farm gate to the field) using open, lined channels. On-farm storages are sometimes used to improve the efficiency with which water can be supplied from the farm gate to the field. It is assumed that, for this development, there would be minimal need for on-farm storage, due to the relatively close proximity of the Green Hills dam to the proposed irrigation area. Once at the field, water would be applied using modern spray-irrigation systems capable of delivering peak water requirements to the crop at periods of high evaporative demand. Overhead sprinklers are used to optimise irrigation efficiency and minimise accessions to groundwater, which could cause watertable levels to rise. Well-managed spray irrigation generates very little tailwater runoff (i.e. water leaving the field following an irrigation event), except during large rainfall events immediately after irrigation on full soil profiles.

Table 8.3 lists the conveyance efficiency assumptions used in this analysis. In total, the conveyance and application efficiency from the storage to the crop is 68%. These values are likely to represent best practice.

Table 8.3 Assumed conveyance efficiencies for the irrigation development associated with the Green Hills dam

COMPONENT	EFFICIENCY (%)	COMMENT
River conveyance efficiency	85%	Distance between dam and sheet piling re-regulating structure is about 20 km. This is likely to be a generous assumption.
Channel distribution efficiency	95%	Representative of evaporation loss from re-regulation structure and channel loss between river and farm gate. Channel is lined due to sandy soils
On-farm distribution efficiency	99%	Representative of on-farm evaporation and seepage loss from farm gate to edge of field. Assumed lined channel*
Field application efficiency (spray)	85%	Assumed majority of loss goes to deep drainage
Overall efficiency	68%	

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

Cost of water supply and irrigation development

Irrigation development involves a wide range of capital, operation and maintenance costs. Some of these are incurred at the scheme scale, some at farm scale, and others at both. Scheme-scale costs are those associated with major infrastructure (e.g. dams, channels, roads, earthworks), approvals (e.g. environmental impact statements) and delivery of water to the irrigation development (e.g. pumps). Farm-scale costs are those associated with irrigation systems and farm equipment.

The Gulf Development Road would pass through the Green Hills dam irrigation development, and, consequently, additional access road requirements are minimal.

Indicative capital, operation and maintenance costs associated with the irrigation development are provided in Table 8.4. Costs of infrastructure that are independent of the size of the irrigation development (e.g. dam, weirs, main access roads) are listed as a fixed price. Costs directly linked to the size of the irrigation development are expressed as a cost per hectare and per megalitre. This enables irrigation developments of different sizes to be quickly evaluated (see Section 2.2). These costs were obtained from information presented in chapters 4 and 5.

Table 8.4 Scheme-scale and farm-scale costs for the irrigation development associated with the Green Hills dam

ITEM		LIFE SPAN (y)	UNIT COST ($)	UNIT	OPERATIONAL AND MAINTENANCE COST (% capital costs)	COMMENT
Scheme-scale costs: capital, operational and maintenance	Large dams	100	$335,000,000	*	0.4%	All costs associated with dam, including access roads, environmental impact statements, legal, contingency
	Weir	40	$55,000,000	*	2%	325 m wide × 3 m high sheet-piling weir
	Access roads	100	$1,580,000	*	1%	5 km of additional all-weather access roads
	Main supply channel	40	$11,790,000	*	1%	Includes structures and overheads (lined)
	Area works	40	$7,740	ha	1%	Includes roads (life span 100 y) earthworks, structures, overheads, contingency and corporate profit
	Pump capital cost (river to channel)	15	$250	ha	2%	
	Pump energy cost (river to channel)	na	$24	ML	na	Assuming 15-m head requirement and pump operated on diesel
Scheme-scale costs: approvals	Area works approvals	na	$6,000,000		na	Includes environmental impact statements, Native Title Claims and cultural heritage
	Legal	na	$1,000,000		na	
Farm-scale costs: capital	Irrigation system (spray)	15	$4,000	ha	**	Includes land development costs, equipment, pumps
	Farm equipment	15	$1,160	ha	**	This refers to equipment not included in the irrigation system (e.g. vehicles, cultivation equipment)
Farm-scale costs: operational	Overheads		$660	ha	na	Includes maintenance costs, employee costs, land lease and other additional business overheads

na = not applicable
* Indicates fixed cost independent of the size of the irrigation development.
** Operational and maintenance costs are captured in farm-scale cost overheads.

Critical infrastructure

In the absence of hard infrastructure (such as roads and energy supplies) and community infrastructure (such as schools and housing), required to support large irrigation developments and the people who work there, investment in infrastructure will need to be made. Table 8.5 summarises critical infrastructure in the Green Hills area. While the infrastructure of the Georgetown area may be able to sustain small irrigation developments, moderate to large developments would require addition investment.

Table 8.5 Critical infrastructure in the Green Hills area

ITEM		COMMENT
Community infrastructure	General	The main town serving the irrigation developments is Georgetown, which currently has fewer than 300 residents. Indicative estimates of labour for crop production have been proposed as 6 full-time employees per 1000 ha, which would correspond to 72 employees for a 12,000-ha irrigation development. Whether this increases the population by this number will depend on the extent to which the town's existing population can meet labour requirements.
	Schools	A primary school in Georgetown currently has 47 enrolments, and hard infrastructure (classrooms) can be added if needed.* Additional staffing needs, if any, would be expected to depend on the number and composition of new enrolments.
	Hospital	Georgetown does not have a hospital. It has a clinic, and the area is serviced by a flying doctor. Facilities could require expansion under population growth.*
	Housing	Georgetown currently has a supply of unoccupied dwellings; however, the quality of available housing, and whether new construction is required, would require further assessment.
	Water	Water for the town is sourced from bedsands of the Etheridge River. It is treated and then gravity-fed to the town. There are concerns about whether the bedsand aquifers could support a larger population. The Etheridge Shire Council has commissioned the construction of a small dam at Forsyth to secure town water supplies. However, the dam can only service small increases in demand and would be unlikely to be sufficient if the population reached 2500 residents. There is no sewerage treatment plant in Georgetown – a septic system is used. If there was a large increase in population, a sewerage treatment plant would needed.*
	Other	Georgetown is close to rivers and the town centre is vulnerable to flooding. Further commercial and residential development would be more appropriately sited a few kilometres west of the current town centre.*
Hard infrastructure	Roads	Gravel roads within Etheridge Shire are likely to require upgrading, depending on traffic flow generated from on-farm labour, suppliers, etc., as well as heavier vehicles (e.g. light trucks).*
	Rail	There is only a tourist train to Einasleigh.
	Energy	The electricity network is maintained by Ergon Energy. This area is serviced by feeders from the Georgetown 66kV zone substation. The projected maximum demand growth (9.4 MVA in 2020) is significantly less than the rated capacity (44 MVA). However, depending on location of the facilities, some infrastructure upgrade to single-wire earth return may be required. Irrigators will need to use diesel for pumping, which is more expensive than electricity.*
	Ports/depots	Peanuts can be delivered to the Atherton Tablelands for processing. The nearest gin is at Emerald. Sorghum (grain) can be delivered to the Atherton Tablelands for local consumption by the poultry industry.** Forage can be sold locally or at other regional locations.
Processing infrastructure	Peanuts	Peanut-processing facilities are located on the Atherton Tablelands, which is a major peanut production area.
	Cotton	The nearest cotton gin is currently in Emerald, approximately 950 km from Georgetown. Transport costs are estimated to be approximately $455/t (~$100/bale), which impacts considerably on the cotton gross margin. A closer cotton gin could considerably improve cotton gross margins.

*Sourced from discussions with elected members and staff of Etheridge Shire Council.
** Greg Mason (DAFF, pers. comm.).

8.5.3 APPLIED IRRIGATION WATER, CROP YIELD AND PRODUCTION RISKS

Overview

Since the mid-1990s, cotton research and commercial-scale test farming on crops from near Broome, Western Australia; the Ord River, Western Australia; Katherine, Northern Territory; and the Burdekin, Queensland, have delivered sustainable production systems that can permit the re-introduction of cotton to the Australian tropics. The biotic risk due to insect pests (e.g. *Helicoverpa armigera* and *Bemisia tabaci*) and climate limitations (radiation, intense rainfall, temperature extremes) have been minimised while yields equivalent to southern Australia have been produced (Yeates et al., 2013). Genetically modified cotton has been a key component of these systems, because it made integrated pest management systems easy to implement, which resulted in significant savings in insecticide and herbicide use, and improved tillage management. However, profitable rotation crops for cotton are essential to manage weeds, diseases and pests, and to provide alternative income in times of low prices.

Peanuts have been successfully grown on the lighter alluvial soils along the Gilbert River in recent years. Peanuts sown in rotation with cotton and winter forage are one of a number of economically attractive options for farmers with access to water for irrigation. Dry-season peanuts sown on a full soil profile in March and April, and grown into the cooler winter months have much higher yields than early-sown wet-season crops. Depending on the time of sowing, crops mature during the spring (150 to 180 days after sowing), and provide suitable cover and soil conditions for cotton sown in early January of the following year.

If sown in early August under irrigation, suitable forage crops such as sweet sorghum or forage millets would provide a number of forage cuts, before returning to a peanut crop in April of the next year. The incorporation of peanuts and fodder into a rotation with cotton complements growing season and integrated pest management requirements (see companion technical report about agricultural production (Webster et al., 2013)).

Under this rotation there would be up to 6000 ha planted to cotton each year.

Water use and crop yield

Applied irrigation water and crop yield for cotton, peanuts and sorghum (forage) were simulated using the Agricultural Production Systems Simulator (APSIM) crop model and a soil representative of the Gilbert irrigation area. Figure 8.8 shows the relationship between irrigation water and crop yield, assuming perfect irrigation timing (i.e. no losses).

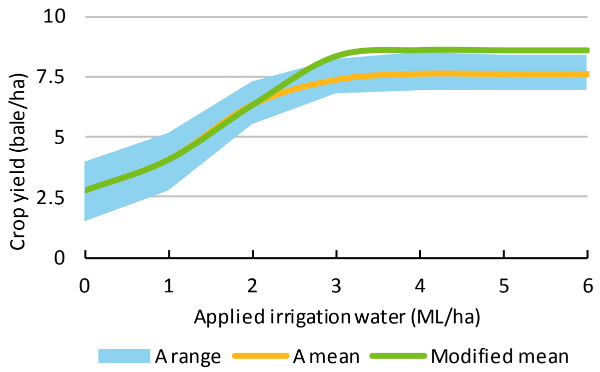
Recent cotton research from the Burdekin catchment (Yeates et al., 2014) indicates that the APSIM model is under predicting cotton yield in the Gilbert catchment at the higher applied irrigation water values presented in Figure 8.8a. This is likely to be due to the difficulty modelling the interaction between temperature, radiation and soil water for the sandy soils in the Gilbert catchment. Based on field analysis presented in Yeates et al. 2014, the APSIM generated cotton yields are adjusted as demonstrated by the modified mean in Figure 8.8a. This better matches recent commercially grown cotton yields in the Burdekin catchment. However, the climate in the Georgetown area is more favourable than the Burdekin during the critical months of cotton bud development and the yields presented in Figure 8.8a may still slightly underestimate the production potential. Further research is required on the potential production of cotton in the Gilbert catchment.

As shown in Figure 8.8a January-planted cotton yields a mean of about 8.5 bales/ha with a mean water use of about 3 ML/ha. Yield reductions are more or less linear with decreasing water below the maximum. The mean irrigation requirement is low because the crop is grown largely during the wet season and has access to post–wet season stored soil water.

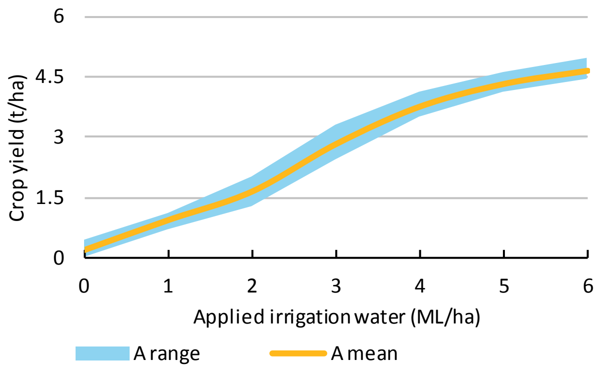
For peanuts sown in March or April, the yield response to water application is more or less linear because there is a low probability of in-season rainfall or access to significant stored soil water. The response of sorghum (forage) to water application is curvilinear because, like cotton, it will rely on irrigation for only the dry (August to perhaps November) period of its growing window, which is August to March. For each crop, the slope of the rising part of the curve provides an insight into the relative response of the crop to irrigation, and could be used to guide decisions about which crops and which areas of crop should preferentially receive irrigation water in the event that it is limiting.

The APSIM results presented in Figure 8.8 are potential yields. Actual yields would be expected to be lower for a range of reasons, including, management practice, the incidence of pests and diseases, and other production risks.

(a)



(b)



(c)

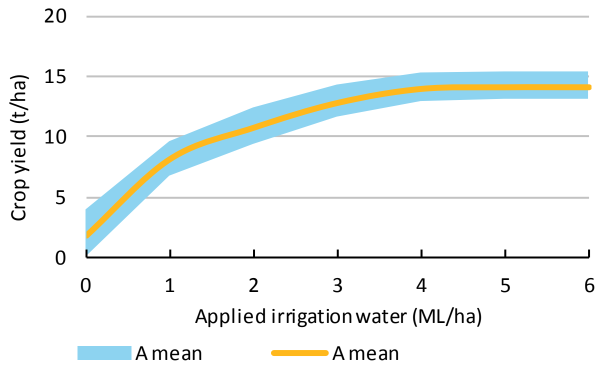


Figure 8.8 Crop yield versus applied irrigation water under Scenario A for (a) cotton, (b) peanuts and (c) sorghum (forage)

Assumes perfect timing of irrigation (i.e. no losses). Representative of the production potential (i.e. assumes no water application losses, nutrient limitations or pest damage). Scenario A is the historical climate (1890 to 2011). The range is the 20th to 80th percentile exceedance.

Production risks

It is important to recognise that actual on-farm crop yields are highly dependent on the irrigators 'management skill' –which determines whether farm decisions and actions occur at the best time. The challenges associated with the relative lack of cropping experience in the Assessment area should not be underestimated. Until a pool of expertise develops over several years, with an increasing ability to anticipate challenges such as pest and disease pressures, actual crop yields would be expected to be significantly lower than potential yields. The difference between actual and potential crop yields, often referred to as the 'yield gap', usually closes slowly over time, and this needs to be factored into individual enterprise and regional development plans.

For cotton, the recent experience in the Lower Burdekin has shown wet-season sown cotton is unlikely to succeed using production practices from southern Australia. A key challenge then is managing the crop recovery when sunshine returns following periods of cloudy or wet conditions during flowering. Fortunately, many of the production practices developed for the Burdekin for managing cotton in wet-season conditions (Grundy et al., 2012) appear to be transferable to the Gilbert River. This knowledge should at least provide some 'cheap experience' for new growers.

8.6 Financial analysis

This section addresses crop yields, crop gross margins and financial analysis at both farm and scheme scale.

This analysis assumes that the whole scheme is funded and operated by a single developer who incurs all of the costs and receives all of the benefits of development. The question asked is: are the projected revenues sufficient to cover all expenditures? The strong possibility of different funding and operation models is recognised, but is beyond the scope of this case study.

The farm-scale analysis considers the net benefits after only farm-scale costs are deducted from gross margins. This analysis assumes that the investor purchases irrigation water from a third-party scheme water supplier who bears the scheme's capital and operating costs. Water prices are initially set at zero, but the farm-scale investor's capacity to pay for water is also calculated. This provides an estimate of the extent to which a scheme developer may recoup operation, maintenance or capital costs through water charges.

All financial analyses in this section are reported in 30-year windows, as this was the selected investment time frame (see the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013) for a discussion on the choice of investment planning period). Using the 121 years of historical data, the total number of 30-year windows is 92. For example, the first 30-year window is 1891 to 1920, and values are calculated for this window. The second window is 1892 to 1921, and a second set of values is calculated for this window. This sampling – and subsequent calculating – was repeated 92 times, with the final window corresponding to 1981 to 2011. The median value from calculations for each of the 92 windows is presented. For example, where a mean value is calculated for each of the 30-year windows, the median 30-year mean (M30M) is reported. A straight-line depreciation approach was used to calculate the residual value of long-life infrastructure (i.e. infrastructure with a service life of more than 30 years). This is a generous assumption compared to the alternative, which is to assume that the infrastructure has no value at the end of the investment period.

Two commonly used terms in this section are 'scheme area' and 'crop area decision'. Scheme area refers to the size of the irrigation development and represents the maximum area that can be planted in any one year. Crop area decision is an annual crop water allocation (e.g. 3 ML/ha) and is used to explore the profitability of different levels of combined physical and financial risk. When cotton is sown in January, the area planted is nominally equal to the water in the storage minus conveyance and application losses, divided by the crop area decision. The actual amount of water needed by the crop rotation will be determined by the crop water requirements and climate during the growing season. It is independent of the crop area decision. The greater the divergence of the crop area decision below the actual crop water requirement, the higher the risk of crop failure. The greater the divergence of the crop area decision above the actual crop water requirement, the more water is stored in the reservoir for the following year. In this simulation, water is preferentially supplied to cotton and peanuts because these generally achieve higher returns than sorghum (forage).

In this case study crop area decision refers to an allocation of water to all three crops in the rotation, rather than a single crop. For example, a crop area decision of 6 ML/ha means that 1 ha of cotton will be sown for every 6 ML of available water (after losses) at cotton sowing time. While the crop area decision is taken at cotton sowing time, it is used for all crops planted that year.

Two financial analyses are presented. The first analysis (in Section 8.6.1) explores an appropriate scheme area for the irrigation development and an appropriate level of (farmer) risk in terms of area planted each year, given knowledge of the water storage at sowing. The results are presented as contour plots of scheme area and crop area decision. It is assumed that land is not a constraint and that all capital costs are incurred in the first year.

In the second analysis (in Section 8.6.2), a single combination of scheme area and crop area decision is selected, based on scheme- or farm-scale profitability, minimum size to support additional processing infrastructure (such as an cotton gin in this case study) or the availability of suitable land.

8.6.1 DIFFERENT COMBINATIONS OF SCHEME AREA AND CROP AREA DECISION

In this section information is presented on how much water is applied to the crop, reservoir behaviour and change to the downstream median flow for different combinations of scheme-area and crop area decision. Information is then presented on crop yield and gross margins and NPV and IRR at both the scheme-scale and farm-scale.

Water supply, reservoir characteristics and changes in downstream flow

Figure 8.9 presents information on mean annual applied irrigation water applied to the cotton, peanut and sorghum (forage) crops. These figures were generated by calculating this value for different combinations of scheme area and crop area decision, and then presenting the information as a contour plot. The different shades of blue and red indicate different amounts of applied irrigation water, indicated by the legend on the right side of the plot. For example in Figure 8.9a, for a scheme area of 20,000 ha and a crop area decision of 10 ML/ha the mean annual applied irrigation is about 30,000 ML. Many figures in this section are of this form.

The larger the scheme area and the lower the crop area decision, the larger the total volume of water supplied to and used by the irrigation development (Figure 8.9a,c,e), but the smaller the amount of water applied per hectare of planted area (Figure 8.9b,d,f). Figure 8.9 shows that considerably more water is supplied to the cotton and peanut crops, and that the sorghum (forage) receives the remaining water.

The requirement to supply all three crops with optimal levels of irrigation, with respect to specific crop yields, equates to roughly 12 ML/ha (Figure 8.8). The minimum crop area decisions utilised in this investigation are far lower than this value since the Green Hills dam continues to fill after the crop area decision time (cotton sowing in January). In effect, the lower crop area decision values are accepting more risk that more inflows to the Green Hills dam will occur after cotton sowing.

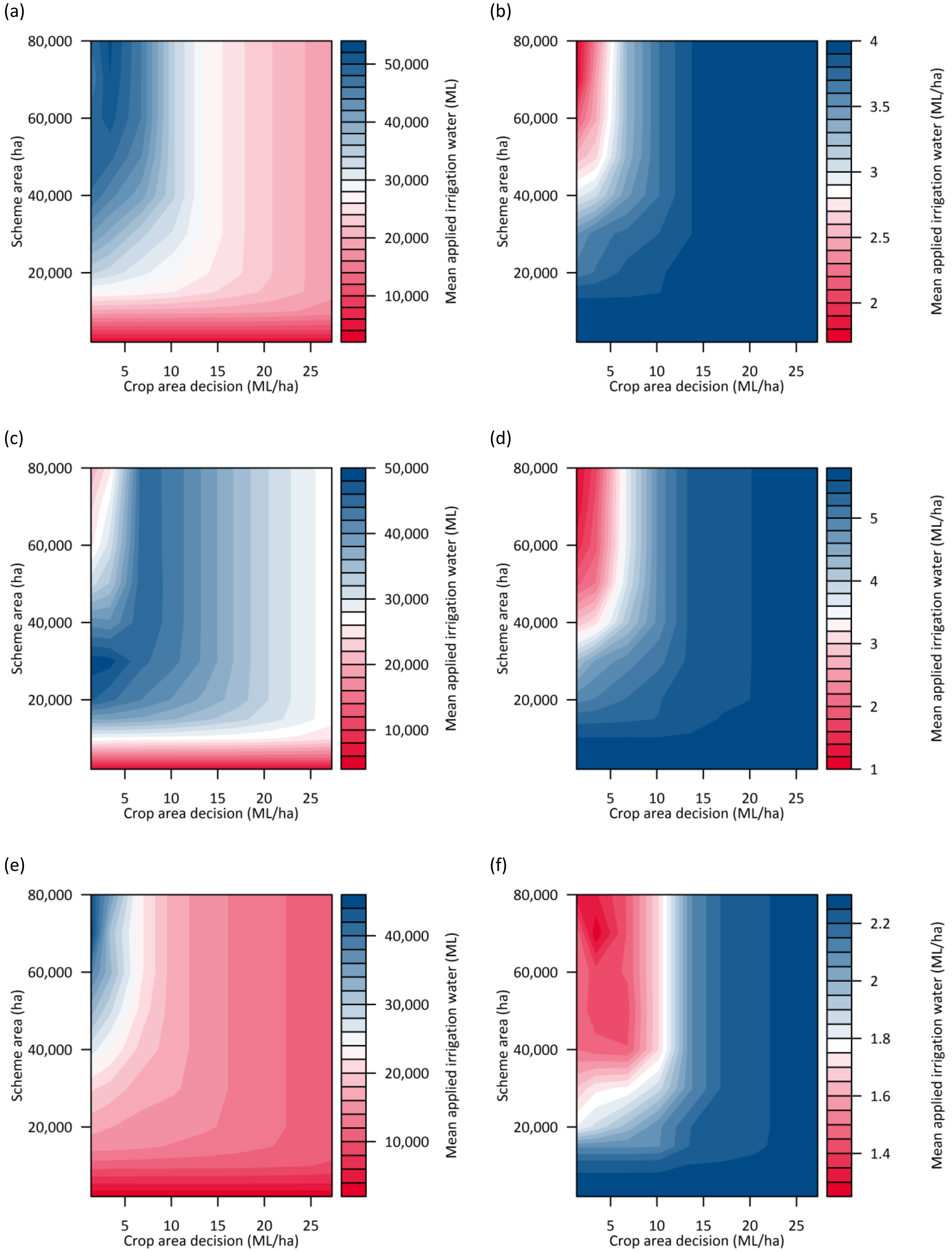


Figure 8.9 Mean annual applied irrigation water supplied to the field in (a) cotton, (c) peanuts and (e) sorghum (forage) in ML, and (b) cotton, (d) peanuts and (f) sorghum (forage) in ML/ha, under Scenario B for the irrigation development associated with the Green Hills dam

Results are presented as a function of scheme area and crop area decision. Applied irrigation water is the water supplied from the dam, with the losses from river conveyance, channel distribution and field application removed. Scenario B is the historical climate (1890 to 2011) with irrigation development.

Figure 8.10a illustrates the median irrigation water applied to the field, and Figure 8.10b illustrates the percentage of years that the entire scheme area is planted for different scheme area and crop area decision combinations. Lower crop area decisions result in the irrigation development being more fully planted in more years.

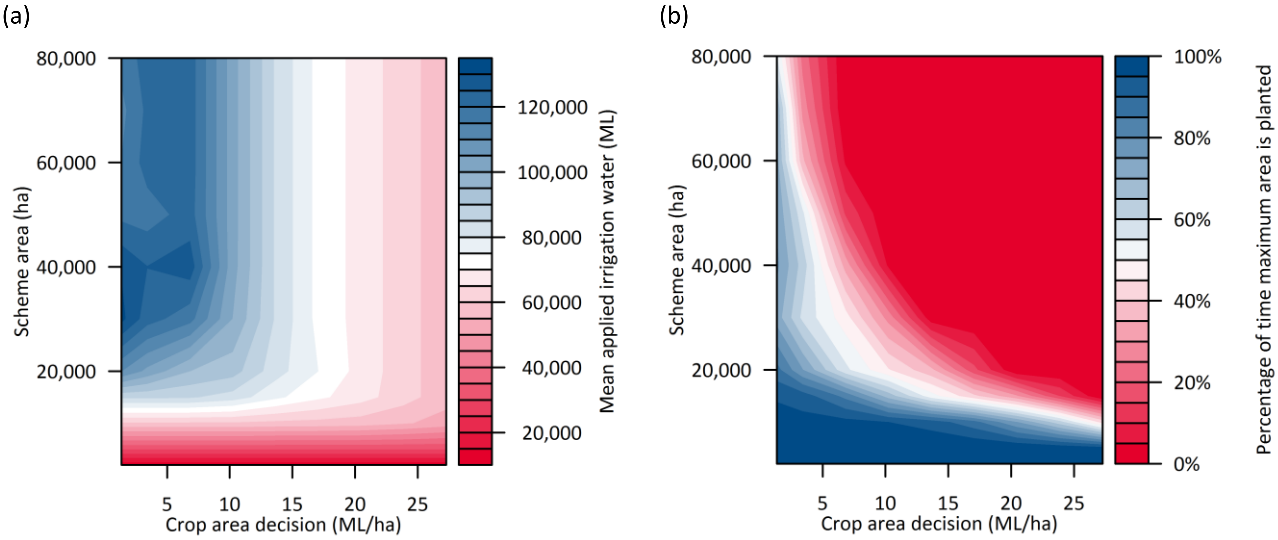


Figure 8.10 (a) Median annual applied irrigation water supplied to the field and (b) percentage of years that the maximum area is planted under Scenario B for the irrigation development associated with the Green Hills dam
Results are presented as a function of scheme area and crop area decision. Applied irrigation water is the water supplied from the dam, with the losses from river conveyance, channel distribution and field application removed. Scenario B is the historical climate (1890 to 2011) with irrigation development.

Figure 8.11a presents the ratio of water lost to evaporation to water supplied at the dam wall. In low-scheme areas, water is not fully used, and some water is lost to evaporation when water is carried over into the following year. In high scheme areas and low crop area decisions, the water evaporation:supply ratio is low because all the water in the reservoir is used immediately (i.e. a large area is planted, which may only receive water from one or two irrigation events before the reservoir is empty). Figure 8.11b shows the percentage of time that the Green Hills dam reservoir is at less than 20% of its full supply level (FSL) volume. This provides an indication of the recreational amenity of the reservoir. For example, for scheme areas less than 20,000 ha, the reservoir is more than 20% full more than 80% of the time. Twenty per cent of the FSL volume corresponds to a depth of about 13 m at the dam wall and 32% of the reservoir FSL surface area. Consequently, the recreational amenity of this reservoir is likely to be quite high on the basis that the reservoir will contain a reasonable volume of water for a large proportion of time.

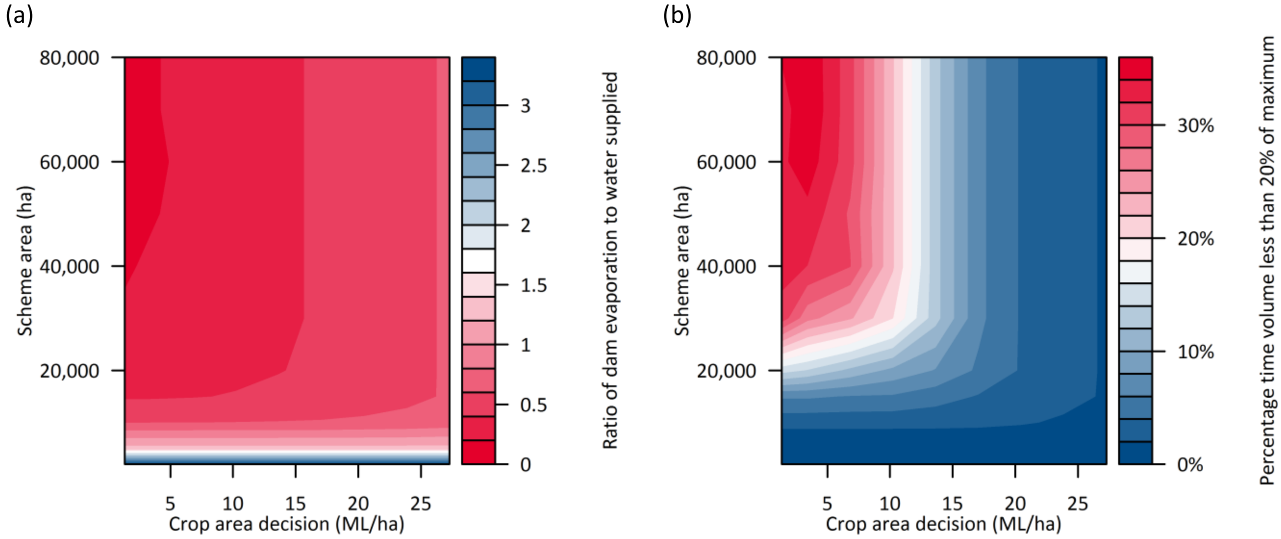


Figure 8.11 (a) Ratio of evaporation from the reservoir to the applied irrigation water and (b) percentage of time the volume of the reservoir is less than 20% of the full supply level volume under Scenario B for the irrigation development associated with the Green Hills dam

Results are presented as a function of scheme area and crop area decision. Applied irrigation water is the water supplied from the dam, with the losses from river conveyance, channel distribution and field application removed. Scenario B is the historical climate (1890 to 2011) with irrigation development.

Figure 8.12 illustrates the median annual streamflow quotient at a streamflow gauging station downstream from the Green Hills dam irrigation development (917001D), and downstream of the confluence of the Gilbert and Einasleigh rivers (917009A). This provides an indication of the extent to which the median annual streamflow may change under irrigation development for different combinations of scheme area and crop area decision. The smaller the number the larger the change in median annual streamflow. For all combinations of scheme area and crop area decision, the median annual streamflow quotient shows that the change in median annual streamflow will be small near the mouth of the Gilbert River. However, the change in median annual streamflow at gauge 917001D ranges from 0.6 to 1, depending on the scheme area and crop area decision. Higher scheme areas and low crop area decisions cause the greatest reduction in median annual streamflow.

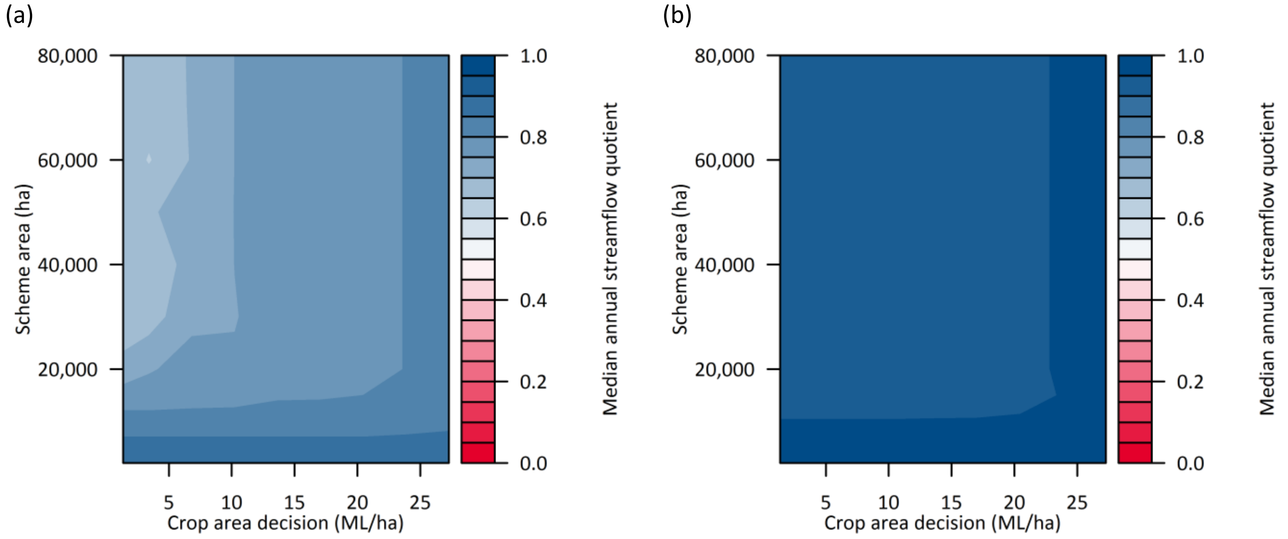


Figure 8.12 Median annual streamflow quotient at (a) gauge 917001D and (b) gauge 917009A for the irrigation development associated with the Green Hills dam
Median annual streamflow quotient is the median annual streamflow under Scenario B divided by the median annual streamflow under Scenario A. Scenario A is the historical climate (1890 to 2011) and current development. Scenario B is the historical climate (1890 to 2011) with irrigation development. Location of streamflow gauging stations shown on Figure 8.2

Crop yield

Larger scheme-scale crop yields are attained for larger scheme areas and smaller crop area decisions. This is because, in the years the reservoir is full or nearly full, the planted area is less constrained by the scheme area. It also occurs because reducing water to the sorghum (forage) crop – for example, by 50% (from the 4 ML/ha full median requirement to 2 ML/ha) – reduces the crop yield by 25% (Figure 8.8). In Figure 8.13b and Figure 8.13d, it can be seen that cotton and peanuts are rarely water stressed for scheme areas of about 12,000 ha and 10,000 ha, respectively. Sorghum, however, is water stressed for most scheme areas and crop area decision combinations. As discussed in Section 8.6, water is preferentially supplied to the cotton and peanut crops over the sorghum (forage).

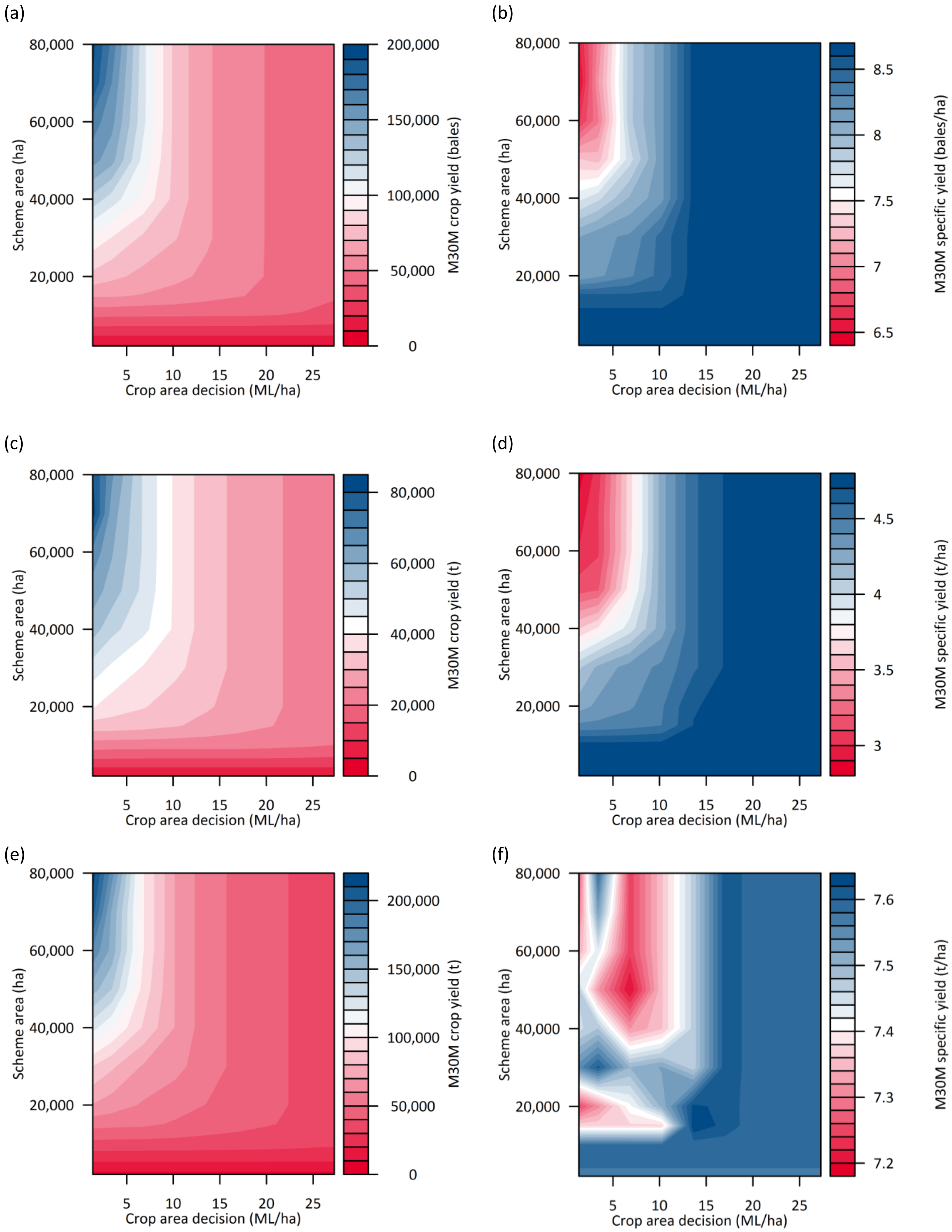


Figure 8.13 (a) Cotton, (c) peanuts and (e) sorghum (forage) median of the 30-year mean (M30M) values for crop yield, and (b) cotton, (d) peanuts and (f) sorghum (forage) M30M values for specific yield, under Scenario B for the irrigation development associated with the Green Hills dam

Results are presented as a function of scheme area and annual crop area decision. Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows in the period from 1890 to 2011.

Crop gross margins

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

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

Water charges are also variable costs when charged on a $/ML basis, but are omitted from the gross margin calculations here (although pumping costs, are included), because water costs are not known. Instead, as part of this financial analysis, farmers' capacity to pay a water charge is determined. The crop gross margin is calculated using simulated crop yield and water use. Table 8.6 to Table 8.8 list the key assumptions in the gross margin calculation for cotton, peanut and sorghum (forage) used in this analysis. For details on crop gross margin calculations, see the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013).

Table 8.6 Key assumptions in the gross margin calculations for cotton under spray irrigation for the irrigation development associated with the Green Hills dam

KEY ASSUMPTIONS	UNIT	VALUE	COMMENTS
Price	$/bale	$450, $600	Default and high price for processed cotton lint
Variable costs			
Freight to gin	$/t/km	$42, $242, $455	Cost of transporting unprocessed cotton to Georgetown, Charters Towers and Emerald, respectively assuming a bale weighs 227 kg
Pumping cost	$/ML	$58.90	Spray irrigation, diesel
Other variable costs	$/ha	$1481	Details provided in Brennan McKellar et al. (2013). This is approximate, with some costs depending on yield

Table 8.7 Key assumptions in the gross margin calculations for peanuts under spray irrigation for the irrigation development associated with the Green Hills dam

KEY ASSUMPTIONS	UNIT	VALUE	COMMENTS
Price	$/t	$850, $900	Default and high price for peanuts
Variable costs			
Freight	$/t	$25	To Atherton Tablelands
Pumping cost	$/ML	$58.90	Spray irrigation, diesel
Other variable costs	$/ha	$2077	Details from in Brennan McKellar et al. (2013). This is approximate, with some costs depending on yield

Table 8.8 Key assumptions in the gross margin calculations for sorghum (forage) under spray irrigation for the irrigation development associated with the Green Hills dam

KEY ASSUMPTIONS	UNIT	VALUE	COMMENTS
Price	$/t hay	$150, $200	Default and high price for sorghum (forage)
Variable costs			
Pumping cost	$/ML	$58.90	Spray irrigation, diesel
Other variable costs	$/ha	$1113	Details provided in Brennan McKellar et al. (2013). This is approximate, with some costs depending on yield

Figure 8.14 indicates that higher M30M gross margins occur for larger scheme areas and smaller crop area decisions. The reason larger scheme-scale gross margins occur at the smallest crop area decision is that when cotton is planted in January, the Green Hill dam reservoir is often not yet filled by the wet-season rain and inflows.

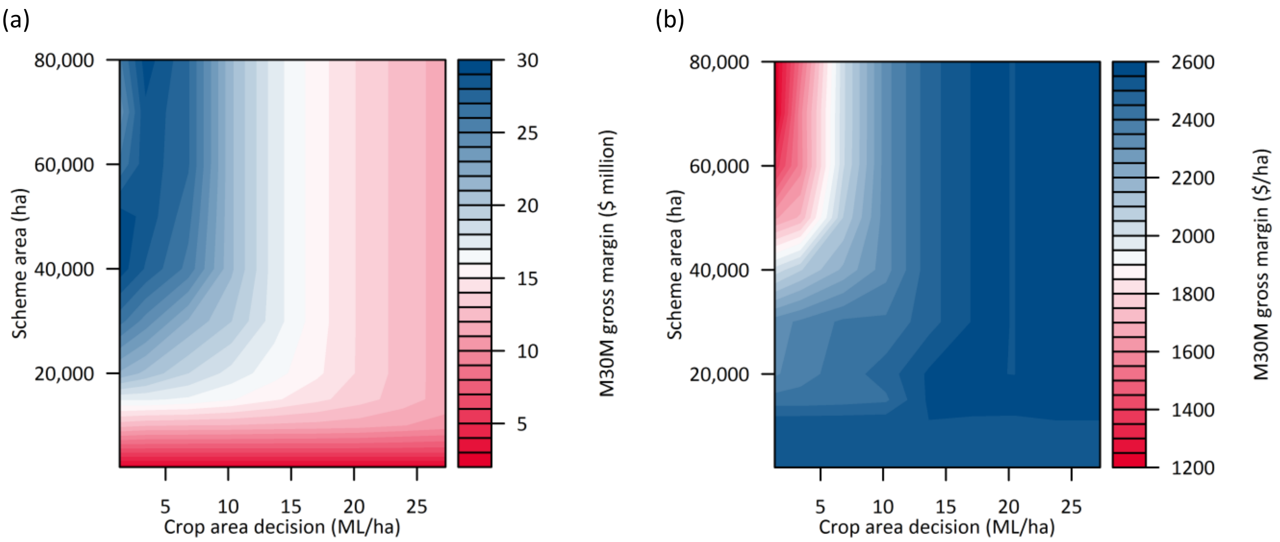


Figure 8.14 (a) Median of the 30-year mean (M30M) values for gross margin and (b) M30M values for gross margin per hectare under Scenario B for the irrigation development associated with the Green Hills dam
Results are presented as a function of scheme area and annual crop area decision. Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows within the period from 1890 to 2011.

Whole-of-scheme net present value

As a new capital project requiring investment in equipment and infrastructure, the irrigation development is assessed for the costs expended and benefits incurred during a 30-year project life. When the costs over this period are subtracted from the benefits to give a net benefit stream, a discount rate of 7% is applied to yield a NPV for the development. A zero or positive NPV value indicates that the scheme is profitable at the specified discount rate.

The whole-of-scheme NPV calculation takes into consideration the scheme- and farm-scale capital, operation and maintenance costs, and scheme-scale gross margins. Asset replacement and residual values are considered within the 30-year project period. Further details on the framework for discounted cash-flow financial analysis and assumptions are presented in the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013).The scheme-scale NPV is negative under all combinations of scheme area and crop area decision, because the revenue generated from the scheme (total crop gross margins) does not offset the capital, operation and maintenance costs of the scheme-scale and on-farm infrastructure during the life of the investment (Figure 8.15a). Under the conditions of this case study, losses are minimised by not undertaking an irrigation development.

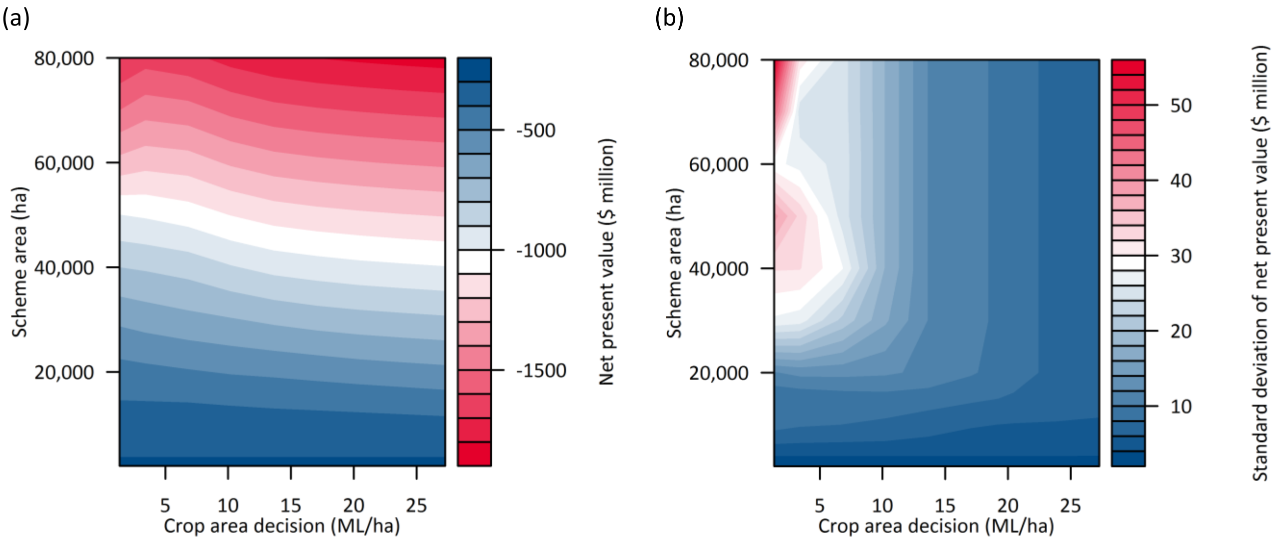


Figure 8.15 (a) Median of the 30-year net present values and (b) standard deviation of the 30-year net present values under Scenario B for the irrigation development associated with the Green Hills dam

Results are presented as a function of scheme area and annual crop area decision. Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows in the period 1890 to 2011. The median and the standard deviation of the mean values for each of the 92 windows are presented.

Farm-scale net present value

A situation may arise involving independent funding and ownership of off-farm (water storage and transmission) and on-farm (land, equipment) development capital. In these circumstances, investment decisions made by irrigators could be confined to consideration of on-farm costs only. For this purpose, the NPV of an on-farm investment is calculated. This calculation considers the capital, annual operation and maintenance (overhead) costs of on-farm infrastructure (Figure 8.16). The capacity to contribute to scheme-scale operation and maintenance costs, and possibly capital costs, through a water price depends on the extent to which the farm-scale NPV is positive.

In this case study, the total crop gross margin is sufficient to cover the capital and overhead costs for the duration of the investment period, for scheme areas less than about 4000 ha.

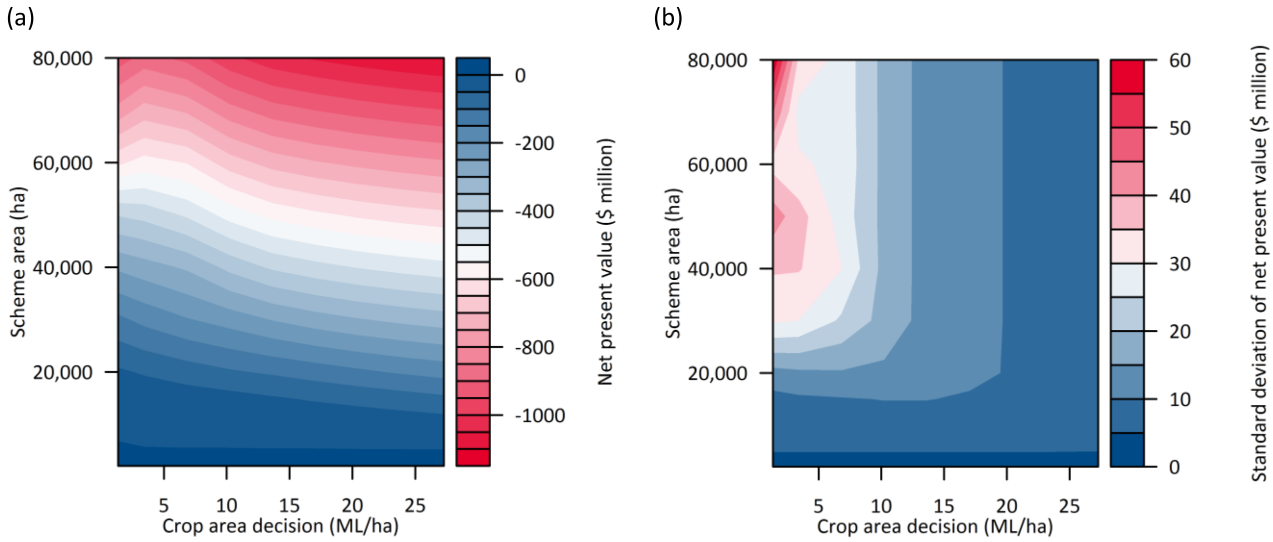


Figure 8.16 (a) Median of the 30-year farm-scale net present values and (b) standard deviation of the 30-year farm-scale net present values under Scenario B for the irrigation development associated with the Green Hills dam
Results are presented as a function of scheme area and annual crop area decision. Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows in the period 1890 to 2011. The median and the standard deviation of the mean values for each of the 92 windows are presented.

8.6.2 DETAILED ANALYSIS FOR A GIVEN SCHEME AREA AND CROP AREA DECISION

To allow more detailed investigation, a scheme area of 12,000 ha and a crop area decision of 4 ML/ha was selected. For this analysis it is assumed there is a cotton gin in Georgetown, unless stated otherwise. Construction costs were staged during the first three years of the 30-year investment period (Table 8.9). This is likely to be a more realistic assumption than presuming that all costs are incurred and full revenue is attained in the first year. Furthermore, in this case study the staging of construction costs is about 7% more profitable than without staging.

Table 8.9 Staging of construction, farm development and crop production

YEAR NUMBER	CONSTRUCTION PROGRAM	FARM DEVELOPMENT	CROP PRODUCTION
1	50% dam costs; 100% approvals and legal costs		
2	50% dam costs; 50% area works costs	50% farm development	
3	50% area works costs	50% farm development	50% revenue
4			100% revenue

Gross margins

Figure 8.17a, Figure 8.18a and Figure 8.19a show time series of annual gross margins ($/ha) for cotton, peanuts and sorghum (forage), respectively, for each year of the 121-year historical climate data and for two prices (Table 8.6). Figure 8.17b, Figure 8.18b and Figure 8.19b show the range, 25th percentile, 50th percentile (median) and 75th percentile values of gross margins for each price. For cotton and peanuts, the range of gross margin values between the 25th and 75th percentile values is small. This is because both of these crops receive their required water in most years. Sorghum, however, has a large range of gross margin values between the 25th and 75th percentile values. This is because, as a lower priority crop, sorghum is water stressed in many years and experiences considerable yield reductions.

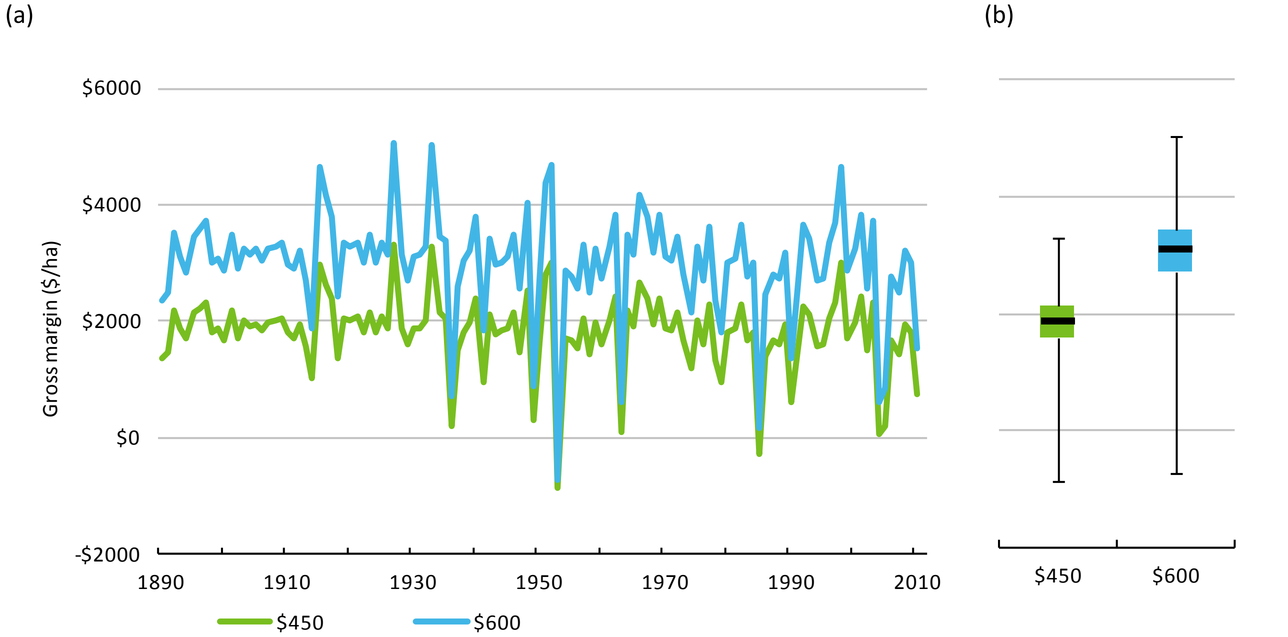


Figure 8.17 Gross margins for cotton under Scenario B for the irrigation development associated with the Green Hills dam, with a scheme area of 12,000 ha and crop area decision of 4 ML/ha: (a) time series and (b) box plot
Scenario B is the historical climate (1890 to 2011) with irrigation development. Results are shown for both the default price for cotton ($450/bale) and the highest price paid in the past 10 years ($600/bale). In (b), the mean for each price is indicated by the black horizontal line and the range is indicated by the black vertical line. The top and bottom of the coloured boxes indicate the 25th and 75th percentile, respectively.

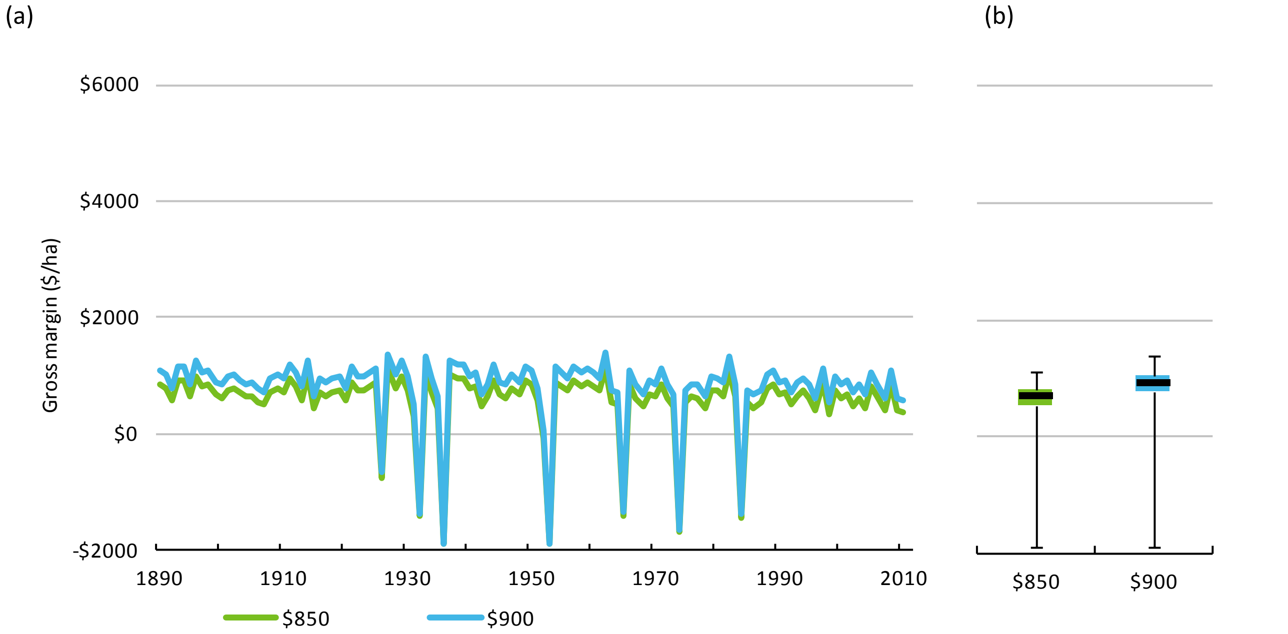


Figure 8.18 Gross margins for peanuts under Scenario B for the irrigation development associated with the Green Hills dam, with a scheme area of 12,000 ha and crop area decision of 4 ML/ha: (a) time series and (b) box plot
Scenario B is the historical climate (1890 to 2011) with irrigation development. Results are shown for both the default price for peanuts ($850/t) and the highest price paid in the past 10 years ($900/t). In (b), the mean for each price is indicated by the black horizontal line and the range is indicated by the black vertical line. The top and bottom of the coloured boxes indicate the 25th and 75th percentile, respectively.

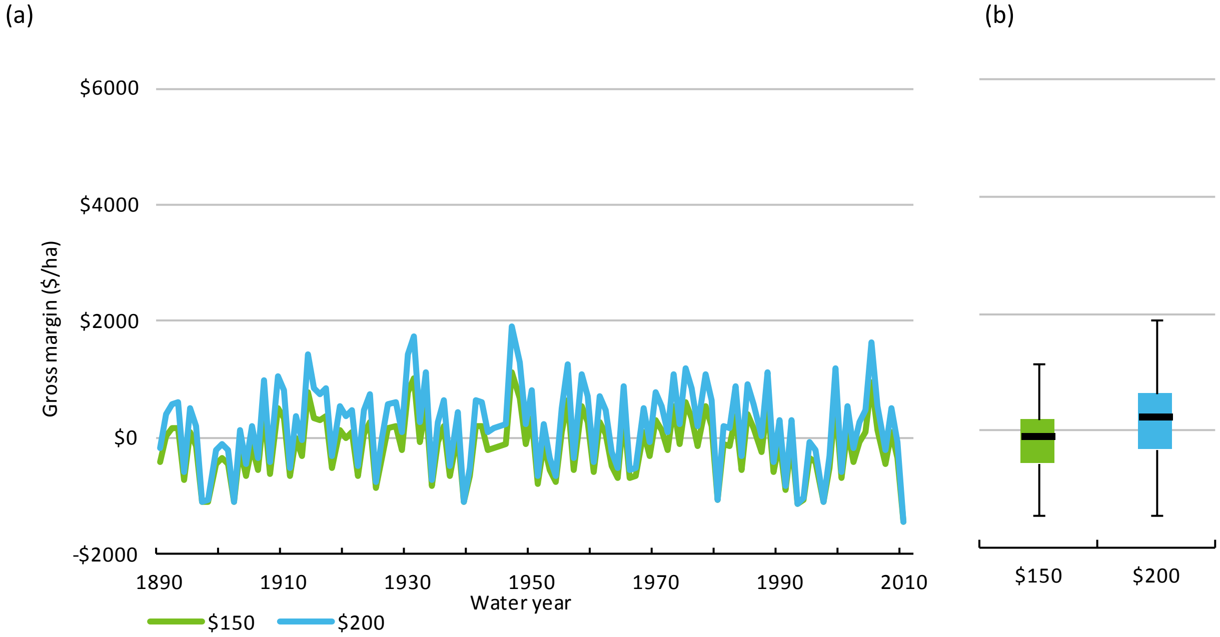


Figure 8.19 Gross margins for sorghum (forage) under Scenario B for the irrigation development associated with the Green Hills dam, with a scheme area of 12,000 ha and crop area decision of 4 ML/ha: (a) time series and (b) box plot
Scenario B is the historical climate (1890 to 2011) with irrigation development. Results are shown for both the default price for sorghum (forage) ($150/t) and the highest price paid in the past 10 years ($200/t). In (b), the mean for each price is indicated by the black horizontal line and the range is indicated by the black vertical line. The top and bottom of the coloured boxes indicate the 25th and 75th percentile, respectively.

Figure 8.20 shows a combined time series of gross margins for cotton, peanuts and sorghum (forage). In all but five years, a positive combined gross margin is achieved, with a combined gross margin exceeding $3500/ha on two occasions.

Variability is a notable feature of this analysis, and this takes on further importance when it is considered that the analysis has been performed with a constant commodity price and that the variability is yield driven in response only to variations in climate and water availability (i.e. through streamflow). In reality, variability in commodity prices and production risks (e.g. pests, disease, flooding, access), combined with yield variability (due to variations in climate and water availability), would increase the modelled variability in gross margins shown in Figure 8.18, Figure 8.19 and Figure 8.20. Figure 8.17a, Figure 8.18a and Figure 8.19a show that, for this selected scheme area and crop area decision, the gross margins for cotton and peanuts are sensitive to price movements, and sorghum (forage) is less so. This is because in many years the yield is reduced and the income does not exceed variable costs.

A range of other factors could also affect the gross margin, such as variability of input, transport or processing costs.

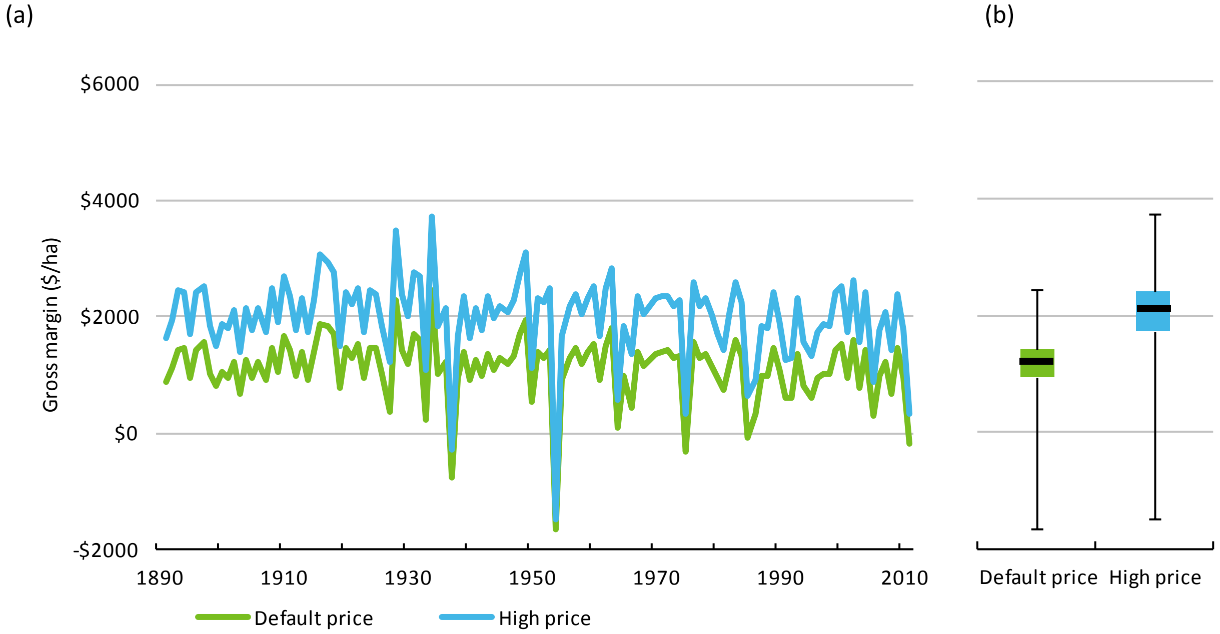


Figure 8.20 Combined gross margins for cotton, peanuts and sorghum (forage) under Scenario B for the irrigation development associated with the Green Hills dam, with a scheme area of 12,000 ha and crop area decision of 4 ML/ha: (a) time series and (b) box plot

Results are shown for the combined gross margin at both default prices and the highest prices paid in the past 10 years for crops shown in Figure 8.19. In (b), the mean for each price is indicated by the black horizontal line and the range is indicated by the black vertical line. The top and bottom of the coloured boxes indicate the 25th and 75th percentile, respectively.

Scheme-scale analysis

Using the 121-year distribution of simulated gross margin outcomes presented in Figure 8.20, it was possible to sample 30-year gross margin windows and calculate the NPV of the income stream after accounting for scheme-scale and on-farm capital and annual operating costs in a 30-year investment planning period. In addition to NPV, internal rate of return (IRR) was calculated. The IRR represents the break-even discount rate — that is, the discount rate that will bring the NPV to zero. A viable investment has an IRR higher than the discount rate.

The purpose of sampling from the 121-year distribution is to show how the overall investment performance is sensitive to the particular set of underlying climate conditions during the 30-year investment period.

The ninety-two 30-year NPV and IRR values are presented in Figure 8.21 as percentage exceedance plots. All of the NPVs are negative (Figure 8.20a), ranging from –$490 million to –$540 million for the default prices for the three crops, and from –$370 million to –$430 million for the high prices. In other words, the cost of the investment exceeds the income during the 30-year investment period for all 92 investment periods. Likewise, in none of the investment periods does the IRR reach a rate that indicates a viable investment for either the default or high price. To generate a positive whole-of-scheme NPV the price of cotton, peanuts and sorghum would need to double over the entire investment period.

The only reason for the difference in the 30-year NPV (and IRR) results is the sampled 30-year window of gross margins. The year-to-year variation in gross margins reflects the climate-driven year-to-year variability in crop yield and water availability. Discounting degrades the value of net benefits the further into the future they are received; and therefore, the timing of high- and low-yielding years can have a notable effect on the NPV and IRR (Section 6.3).

(a) (b)

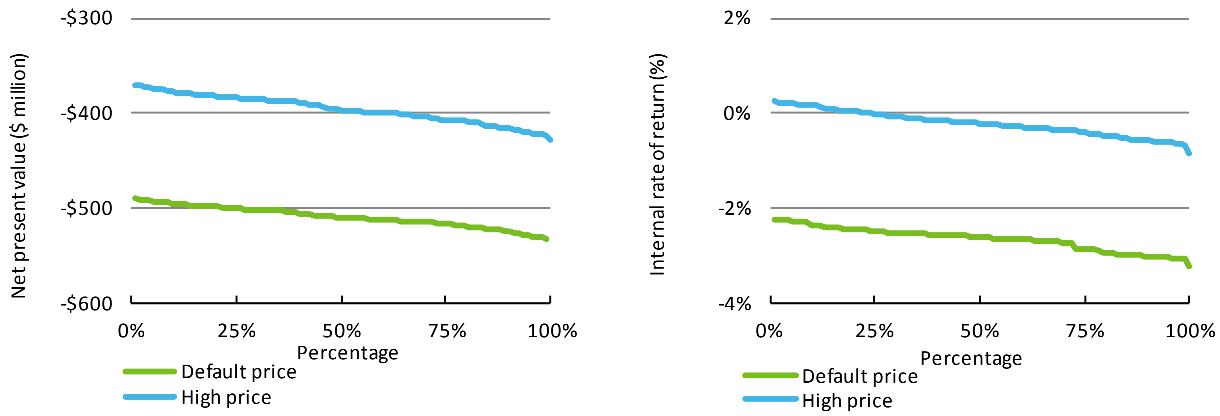


Figure 8.21 Percentage exceedance plots of (a) net present value and (b) internal rate of return under Scenario B for the scheme-scale 12,000-ha irrigation development associated with the Green Hills dam
This financial analysis includes all scheme-scale and farm-scale capital and operating costs, and income from crop gross margins. Values are for a 30-year investment period.

The financial analyses are restricted to the question of whether projected revenues from the sale of cotton, peanuts and sorghum are sufficient to cover the costs of irrigation development and the production of these crops. An alternative investment perspective would produce different financial outcomes – for example, in an integrated growing and cotton gin investment, cotton would be an input in the generation of products that could provide revenues from the cotton gin. No particular investment model is proposed as performing better than another. This case study did not extend to these alternative options, but investigation of alternatives could build on the analyses presented here.

Farm-scale analysis

In the farm-scale analysis, all capital, operation and maintenance costs associated with the scheme-scale infrastructure are excluded. Similar to scheme-scale analyses, financial assessments use 30-year windows.

The results in Figure 8.22a indicate that investment at this scale is unlikely to be viable under the default prices because most NPVs are negative. If the crop prices increased by about 3%, the investment would break even (i.e. an NPV of zero) and high crop prices would result in an IRR of between 18 and 36%.

For the default crop prices and for the median 30-year NPV, the investor would have to be payed $24/ML for irrigation water to break even (i.e. an NPV of zero). At the high crop prices the investor could pay $163/ML or irrigation water and break even. Consequently, there is some capacity for investors to pay a water charge but it is highly sensitive to crop price.

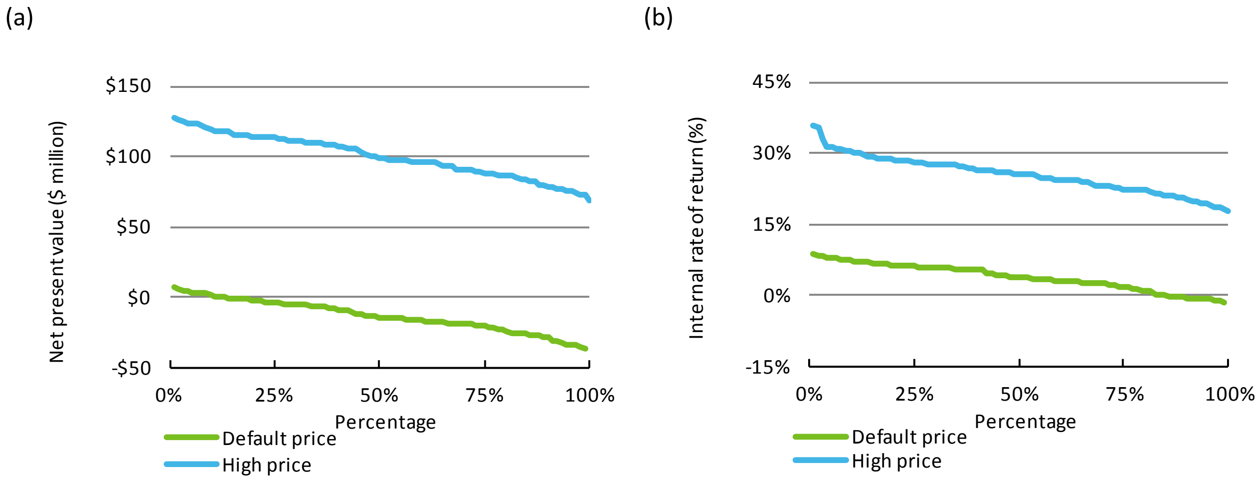


Figure 8.22 Percentage exceedance plots of (a) net present value and (b) internal rate of return under Scenario B for the farm-scale 12,000-ha irrigation development associated with the Green Hills dam
This financial analysis includes all scheme-scale and farm-scale capital and operating costs, and income from crop gross margins. Values are for a 30-year investment period.

The effect of transport to processing facility on the investment

The TRAnsport Network Strategic Investment Tool (McFallan et al., 2013) was used to calculate the cost of transporting cotton from the case study area to Emerald (Brennan McKellar et al., 2013). The impact of transporting unprocessed cotton from the Green Hills dam irrigation development to three alternative gin locations is illustrated in Table 8.10.

Table 8.10 The impact of transporting unprocessed cotton to three alternative locations from the Green Hills dam irrigation development
Summarised from the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013)

GIN LOCATION	DISTANCE (km)	COST ($/t)	M30M COTTON GROSS MARGIN* ($)	MEDIAN 30-YEAR NET PRESENT VALUE ($ million)	CAPACITY TO PAY WATER CHARGE ($/ML)	M30M COTTON GROSS MARGIN* ($)	MEDIAN 30-YEAR NET PRESENT VALUE ($ million)	CAPACITY TO PAY WATER CHARGE ($/ML)
			Default cotton price ($450)			High cotton price ($600)		
Georgetown	50	$42	$1879	–$14	–$24	$3109	$98	$163
Charters Towers	470	$242	$821	–$79	–$131	$2060	$33	$55
Emerald	950	$455	–$278	–$147	–$246	$928	–$35	–$59

M30M = median of 30-year means
* Gross margin includes cost of transporting unprocessed product to the cotton gin.

For the default price, the median 30-year NPV is only positive for the alternative of a gin in Georgetown and a high cotton price. A further advantage to having a gin in Georgetown is that cotton seed contains about 20% crude protein and this can be used as a major component in drought feed when mixed with molasses or grain. Regional processing of cotton could supply local cattle producers with a cost-effective high-quality feed supplement.

At the high crop prices, it is profitable to transport unprocessed cotton to a gin in Charters Towers (Table 8.10). Transporting cotton to a gin in Charters Towers would cost growers in the Lower Burdekin $91.50, a saving of $218.50/t compared to transporting unprocessed cotton to Emerald.

If cotton had to be transported to Charters Towers, it is unlikely that it would be profitable year-on-year because of high transportation costs. Under these circumstances, cotton may only be grown as an opportunistic crop when prices are high enough to more than cover the cost of transport. In these circumstances, it may be a challenge to maintain in the region critical industry skills, equipment and knowledge.

The minimum number of bales required to sustain a cotton gin is very dependent on the reliability of production among seasons. In regions where production is consistent, such as Theodore, Queensland, a gin can be sustained with a median of about 50,000 bales each season. However, for regions with less-reliable production due to variable water supply, a greater production capacity would be required in good water supply seasons to compensate for drought.

The high reliability of water supply from the Green Hills dam means that it is possible that a 12,000-ha irrigation development (of which 6000 ha would be cotton at any one time), producing a mean of 8.5 bales/ha of cotton, could support a local cotton gin at Georgetown. It is also possible for the Green Hills dam to support a larger irrigation development at lower reliability.

8.7 On-site and off-site impacts

Prior to irrigation development, the area would require more intensive assessment of any ecological impacts. This section provides an overview of some of the potential on-site and off-site impacts that may result from the 12,000-ha irrigation development analysed in Section 8.6.2.

8.7.1 RISK OF RISE IN WATERTABLE LEVELS AND SECONDARY SALINISATION

Based on the best available information, a rise in watertable level is thought to be unlikely under well-managed irrigation in the Green Hills dam irrigation development. Furthermore, there is little evidence of salt accumulation in the highly permeable soils and substrata. More detailed investigations would be required to confirm these results.

The rise in groundwater levels (Table 8.11) was assessed using an analytical groundwater model developed as part of the Assessment. The irrigation development is assumed to commence 2 km from the river, allowing for a riparian buffer. Recharge is calculated using annual simulated irrigation and rainfall data under Scenario B (see Jolly et al., 2013). The parameters and their values used in the analytical model are listed in Table 8.11. No field-based measurements of aquifer parameters were available for this part of the Gilbert catchment. The values used in Table 8.11 are considered a likely range, based on bore log information (Section 2.2). For more detail, see the companion technical report about surface water – groundwater connectivity (Jolly et al., 2013).

Table 8.11 Range of parameter values used in analytical groundwater model at Green Hills dam irrigation development

AQUIFER PARAMETER	VALUE	COMMENT
Aquifer thickness	29 m	Nearest bore log information
Depth to groundwater	13 m	
Distance from river	2 km	
Recharge rate	122 or 200 mm/year	Lower and higher estimate. Recharge as a result of irrigation and rainfall
Saturated hydraulic conductivity (K)	1, 10 or 100 m/day	Lower, middle and higher estimate.
Specific yield	0.2	Only has bearing on rate of rise, not maximum rise

It is unlikely that the watertable would rise close to the ground surface under well-managed irrigation in the Green Hills dam irrigation development. This is because alluvial material adjacent to the Gilbert River has highly permeable soil and substrate material and consequently low salt concentrations, as evident from soil, bore log and airborne electromagnetic data. There is also a high likelihood of prior streams and the Gilbert River is relatively incised, meaning it has a relatively high drainage capacity. Consequently, in Figure 8.23, the saturated hydraulic conductivity of the soil and substrate is likely to be closer to 100 m/day than 10 m/day. Under these assumptions, the drainage capacity of the aquifer is higher, which results in a slower rise in the watertable.

Figure 8.23 indicates that, under a saturated hydraulic conductivity of 10 m/day, the ground watertable under the 12,000-ha irrigation development will reach within 2 m of the ground surface in 10 or 25 years, depending on the recharge rate. For the higher estimate of saturated hydraulic conductivity (100 m/day) the drainage capacity of the aquifer is higher, which results in a slower rise in the ground watertable.

Geophysical investigations of the alluvial landscapes adjacent to the Gilbert River shows little indication of salt accumulation, as would be expected from the high permeability of the soil and substrate material, and lack of salt source from surrounding geologies (Munday et al., 2013).

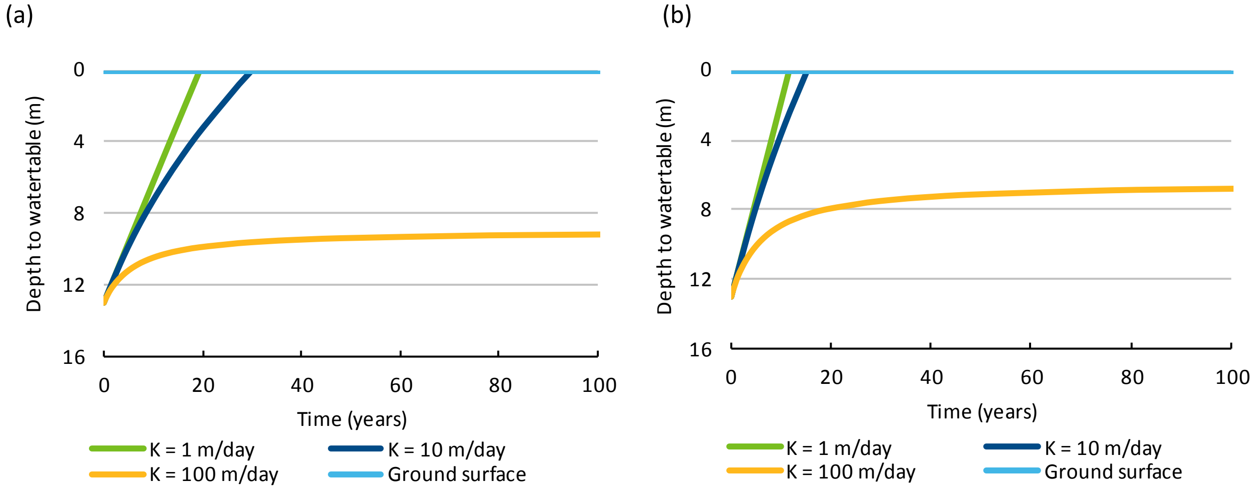


Figure 8.23 Change in depth to watertable for different values of saturated hydraulic conductivity (K): (a) lower recharge rate of 120 mm/year and (b) higher recharge rate of 200 mm/year

8.7.2 ECOLOGICAL, SOCIAL AND CULTURAL CONSIDERATIONS

Table 8.12 summarises the potential ecological, social and cultural considerations with respect to the 12,000-ha Green Hills dam irrigation development.

Table 8.12 Summary of potential ecological, social and cultural considerations with respect to the 12,000-ha Green Hills dam irrigation development

ECOLOGICAL AND SOCIAL CONSIDERATIONS	COMMENT
Vegetation at reservoir and irrigation development	This dam will capture a large catchment and inundation area. The vegetation covered will include mixed and open woodland. Also, the sandy riverbed channels include patches of ephemeral grassland, herbland and sedgeland (Petheram et al., 2013). The site also contains riverine wetland or fringing riverine wetland vegetation that will be lost to inundation (Petheram et al., 2013).
Sediment infill of reservoir	It is predicted that about 6% (range of between 1 and 11%) of the storage volume of Green Hills reservoir will infill with sediment after 30 years, and 20% (range of between 3 and 39%) of the storage volume will infill with sediment after 100 years (Tomkins, 2013).
Reservoir water quality	The risk of blue-green algal blooms is moderate. The water column is predicted to be strongly thermally stratified from September to mid-May, but has the potential to be mixed during summer inflow events. The climate will support blooms in summer and has the potential to support blooms in spring (Petheram et al., 2013). In light of the development of permanent stratification, downstream delivery of water needs to be carefully managed to avoid delivery of cold oxygen-depleted water. Thermal impacts associated with release of such water are likely to be limited spatially during periods of warm weather, but may be spatially extensive during the cooler months and at night.
Sediment, nutrient and pesticide loads from irrigation development	Three crops, sorghum (forage), cotton and peanuts, are planned for this development. There is only information on the impact of sorghum and cotton on nutrient load. At the scale chosen for this development, sorghum is predicted to increase nitrogen loads by 4% and phosphorus loads by 30%. Cotton is predicted to increase nitrogen loads by 10% and phosphorus loads by 6% (Waltham et al., 2013)
Sediment, nutrient and pesticide loads	A dam at this location in the Gilbert catchment is likely to trap suspended sediment and nutrients, but probably only during the wet-season flow. The river downstream of the dam might experience some problems with water quality – in particular, with reduced flow during wet season and/or bedsand channel flow. Waterholes may experience increased water temperatures and low dissolved oxygen. An increase in turbidity in downstream waterholes would also alter nutrient cycling and habitat opportunities for freshwater fauna (Waltham et al., 2013). If trapped sediment remains suspended well into the dry season, there is potential for released water to elevate the turbidity of downstream receiving environments – the ecology of these waters is particularly susceptible to impacts from even small increases in turbidity.
Fish passage	A dam at Green Hills, and associated re-regulating weirs, will act as a local fish passage barrier, but are at or beyond the maximum upstream extent of key fish species of high-conservation value – freshwater sawfish, barramundi and giant whipray. None-the-less, the dam (20 m high) and weir (3 m high) are significant barriers and would potentially alienate an extensive length of the Gilbert River and its upstream tributaries from downstream reaches. Most freshwater fishes of the region move extensively either to access newly inundated habitat or to reproduce. Reducing access is likely to result in significant changes in fish assemblage structure and even the long-term persistence of species as any local extinctions due to chance or drought will not be reversed by recolonisation from downstream refugia.

Table 8.12 Summary of potential ecological, social and cultural considerations with respect to the 12,000-ha Green Hills dam irrigation development
(continued)

ECOLOGICAL AND SOCIAL CONSIDERATIONS	COMMENT
Freshwater and coastal aquatic ecology in response to flow alteration	The dam traps a significant proportion of water in the Gilbert River, having a very strong localised impact on flow regimes and trapping early wet-season flows critical for the flushing of downstream waterholes. Moreover, the dam reduces flood flows by about 20% and this may result in changes to downstream riparian vegetation, weed encroachment, instream habitat structure and, ultimately, channel form. These impacts are likely to be extensive as changes in wet-season flows are experienced as far downstream as the most downstream gauge (917009A) when both this dam and the Dagworth scheme are in place. Dry-season water releases from the dam to the downstream re-regulating weirs will alter seasonal patterns of river flow and its water quality along the affected reach. Although unnatural, these releases may extend persistence of instream aquatic habitats providing some benefit to aquatic productivity. In other irrigation areas, such dry-season releases have, when in large volumes, greatly altered instream ecology, including allowing the development of instream vegetation and weed communities that would normally perish in the dry season. Modelling of the flow downstream of the dam has been completed for scenarios before and after development of the dam (Holz et al., 2013). Mean and median annual flow is reduced by approximately 14% and 22%, respectively, at the nearest downstream gauging station (917001D), and by 2% and 4%, respectively, at the most downstream gauging station (917009A). The effect of this on coastal ecosystems is not clear, but likely to be minor. There are few perennial waterholes in the reaches of the Gilbert River downstream of Green Hills dam (McJannet et al., 2013) However, the lower reaches of the Gilbert River (below the confluence with the Einasleigh River) are distinguished by significant dry-season baseflow. Under a development scenario, median dry-season flows are reduced by about 20%, resulting in an increase in the median length of maximum length of zero flow from 0 days to about 50 days, and an increase in the absolute maximum dry spell length from about 22 days to more than 100 days. Such changes are likely to result in substantial ecological change in the lower reaches. These changes essentially transform the lower river from a large-sized perennial system to a moderate-sized intermittent one. In addition to these changes, the flow regime of the Gilbert River was predicted to become more variable, which has consequences for biotic assemblage structure and regulation.
Terrestrial ecology	The effect on terrestrial ecology requires site-based assessment, including examination of existing terrestrial flora and fauna databases.
Impoundment ecology	The impoundment offers to provide new, albeit unnatural, aquatic habitat in an otherwise relatively dry catchment. Large dams may retain colloidal sedimentary material washed in during rain and flow events, in suspension for some time (e.g. Burdekin Falls Dam – see Burrows, 1999). If such turbid water is released for irrigation, this will have a large impact on downstream waterholes, whose ecology is based on their high water clarity and depth of sunlight penetration. The Green Hills dam location is upstream of the natural limit of barramundi and any calls to stock this impoundment with this species will need to be very carefully considered. Occupation of the impoundment will allow barramundi access to an extensive length of river from which they are currently absent. This large predator has significant effects on other fish species and invertebrates.

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9 Dagworth and Green Hills dams and irrigated sugarcane

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In this case study, the potential of an irrigation development involving two dams on the Gilbert and Einasleigh rivers was investigated, both as a pair and singly (Figure 9.1). The development under consideration would enable sugarcane to be supplied to a newly established sugar mill in the Gilbert catchment. Irrigation water would be supplied from dams built at one or both of Green Hills and Dagworth stations.

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

- the physical capacity to create a water storage and water distribution scheme, supply water to agriculturally suitable soils and grow sugarcane
- the capacity of the scheme to generate positive net revenues, based on a consolidated developer–owner–operator model
- the capacity of the farm to generate positive net revenues, when water development and supply costs are borne by off-farm interests
- the capacity to develop and sustain a sugar mill at Georgetown.

The financial analysis for this case study investigates whether the projected revenues from the sale of sugarcane is sufficient to cover the costs of irrigation development and sugarcane production. This perspective is appropriate to adopt if the investor does not have interests in sugarcane milling, but no assumptions are made that this is a likely or appropriate investment model. Rather, the analysis, consistent with the other case studies, is seeking to provide insights into the transformation of irrigation investments into agricultural output and what costs and benefits are incurred within these bounds. The case studies are indicative rather than definitive. The strong interconnectedness of the component parts of the sugar industry supply chain is acknowledged, and this brings the likelihood of a range of investment models and financial outcomes for irrigation development, some of which could connect growing and milling interests.

The analysis of the irrigation development is presented at both the scheme scale and the farm scale, using results under scenarios A and B. Both scenarios use the same 121-year historical climate data (from 1890 to 2011). Scenario A includes historical climate and current development, while Scenario B includes historical climate and future irrigation development (i.e. such as the irrigation development specified in this case study). All results in the Assessment are reported over the ‘water year’, defined as the period 1 July to 30 June. This allows each wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons).

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

In undertaking this analysis, the case study assessment included an allowance to avoid impacts on the reliability with which existing entitlement holders could extract water. For more details see Holz et al. (2013).

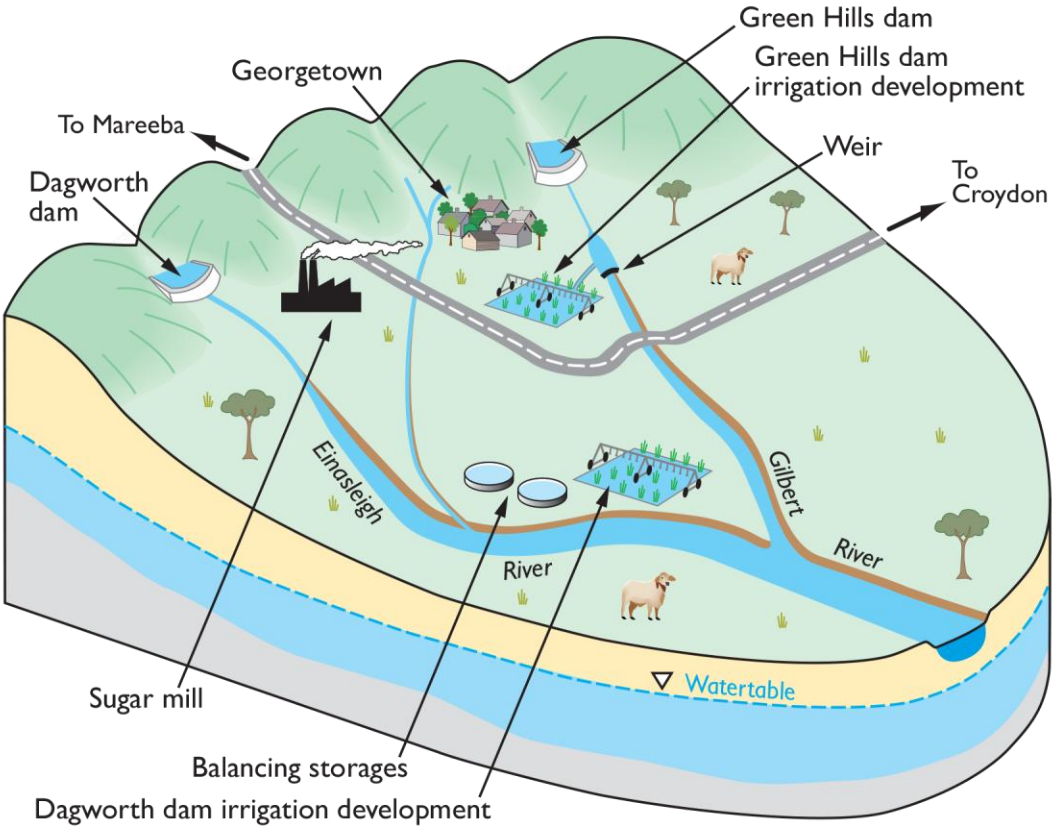


Figure 9.1 Schematic diagram illustrating the components of the case study for the irrigation developments associated with Green Hills and Dagworth dams

9.1 Summary

The case study concludes that the physical conditions exist to enable a combined dam, irrigation and sugar mill development.

- Dams capable of storing a combined volume of 725 GL were identified near Green Hills (227 GL) and Dagworth (498 GL) properties on the Gilbert and Einasleigh rivers, respectively. The combined annual water yield of these two dams is 498 GL at the dam wall at 85% reliability. The estimated cost of these two water storages is $809 million (with a likely range of $730 million to $1050 million) which would enable the controlled release of water from the storage at a unit cost of $1625/ML.
- For the two dams approximately 40% (weighted average) of the water at the dam wall would be lost in transmission and application to the crop. Delivery to crop from the potential Green Hills dam would be considerably more efficient (68%) than from the potential Dagworth dam (48%). This is largely due to the former’s closer proximity to proposed irrigated land and the difficulty in constructing and maintaining a re-regulation structure on the wide Einasleigh River.
- More than 25,000 ha of soils moderately suited to irrigated sugarcane production were identified within 10 km of the Gilbert River between the potential Green Hills dam and where the Gulf Development Road crosses the Gilbert River. More than 50,000 ha of soils moderately suited to irrigated sugarcane production were identified within 10 km from the Einasleigh River channel downstream of the potential Dagworth dam. Given adequate irrigation, the alluvial sandy silt loam soils of the case study area could potentially support mean sugarcane yields of between 110 and 120 t/ha per year (averaged over a 5-year rotation). With appropriate fertiliser and irrigation management, yields over 130 t/ha could be attainable on the heavier textured clay soils, adjacent to some parts of the Einasleigh River.
- Secondary salinity risk is relatively low on the highly permeable soils – large rises in watertable levels are unlikely and there are low levels of accumulated salts. Before irrigation development, however, the

area would require more intensive assessment of the usable soils and to assess the risk of secondary salinisation, particularly on the heavier soils associated with the Dagworth dam irrigation development.

Combined dam and irrigation developments paid for and operated by the same entity were not, under the conditions examined in this case study, able to be economically sustained for either the paired or individual dams. Examination of 92 separate 30-year investment windows occurring in each of the past 121 years was unable to identify any conditions under which a positive net present value (NPV) or internal rate of return (IRR) could be generated from investment in combined water supply and farm operations. To generate a positive NPV, at the specified discount rate of 7%, the Dagworth dam irrigation development would require the price of sugarcane to be $77/t and the Green Hills dam irrigation development would require the price of sugarcane to be $68/t. Market prices for sugarcane are highly variable but are in the vicinity of $39/t. A high price for sugarcane is $45/t.

With a sugar mill in Georgetown there was, however, a clear capacity to generate on-farm profits using water and related capital supplied by and paid for by a third party. Using default sugarcane prices ($39/t), positive farm-scale gross margins were possible in all years, and NPVs analysed for 92 thirty-year windows were all positive at the specified discount rate of 7%. At the default price for sugarcane and for the median 30-year NPV, farmers at Green Hills dam and Dagworth dam irrigation developments would have the capacity to pay a water charge of about $34/ML and $24/ML, respectively, to help offset operation and maintenance of the scheme. For both the irrigation developments and for the default price, the median 30-year NPV is only positive when a mill is located in Georgetown.

To be profitable to transport sugarcane from the Green Hills dam irrigation development to a mill in Mareeba, the price of sugarcane would need to be $69/t if the mill paid 50% of the transport costs and $103/t if the grower had to pay 100% of the transport costs. To be profitable to transport sugarcane from the Dagworth dam irrigation development to a mill in Mareeba, the price of sugarcane would need to be $77/t if the mill paid 50% of the transport costs and $118/t if the grower had to pay 100% of the transport costs. These are well in excess of current market prices.

9.2 Storyline for this case study

This case study assesses the viability of a sugarcane growing district located along the Einasleigh and Gilbert rivers. Water for the sugarcane district would be supplied from dams on either the Einasleigh River at the Dagworth station or a dam on the Gilbert River on the Green Hills station, or both (Figure 9.2). Sugarcane would be transported to a factory near Georgetown or Mareeba for processing to raw sugar, which would then be transported by road to the Port of Townsville for export. Sugarcane was selected because sugar is a well-established industry in north Queensland, with considerable existing infrastructure and bulk-handling facilities at the Port of Townsville. Sugar is also a high-value export commodity, with well-established export markets and marketing infrastructure.

In the Georgetown area, sugarcane would be planted after the wet-season rains have ceased, generally from about April, and the planting season would continue until June. Sugarcane is a perennial crop, harvested the year after it is planted. The harvesting season would extend from June to about November, although there may be benefits in starting the harvest in May. After harvesting the plant crop, the crop regrows (called ratooning) and the first ratoon crop grows for a further year before being harvested. The crop will continue to ratoon after each harvest, but yields tend to decline with subsequent ratoons. Most farmers only harvest three or four ratooned crops before ploughing in the crop and replanting. Between ploughing in the final ratooned crop and planting the next crop, a fallow period of approximately six months is done, during which a legume break crop such as cowpea or soybean is often grown. The consequence of this fallow is that there is a year in the sugarcane growing cycle when there is no sugarcane harvest. However, the plant crop tends to be higher yielding, in part because it has a longer growing season. In reality, all sugarcane farms have a mix of different-aged crops, so farmers that routinely practise cropping with three ratoons have 20% of their farms assigned to each crop age (including the fallow), and only harvest 80% of their area in any single year.

Sugarcane requires crushing at a mill before export and needs to be crushed within 24 hours of harvest to prevent quality deterioration, which can result in loss of raw sugar in the final product. The majority of sugar mills in Australia are located on the north-east Queensland coast. Because cane transport is a significant cost in the supply chain, and raw sugar comprises only about 15% of the mass of a sugarcane crop, sugar mills are typically located within about 50 km of sugar-growing farms.

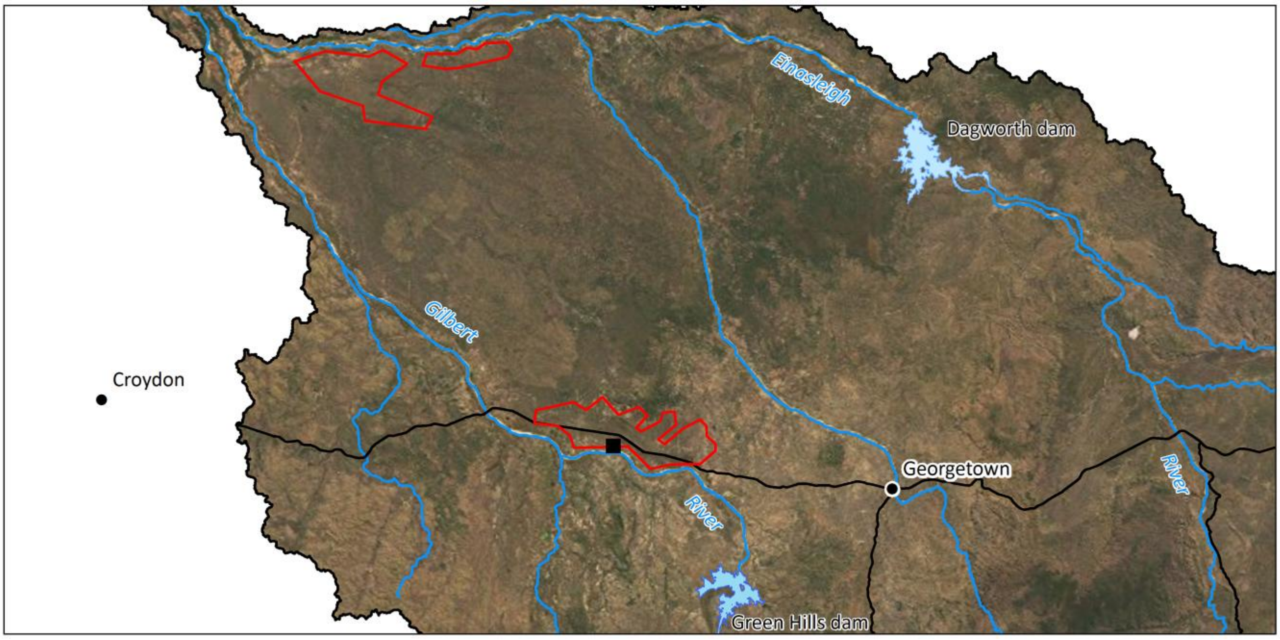
The nearest sugar mill to the Georgetown area is at Mareeba, 346 km from Georgetown. Transporting sugarcane using B-double trucks from the Dagworth dam and Green Hills dam irrigation developments to Mareeba has a cost of about $81/t (406 km) and $67/t (~500 km), respectively (Brennan McKellar et al., 2013). Comparably, it only costs $8.3/t to transport cane to the mill from the farms supplying the Maryborough sugar mill, a typical sugar mill on the east Queensland coast. For this reason, this case study investigates the viability of sugarcane irrigation developments in the Gilbert catchment when sugar is transported (i) to the existing mill in Mareeba and (ii) to a newly constructed mill located in Georgetown.

The outline of this case study is as follows.

- Section 9.3 describes the soils of the case study area.
- Section 9.4 describes the suitability of the climate for growing sugarcane near Georgetown.
- Section 9.5 describes the configuration of the irrigation developments and cropping systems.
- Section 9.6 describes two financial analyses.
  - The first (in Section 9.6.1) surveys different 'scheme areas'.
  - The second (in Section 9.6.2) undertakes a more detailed assessment of the profitability at the scheme and farm scale for a single scheme area. The profitability of alternative locations of a sugar mill are considered.
- Section 9.7 describes some potential on-site and off-site impacts associated with the scheme area selected in Section 9.6.2.

The case study area is shown in Figure 9.2. To provide a sense of scale and an indicative sense of place, a potential irrigation development of 19,200 ha is delineated for each dam. Before irrigation development, the area would require a more intensive assessment of usable areas.

(a)



(b)

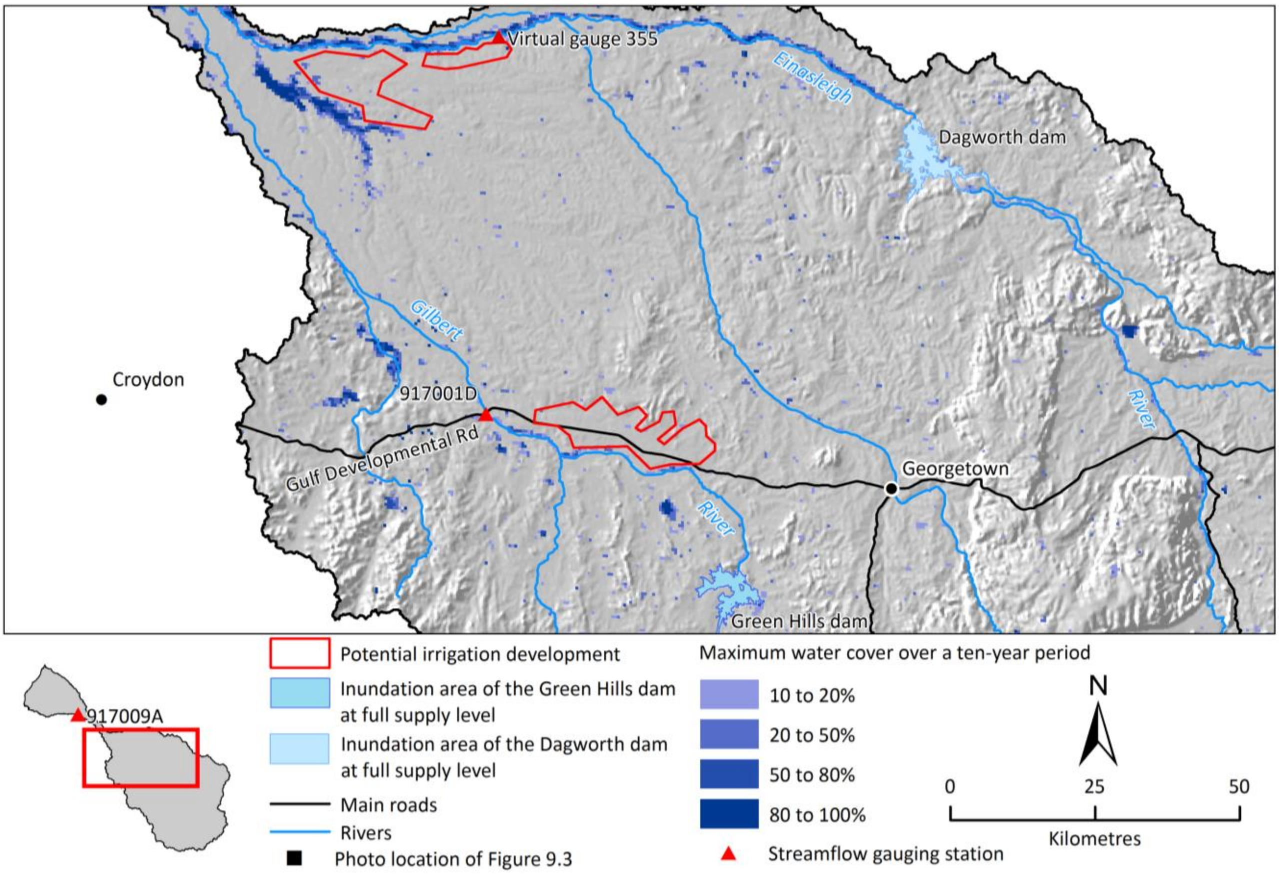


Figure 9.2 (a) Satellite image and (b) relief map area surrounding Green Hills and Dagworth dams
Data used to develop flood map was captured using MODIS satellite imagery. This figure illustrates the maximum percentage of MODIS pixels inundated between 2000 and 2010.

9.3 Soils along the Gilbert and Einasleigh rivers

This section describes the soils of the Green Hills dam and Dagworth dam irrigation developments.

The Green Hills dam irrigation development is confined to the dominant alluvial plain along the Gilbert River upstream of the Georgetown to Croydon Road crossing (Figure 9.4). These alluvial plains are largely influenced by the diverse range of rock types in the Gilbert catchment, such as strongly altered metamorphic rocks as well as granites and sedimentary rocks. There are also shallow rocky soils on undulating to steep low hills and rises adjacent to the alluvial plains, which have limited development potential. The landscape of the Gilbert River case study area is shown in Figure 9.3.

The Dagworth dam irrigation development is located above the confluence of the Einasleigh and Gilbert rivers at Strathmore station (Figure 9.4), and contains several landscapes. The area is dominated by alluvial plains that are largely influenced by the diverse range of geologies in the Einasleigh catchment, including metamorphic rocks, granites, sedimentary rocks and basalt. The other prominent landscapes adjacent to the irrigation development are the 'downs' on the Great Artesian Basin in the vicinity of Abingdon station, and the old highly weathered sedimentary rock that forms plateaus, plains and dissected hills from Abington station to Strathmore station.

Alluvial plains along the Gilbert River downstream of Green Hills dam

Adjacent to the Gilbert River and upstream of where the Georgetown to Croydon Road crosses the Gilbert River, there are 4150 ha of very deep, well-drained, loamy-textured, brown massive and structured soils (corresponding to friable non-cracking clay or clay loam soils, and sand or loam over friable earthy clay). Subsoils may have clay textures. These moderately permeable soils are very deep with a moderate to moderately high water-holding capacity and are well suited to a wide variety of irrigated crops, particularly using spray- and micro-irrigation methods. Soils may be inundated by occasional floods. The main restriction in this area is the narrow width of the alluvial soil plains, restricting the area most suited for cropping.

The plains further from the river are dominated by very deep, texture contrast and gradational soils (corresponding to loam over sodic/intractable clay soils) with a loamy to silty surface over imperfectly to moderately well-drained, slowly permeable, dispersible clay subsoils (4050 ha). Soils have moderate water-holding capacity and development potential for furrow-irrigated crops; the main restrictions being surface sealing and difficulty with plant establishment and water infiltration. The relatively narrow areas make cropping of large areas difficult. Areas may be subject to occasional flooding and seasonal waterlogging.

In the low-lying areas, generally occurring as depressions on the alluvial plains, there are 5400 ha of imperfectly to poorly drained, slowly permeable, mottled hard-setting, mottled grey gradational soils (corresponding to friable non-cracking clay or clay loam soils, and sand or loam over friable or earthy clay) and minor grey cracking clays. These soils have some limited potential for spray- or furrow-irrigated crops that can withstand regular flooding and seasonal waterlogging. The other restriction is the relatively small size of uniform areas.

Either side of the Gilbert River (but mainly on the eastern side), there are over 15,000 ha of high-level, flood-free, very deep, well-drained to imperfectly drained, moderately permeable, sandy- to loamy-surfaced soils (corresponding to sand or loam over friable or earthy clay soils) on elevated, gently undulating, alluvial plains. Subsoils are massive to structured red and brown clays. Low-lying areas correspond to imperfectly drained, mottled brown subsoils. These soils have a moderate water-holding capacity. Moderately large areas are moderately suitable to spray-irrigated field crops and micro-irrigated horticulture. Seasonal waterlogging may be a restriction on lower slopes.

From the soils available, a potential area of about 19,400 ha has been delineated in Figure 9.2. This area predominately contains sand or loam over friable or earthy clay soils (high-level, flood-free alluvium). These soils are relatively close to the river, the proposed dam site and a potential mill at Georgetown. According to the regional land suitability assessment, these soils are potentially the best available (Figure 9.4). Their actual distance from the river will incur relatively high pumping costs and soils are only marginally suitable for construction of on-farm storages due to the moderate to high subsoil permeability. Before irrigation development, the area would require a more intensive assessment of usable areas.

There are more than 25,000 ha of soil moderately suitable for irrigation between the Green Hills dam and where the Gulf Development Road crosses the Gilbert River.

Alluvial plains along the Einasleigh River downstream of Dagworth dam

The soils adjacent to the river channel in the Einasleigh River case study area comprise 5700 ha of very deep, well-drained, loamy textured, brown massive or structured soils (corresponding to friable non-cracking clay or clay loam soils, and sand or loam over friable or earthy clay). Subsoils may have clay textures. These moderately permeable soils are very deep with a moderate to moderately high water-holding capacity and are moderately suitable to a wide variety of irrigated crops, particularly using spray- and micro-irrigation methods. Soils may be inundated by occasional floods. Downstream of Abingdon, the alluvial plain widens with a complex distribution of soils due to the migration of the Einasleigh River over the alluvial plains. The main restriction in this area is the narrow width of the soil most suited for cropping.

The alluvial plains further from the river (15,250 ha) are dominated by texture contrast (duplex) and gradational soils with a loamy to silty surface over imperfectly to moderately well-drained, slowly permeable, dispersible clay subsoils. Soils have moderate water-holding capacity with development potential for furrow-irrigated crops. The main restrictions are surface sealing, and difficulties with plant establishment and water infiltration. The relatively narrow width of this soil makes cropping of large areas difficult. Areas may be subject to occasional flooding and seasonal waterlogging.

The low-lying areas, generally occurring as depressions on the plains, cover 17,100 ha and have imperfectly to poorly drained, slowly permeable, mottled grey cracking clays and hard-setting, mottled grey gradational soils. The clay soils are a reflection of the large areas of basalt in the upper catchment. The broader alluvial plains downstream of Abingdon station have a complex distribution of soils due to previous migration of the river over the broad plains. These soils have limited potential for spray- or furrow-irrigated crops that can withstand regular flooding and seasonal waterlogging. The other restriction is the complex distribution of soils, resulting in relatively small uniform areas.

Either side of the Einasleigh River, high-level flood-free, very deep, moderately well-drained, moderately permeable, sandy-surfaced soils occur on elevated gently undulating alluvial plains. Subsoils are massive to structured clays. Dense gravel is common on lower slopes, usually corresponding to imperfectly drained mottled yellow and brown subsoils. These soils cover 19,800 ha and have a moderate water-holding capacity, limited by the sandy topsoil. Moderately large areas are suited to spray-irrigated crops and micro-irrigated horticultural crops. Seasonal waterlogging and gravel patches may be a restriction on lower slopes.

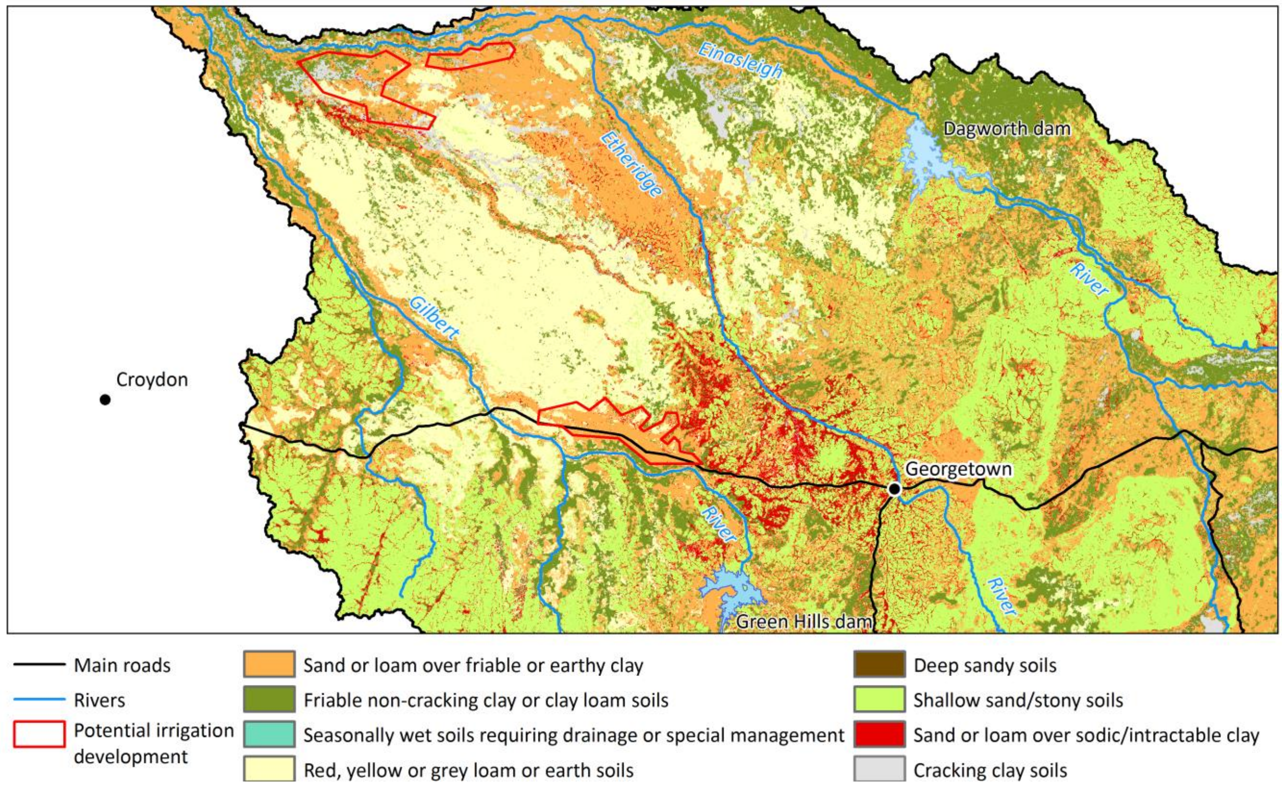
Adjacent to the case study area, red, yellow and grey loamy and earthy soils are mainly associated with plains and dissected tablelands on the deeply weathered sedimentary rocks between the confluence of the Gilbert and Einasleigh rivers. These moderately permeable soils have variable soil depth over short distances, but are predominantly moderately deep (0.5–1.0 m) and occasionally deep (1.0–1.5 m). Soil water storage is low to moderate (50–100 mm) with higher water storage on the deeper soils (75–100 mm). Well-drained red earthy soils occur on the rises and edges of the plateaus, while imperfectly drained yellow and grey earthy soils occur on the plains and lower landscape positions. An attribute of all of these soils is that they are nutrient deficient; hence, irrigated cropping would require very high fertiliser inputs. On the deeper of these soils, irrigation potential is limited to spray- and drip-irrigated crops. Seepage from irrigation development above scarps may contribute to rising watertable levels and salinity issues below the scarps, particularly at the break of slope. Due to localised variability, this area requires further investigation before development.

A potential area of 19,200 ha is delineated with two polygons shown in Figure 9.4. It has a complex distribution of friable clays, sand or loam over friable or earthy clay soils (high-level flooded and flood-free alluvium), regular and grey loam earthy soils and relatively minor grey cracking clays, and sand or loam over sodic or intractable clays. Seasonal wetness will restrict farming operations and access during the wet season. These soils are a considerable distance from the river. Soils are suitable for construction of on-farm storages on the heavy textured impermeable clay soils. Before irrigation development, the area would require more intensive assessment of usable areas due to the complex distribution of sand, loamy and clay soils.

There are more than 50,000 ha of soil moderately suitable for irrigation within 10 km of the Einasleigh River downstream of Dagworth dam.

Figure 9.3 Photo of the landscape near the potential Green Hills dam irrigation development
Site where the photograph was taken is shown in Figure 9.2.

(a)



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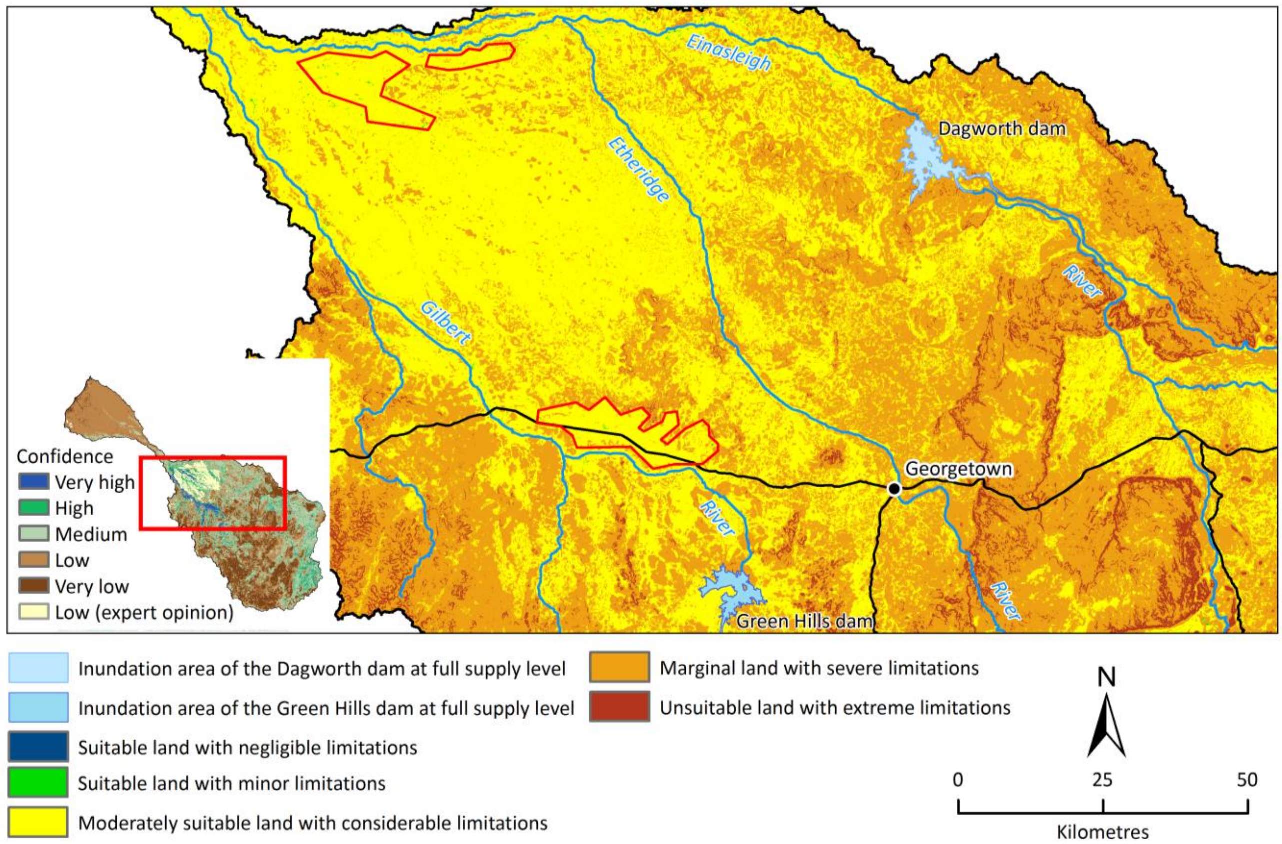


Figure 9.4 (a) Soil generic group map and (b) land suitability map for the middle reaches of the Gilbert and Einasleigh rivers for spray-irrigated sugarcane

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

9.4 Climate suitability of sugarcane in the Georgetown area

Rainfall in the Gilbert catchment is highly variable among years and highly seasonal – 90% of rain falls between December and March (Figure 9.5). Although potential evaporation is also seasonal (Figure 9.5), driven largely by temperature (Figure 9.6), there is very little year-to-year variation in evaporative demand (Figure 9.5b). The daily average maximum temperature remains above 30°C year round, with greater seasonal variation in the average minimum temperature (Figure 9.6). Consequently, with sufficient water, a tropical perennial grass crop such as sugarcane could produce high biomass yields. Like the Burdekin region, the dry winter months would allow withholding of irrigation to allow the soil to dry down, reduce growth and potentially increase sucrose content before harvest. However, there is some evidence from the Ord district that in that environment, the sugarcane crop does not respond in a similar way to the established regions in Queensland (Leslie and Byth, 2000; Bonnett et al., 2006). Therefore, caution is needed in translating results based on these other regions to new regions. The lack of rain during May to October also provides an ideal break for harvesting sugarcane.

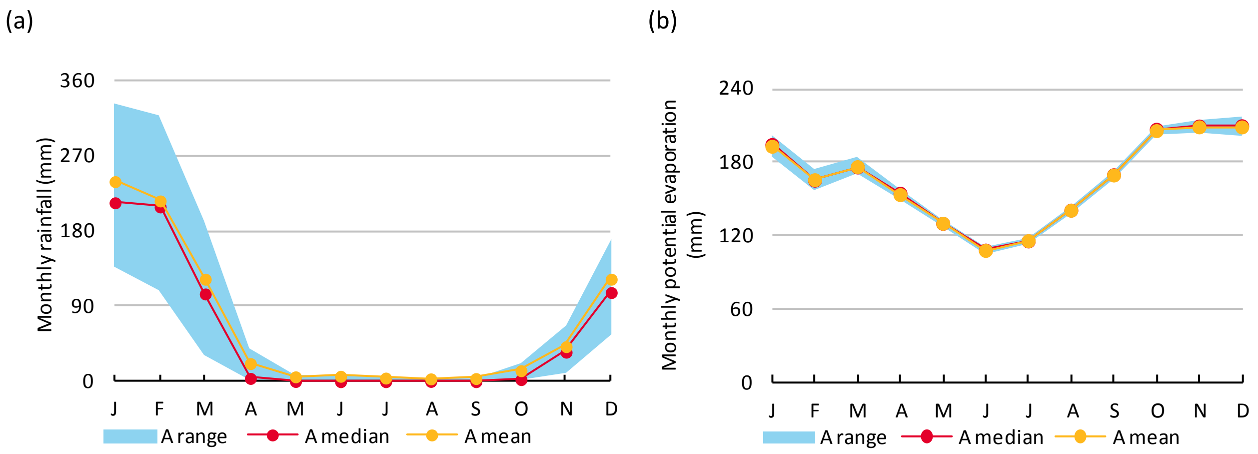


Figure 9.5 (a) Monthly rainfall and (b) monthly potential evaporation, under Scenario A at Dagworth
Scenario A is the historical climate (1890 to 2011). The A range is the 20th to 80th percentile exceedance.

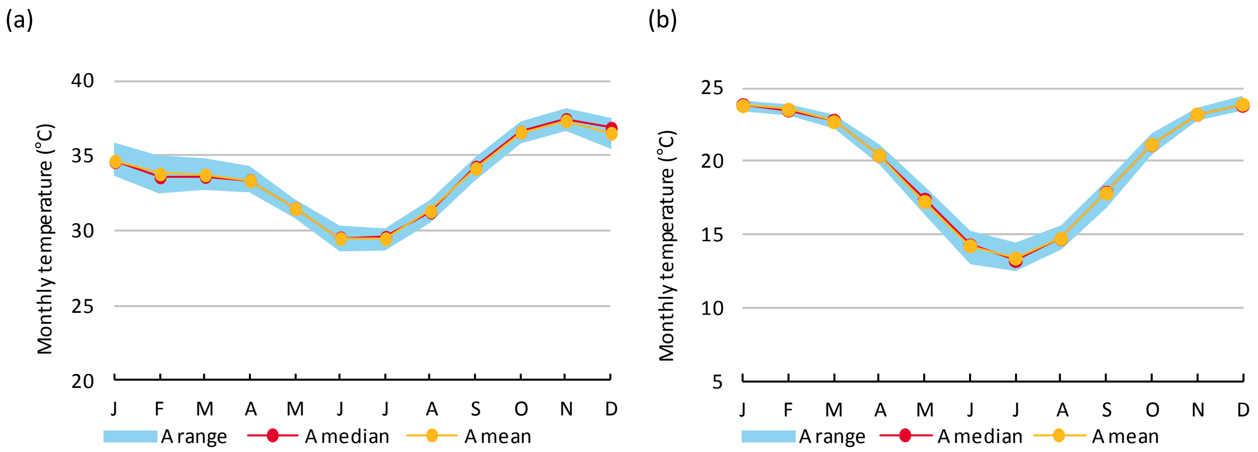


Figure 9.6 (a) Maximum monthly temperature and (b) minimum monthly temperature, under Scenario A at Dagworth
Scenario A is the historical climate (1890 to 2011). The A range is the 20th to 80th percentile exceedance.

9.5 Scheme configuration and cropping systems

This section provides a description of the configuration of the irrigation developments and cropping systems associated with the Green Hills and Dagworth dams. It provides information on the dams, outlines the configuration and costs for water supply and irrigation development, examines the relationship between applied irrigation water and crop yield at production potential and discusses production risks.

9.5.1 GREEN HILLS AND DAGWORTH DAMS

The potential Green Hills and Dagworth dams are 20 m and 30 m high roller compacted concrete dams, respectively. The Green Hills dam is located on the Gilbert River and the Dagworth dam is located on the Einasleigh River (Figure 9.4). Streamflow characteristics at the location of the dams on the Gilbert and Einasleigh rivers are given in Table 9.1. For a given mean annual streamflow, the larger the variability in streamflow, the smaller the water yield from the dam. The streamflow in the Gilbert and Einasleigh rivers is about two to three times more variable than rivers of the rest of the world of the same climate type (Petheram et al., 2008). This variation is highlighted in Figure 9.7 and Figure 9.8 where even when smoothed by presenting a 10-year moving average (calculated from a moving window centred on the year in question), large variation remains.

Table 9.1 Streamflow on the Gilbert and Einasleigh rivers at the potential Green Hills and Dagworth dam sites under Scenario A

RIVER NAME	MAXIMUM FLOW (GL/y)	20% EXCEEDANCE FLOW (GL/y)	50% EXCEEDANCE FLOW (GL/y)	80% EXCEEDANCE FLOW (GL/y)	MINIMUM FLOW (GL/y)	MEAN FLOW (GL/y)	COEFFICIENT OF VARIATION
Gilbert River	8,653	1096	503	201	17	802	1.29
Einasleigh River	11,578	1521	777	245	12	1186	1.24

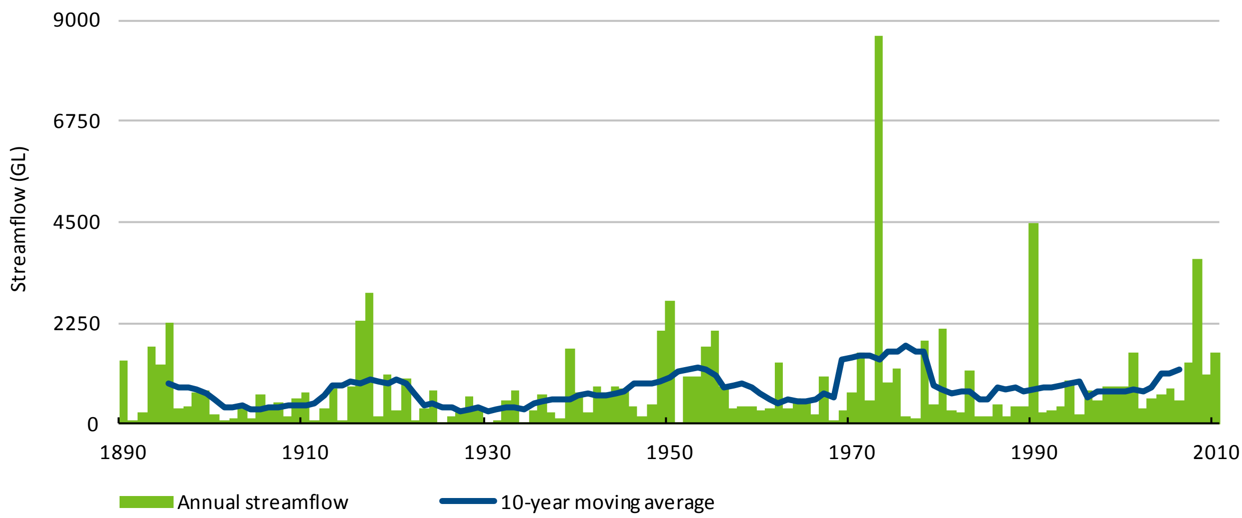


Figure 9.7 Annual streamflow on the Gilbert River at the Green Hills dam site under Scenario A
Blue line indicates the 10-year moving average.

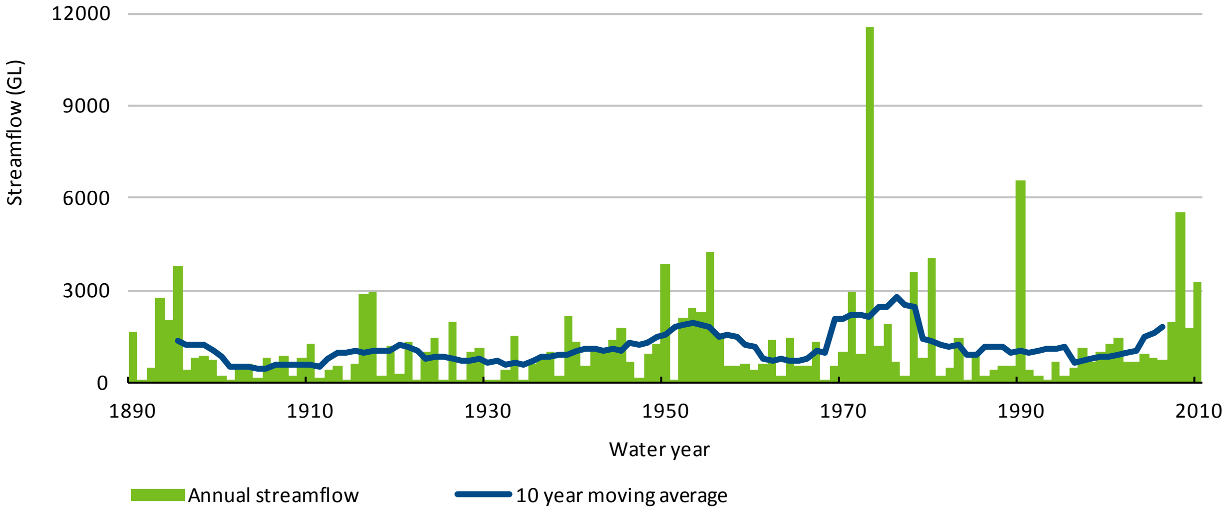


Figure 9.8 Annual streamflow on the Einasleigh River at the Dagworth dam site under Scenario A
Blue line indicates the 10-year moving average.

Green Hills and Dagworth are two of the most promising dam sites in the Gilbert catchment. The spillway height of the dam at the Green Hills site and Dagworth site is 20 m and 30 m respectively. This was deemed to be the optimal height without excessively large saddle dam requirements. The Green Hills roller compacted concrete dam and Dagworth roller compacted concrete dam are likely to cost between $300 million and $435 million and $425 million and $615 million, respectively. Their key parameters are summarised in Table 9.2. For more detail, see Petheram et al. (2013).

Table 9.2 Green Hills and Dagworth dam parameters

DAM NAME	DAM TYPE	CATCHMENT AREA (km^2)	SPILLWAY HEIGHT (m)	CAPACITY (GL)	FULL SUPPLY LEVEL (m)	ANNUAL WATER YIELD * (GL)	COST** ($ million)	UNIT COST*** ($/ML)
Green Hills	Roller compacted concrete	8,310	20	227	254	172	$335	$1950
Dagworth	Roller compacted concrete	15,351	30	498	227	326	$474	$1450
Total				**725**		**498**	**$809**	**$1625 (average)**

* 85% annual time-based reliability using a perennial demand pattern for the baseline model under Scenario A. This is yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These yield values do not take into account downstream existing entitlement holders or environmental considerations.
** Likely cost range is –10 to +30%. Price includes saddle dams. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher.
*** This is the unit cost of annual water yield and is calculated as the capital cost divided by the water yield at 85% annual time reliability.

9.5.2 CONFIGURATION AND COSTS FOR WATER SUPPLY AND IRRIGATION DEVELOPMENT

Due to the geographic separation of the Green Hills dam and Dagworth dam irrigation developments, they are examined separately in this analysis.

Configuration for water supply for Green Hills dam irrigation development

Under this nominal configuration, water would be released from the Green Hills dam to a re-regulating structure (sheet-piling weir) at Prestwood, approximately 20 km downstream of the dam. The re-regulating structure allows for more efficient releases of water from the dam at key times required by irrigators, thereby reducing the transmission losses normally involved in supplemented river systems. As it is unlikely that rock foundations would be present, it is assumed that a 325-m wide, 3-m high sheet-piling weir would need to be constructed. This would be an unusually wide weir.

Water would be pumped from behind the weir in the river (assuming a 10-m head requirement) into a main distribution channel on the right bank. This channel would need to be lined due to the sandy nature of the soils. The potential irrigation development is situated 2 km from the river due to the presence of marginally suitable land in the vicinity of the river (Figure 9.4b). This enables a 2-km wide riparian zone to be maintained between the irrigation development and the river.

It is assumed that irrigation water is distributed within farm (i.e. from the farm gate to the field) using open, lined channels. On-farm storages are sometimes used to improve the efficiency with which water can be supplied from the farm gate to the field. It is assumed that, for this development, there is minimal need for on-farm storage due to the relatively close proximity of the Green Hills dam and the proposed irrigation area. Once at the field, water is applied using modern spray irrigation systems capable of delivering peak water requirements to the cane crop at periods of high-evaporative demand. Overhead sprinklers are used to optimise irrigation productivity and minimise accessions to groundwater, which have the potential to cause watertable levels to rise and increase salinity risk. Well-managed spray irrigation generates very little tailwater runoff (i.e. water leaving the field following an irrigation event), except during large rainfall events that may occur immediately after irrigation on full soil profiles.

Table 9.3 lists the conveyance efficiency assumptions used in this analysis. In total, the conveyance and application efficiency from the storage to the crop is about 68%. These values are likely to be representative of best practice.

Table 9.3 Conveyance efficiency assumptions for the irrigation development associated with the Green Hills dam

COMPONENT	EFFICIENCY (%)	COMMENT
River conveyance efficiency	85%	Distance between dam and sheet-piling re-regulating structure is about 20 km. This is likely to be a generous assumption.
Channel distribution efficiency	95%	Representative of evaporation loss from re-regulation structure and channel loss between river and farm gate. Channel is lined due to sandy soils.*
On-farm distribution efficiency	99%	Representative of on-farm evaporation and seepage loss from farm gate to edge of field. Assumed lined channel.[1]
Field application efficiency (spray)	85%	Assumed majority of loss goes to deep drainage.
Overall efficiency	68%	

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

Configuration for water supply for Dagworth dam irrigation development

The width of the Einasleigh River downstream of Dagworth dam varies between 500 m to more than 1 km. The width of the river is such that the construction of a weir adjacent to the irrigation development would be very challenging. Under this nominal configuration, water would be released from the potential Dagworth dam to a series of sand dams approximately 70 km away. These sand dams are low embankments comprising river bedsands that partially span the lower Einasleigh River. They are constructed downstream of a natural waterhole to form a pool sufficiently deep from which to pump water. Although sand dams are cheap to construct, compared with a concrete or sheet-piling weir, they have much larger seepage losses beneath and through the dam wall, and need to be rebuilt every year.

Water is pumped from behind the sand dams (assuming a 15-m head requirement) into one of two 4000-ML ring tanks. These ring tanks act as balancing storages and serve to improve the efficiency with which water can be supplied from the Dagworth dam to the irrigation development. The potential irrigation development is situated 2 km from the river, enabling a riparian zone to be maintained between the irrigation development and the river. Water is supplied from the ring tanks to the irrigation farms by an open channel. Once at the field, water is applied using spray irrigation.

Making this water supply scheme configuration operational is likely to be challenging and losses are likely to be high (Table 9.4). Overall, the efficiency is estimated to be 48%.

Table 9.4 Assumed conveyance efficiency assumptions for the irrigation development associated with the Dagworth dam

COMPONENT	EFFICIENCY (%)	COMMENT
River conveyance efficiency	70%	Distance between dam and sand dam re-regulating structure is about 70 km. Supplemented by flows from Etheridge River (tributary of Einasleigh River). When Etheridge River is flowing, it would in effect reduce transmission losses of water released from dam. Nevertheless a conveyance efficiency is likely to be generous.
Sand dam – re-regulation infrastructure	80%	Loss from sand dams (seepage) and balancing storages (seepage and evaporation).
Channel distribution efficiency	90%	Loss from balancing storage to farm gate* channel not lined.
On-farm distribution efficiency	95%	Loss from farm gate to field due to on-farm evaporation and seepage loss[1] channels on-farm not lined.
Field application efficiency (spray)	85%	
Overall efficiency	48%	

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

Costs for water supply for Green Hills dam irrigation development

Irrigation development involves a wide range of capital, operation and maintenance costs. These are incurred at both the scheme and farm scale. Scheme-scale costs are those associated with major infrastructure (e.g. dams, channels, roads, earthworks), approvals (e.g. environmental impact statements) and delivery of water to the irrigation development (e.g. pumps). Farm-scale capital, operation and maintenance costs are those associated with irrigation systems and farm equipment.

The Gulf Development Road passes through the potential Green Hills dam irrigation development and, consequently, additional access road requirements are minimal.

Indicative capital, operation and maintenance costs associated with the irrigation development are provided in Table 9.5. Costs of infrastructure that are independent of the size of the irrigation development (e.g. dam, weirs, main access roads) are listed as a fixed price. Costs directly linked to the size of the irrigation development are expressed as a cost per ha and per ML. This enables irrigation developments of different sizes to be quickly evaluated (see Section 2.2). These costs were obtained from information presented in Chapter 4 and 5.

Table 9.5 Scheme- and farm-scale costs for the irrigation development associated with Green Hills dam

ITEM		LIFESPAN (y)	UNIT COST ($)	UNIT	OPERATION AND MAINTENANCE COST (% capital costs)	COMMENT
Scheme-scale costs: capital, operational and maintenance	Large dam	100	$335,000,000	*	0.4%	All costs associated with dam, including access roads, environmental impact statements, legal, contingency
	Weir	40	$55,000,000	*	2%	325-m wide × 3-m high sheet-piling weir
	Access roads	100	$1,580,000	*	1%	5 km of additional all-weather access road
	Main supply channel	40	$9,420,000	*	1%	Includes structures and overheads
	Area works	40	$7,740	ha	1%	Includes roads (life span 100 y) earthworks, structures, overheads, contingency and corporate profit
	Pump capital cost (weir to channel)	15	$250	ha	2%	
	Pump energy cost (weir to channel)	na	$24	ML	na	Assuming 15-m head requirement and pump operated on diesel
Scheme-scale costs: approvals	Area works approvals	na	$6,000,000			Includes environmental impact statements, Native Title Claims and cultural heritage
	Legal	na	$1,000,000			
Farm-scale costs: capital	Irrigation system (spray)	15	$4,000	ha	**	Includes land development costs, equipment, pumps
	Farm equipment	15	$1,160	ha	**	This refers to equipment not included in the irrigation system (e.g. vehicles, cultivation equipment)
Farm-scale costs: operational	Overheads	1	$660	ha		Includes maintenance costs, employee costs, land lease and other business overheads

na = not applicable
* Indicates fixed cost independent of the size of the irrigation development.
** Operation and maintenance costs are captured in farm-scale cost overheads.

Costs for water supply for Dagworth dam irrigation development

Currently, an unsealed road links the sealed Gulf Development Road to the potential irrigation development. The unsealed road would need to be upgraded to a sealed road to ensure year-round access for vehicles and heavy machinery to the irrigation development, sand dams and pumping infrastructure. Inspection of digital elevation data and satellite imagery indicates the topography between the Gulf Development Road and potential irrigation development is gently undulating and there are several creek crossings. This road would be moderately expensive to construct.

Indicative capital, operation and maintenance costs associated with the irrigation development are provided in Table 9.6. Costs of infrastructure that are independent of the size of the irrigation development (e.g. dam, sand dams, main access roads) are listed as a fixed price. Those costs directly linked to the size of the irrigation development are expressed as a cost per hectare and per megalitre. This enables irrigation developments of different sizes to be quickly evaluated. These costs were obtained from information presented in Chapter 5.

Table 9.6 Indicative irrigation development, scheme-scale and farm-scale costs associated with the Dagworth dam irrigation development

ITEM		LIFE SPAN (y)	UNIT COST ($)	UNIT	OPERATIONAL AND MAINTENANCE COST (% capital costs)	COMMENT
Scheme-scale costs: capital, operational and maintenance	Large dam	100	$474,000,000	*	0.4%	All costs associated with dam, including access roads, environmental impact statements, legal, contingency
	Sand dams	1	$150,000	*	NA	Two sand dams
	Balancing storages	40	$10,000,000	*	1%	Two 4000-ML ring tanks
	Main access road	100	$33,250,000	*	1%	Approximately 70 km of road requiring upgrading
	Main supply channels	40	$21,230,000	*	1%	Includes structures and overheads
	Area works	40	$7,740	ha	1%	Includes roads (life span 100 y) earthworks, structures, overheads, contingency and corporate profit
	Pump capital cost (sand dam to on-farm channel)	15	$250	ha	2%	
	Pump energy cost (river to channel)	na	$24	ML	na	Assuming 15-m head requirement and pump operated on diesel
Scheme-scale costs: approvals	Area works approvals	na	$6,000,000		na	Includes environmental impact statements, Native Title Claims and cultural heritage
	Legal	na	$1,000,000		na	
Farm-scale costs: capital	Irrigation system (spray)	15	$4,000	ha	**	Includes land development costs, equipment, pumps
	Farm equipment	15	$1,160	ha	**	This refers to equipment not included in the irrigation system (e.g. vehicles, cultivation equipment)
Farm-scale costs: operational	Overheads		$660	ha	na	Includes maintenance costs, employee costs, land lease and other business overheads

na = not applicable
* Indicates fixed cost independent of the size of the irrigation development.
** Operation and maintenance costs are captured in farm-scale cost overheads.

Critical infrastructure

In the absence of hard infrastructure (such as roads and energy supplies) and community infrastructure (such as schools and housing), required to support large irrigation developments and the people who work there, investment in infrastructure will need to be made. Table 9.7 summarises critical infrastructure in the Georgetown area. With the exception of processing infrastructure, hard and community infrastructure is unlikely to be a barrier to small- to medium-sized irrigation developments.

Table 9.7 Critical infrastructure requirements in the Georgetown area

ITEM		COMMENTS
Community infrastructure	General	The main town serving the irrigation developments is Georgetown, which currently has fewer than 300 residents. Indicative estimates of labour for crop production have been proposed as 6 full-time employees per 1000 ha, which would correspond to 96 employees for a 16,000-ha irrigation development. Whether this increases the population by this number will depend on the extent to which the town's existing population can meet labour requirements.
	Schools	A primary school in Georgetown currently has 47 enrolments and hard infrastructure (classrooms) can be added if needed.* Additional staffing needs, if any, would be expected to depend on the number and composition of new enrolments.
	Hospital	Georgetown does not have a hospital. It has a clinic, and the area is serviced by a flying doctor and nurse. Facilities could require expansion under population growth.*
	Housing	Georgetown currently has a supply of unoccupied dwellings; however, the quality of available housing, and whether new construction is required, would require further assessment.
	Water	Water for the town is sourced from bedsands of the Etheridge River. It is treated and then gravity fed to the town. There are concerns about whether the bedsand aquifers could support a larger population. The Etheridge Shire Council has commissioned the construction of an 8-ML dam at Forsyth to secure town water supplies. However, the dam can only service small increases in demand and would be unlikely to be sufficient if the population reached 2500 residents. There is no sewerage treatment plant in Georgetown – a septic system is used. If there was a large increase in population, a sewerage treatment plant would be needed. *
	Other	Georgetown is close to rivers and the town centre is vulnerable to flooding. Further commercial and residential development would be more appropriately sited a few kilometres west of the current town centre.*
Hard infrastructure	Roads	Gravel roads within Etheridge Shire are likely to require upgrading, depending on traffic flow generated from on-farm labour, suppliers, etc., as well as heavier vehicles (e.g. light trucks).*
	Rail	There is a tourist train to Einasleigh.
	Energy	The electricity network is maintained by Ergon Energy. This area is serviced by feeders from the Georgetown 66 kV zone substation. The projected maximum demand growth (9.4 MVA in 2020) is significantly less than the rated capacity (44 MVA). However, dependent on location of the facilities some infrastructure upgrade to single-wire earth return may be required. Irrigators will need to use diesel for pumping, which is more expensive than electricity.* Irrigators will need to use diesel for pumping, which is more expensive than electricity.*
	Ports	Existing sugar bulk-handling facilities at Townsville would be used (this will require an analysis of current capacity and how additional deliveries could be managed).
Processing infrastructure	Mill	The nearest mill is at Mareeba. High transport costs warrant investigation into a local mill.

* Sourced from discussions with elected members and staff of Etheridge Shire Council.

9.5.3 APPLIED IRRIGATION WATER, CROP YIELD AND PRODUCTION RISK

Applied irrigation water and crop yield data for sugarcane were simulated using the sugarcane module of the Agricultural Production Systems Simulator (APSIM) crop model, and soils representative of the Green Hills dam and Dagworth dam irrigation developments. Figure 9.9 illustrates the relationship between applied irrigation water and crop yield assuming perfect irrigation timing (i.e. no losses). Mean sugarcane yields of about 110 to 120 (t/ha) occur at the mean water application rate of 12.5 ML/ha. At applications of less than 12.5 ML/ha, the crop becomes increasingly water stressed and reductions in yield occur as the allocation has insufficient water to meet the crop demand. Reducing water application by 50% from fully irrigated reduces crop yield by about 40%.

The APSIM results presented in Figure 9.9 are modelled production potential under optimum management (i.e. nutrients are not limiting; there is no damage to the crop due to disease, pests, flood, cyclone or poor management practice), for a soil that is representative of a 'sand or loam over relatively friable clay subsoils' (Bartley et al., 2013). This soil type is found in many parts of the case study area (Figure 9.4). The companion technical report about agricultural productivity (Webster et al., 2013) presents sugarcane yield potential for this soil, plus three other generic soil groups identified in the Gilbert catchment from the companion technical report about land suitability (Bartley et al., 2013). The other three soils had higher modelled yield potentials than the 'sand or loam over relatively friable clay subsoils' used in this case study. The median sugarcane yield value of 128 t/ha reported in Section 5.5, is an average of all modelled soils in the Gilbert catchment, and hence is higher than the values reported in this case study.

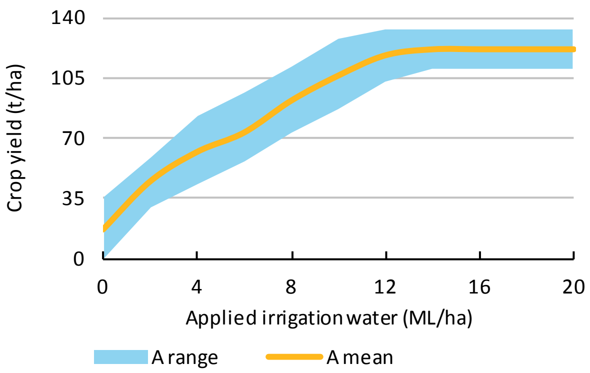


Figure 9.9 Crop yield versus applied irrigation water under Scenario A for sugarcane for a sand or loam over relatively friable clay subsoil

Green Hills Assumes perfect timing of irrigation. Results are an average of the plant crop and four ratoons. Representative of the production potential (i.e. assumes no nutrient limitations or pest damage). Scenario A is the historical climate (1890 to 2011). The range is the 20th to 80th percentile exceedance.

Production risks

Although sugarcane is a generally resilient crop, it will require irrigation through the dry-season climate experienced in the Gilbert catchment. With full irrigation, mean potential crop yields of 110 to 120 t/ha are possible on the 'sand or loam over relatively friable clay subsoils' Gilbert catchment, which are considered good by industry standards. In years when insufficient irrigation water is available through the dry season, there is a risk the crop could be killed. If sugarcane crops are killed, they need to be replanted; if large areas of crop are killed, there can be a whole season of very little sugarcane harvested. Planting is an expensive exercise and, usually, only 20% of a farm would need to be planted each year. Under extreme scenarios where all of the sugarcane is killed, there would be nothing available on-farm to plant (sugarcane is planted vegetatively from existing sugarcane plants). This could be mitigated in part by concentrating the application of any water available to those crops that could supply the material to replant. Analyses later in the chapter, however, show that this would be a rare occurrence under a historical climate scenario and a 16,000 ha planting. The financial consequences of a killed crop are severe.

Sugarcane mills require a critical area of sugarcane to be grown and delivered to remain financially viable. For the operation of a sugarcane mill to be established in the Gilbert catchment, it is crucial that there be enough land, farmers and infrastructure to supply sugarcane sufficient to support the mill. There would be considerable 'ramp up' required in producing enough sugarcane in a district to support a mill, and these costs would need to be factored into establishing a milling enterprise. As with any agricultural industry in the Gilbert catchment, there is very little local expertise or labour force currently in residence. Fortunately, sugarcane growing districts are relatively close and expertise is accessible. In districts with established sugarcane industries, there are fertiliser- and agri–input supply facilities, agronomic advisors, mill staff and a casual labour force (at least ten harvesting contractors would be needed to harvest 1 million t of sugarcane).

Cyclones and flooding would not pose a serious risk to sugarcane production, so long as vulnerable flood areas are avoided. Sugarcane can survive damaging cyclonic winds on the coast (with reduced crop yield and quality from lodging), and strong winds are likely to be much less prevalent and severe in the Gilbert catchment compared to the coast.

Pests, diseases and weeds need to be managed in sugarcane production and, with good management, they do not severely limit crop production. Occasionally, a pest or disease (such as sugarcane smut) can cause district-wide problems, and the Gilbert catchment would be no more or less sensitive to these than existing cane-growing areas.

Soils in the potential irrigation areas may include some soils poor in nutrients. These soils are more difficult to manage, requiring greater monitoring, and fertiliser and ameliorant input. With excessive ploughing, these soils can also have reduced water infiltration rates, resulting in waterlogging and reduced crop yields.

9.6 Financial analysis

This section addresses crop yields, crop gross margins and financial analysis at both farm scale and scheme scale.

The scheme scale analysis assumes that the whole scheme is funded and operated by a single developer who incurs all of the costs and receives all of the benefits of development. The question asked is, are the projected revenues sufficient to cover all expenditures? The strong possibility of different funding and operation models is recognised, but is beyond the scope of this case study.

The farm-scale analysis considers the net benefits after only farm-scale costs are deducted from gross margins. This analysis assumes that the investor purchases irrigation water from a third-party scheme water supplier who bears the scheme's capital and operating costs. Water prices are initially set at zero, but the farm-scale investor's capacity to pay for water is also estimated. This provides an estimate of the extent to which a scheme developer may recoup operation, maintenance or capital costs through water charges.

All financial analyses in this section are reported in 30-year investment windows, as this was the selected investment time frame (see the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013) for a discussion on the choice of investment planning period). Using the 121 years of historical data, the total number of 30-year investment windows is 92. For example, the first 30-year window is 1891 to 1920, and values are calculated for this window. The second window is 1892 to 1921, and a second set of values are calculated for this window. This sampling – and subsequent calculating – was repeated 92 times in total, with the final window corresponding to 1981 to 2011. The median value from calculations for each of the 92 windows is presented. For example, where a mean value is calculated for each of the 30-year windows, the median 30-year mean (M30M) is reported. A straight-line depreciation approach was used to calculate the residual value of long-life infrastructure (i.e. infrastructure with a service life of greater than 30 years). This is a generous assumption compared with the alternative, which is to assume the infrastructure has no value at the end of the investment period.

A commonly used term in this section is 'scheme area'. Scheme area refers to the maximum area that is planted to sugarcane at any one time. In addition to this area, there will be an additional 20% of land under fallow, which is included in the area works calculation.

Two financial analyses are presented. The first analysis (in Section 9.6.1) explores an appropriate scheme area for the irrigation development. Because sugarcane is a perennial crop, typically lasting five years (the plant crop plus four ratoons), it is not realistic to change the planted area each season based upon the water level in the dam reservoir, as occurred in analyses of annual crops in other case studies. It is assumed that land is not a constraint and that all capital costs were incurred in the first year. It also assumes a local mill at Georgetown.

In the second analysis (in Section 9.6.2), a single scheme area is selected, based on scheme- or farm-scale profitability, minimum size to support additional processing infrastructure (such as a sugar mill in this case study) or the availability of suitable land.

Because there are two irrigation developments being examined, one supplied by the Green Hills dam and one supplied by the Dagworth dam, the results are presented as column charts for each development as well as contour plots for both the Green Hills and Dagworth scheme areas. The selected scheme areas for one or both irrigation developments are then chosen based upon scheme- or farm-scale profitability, or minimum crop size required to support additional processing infrastructure mentioned in the storyline, in this case a sugar mill.

9.6.1 DIFFERENT COMBINATIONS OF SCHEME AREA FOR GREEN HILLS DAM AND DAGWORTH DAM IRRIGATION DEVELOPMENTS

In this section information is presented on how much water is applied to the crop, reservoir behaviour and change to the downstream median flow for different combinations of scheme-area for the Green Hills and Dagworth dam irrigation developments. Information is then presented on crop yield and gross margins and NPV and IRR at both the scheme-scale and farm-scale.

Water supply, reservoir characteristics and changes in downstream flow

Figures of the style presented in Figure 9.10 allow the reader to explore different combinations of scheme area for the Green Hills dam and Dagworth dam irrigation developments. For example in Figure 9.10a, if the scheme area of the Dagworth dam irrigation development is 10,000 ha and the scheme area of the Green Hills dam irrigation development is 5,000 ha, then their combined mean annual applied irrigation water is about 160,000 ML. Similarly, if the scheme area for Dagworth dam irrigation development is 16,000 ha and the Green Hills dam irrigation development did not exist (i.e. a scheme area of 0 ha), then the mean annual applied irrigation water would be about 160,000 ML.

The larger the scheme area, the larger the total volume of water supplied to and used by the irrigation development (Figure 9.10a), but the lower the amount of water supplied to each hectare of the crop (Figure 9.10b).

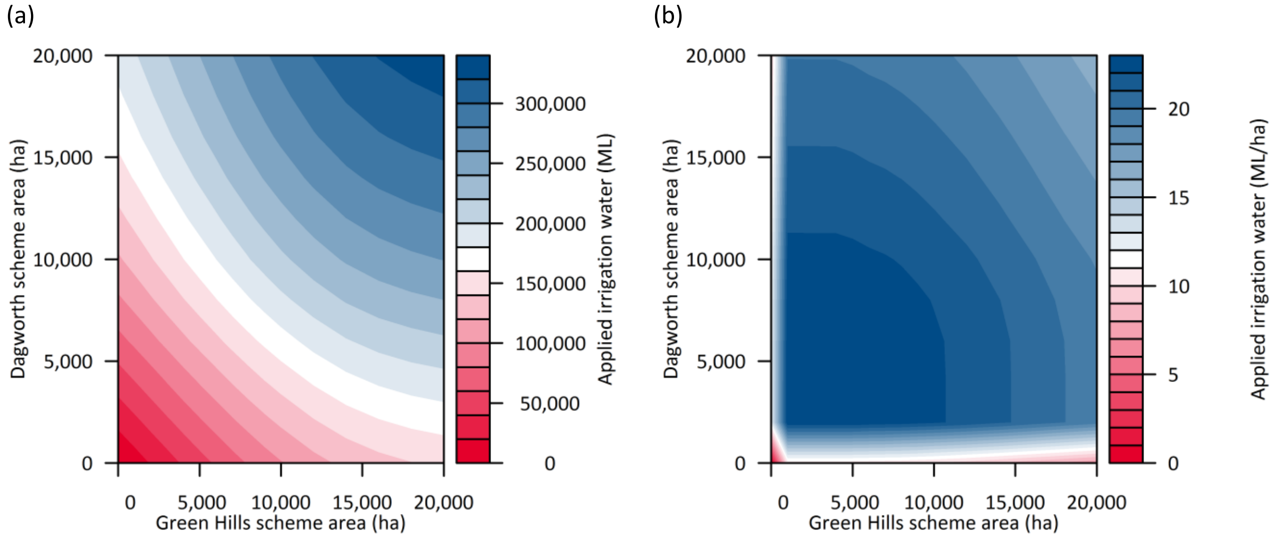


Figure 9.10 (a) Mean annual total applied irrigation water supplied to the field (ML) and (b) ML applied per hectare under Scenario B for the irrigation developments associated with Green Hills and Dagworth dams
Applied irrigation water is the water supplied from the dam, with the losses from river conveyance, channel distribution and field application removed. Scenario B is the historical climate (1890 to 2011) with irrigation development.

Figure 9.11 presents the ratio of water lost to evaporation to water supplied at the dam wall for Green Hills and Dagworth dams. With low scheme areas, water is not fully used and, if water is carried over to the following year, a large amount of water is lost to evaporation. With high scheme areas, the ratio of evaporation to supply is low because all available water is used every year (i.e. reservoir is treated as within-year storage).

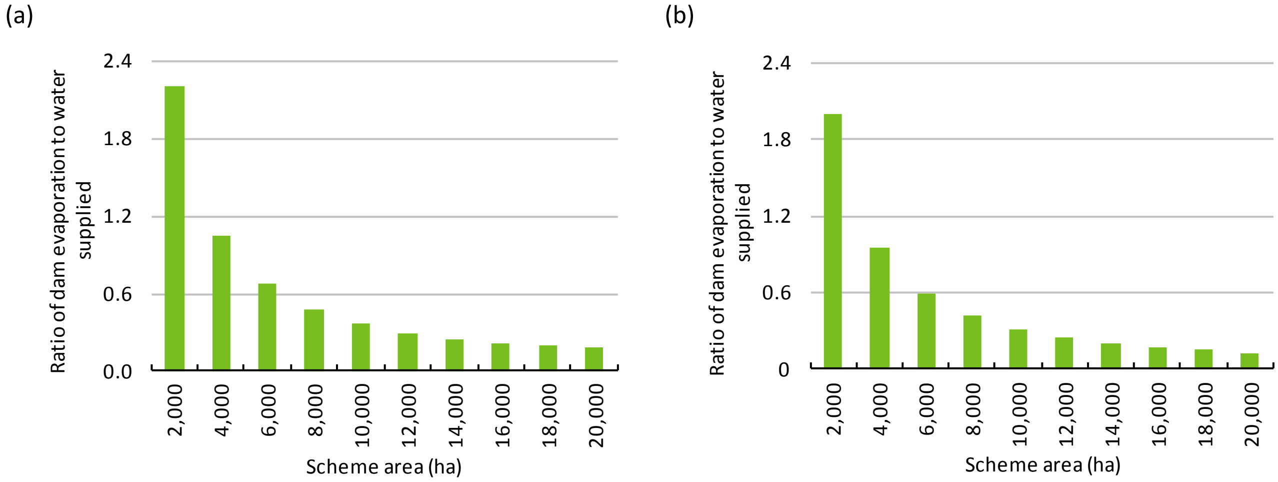


Figure 9.11 Ratio of evaporation from the reservoir to the applied irrigation water under Scenario B for (a) Green Hills dam and (b) Dagworth dam
Applied irrigation water is the water supplied from the dam, with the losses from river conveyance, channel distribution and field application removed. Scenario B is the historical climate (1890 to 2011) with irrigation development.

Figure 9.11 shows the percentage of time that the Green Hills and Dagworth dam reservoirs are less than 20% of its full supply level (FSL) volume. This provides an indication of the recreational amenity of these reservoirs. For example, for scheme areas greater than 20,000 ha, both reservoirs are less than 20% full for more than 25% of the time. In these circumstances, there may be reduced opportunity to use the reservoirs recreationally.

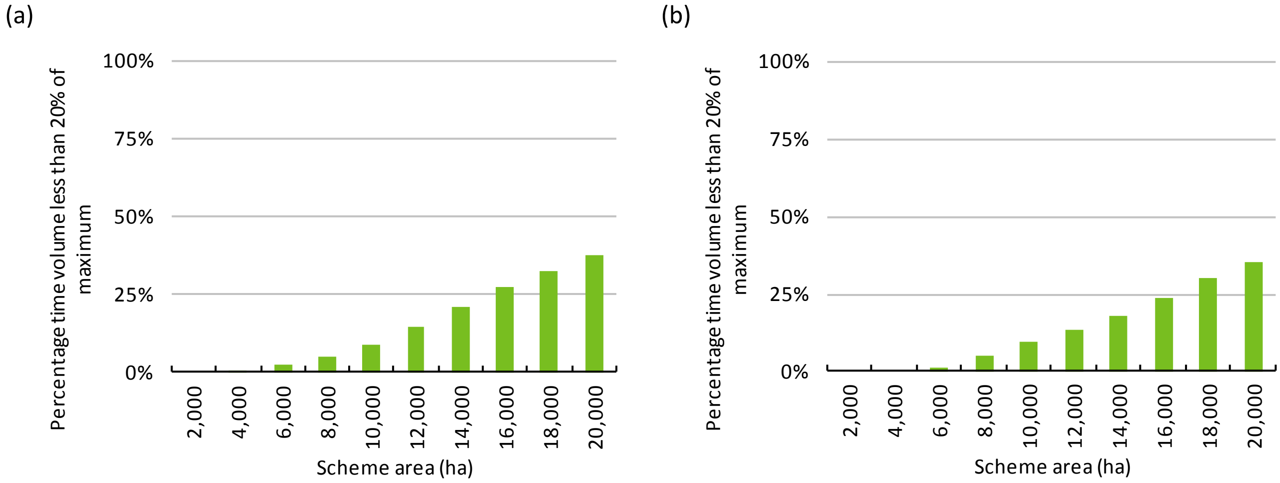


Figure 9.12 Percentage of time the volume of the reservoir is less than 20% of the full supply level volume under Scenario B for (a) Green Hills dam and (b) Dagworth dam
Scenario B is the historical climate (1890 to 2011) with irrigation development.

Figure 9.13 shows the median annual flow quotient at locations just below the irrigation areas for both the Green Hills dam and Dagworth dam. This provides an indication of the extent to which the median annual streamflow may change under different size irrigation developments. The smaller the number the larger than change in median annual streamflow. The median annual streamflow quotient is between 0.62 and 0.88 below the Green Hills dam irrigation development at 917001D and between 0.7 and 0.9 below the Dagworth dam irrigation development (virtual gauge 355).

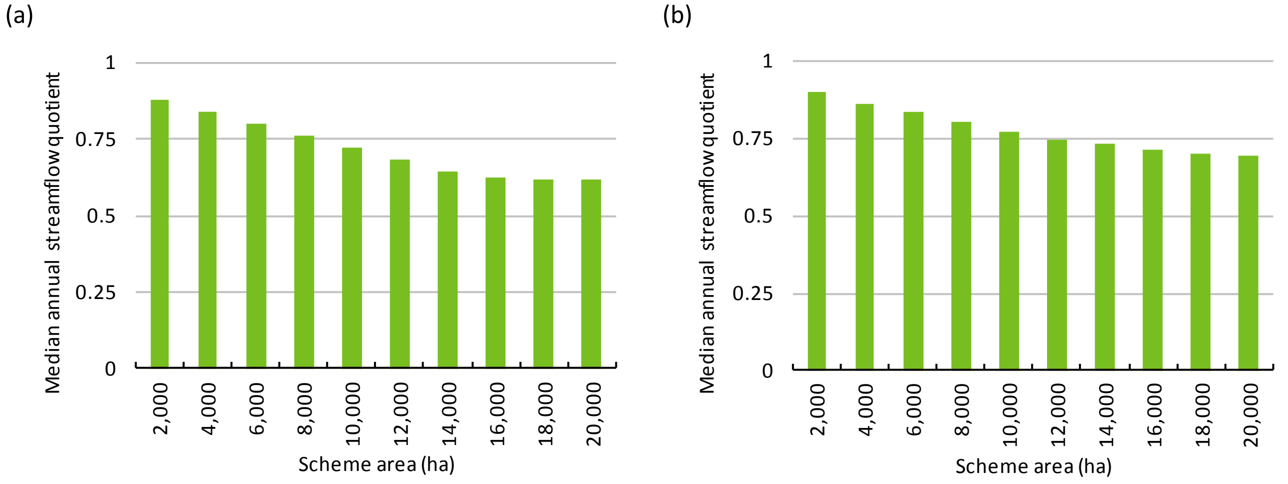


Figure 9.13 Median streamflow quotient at (a) Green Hills dam (gauge 917001D) and (b) Dagworth dam (virtual gauge 355)

Median streamflow quotient is the median annual streamflow under Scenario B divided by the median annual streamflow under Scenario A. Scenario A is the historical climate (1890 to 2011) and current development. Scenario B is the historical climate (1890 to 2011) with irrigation development. Location of streamflow gauging stations shown on Figure 9.2

Crop yield

Larger scheme-scale median 30-year crop yields are attained for larger scheme areas. Because sugarcane yield declines by only 40% with a 50% reduction in irrigation volume from that required for maximum yield (Figure 9.14a), larger scheme-scale median 30-year yields are attained at high scheme areas even if there is insufficient water to meet full irrigation needs. However, the variability in 30-year crop yields is high and increases for larger scheme areas (Figure 9.14b).

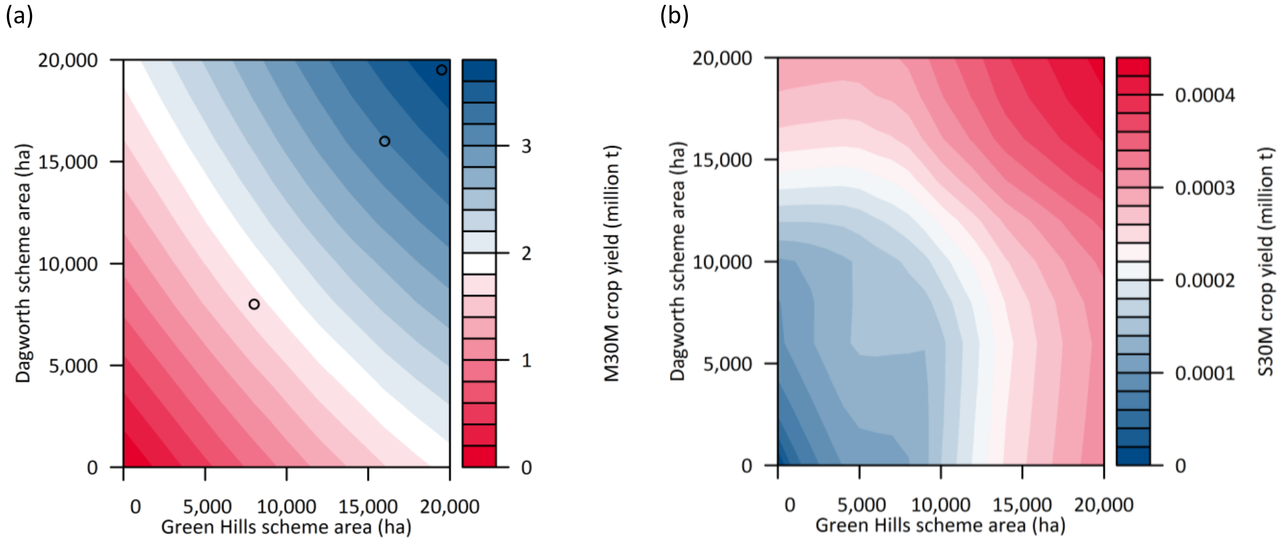


Figure 9.14 (a) Median of the 30-year mean (M30M) values for crop yield and (b) standard deviation of the 30-year mean values (S30M) for crop yield, under Scenario B for the irrigation development associated with the Green Hills and Dagworth dams. Circles in (a) correspond with lines in Figure 9.15

Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows from 1890 to 2011. Both the median and the standard deviation of the mean values for each of the 92 windows are presented.

The higher crop yields and higher variability for larger scheme areas are illustrated in Figure 9.15. Although the combined 16,000-ha of sugarcane (i.e. 8000-ha at Green Hills irrigation development and 8000-ha at Dagworth irrigation development) has the lowest combined crop yield, there is always sufficient water in the dam to ensure a constant supply of sugarcane from the two irrigation developments. Larger scheme areas have larger yields but also exhibit large variation.

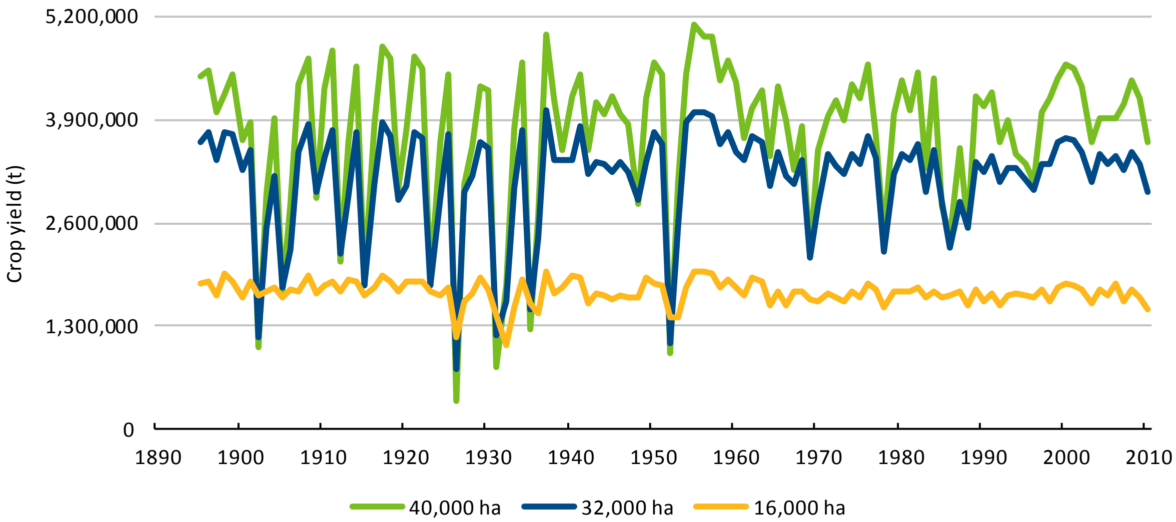


Figure 9.15 Crop yield from the combined scheme area under Scenario B for three different scheme areas marked in Figure 9.14a

Lines correspond with circles in Figure 9.14 Note that the crop yields are the combined crop yields of the Dagworth dam and Green Hills dam irrigation developments.

Figure 9.16a illustrates the percentage of years that 2 million t of sugar cane is exceeded in the two irrigation developments. For example, if each irrigation development had a scheme area of 5000 ha, their combined production does not exceed 2 million t of sugarcane in any year. If each irrigation development had a scheme area of 16,000 ha, their combined production would exceed 2 million t of sugarcane in more than 95% of the years. The median 30-year mean specific yield (i.e yield per hectare) is presented in Figure 9.16b. If Green Hills and Dagworth irrigation developments each had a scheme-area of 16,000 ha the M30M specific yield (yield per hectare) is between 100 and 105 t/ha. This is lower than the mean crop yield per hectare under modelled production potential (Figure 9.9) because water is limiting crop yield in some years.

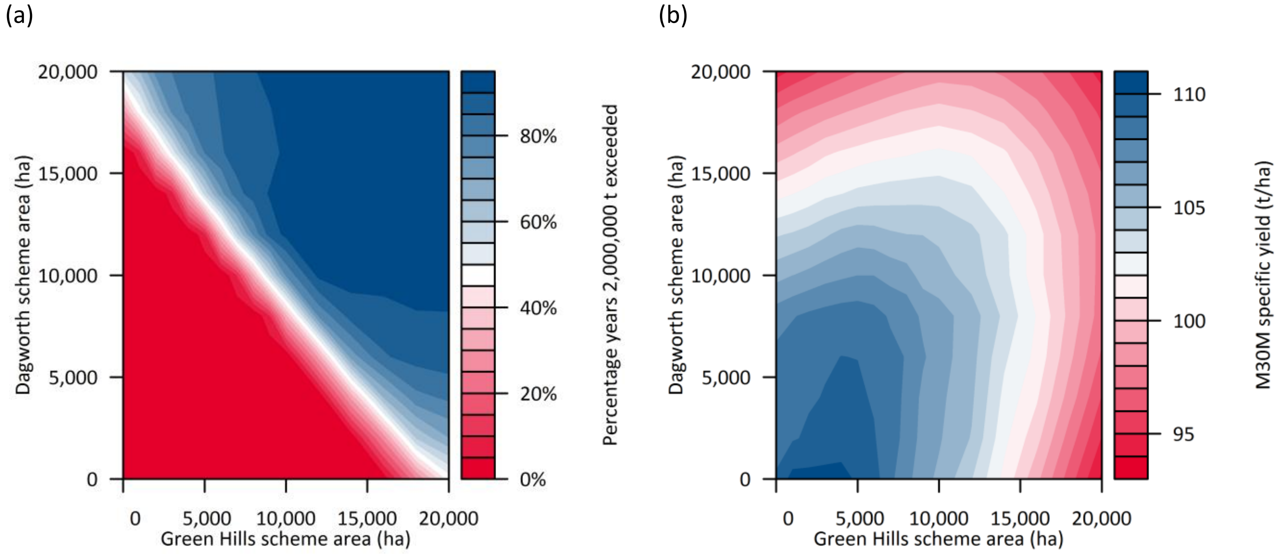


Figure 9.16 (a) Median of the 30-year mean values (M30M) for specific yield and (b) percentage of time 2 million t of sugarcane is exceeded under Scenario B for the irrigation developments associated with the Green Hills and Dagworth dams
Scenario B is the historical climate (1890 to 2011) with irrigation development.

Crop gross margins

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

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

Water charges are also a variable cost when charged on a $/ML basis, but are omitted from the gross margin calculations here because water costs are not known. Instead, as part of this financial analysis, farmers' capacity to pay a water charge is determined. The crop gross margin is calculated using simulated crop yield and water use. Table 9.8 lists the key assumptions in the gross margin calculations for sugarcane used in this analysis. For details on crop gross margin calculations, see the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013).

Table 9.8 Key assumptions in the gross margin calculations for sugarcane
See Brennan McKellar et al. (2013) for more detail.

KEY ASSUMPTIONS	VALUE	COMMENTS
Sugarcane price ($/t)	$39, $45	Default and maximum price
Variable costs		
Harvest and transport to siding ($/t)	$8.20	
Siding to mill ($/t)	$0	Mill responsible for costs
Pumping cost ($/ML)	$58.90	Spray irrigation, diesel
Other ($/ha)	$642	Average for all plant crop, ratoons and fallow. Details provided in Brennan McKellar et al. (2013)

Figure 9.17a shows that total scheme-scale gross margins are higher at larger scheme areas because the gross margin per hectare is being multiplied over larger areas. Figure 9.17b shows the median 30-year gross margin per hectare.

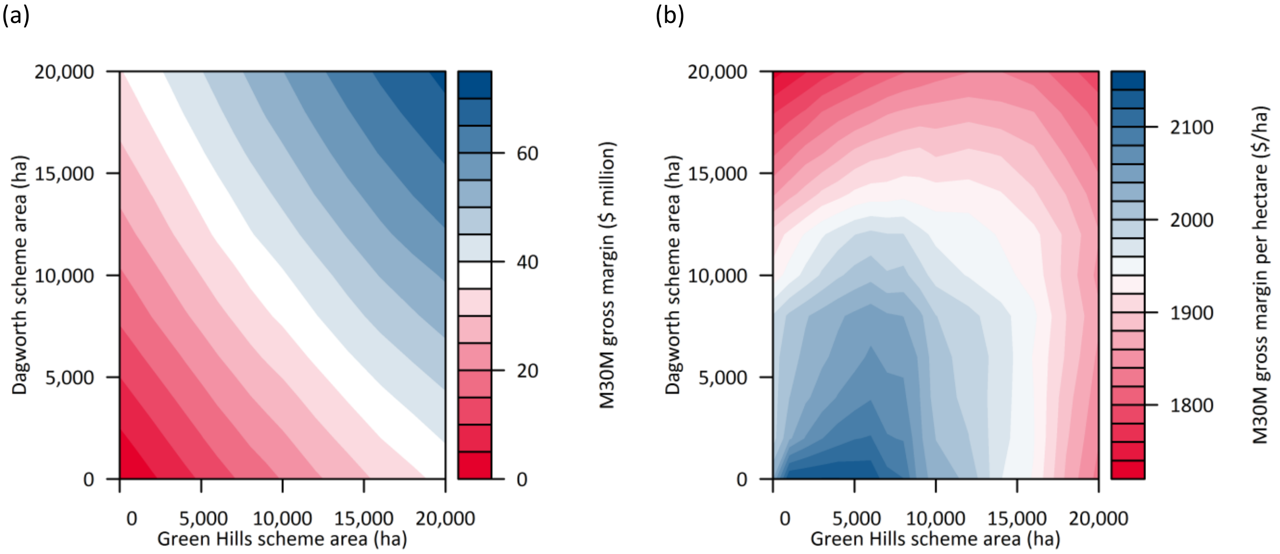


Figure 9.17 (a) Median of the 30-year mean (M30M) values for crop gross margin and (b) M30M values for gross margin per hectare under Scenario B for the irrigation developments associated with the Green Hills and Dagworth dams

Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows from 1890 to 2011. The median of the mean values for each of the 92 windows are presented.

Whole-of-scheme net present value

As a new capital project requiring investment in equipment and infrastructure, the irrigation development is assessed for the costs expended and benefits incurred over a 30-year project life. When the costs for this period are subtracted from the benefits to give a net benefit stream, a discount rate of 7% is applied to yield a NPV for the development. A zero or positive NPV value indicates that the scheme is profitable at the specified discount rate.

The whole-of-scheme NPV calculation takes into consideration the scheme- and farm-scale capital, operational and maintenance costs, and scheme-scale gross margins. Asset replacement and residual values are considered within the 30-year project period. Further details on the framework for discounted cash-flow financial analysis and assumptions are presented in the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013).

The scheme-scale NPV is negative under all combinations of scheme areas, because the revenue generated from the scheme (total crop gross margins) does not offset the capital, operation and maintenance costs of the scheme-scale and on-farm infrastructure for the life of the investment (Figure 9.18a). Therefore, losses are minimised by not developing an irrigation development.

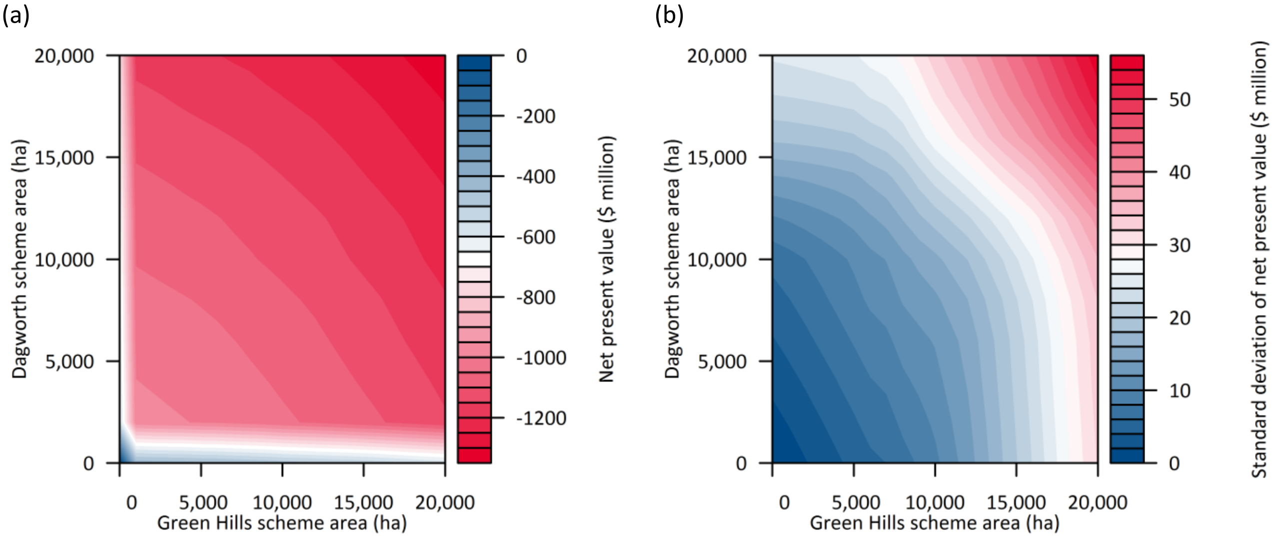


Figure 9.18 a) Median of the 30-year mean (M30M) values for scheme-scale net present value and (b) standard deviation of the 30-year mean (S30M) values for scheme-scale net present value under Scenario B for the irrigation developments associated with the Green Hills and Dagworth dams

Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows from 1890 to 2011. The median and the standard deviation of the mean values for each of the 92 windows are presented.

Farm-scale net present value

A situation may arise involving independent funding and ownership of off-farm (water storage and transmission) and on-farm (land, equipment) development capital.

In these circumstances, investment decisions made by irrigators could be confined to consideration of on-farm costs only. For this purpose, the NPV of an on-farm investment is calculated. This calculation considers the capital, annual operating and maintenance (overhead) costs of on-farm infrastructure. The capacity to contribute to scheme-scale operation and maintenance costs, and possibly capital costs, through a water price depends on the extent to which the NPV is positive.

In this case study, the total crop gross margins are sufficient to cover the capital and overhead costs over the investment period (Figure 9.19). The largest farm-scale NPVs occur when each irrigation development has a scheme area of 16,000 ha.

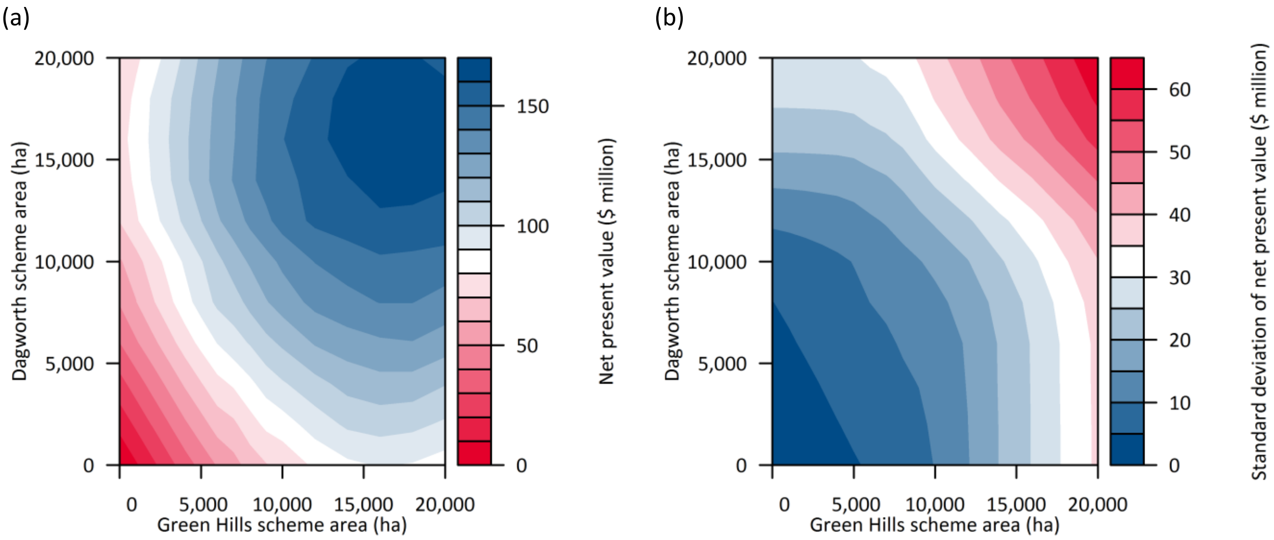


Figure 9.19 Median of the 30-year mean values for farm-scale net present values and (b) standard deviation of the 30-year mean values for farm-scale net present value, under Scenario B for the irrigation developments associated with the Green Hills and Dagworth dams
Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows from 1890 to 2011. The median and the standard deviation of the mean values for each of the 92 windows are presented.

9.6.2 DETAILED ANALYSIS FOR A GIVEN SCHEME AREA

To allow more detailed investigation, a scheme area of 16,000 ha (with an extra 20% fallow at any one period in time) was selected for each of the Green Hills dam and Dagworth dam irrigation developments. For this analysis, construction costs were staged during the first three years of the 30-year investment time period (Table 9.9). This is likely to be a more realistic assumption, compared with assuming that all costs are incurred and full revenue is attained in the first year. Furthermore, for this case study, staging construction costs is about 10% more profitable than without staging.

Table 9.9 Staging of construction, farm development and crop production

YEAR NUMBER	CONSTRUCTION PROGRAM	FARM DEVELOPMENT	CROP PRODUCTION
1	50% dam costs; 100% approvals and legal costs		
2	50% dam costs; 50% area work costs	50% farm development	
3	50% area works costs	50% farm development	50% revenue
4			100% revenue

Gross margins

Figure 9.20 (Green Hills dam) and Figure 9.21 (Dagworth dam) present a time series of annual gross margins ($/ha) simulated using APSIM for each year of the 121-year historical climate record, assuming various market prices for sugarcane. On the right-hand side of the plot, the range of gross margins for each sugarcane price assumption is indicated by a black vertical line and the median (50th percentile) is indicated by the black horizontal line. The top and bottom of the coloured box indicates the gross margin at the 25th and 75th percentile. The large difference between the 75th percentile and the minimum gross margin indicates that relatively few very low gross margins were simulated.

Gross margins per hectare are notably higher at the Dagworth dam irrigation development than at the Green Hills dam irrigation development because of the larger volume of water that can be supplied from the Dagworth dam and the higher the crop yield per unit water at the Dagworth dam irrigation development.

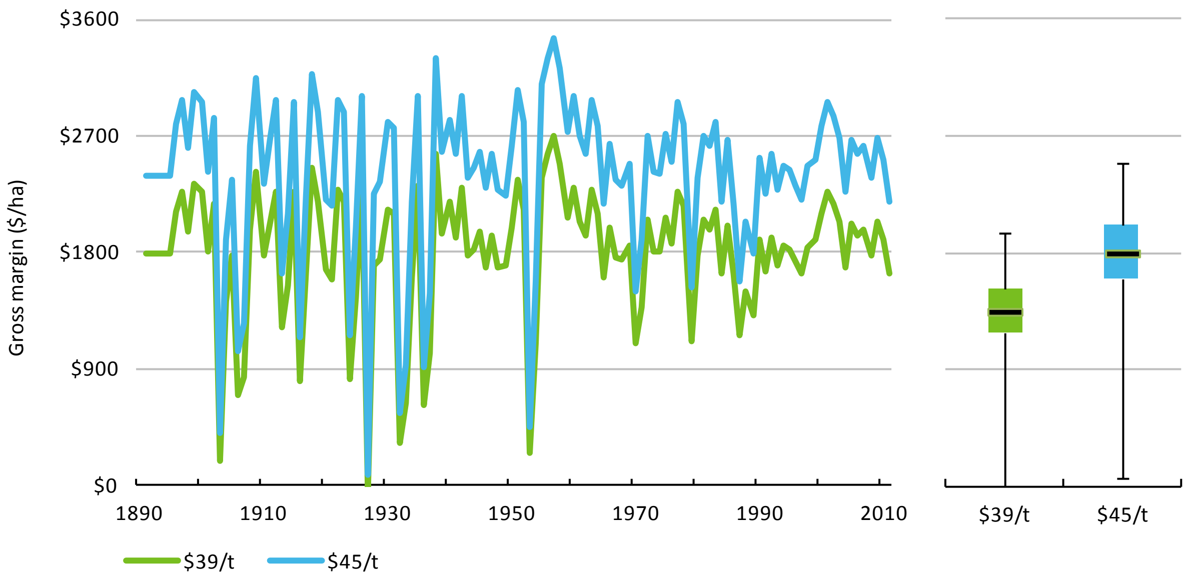


Figure 9.20 Gross margins for sugarcane ($/ha) under Scenario B for the irrigation development associated with Green Hills dam: (a) time series and (b) box plot

Scenario B is the historical climate (1890 to 2011) with irrigation development. Results are shown for both the default price of sugarcane ($39/t) and the highest price paid in the past 10 years ($45/t). In (b), the mean for each price is indicated by the black horizontal line, and the range is indicated by the black vertical line. The top and bottom of the coloured boxes indicate the 25th and 75th percentile, respectively.

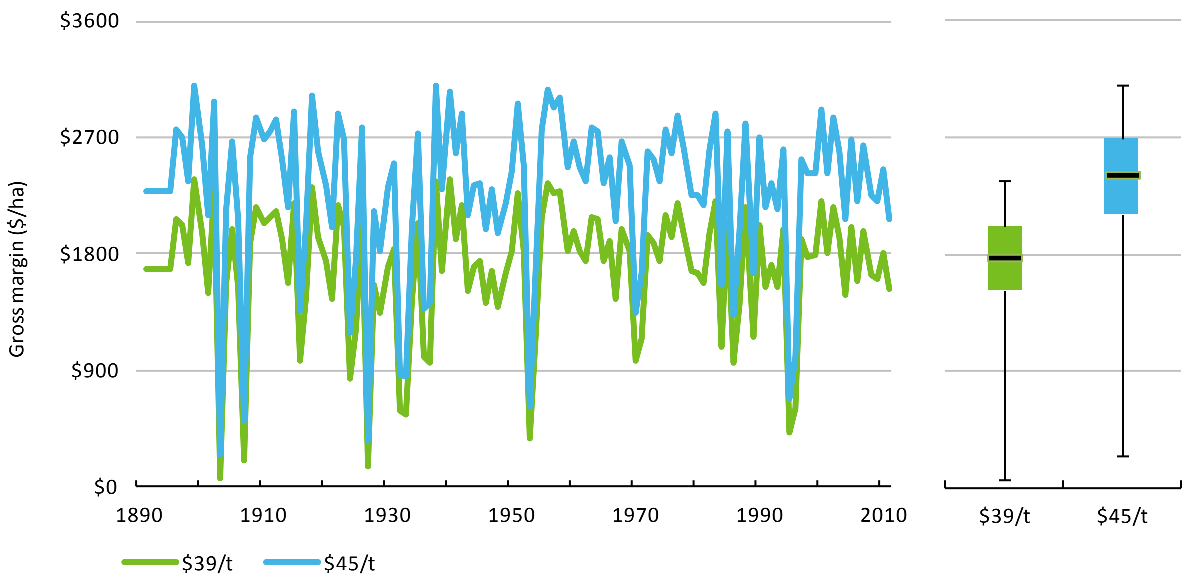


Figure 9.21 Gross margins for sugarcane ($/ha) under Scenario B for the irrigation development associated with Dagworth dam: (a) time series and (b) box plot

Results are shown for both the default price of sugarcane ($39/t) and the highest price paid in the past 10 years ($45/t). In (b), the mean for each price is indicated by the black horizontal line, and the range is indicated by the black vertical line. The top and bottom of the coloured boxes indicate the 25th and 75th percentile, respectively.

A range of other costs could also impact on the gross margin. If, for example, sugarcane had to be delivered to a distant mill, then the cost of transport may need to be incorporated into the gross margin calculation. This is examined below. It should also be noted that the gross margins presented in Figure 9.20 and Figure

9.21 do not include a water charge ($/ML). This is, however, another cost that would be expected to be reflected in the gross margin.

Scheme-scale analysis

Using the 121-year distribution of simulated gross margin outcomes presented in Figure 9.20, it was possible to sample 30-year gross margin windows and calculate the NPV of the income stream after accounting for scheme-scale, and on-farm capital and annual operating costs in a 30-year investment planning period. In addition to NPV, IRR was calculated. The IRR represents the break-even discount rate – that is, the discount rate that will bring the NPV to zero. A viable investment has an internal rate of return higher than the discount rate.

The purpose of sampling from the 121-year distribution is to show how the overall investment performance is sensitive to the particular set of underlying climate conditions during the 30-year investment period.

For this analysis, it is assumed that there is a sugar mill in Georgetown. The cost of construction and operating a mill is not included in the analysis.

9.6.2.1.1 Green Hills

The ninety-two 30-year NPV and IRR values are presented in Figure 9.22 as percentage exceedance plots. All of the NPVs are negative (Figure 9.22a), ranging from –$460 million to –$545 million for the default price for sugarcane, and from –$345 million to –$450 million for the high prices. In other words, the cost of the investment exceeds the income over the 30-year investment period, for all 92 investment periods. The IRR is negative at the default and high price (Figure 9.22b). For the Green Hills dam irrigation development, to break even at a 7% discount rate (i.e. NPV equal to zero) the price of sugarcane would need to be $68/t assuming a sugar mill in Georgetown.

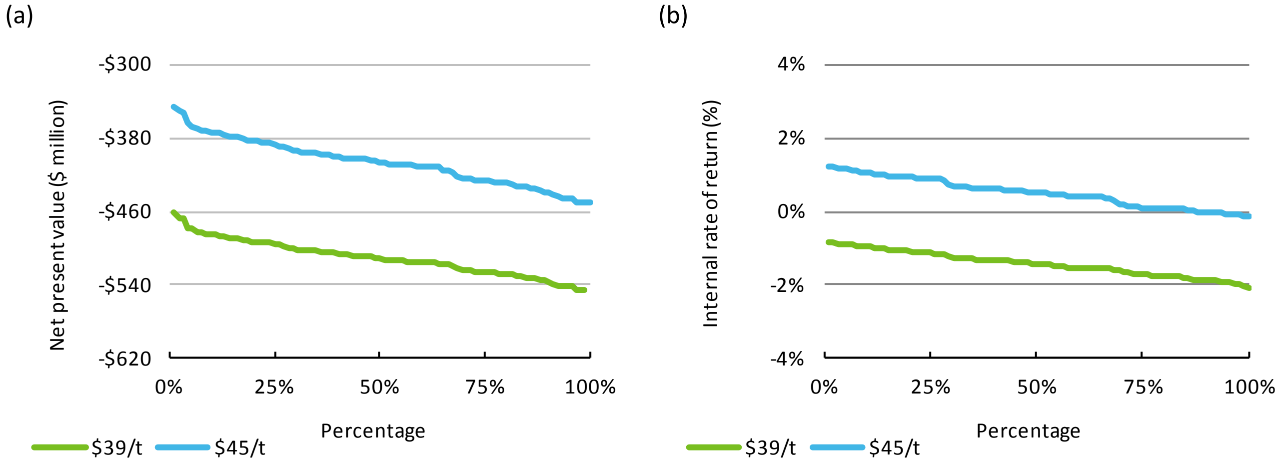


Figure 9.22 Percentage exceedance plots of (a) net present value and (b) internal rate of return under Scenario B for the scheme-scale irrigation development of 16,000 ha associated with the Green Hills dam
This financial analysis includes all scheme-scale and farm-scale capital and operating costs, and income from crop gross margins. Values are for a 30-year investment period.

9.6.2.1.2 Dagworth

The ninety-two 30-year NPV and IRR values are presented in Figure 9.23 as percentage exceedance plots. All of the NPVs are negative, ranging from –$605 million to –$685 million for the default prices for sugarcane, and from –$490 million to –$590 million for the high prices. In other words, the cost of the investment exceeds the income over the 30-year investment period, for all 92 investment periods. For the Dagworth dam irrigation development to break even at a 7% discount rate (i.e. NPV equal to zero) the price of sugarcane would need to be $76/t, assuming a sugar mill in Georgetown.

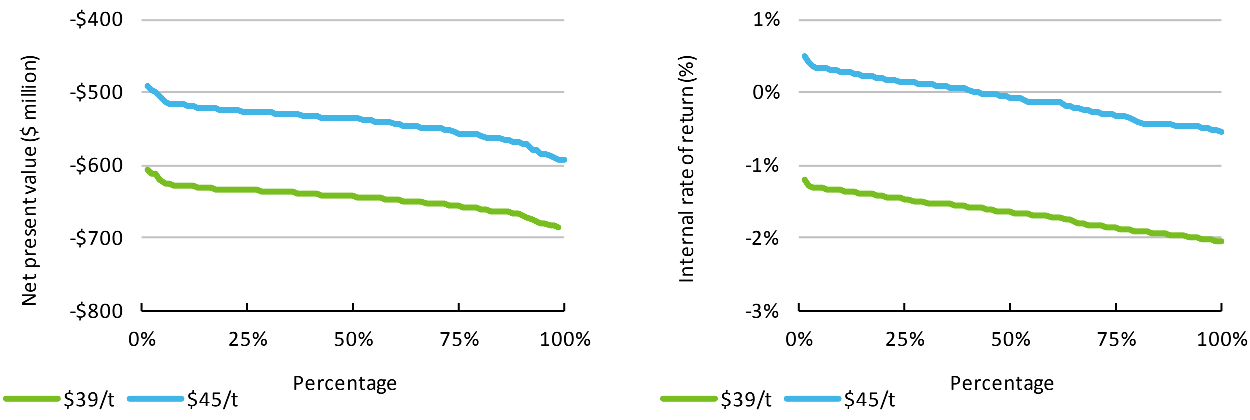


Figure 9.23 Percentage exceedance plots of net present value, under Scenario B for the scheme-scale irrigation development of 16,000 ha associated with the Dagworth dam
This financial analysis includes all scheme-scale and farm-scale capital and operating costs, and income from crop gross margins. Values are for a 30-year investment period.

The scheme-scale NPVs are more negative for the Dagworth dam irrigation development than the Green Hills dam irrigation development because the Dagworth dam infrastructure costs are larger and this is only partially offset by higher scheme-scale gross margins.

The financial analyses are restricted to the question of whether projected revenues from the sale of sugarcane are sufficient to cover the costs of irrigation development and sugarcane production. An alternative investment perspective would produce different financial outcomes – for example, in an integrated growing and milling investment, sugarcane would be an input in the generation of products that could provide revenues from sugarcane milling, such as electricity, sugar, and ethanol. No particular investment model is proposed as performing better than another. This case study did not extend to these alternative options, but investigation of alternatives could build on the analyses presented here.

Farm-scale analysis

In the farm-scale analysis, all capital, operation and maintenance costs associated with the scheme-scale infrastructure are excluded from this analysis. Similar to the scheme-scale analysis, financial assessments are undertaken using 30-year windows and, unless otherwise stated, it is assumed there is a sugar mill in Georgetown.

9.6.2.1.3 Green Hills

The results in Figure 9.24a indicate that this investment at this scale is viable under the default prices, as all NPVs are positive. At the default price and high price, the IRR ranges between 8% and 23%, and 17% and 37%, respectively (Figure 9.24b).

For the default crop prices and for the median 30-year NPV, the investor could pay $34/ML for irrigation water and break even (i.e. an NPV of zero). Consequently, investors have some capacity to pay a water charge to help offset the operation and maintenance costs of the scheme.

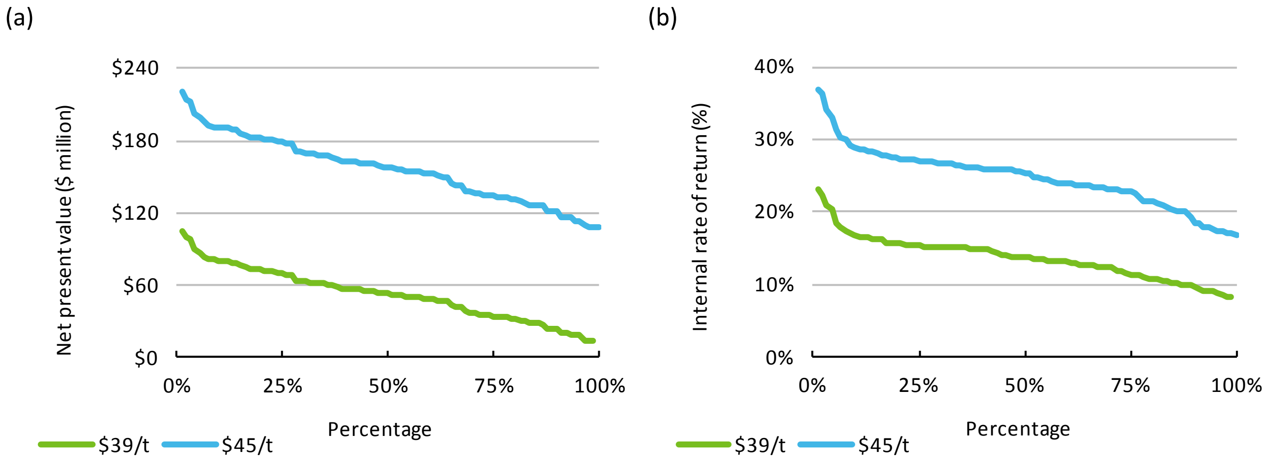


Figure 9.24 Percentage exceedance plots of (a) net present value and (b) internal rate of return under Scenario B for the farm-scale irrigation development of 16,000 ha associated with the Green Hills dam
This financial analysis includes farm-scale capital and operational costs, and crop gross margins. Values are for a 30-year window internal rate of return.

9.6.2.1.4 Dagworth

The results in Figure 9.25a indicate that this investment at this scale is viable under the default prices, as all NPVs are positive. At the default price and high price, the IRR ranges between 6% and 18%, and 15% and 32%, respectively (Figure 9.25b).

For the default crop prices and for the median 30-year NPV, the investor could pay $24/ML for irrigation water and break even (i.e. an NPV of zero). Consequently, investors have some capacity to pay a water charge to help offset operation and maintenance costs of the scheme.

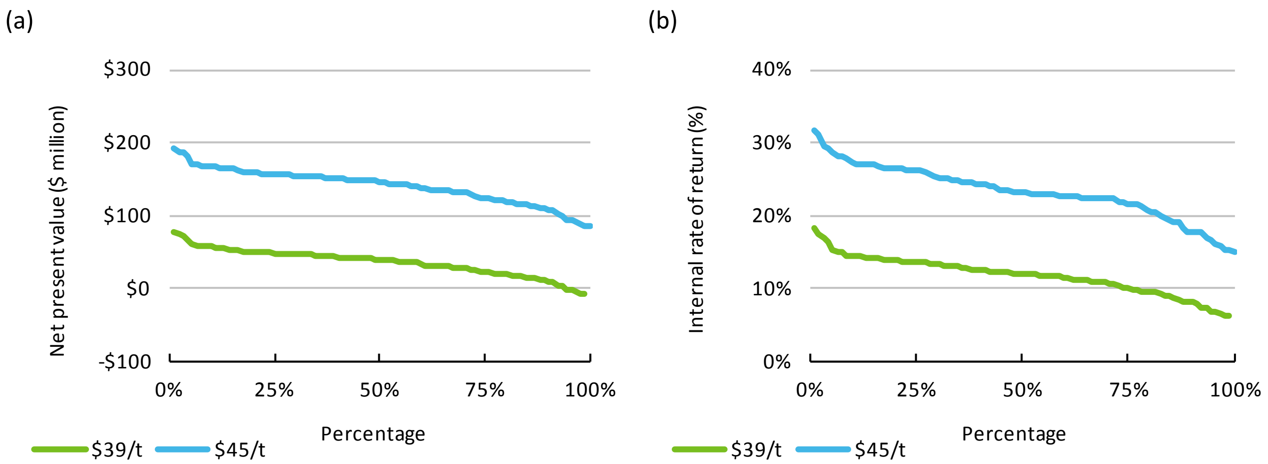


Figure 9.25 Percentage exceedance plots of (a) net present value and (b) internal rate of return under Scenario B for the farm-scale irrigation development of 16,000 ha associated with the Dagworth dam
This financial analysis includes farm-scale capital and operating costs, and crop gross margins. Values are for a 30-year window internal rate of return.

The effect of transport to processing facility on the investment

The TRAnsport Network Strategic Investment Tool (McFallan et al., 2013) was used to calculate the cost of transporting sugarcane from the case study areas to Mareeba (Brennan McKellar et al., 2013). The impact of transporting sugarcane from the irrigation developments associated with Green Hills dam and Dagworth dam to Mareeba are illustrated in Table 9.10 and Table 9.11.

Two alternatives are explored. In the first, the grower pays 50% of the transportation cost to the Mareeba mill and the mill pays the other 50% of the transportation costs. In the second alternative, the grower pays 100% of the transportation cost to Mareeba. These are compared to the default alternative of a new mill in Georgetown.

Table 9.10 The impact of transporting sugarcane from the irrigation development associated with Green Hills dam to Georgetown and Mareeba

MILL LOCATION	COST ($/t)	% PAID BY GROWER	M30M SUGARCANE GROSS MARGIN ($/ha)	MEDIAN 30-YEAR NET PRESENT VALUE ($ million)	CAPACITY TO PAY WATER CHARGE ($/ML)	M30M SUGARCANE GROSS MARGIN ($/ha)	MEDIAN 30-YEAR NET PRESENT VALUE ($ million)	CAPACITY TO PAY WATER CHARGE ($/ML)	BREAK-EVEN PRICE ($/t)
			Default price ($39/t)			Default price ($45/t)			
Georgetown	na	na	$1,873	$53	$34	$2,498	$159	$102	$36
Mareeba	$67	50%	−$1,591	−$538	−$343	−$956	−$432	−$276	$69
Mareeba	$67	100%	−$5,103	−$1,129	−$721	−$4,487	−$1,023	−$653	$103

M30M = median of the 30-year mean; na = not applicable.

Table 9.11 The impact of transporting sugarcane from the irrigation development associated with Dagworth dam to Georgetown and Mareeba

MILL LOCATION	COST ($/t)	% PAID BY GROWER	M30M SUGARCANE GROSS MARGIN ($/ha)	MEDIAN 30-YEAR NET PRESENT VALUE ($ million)	CAPACITY TO PAY WATER CHARGE ($/ML)	M30M SUGARCANE GROSS MARGIN ($/ha)	MEDIAN 30-YEAR NET PRESENT VALUE ($ million)	CAPACITY TO PAY WATER CHARGE ($/ML)	BREAK-EVEN PRICE ($/t)
			Default price ($39/t)			Default price ($45/t)			
Georgetown	na	na	$1,779	$40	$24	$2,417	$145	$86	$37
Mareeba	$81	50%	−$2,459	−$667	−$395	−$1,834	−$562	−$333	$77
Mareeba	$81	100%	−$6,715	−$1,373	−$814	−$6,100	−$1,269	−$752	$118

M30M = median of the 30-year mean; na = not applicable.

For both the irrigation developments and for the default price, the median 30-year NPV is only positive when a mill is located in Georgetown.

To be profitable to transport sugarcane from the Green Hills irrigation development to a mill in Mareeba, the price of sugarcane would need to be $69/t if the mill paid 50% of the transport costs and $103/t if the grower had to pay all of the transport costs. To be profitable to transport sugarcane from the Dagworth irrigation development to a mill in Mareeba, the price of sugarcane would need to be $77/t if the mill paid 50% of the transport costs and $118/t if the grower had to pay all of the transport costs.

9.7 On-site and off-site impacts

Prior to irrigation development, the area would require more intensive assessment of any ecological impacts. This section provides an overview of some of the potential on-site and off-site impacts that may result from each of the irrigation developments analysed in Section 9.6.2. More detailed analysis of these issues is beyond the scope of this case study.

9.7.1 RISK OF RISE IN WATERTABLE LEVEL AND SECONDARY SALINISATION

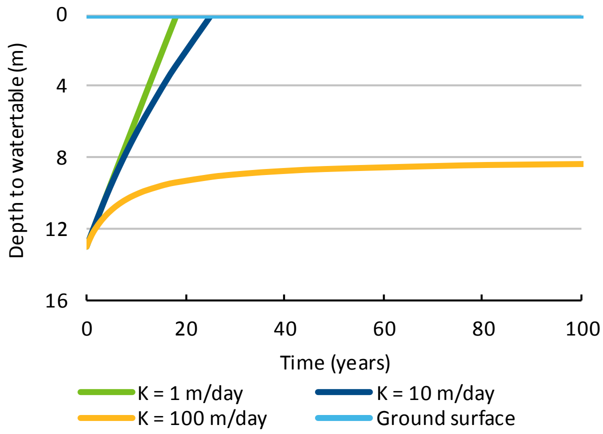
Based on the best available information, a rise in watertable level is thought to be unlikely under a well-managed irrigation development associated with the Green Hills dam. Furthermore, there is little evidence of salt accumulation in the highly permeable soils and substrata. A rise in watertable level is thought more likely to occur under the more variable soils of the irrigation development associated with Dagworth dam. More detailed investigations would be required.

The rise in groundwater levels (Figure 9.26) was assessed using an analytical groundwater model developed as part of the Assessment. The irrigation development is assumed to commence 2 km from the river, allowing for a riparian buffer. A size of 14,400 ha is assessed because this is about the size of the larger of the two Dagworth irrigation development polygons delineated in Figure 9.1 and Figure 9.2. Recharge is calculated using annual simulated irrigation and rainfall data under Scenario B (see Jolly et al., 2013). The parameters and their values used in the analytical model are listed in Table 9.12. No field-based measurements of aquifer parameters were available for this part of the Gilbert catchment. The values used in Table 9.12 are considered a likely range, based on bore log information (Section 2.2). For more detail, see companion technical report about surface water – groundwater connectivity (Jolly et al., 2013).

Table 9.12 Range of parameter values used in analytical groundwater model at Dagworth dam and Green Hills dam irrigation developments

AQUIFER PARAMETER	VALUE	COMMENT
Aquifer thickness	29 m	
Depth to groundwater	13 m	
Distance from river	2 km	
Recharge rate	131 and 215 mm/year	Lower and higher estimate. Recharge as a result of irrigation and rainfall
Saturated hydraulic conductivity (K)	1, 10 and 100 m/day	Lower, middle and higher estimate
Specific yield	0.2	Only has bearing on rate of rise, not maximum rise

It is thought unlikely that the watertable would rise close to the ground surface under well-managed irrigation on sand or loam over friable or earthy clay soils adjacent to the Gilbert and Einasleigh rivers. This is because these soils are highly permeable, and as a consequence have low salt concentrations, as evident from soil, bore log and airborne electromagnetic data. The saturated hydraulic conductivity of these soils and their substrate is likely to be closer to 100 m/day than 10 m/day. Hence under these assumptions, the drainage capacity of the aquifer is higher, which results in a slower rise in the watertable (Figure 9.26). On those parts of the Dagworth irrigation development with heavier soils there is a greater risk of watertable rise. Irrigation developments further from these rivers are also likely to have a greater risk of watertable rise as they will have a lower drainage capacity (see Section 7.2). More detailed investigations would be required if irrigation developments were to proceed.



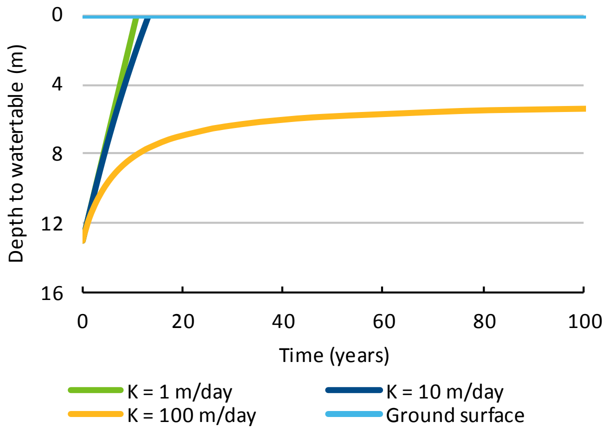


Figure 9.26 Change in depth to watertable for different values of saturated hydraulic conductivity (K): (a) low recharge rate 130 mm/year and (b) high recharge rate of 215 mm/year

9.7.2 ECOLOGICAL, SOCIAL AND CULTURAL CONSIDERATIONS

Table 9.13 summarises the potential ecological, social and cultural considerations with respect to the irrigation development associated with the Green Hills and Dagworth dams. Irrigation areas were set at 19,200 ha with about 16,000 ha planted in any season. This is similar in scale to the analysis undertaken in Section 9.6.2.

Table 9.13 Summary of likely ecological changes as a result of the Dagworth dam and Green Hills dam irrigation developments. This involved analysis of 16,000 ha of sugarcane under spray irrigation at both locations

ECOLOGICAL AND SOCIAL CONSIDERATIONS	COMMENT
Vegetation at reservoir and irrigation development	The area inundated at full supply level for Dagworth and Green Hills dams covers a large area of regional vegetation communities that are a mixture of ‘Of concern’, ‘Not of Concern’ and ‘Non-remnant’ types. The site also contains riverine wetland or fringing riverine wetland vegetation that will be lost to inundation (Petheram et al., 2013).
Sediment infill of reservoir	It is predicted that about 5% (range of between 0.7% and 10%) of the storage volume of both Dagworth and Green Hills dam will infill with sediment after 30 years, and 18% (range of between 2% and 32%) of the storage volume will infill with sediment after 100 years (Tomkins, 2013).
Reservoir water quality	For both storages, the risk of blue-green algal blooms is moderate. The water column is predicted to be strongly thermally stratified from September to mid-May, but has the potential to be mixed during summer inflow events. The light climate will support blooms in summer and has the potential to support blooms in spring (Petheram et al., 2013). In light of the development of permanent stratification, downstream delivery of water needs to be carefully managed to avoid downstream delivery of cold oxygen-depleted water. Thermal impacts associated with release of such water are likely to be limited spatially during periods of warm weather, but may be spatially extensive during the cooler months and at night.
Sediment, nutrient and pesticide loads from irrigation development	An analysis at about the scale of this development is that phosphorus and nitrogen loads would increase 29% and 23%, respectively (Waltham et al., 2013). It is not possible to model likely losses of pesticides given lack of pesticide data for this land use type (Waltham et al., 2013).

Table 9.13 Summary of likely ecological changes as a result of the Dagworth dam and Green Hills dam irrigation developments. This involved analysis of 16,000 ha of sugarcane under spray irrigation at both locations (continued)

ECOLOGICAL AND SOCIAL CONSIDERATIONS	COMMENT
Sediment, nutrient and pesticide loads	The dams at Dagwood and Green Hills are likely to trap suspended sediment, nutrients and pesticides, but probably only during the wet-season flow. If trapped sediment remains in suspension for a significant portion of the year, then releases during the dry season may also contain high levels of suspended sediment. This is an important consideration in the Gilbert catchment given the large number of persistent waterholes within this region (McJannet et al., 2013). Even small increases in turbidity, especially in deep waterholes (which are typically the most ecologically significant in intermittent streams), can have significant negative impacts on the ecosystem processes and ecology of these waterholes. Other water quality problems may be experienced downstream of the dam. Waterholes may experience altered water temperatures regimes, depending on the location of water offtake, and low dissolved oxygen levels, which may also alter ecosystem processes and health of freshwater fauna (Waltham et al., 2013).
Fish passage	Dams at Dagworth and Green Hills and associated re-regulating weirs will act as local fish passage barriers. The dam at Dagworth is within the known extent of key fish species such as freshwater sawfish and barramundi, but their abundance and distribution upstream of the re-regulating weir is not well defined. Many hundreds of kilometres of stream are located above the Dagworth dam and access to this large area of instream aquatic habitat should be maintained for all aquatic species. The Dagworth dam is projected to be 30 m in height and will pose a significant challenge to the maintenance of fish passage. Passage is not just confined to fish, but also to turtles, crocodiles and invertebrates such as the Giant Freshwater Prawn (*Macrobrachium spinipes*), which migrate seasonally within northern rivers and its distribution extends to the very headwaters of most systems. These species are both culturally and ecologically important. The dam at Green Hills is at or beyond the maximum upstream extent of key fish species of high conservation value – freshwater sawfish, barramundi and giant whipray. Nonetheless, the dam (20 m high) and weir (3 m high) are significant barriers and would potentially alienate an extensive length of the Gilbert River and its upstream tributaries from downstream reaches. Most freshwater fishes of the region move extensively either to access newly inundated habitat or to reproduce. Reducing access is likely to result in significant changes in fish assemblage structure and even the long-term persistence of species as any local extinctions due to chance or drought will not be reversed by recolonisation from downstream refugia.
Freshwater and coastal aquatic ecology in response to flow alteration	The dams at Dagworth and Green Hills trap a significant proportion of flow of the upper Einasleigh River and Gilbert River, respectively. This will have a strong localised impact on flow regimes and trapping early wet-season flows critical for the flushing of downstream waterholes. Wet-season flood flows are also critical cues for migration and spawning in many species of freshwater fish and macrocrustaceans; it is likely that these functions will be shifted back in time. Reproductive success may be compromised by such a delay, because the length of time available for growth and acquisition of energy reserves necessary to enable organisms to persist during the dry season may be too short. The effect of the flow reduction shown in Figure 9.13 on coastal ecosystems is not clear, but worthy of further consideration. More importantly, however, the catchment located seaward of this gauge hosts a large number and area of wetlands requiring seasonal inundation. This floodplain area is likely to be of great significance to the ecology of the river and greater attention needs to be given to the impact of the dam on this area. The stream reach containing, and downstream of, the Dagworth impoundment, has been identified as containing a higher number of persistent waterholes compared to the rest of the Gilbert catchment (McJannet et al., 2013). Increased dry-season flows will connect these waterholes, which are often separated from each other. This alters their individual characters, making them more similar to each other, thus reducing diversity. Permanently watering otherwise intermittent reaches facilitates the movement of predatory fish species over large distances, which impacts on the assemblage structure of fish communities in pools.

Table 9.13 Summary of likely ecological changes as a result of the Dagworth dam and Green Hills dam irrigation developments. This involved analysis of 16,000 ha of sugarcane under spray irrigation at both locations (continued)

ECOLOGICAL AND SOCIAL CONSIDERATIONS	COMMENT
Freshwater and coastal aquatic ecology in response to flow alteration (continued)	There are few perennial waterholes in the reaches of the Gilbert River downstream of the Green Hills dam (McJannet et al., 2013) However, the lower reaches of the Gilbert River (below the confluence with the Einasleigh River) are distinguished by significant dry-season baseflow. Under a development scenario, median dry-season flows are reduced by about 20%, resulting in an increase in the median length of maximum length of zero flow from 0 days to about 50 days, and an increase in the absolute maximum dry-spell length from about 22 days to more than 100 days. Such changes are likely to result in substantial ecological change in the lower reaches. These changes essentially transform the lower river from a large-sized perennial system to a moderate-sized intermittent one. In addition to these changes, the flow regime of the Gilbert River was predicted to become more variable and this has consequences for biotic assemblage structure and regulation. The Green Hills dam reduces flood flows by about 20% and this may result in changes to downstream riparian vegetation, weed encroachment, instream habitat structure and, ultimately, channel form. These impacts are likely to be extensive, because changes in wet-season flows are experienced as far downstream as the most downstream gauge (917009A) when both this dam and the Dagworth scheme are in place. Dry-season water releases from the dam to the downstream re-regulating weirs will alter seasonal patterns of river flow and its water quality along the affected reach. Although unnatural, these releases may extend persistence of instream aquatic habitats providing some benefit to aquatic productivity. In other irrigation areas, such dry-season releases have, when in large volumes, greatly altered instream ecology, including allowing the development of instream vegetation and weed communities that would normally perish in the dry season.
Terrestrial ecology	Requires site-based assessment, including examination of existing terrestrial flora and fauna databases. A number of protection and conservation areas that would support a range of plants and animals are present downstream of this site, which would require consideration.
Impoundment ecology	The impoundments offers new, albeit unnatural, aquatic habitat in otherwise relatively dry catchments, and may also offer new recreational opportunities. Proposals for recreational fishery enhancement by stocking need to be very carefully considered. In this case, the proposed dam is within the natural distributional limits of barramundi, a popularly stocked species, and it may therefore be a suitable species for consideration. The fact that it may naturally occur in the region does not mean that large numbers of fish of reservoir origin may not have impacts upstream or indeed downstream if they leave the dam at times of overflow. Large dams may retain colloidal sedimentary material washed in during rain or flow events, in suspension for some time (e.g. Burdekin Falls Dam – see Burrows, 1999). Where such turbid water is released for irrigation, this will impact significantly upon downstream waterholes whose ecology is based on their high water clarity and depth of sunlight penetration. The Green Hills dam is upstream of the natural limit of barramundi and any calls to stock this impoundment with this species will need to be very carefully considered. Occupation of the impoundment will allow barramundi access to an extensive length of river from which they are currently absent. This large predator has significant effects on other fish species and invertebrates.
Human ecology	The creation of a large, new standing body of water may have a range of effects on human behaviour and human use of the landscape. Recreational opportunities may be possible, but the shallow nature of the storage and frequency of low water levels may preclude boating and fish stocking. Altered or diminished downstream flow may impact on economic, recreational, subsistence, amenities and cultural values downstream (Barber, 2013).
Cultural heritage considerations	No previous archaeological reporting relating specifically to the Dagworth or Green Hills case study areas has been located. However, results of investigations in these catchments more generally indicate that these areas are likely to have high archaeological potential. Further field surveys are required to assess the potential Indigenous archaeological impact of works in these case study areas. Any such investigation should be undertaken in consultation with the registered Aboriginal Party, the Ewamian people (Tamwoy et al., 2013).

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10 Kidston Dam and irrigated Rhodes grass

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In this case study, a potential irrigation development below Kidston Dam (officially known as the Copperfield River Gorge Dam) near the town of Einasleigh (Figure 10.1) was investigated. The development is based on the irrigation of Rhodes grass, which could provide a means of supplementary feeding to enable better finishing of livestock for market, as well as a valuable feed for drought relief in dry years.

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

- the physical capacity of the existing water storage and new water distribution infrastructure, to supply water to agriculturally suitable soils, and to grow crops
- the capacity of the scheme to generate positive net revenues, based on a consolidated developer–owner–operator model
- the capacity of the farm to generate positive net revenues, when water development and supply costs are borne by off-farm interests.

The analysis of the irrigation development is presented at both the scheme scale and the farm scale, using results under scenarios A and B. Both scenarios use the same 121-year historical climate data (from 1890 to 2011). Scenario A uses historical climate and current development, whereas Scenario B uses historical climate and future irrigation development (such as the irrigation development specified in this case study). All results in the Assessment are reported over the 'water year', defined as the period 1 July to 30 June. This allows each wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons).

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

In undertaking this analysis, the case study assessment included an allowance to avoid impacts on the reliability with which existing entitlement holders could extract water. For more details see Holz et al. (2013).

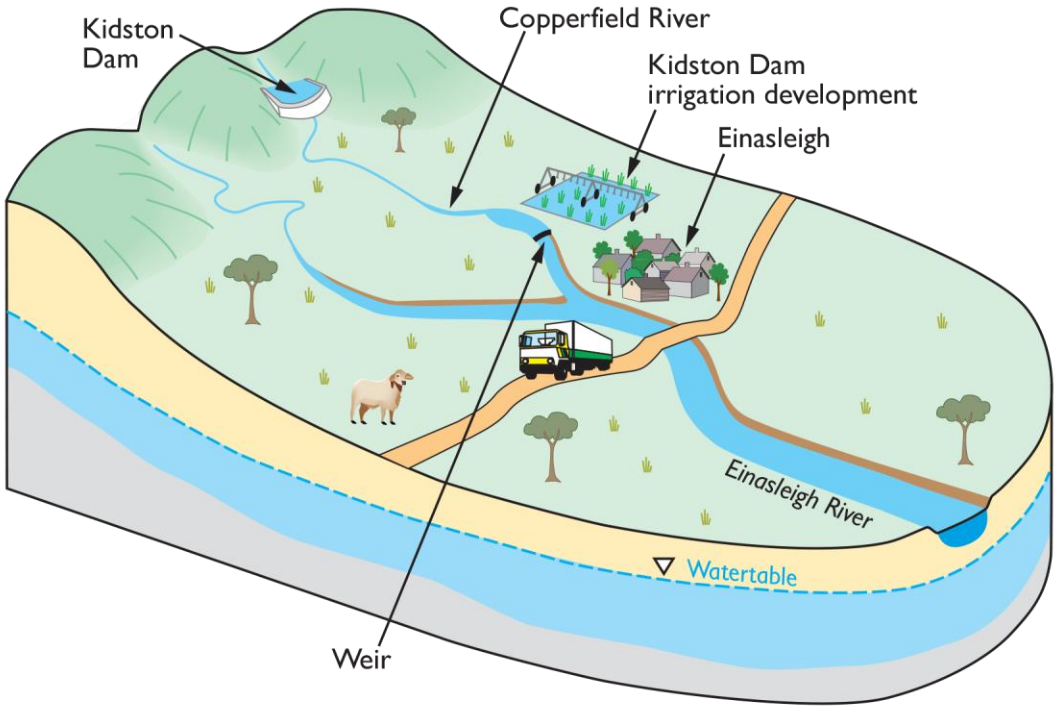


Figure 10.1 Schematic diagram illustrating the components of the case study for an irrigation development associated with Kidston Dam

10.1 Summary

The physical conditions at Kidston Dam and around the town of Einasleigh would enable the development of 1000 ha of irrigated Rhodes grass. The case study found the following:

- Kidston Dam is capable of storing 20 GL of water and can yield 15 GL of water annually (at 85% reliability). Raising the dam wall by 2 m would increase the storage capacity of the dam to 25 GL and the annual water yield would be 17 GL (at 85% reliability). The estimated cost of raising the dam and associated water distribution infrastructure is $34 million at a unit cost of $1990/ML. Approximately 45% of this water yield at the dam wall would be lost in conveyance and application to the crop.
- More than 6000 ha of soils moderately suited to irrigated crop production are located downstream of the Kidston Dam and around the town of Einasleigh. Given adequate irrigation and crop management, these soils are capable of supporting median crop yields of approximately 12 to 14 t dry matter of Rhodes grass per hectare per year.
- Based on the best available information, it is estimated that the watertable level under a 1000-ha irrigation development is likely to rise to within 2 m of the ground surface within 10 to 40 years. Rise in watertable level is likely to mobilise soluble salts in the substrate and clay subsoils, which could potentially cause secondary salinisation when watertable level rises to within 2 m of the ground surface.

Under the conditions examined in this case study, a dam and irrigation development paid for and operated by the same entity is not likely to be economically sustained. Examination of 92 separate 30-year investment windows occurring in each of the past 121 years failed to identify any conditions under which a positive net present value (NPV) could be generated from a combined investment in water supply and farm operations. To generate a positive NPV, at the specified discount rate of 7%, the price of Rhodes grass would need to be $400/t. Market prices are highly variable but are in the vicinity of $150/t. A high price for Rhodes grass is about $250/t.

There is no clear capacity to generate on-farm profits using water, dam infrastructure and related capital supplied by and paid for by a third party. Using the default price for Rhodes grass hay, all farm-scale NPVs are negative. At the high price, all of the 92 investment windows (over the past 121 years) generated positive NPV. At the default hay price, the investor would require a payment of $49/ML of water to break even; at the high hay price, the investor could pay up to $136/ML.

Therefore, while it is physically possible for the existing Kidston Dam to support a small irrigation development near the town of Einasleigh, there is limited economic capacity to support such a forage-based development under the default price of hay.

10.2 Storyline for this case study

In this case study, the viability of the existing Kidston Dam on the Copperfield River is assessed, in terms of its ability to support irrigated fodder production near the town of Einasleigh in the Gilbert catchment.

The main agricultural industry in the Gulf region is extensive grazing. During the dry season, there is a local demand for hay (e.g. Rhodes grass, Lablab, Centro) and silage (e.g. from forage sorghum and millets) from the light cattle trade and for early-weaned calves.

Access to a reliable supply of water could be the catalyst for small-scale hay production along the Copperfield River and downstream of Kidston Dam, where there are small areas of alluvial soils that may be suitable for irrigation. The first large area of suitable land is near the town of Einasleigh, where a natural basalt structure downstream of the township resulted in deposition of alluvial sediments.

In this case study, Bambatsi (*Panicum coloratum*) is used in the Agricultural Production Systems Simulator (APSIM) crop model as a surrogate for an irrigated Rhodes grass (*Chloris gayana*) pasture. However, results could equally be applied to a range of potential improved forage pastures, including Guinea grass (*Panicum maximum*), Sabi grass (*Urochloa mosambicensis*) and forage sorghums (*Sorghum* spp.), or forage legumes such as *Centrosema pascuorum* (cv Bundey or Cavalcade), that could be grown under irrigation on suitable soils. Rhodes grass is widely adapted and spreads easily; it is tolerant of moderate levels of soil salinity and drought. It has been successfully grown under irrigation for hay production in the Georgetown region, at Richmond (Flinders catchment), and in the Northern Territory at Katherine and Douglas Daly. There is currently an 850-ha irrigated Rhodes grass development in the Pilbara region of Western Australia, associated with water available from mine de-watering. Irrigated fodder production near Einasleigh could provide valuable local drought relief, as well as a means of supplementary feeding to turn off better finished stock or to feed early-weaned calves.

Water would be supplied from the existing Kidston Dam, which was constructed in 1984 to provide water to the Kidston Gold Mine. Under the terms of the lease of land covering the dam and storage area, the lease to the company ended when mining activity ceased in 2005. The dam is now owned by the State of Queensland and is managed by the Department of Energy and Water Supply. Since 2005, the dam has been largely unused, the only releases of water occurring in October each year (approximately 3000 ML annually). Because the Kidston Dam yields only a modest amount of water (15 GL at 85% reliability), this case study also investigated the viability of various options to augment the water supplied from the dam. These options include raising the dam wall by 2 m, constructing a large ring tank on the Einasleigh River, and a combination of raising the dam wall and constructing a large ring tank.

Of the four options investigated, the most profitable was using water from the existing dam and harvesting water (from runoff generated between the dam and the irrigation site) during the wet season for direct application to the forage crop. That option is reported in this case study.

The outline of this case study is as follows.

- Section 10.3 describes the soils of the case study area.
- Section 10.4 describes the results of a geophysical investigation.
- Section 10.5 describes the suitability of the climate for growing Rhodes grass for cattle fodder.
- Section 10.6 describes the configuration of the irrigation scheme developments and cropping systems.
- Section 10.7 describes two financial analyses.
  - The first (Section 10.7.1) surveys different ‘scheme areas’.

- The second (Section 10.7.2) undertakes a more detailed assessment of the profitability at the scheme and farm scale for a single scheme area.

- Finally, Section 10.8 provides a high-level analysis of some potential on-site and off-site impacts associated with the selected scheme area.

The case study area is shown in Figure 10.1 and Figure 10.2. To provide a sense of scale and an indicative sense of place, a potential irrigation development of 1000 ha is shown in these figures. This is referred to in this case study as the Kidston Dam irrigation development. Before the irrigation development proceeds, the area would require more intensive assessment of usable soils and areas.

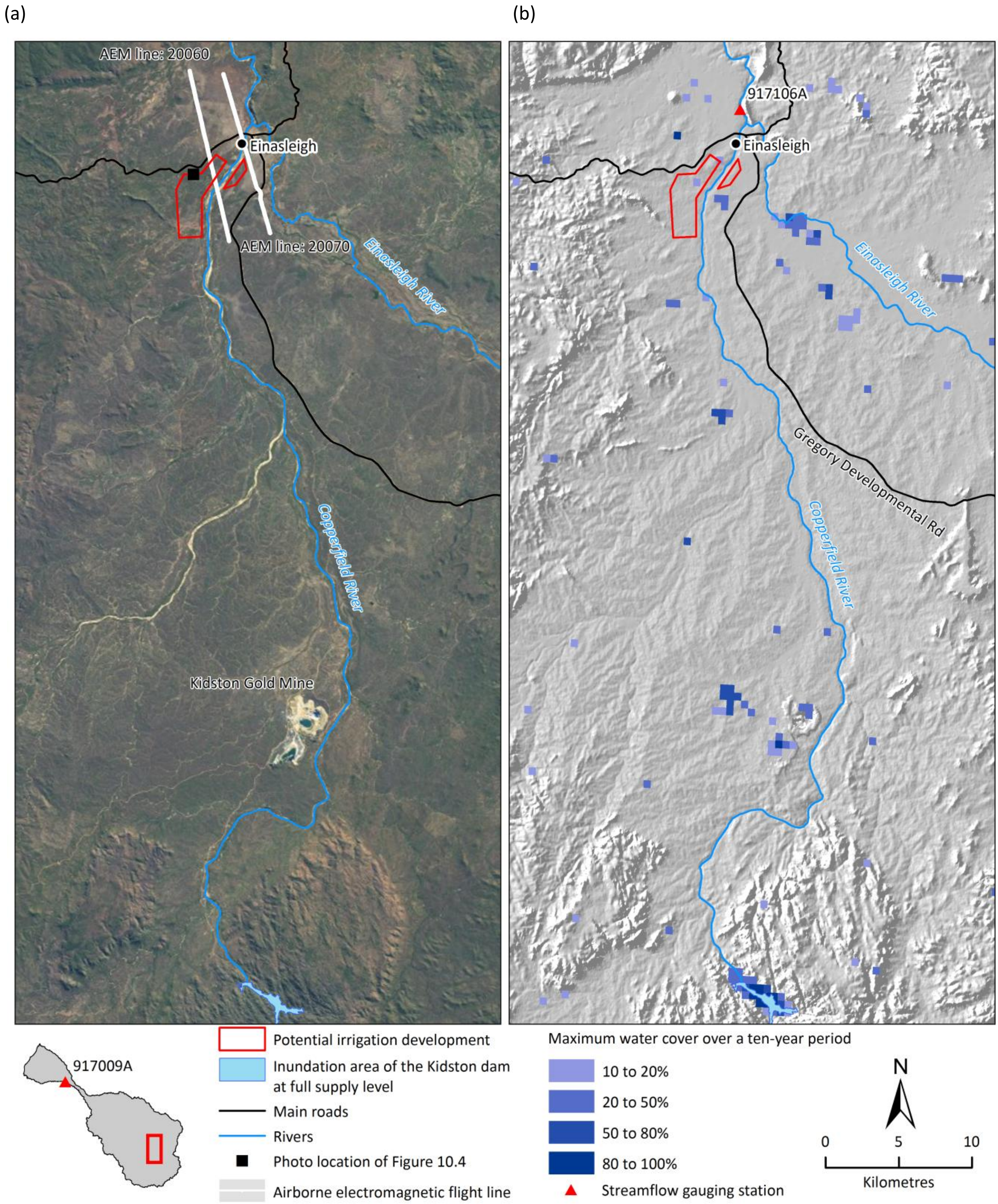


Figure 10.2 (a) Satellite image and (b) relief map of the area surrounding Kidston Dam

10.3 Soils near Einasleigh

Soil type, fertility and available soil water contribute to the persistence and quality, and therefore the profitability, of any improved pasture species. With suitable long-term management, improved pasture or pasture legumes can provide environmental benefits in terms of increased soil carbon, increased soil nitrogen, reduced erosion and improved water quality of streamflow. Suitable soils in the Einasleigh region along the river can be described as friable non-cracking clay and clay loams, with areas of sand or loam over sodic clay subsoil. These soils are well suited to forage production with access to irrigation. The landscape in the Einasleigh area is shown in Figure 10.4.

The case study area is restricted to the alluvium plains of the Copperfield River from Kidston to Einasleigh. The soils are largely influenced by the diverse range of rock types in the catchment, including very old rocks altered by heat and pressure, granites and basalt. The hills immediately north of Einasleigh dammed the basalt that flowed down the Einasleigh River. This basalt constriction caused the deposition of alluvial sediments up to 2 km wide either side of the river at Einasleigh. Upstream, the alluvial plains are generally narrow, ranging in width from less than 200 m below the dam to 300–500 m towards Einasleigh.

The soils adjacent to the river channel in the case study area comprise very deep, well-drained sandy- to loamy-surfaced brown massive or structured soils. Subsoils may have clay textures. These moderately permeable, very deep soils, cover an area of 820 ha and have a moderate to moderately high water-holding capacity. These soils are well suited to a wide variety of irrigated crops, particularly using spray and micro-irrigation methods. Soils may be inundated by occasional floods. In the Einasleigh area, however, the soils are rarely flooded. The main restriction in this area is the narrow width of the soil area, which restricts the area that can be used for cropping, particularly upstream of Einasleigh. Forage cropping (and preservation) to support the local grazing industry is the most likely irrigation use.

The plains further from the river (4400 ha) are dominated by texture contrast and gradational soils with a loamy to silty surface over imperfectly to moderately well-drained, slowly permeable, dispersible clay subsoils (corresponding to loam over sodic/intractable clay soils). Soils have moderate water-holding capacity, with potential for furrow-irrigated crops. The main restrictions are surface sealing, and difficulty with plant establishment and water infiltration. The relatively narrow width of this soil band makes cropping of large areas difficult, particularly upstream of Einasleigh. Areas may be subject to occasional flooding and seasonal waterlogging.

The low-lying areas, generally occurring as depressions on the plains around Einasleigh, have imperfectly drained, very slowly permeable, mottled grey cracking clays which cover an area of 460 ha. The soil surface can be soft or hard-setting. The clay soils are a reflection of the large areas of basalt in the upper catchment. The broader alluvial plains have a complex distribution of texture contrast and clay soils, with some clay soil having abundant surface rock that originated from the underlying basalt. Gilgai (natural hollows and mounds) is prevalent in some areas. These soils have potential for both flood- and spray-irrigated crops. Cropping potential is restricted mainly by rooting depth and a moderate water-holding capacity, due to very high salt levels in the subsoil (around 1 m). The high salt levels will not cause salinity issues unless the watertable level rises close to the surface through over-irrigation. Good irrigation management is therefore essential. The shallow saline groundwater in the Einasleigh area will require monitoring to ensure that any rise in watertable level from over-irrigation does not cause salinity issues and threaten crop production. The other constraint is the complex distribution of soils, resulting in relatively small uniform areas and gilgais in some areas – this restricts the ability to level the soils for efficient irrigation.

To the south-east of Einasleigh, the potential irrigation site is dominated by high-grade metamorphic rocks on gently undulating to undulating rises, with shallow gravelly loam over friable clay, and friable clay loam soils on upper slopes, grading to moderately deep, moderately well-drained loam over friable clay and friable non-cracking clay soils. Relatively large uniform areas moderately suitable for irrigated forage and grain crops occur on the lower slopes. However, the upper slopes are shallow and gravelly, and crests occur regularly throughout the area; this makes it difficult to find large areas of uniform soils suitable for irrigation.

Irrigation development beyond the extent of the survey undertaken by Enderlin (2000), would require more intensive assessment of potentially usable areas. A potential area of about 1000 ha has been delineated in Figure 10.3.

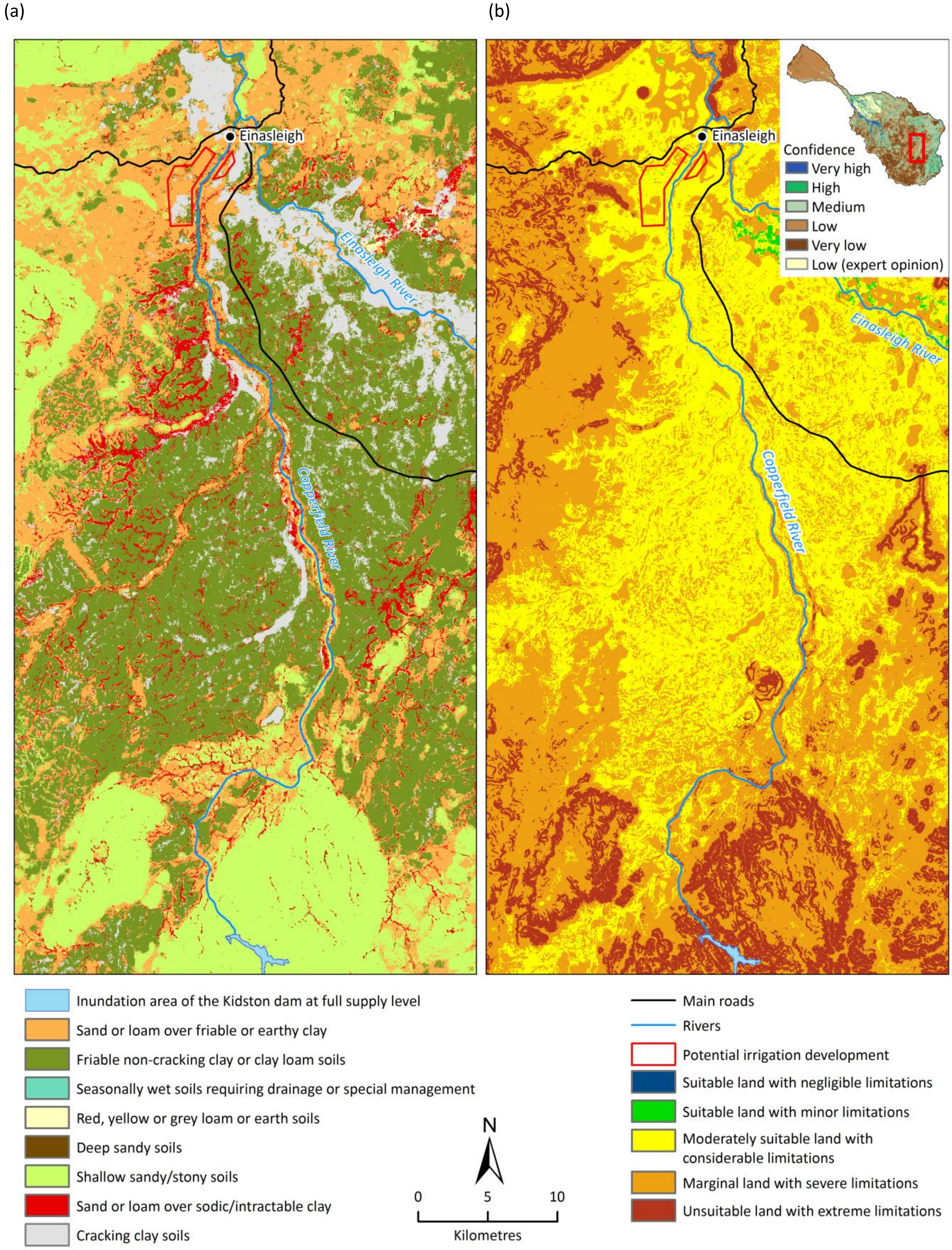


Figure 10.3 (a) Soil generic group map and (b) land suitability map of the area surrounding Kidston Dam for spray-irrigated Rhodes grass

The land suitability map does not account for flood risk, risk of secondary salinity or water availability.

Figure 10.4 Landscape of the potential Kidston Dam irrigation development
Site where the photograph was taken is shown in Figure 10.2.

10.4 Geophysics investigation

The Assessment undertook an airborne geophysical investigation of selected areas of the Gilbert catchment (Munday et al., 2013), using a helicopter airborne electromagnetic (AEM) system, to ascertain the nature of the subsurface and identify areas of salt accumulation.

Conductivity-depth sections (Figure 10.5 and Figure 10.6), which transect the Copperfield River and show the ground conductivity of the soils and regolith of the Einasleigh Common area north and south-east of the town, are relatively high. These observations agree with information collected over these areas in other studies, which suggests that a combination of high subsoil salinity and saline groundwater, coupled with poor drainage, could make these areas challenging to develop for irrigation.

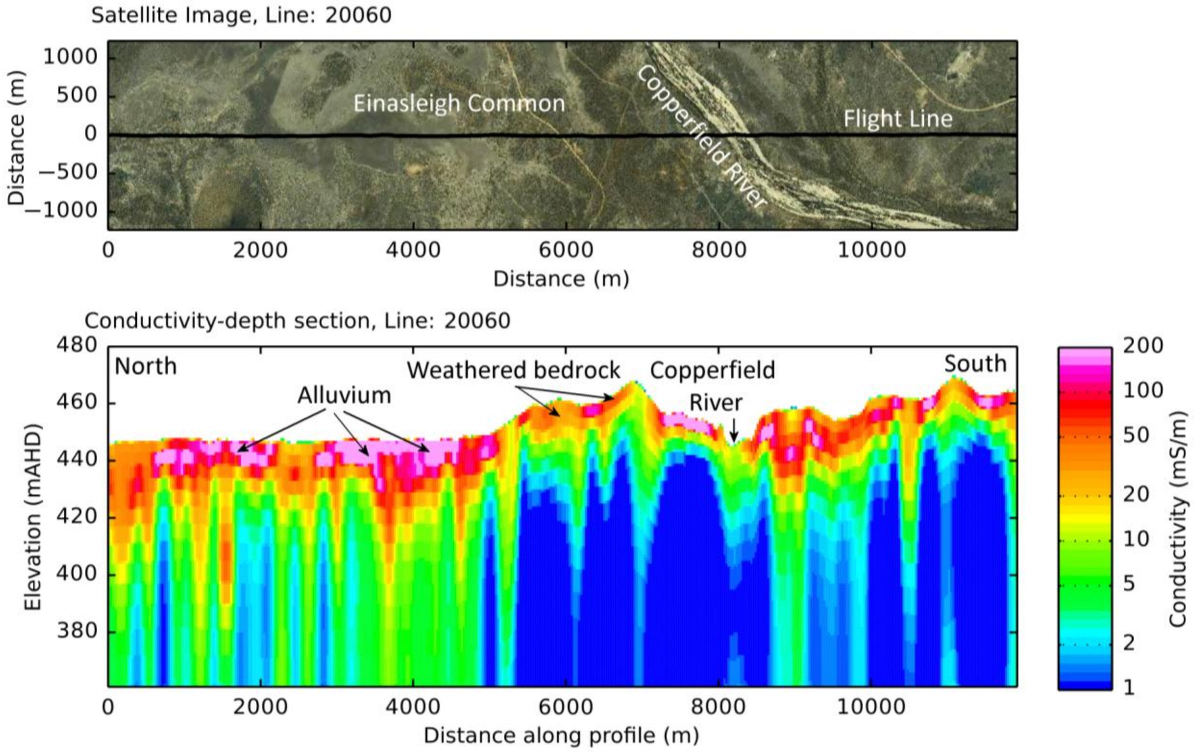


Figure 10.5 Conductivity–depth section (lower panel) for flight line 20060

The flight line transects the Copperfield River in the south and covers part of Einasleigh Common to the north (left side of section). High conductivities greater than 10-m thick are noted over the common. Location of flight line shown on Figure 10.2a.

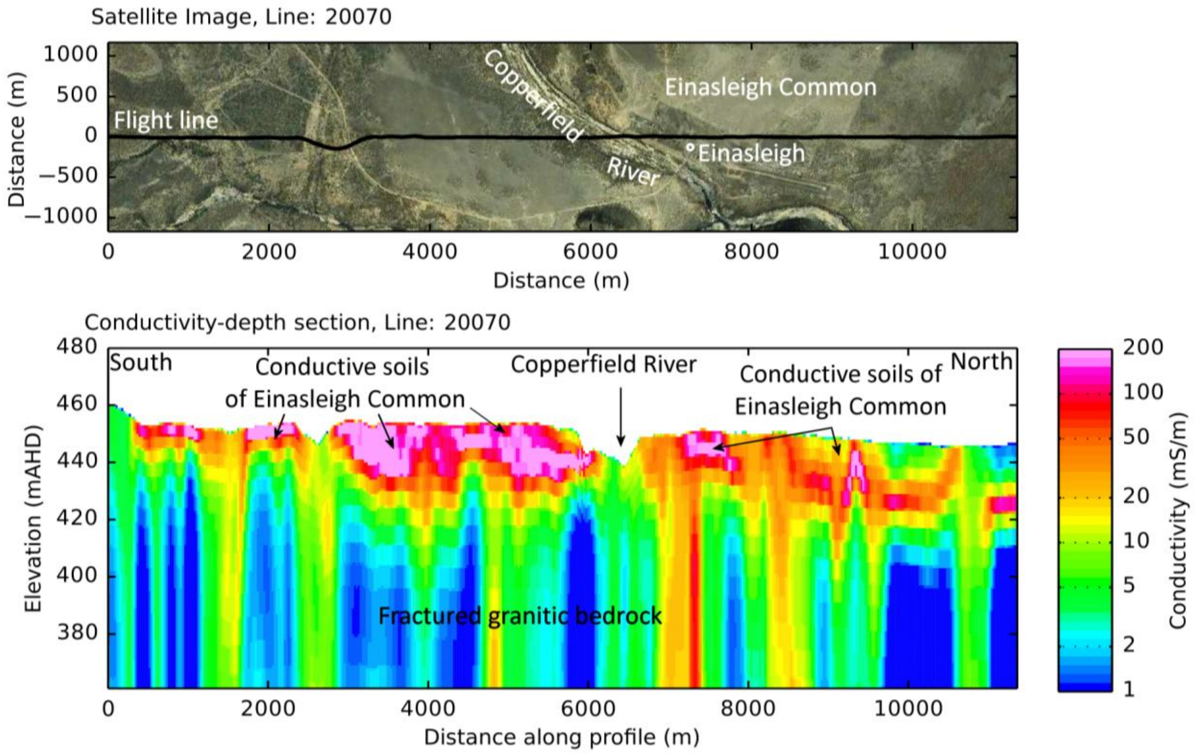


Figure 10.6 Conductivity–depth section (lower panel) for flight line 20070

The flight line transects the Copperfield River and the township of Einasleigh and extends across Einasleigh Common to the north (right side of section) and south (left side of section). High conductivities greater than 10-m thick are noted over the common. Location of flight line shown on Figure 10.2a.

10.5 Climate suitability for irrigated forage crops near Einasleigh

The mean and median annual rainfalls at Einasleigh under Scenario A are 712 mm and 687 mm, respectively. Rainfall at Einasleigh in the Gilbert catchment is highly variable between years and highly seasonal (Figure 10.7), with the majority of rain falling from December to March (82%). Perennial pastures such as Rhodes grass are persistent year-round, although naturally dormant during the drier winter months; active and vigorous growth occurs during the summer rainfall period of December to March. Hay crops are generally grown over a long period, up to several years. Grass is grown and cut for hay, and will regrow again with adequate water, allowing two to four cuts per year. Hay production can use summer rainfall, and the grass can be left dormant in seasons when irrigation water is not available, with renewed growth occurring during the next summer season. When hay production is managed under irrigation, the production period can be extended beyond the natural rainfall-dominated growing window, supplying additional feed to livestock during late winter and early spring. Sowing in late January to March on good subsoil moisture minimises competition with summer-active weeds, and the risk posed to seedling establishment by high soil temperatures and high evaporation rates in late spring and early summer. Nutritional management, water availability and seasonal conditions influence the timing and number of harvests each season. Two to three cuts for hay production are expected in most years. Poor trafficability of wet soils may be a problem in establishing new pasture in very wet seasons, but this is unlikely to be a problem for harvesting and other operations on well-established Rhodes grass pastures.

Unlike in the Flinders catchment, frost is not considered a risk during late plant establishment in the Gilbert catchment.

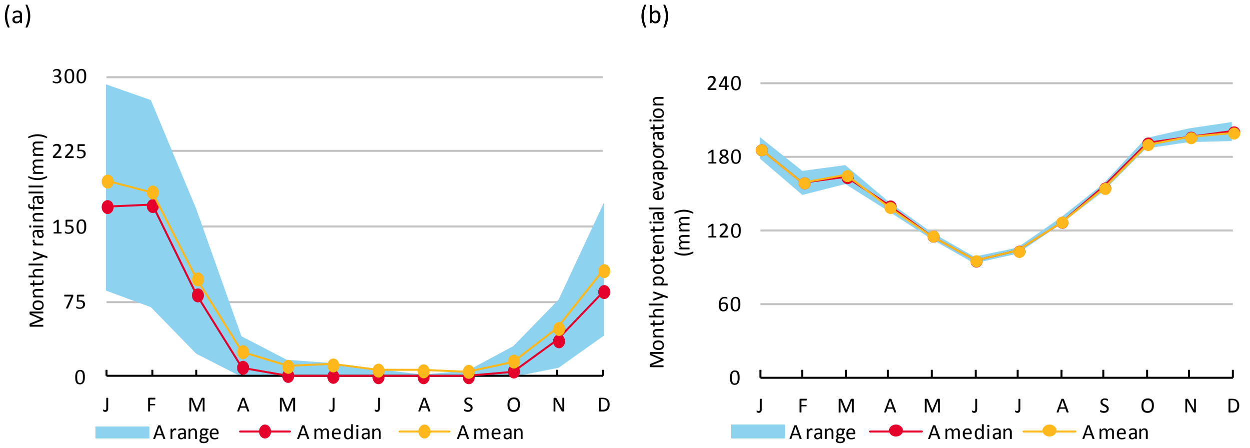


Figure 10.7 (a) Monthly rainfall and (b) monthly potential evaporation under Scenario A at Einasleigh
Scenario A is the historical climate (1890 to 2011). The A range is the 20th to 80th percentile exceedance.

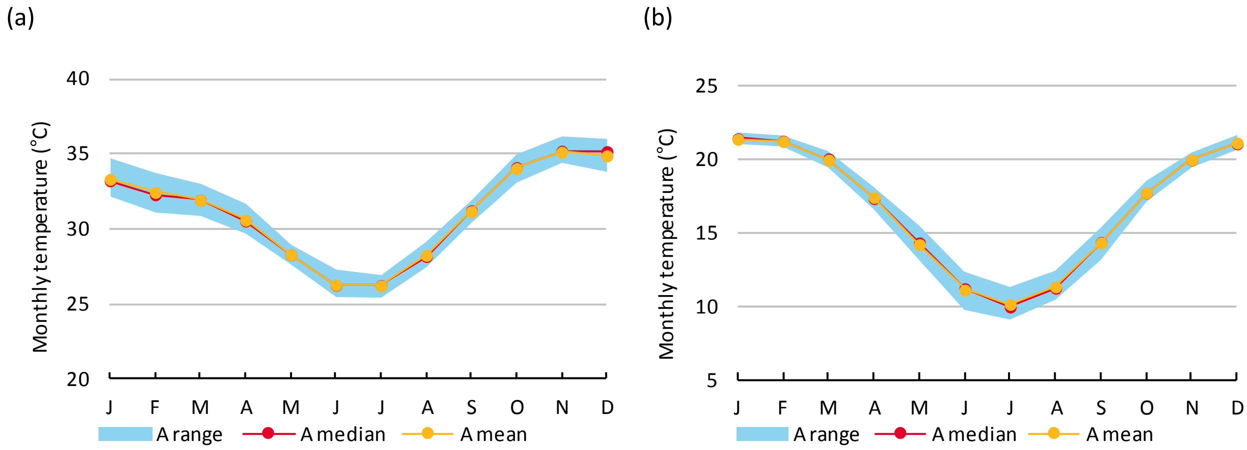


Figure 10.8 (a) Maximum monthly temperature and (b) minimum monthly temperature under Scenario A at Einasleigh

Scenario A is the historical climate (1890 to 2011). The A range is the 20th to 80th percentile exceedance.

10.6 Configuration of irrigation developments and cropping systems

This section provides a description of the configuration of the irrigation developments and cropping systems associated with the Kidston Dam. It provides information on Kidston Dam, outlines the configuration and costs for water supply and irrigation development, examines the relationship between applied irrigation water and crop yield at production potential and discusses production risks.

10.6.1 KIDSTON DAM

The existing Kidston Dam is a 40-m roller compacted concrete dam located on the Cloncurry River about 70 km upstream of Einasleigh. Median annual inflows to the dam are 72 GL (Table 10.1) and streamflow is highly variable between years (Figure 10.9). The coefficient of variation of annual streamflow in Table 10.1 provides a measure of the degree of variability in the system. For a given mean annual streamflow, the larger the variability in streamflow from one year to the next, the smaller the water yield from the dam. Similar to other rivers in the Gilbert catchment, the Copperfield River is about two to three times more variable than other rivers in the world that have a similar climate and mean annual streamflow (Petheram et al., 2008).

Table 10.1 Streamflow on the Copperfield River at the Kidston Dam under Scenario A

RIVER NAME	MAXIMUM FLOW (GL/y)	20% EXCEEDANCE FLOW (GL/y)	50% EXCEEDANCE FLOW (GL/y)	80% EXCEEDANCE FLOW (GL/y)	MINIMUM FLOW (GL/y)	MEAN FLOW (GL/y)	COEFFICIENT OF VARIATION
Copperfield River	1335	250	72	17	1	165	1.32

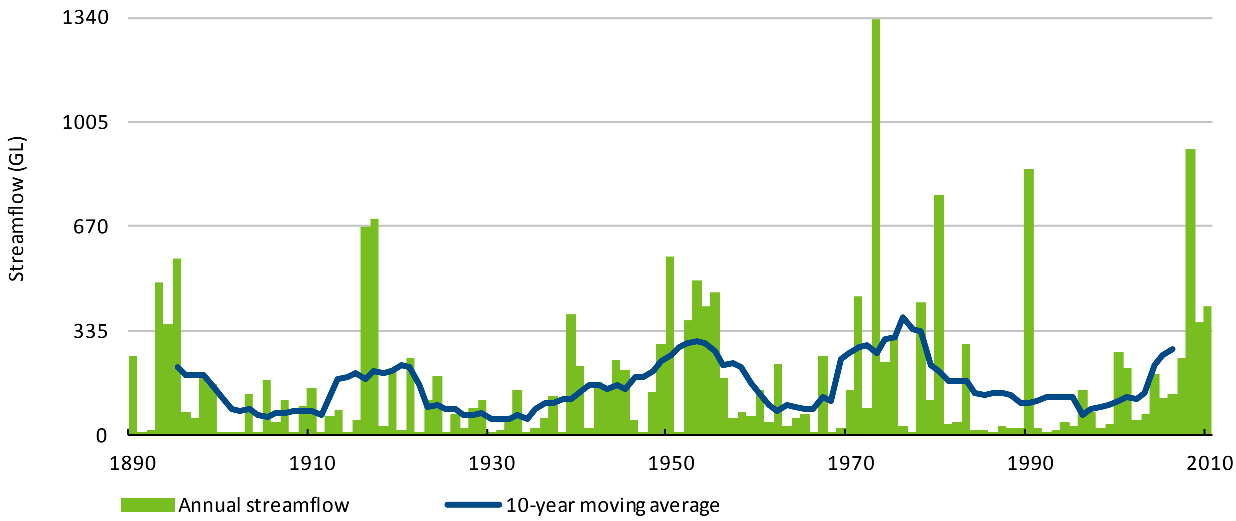


Figure 10.9 Annual streamflow at the Kidston Dam under Scenario A
Blue line indicates the 10-year moving average.

The Kidston Dam has a relatively small storage capacity (20 GL) and yields a modest amount of water (15 GL at 85% reliability). For this reason, various options were investigated to supplement the water supplied from the dam. One of these was raising the dam wall by 2 m, which would incur modest costs but increase the water yield to 17 GL at 85% reliability (Table 10.2). Raising the dam wall is unlikely to have an environmental footprint larger than the existing Kidston Dam, though it would trigger the need to assess the requirement for a fish transfer facility.

Another option investigated was the construction of a large ring tank (~10,000 ML capacity) on the Copperfield River, near the irrigation development. This would enable water in the Kidston Dam to be saved for use during the dry season. It is also possible that a ring tank could be sited on the Einasleigh River. Although this may provide more water during the wet season than a ring tank on the Copperfield River, it would require more diversion infrastructure and large pumping capacity, and would probably provide more water for irrigation than available land. This option was not investigated.

A combination of raising the dam wall and construction of a large ring tank was also investigated.

Of the four options investigated, the most profitable was using water from the existing dam and harvesting water (from runoff generated between the dam and the irrigation site) during the wet season for direct application to the forage crop. This option is reported here. More detail on the Kidston Dam can be found in Section 5.2.

Table 10.2 Parameters for Kidston Dam

ALTERNATIVE	CATCHMENT AREA (km^2)	HEIGHT (m)	CAPACITY (GL)	FULL SUPPLY LEVEL (mEGM96)	ANNUAL WATER YIELD (GL)	COST** ($ million)	UNIT COST ($/ML)
Existing dam	1244	40	20	586	15	$12	$860
Existing dam raised by 2 m	1244	42	25	588	17	$34	$1990

* Water yields are for an 85% annual time-based reliability using a perennial demand pattern for the baseline model under Scenario A. This is yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These yield values do not take into account downstream existing entitlement holders or environmental considerations.
** Includes water distribution infrastructure as estimated by McIntyre and Associates (1998).

10.6.2 WATER SUPPLY AND IRRIGATION SCHEME CONFIGURATION AND COSTS

Water supply scheme configuration

Under this configuration, water would be released from the Kidston Dam to a series of weir re-regulating structures upstream of the town of Einasleigh. The re-regulating structure allows for more efficient releases from the storages, thereby reducing the transmission losses normally involved in supplemented river systems.

Two pump stations would be established, one supplying water to the northern side of the river and the other supplying water to the southern side. Water would be pumped from the river (assuming a 10-m head requirement) into an open distribution channel. There is limited land suitable for irrigation and irrigation development is restricted to areas more than 100 m from the Copperfield River.

It is assumed that irrigation water is distributed within a farm (i.e. from the farm gate to the field) using open channels. On-farm storages are sometimes used to improve the efficiency with which water can be supplied from the farm gate to the field. For this small-scale development, it is assumed that there is minimal need for on-farm storage. Once at the field, water is applied using spray irrigation – more specifically, lateral move sprinklers. Lateral move sprinklers are used to optimise irrigation productivity from the limited water supply and minimise accessions to groundwater, which have the potential to cause secondary salinity problems in the area. Well-managed spray irrigation generates very little tailwater runoff (i.e. water leaving the field following an irrigation event), except during large rainfall events that occur immediately after irrigation on full soil profiles. In this case study area, irrigation occurs during the dry season, and it is assumed that there is no need for on-farm tailwater recycling and on-farm water storages. Runoff generated from heavy rainfall events during the wet season would be directed back into the river system.

Table 10.3 lists the conveyance efficiency assumptions used in this analysis. In total, the conveyance and application efficiency from the storage to the crop is about 56%. These values are likely to represent best practice and the river conveyance efficiency estimate is likely to be generous.

Table 10.3 Assumed conveyance efficiencies for the irrigation development associated with the Kidston Dam

COMPONENT	EFFICENCY (%)	COMMENT
River conveyance efficiency	75%	Distance between dam and re-regulating structure is about 70 km.
Channel distribution efficiency	90%	Representative of evaporation loss from re-regulation structure and channel loss between river and farm gate
On-farm distribution efficiency	97%	Representative of on-farm evaporation and seepage loss from farm gate to edge of field
Field application efficiency (spray)	85%	Lateral moving sprinklers
Overall efficiency	56%	

Water supply and irrigation scheme costs

Indicative capital, operation and maintenance costs associated with the irrigation development are provided in Table 10.4. Costs of infrastructure that are independent of the size of the irrigation development (e.g. dam, weirs, main access roads) are listed as a fixed price. Costs directly linked to the size of the irrigation development are expressed as a cost per hectare and per megalitre. This enables irrigation developments of different sizes to be quickly evaluated (see Section 2.2). These costs were obtained from information presented in Chapter 5.

Table 10.4 Scheme-scale and farm-scale costs for the irrigation development associated with the Kidston Dam

ITEM		LIFE SPAN (y)	UNIT COST ($)	UNIT	OPERATION AND MAINTENANCE COST (% capital costs)	COMMENT
Scheme-scale costs: capital, operation and maintenance	Dam maintenance	1	$220,000			Estimate of annual maintenance on existing dam.
	Weirs, diversion infrastructure and pumps	100	$12,000,000	*	0.4%	Diversion infrastructure based information provided by McIntyre & Associates (1998) and index to 2012.
	Area works	40	$7,740	ha	1%	Includes roads (life span 100 years), earthworks, structures, overheads, contingency and corporate profit
	Pump energy cost (river to channel)	na	$24	ML		Assuming 15 m head requirement and pump operated on diesel
Scheme-scale costs: approvals	Area works approvals	na	$2,000,000			Includes environmental impact statements, native title and cultural heritage
	Legal	na	$300,000			
Farm-scale costs: capital	Irrigation system (spray)	15	$4,000	ha	**	
	Farm equipment	15	$1,160	ha	**	Based on $580,000 expenditure per 500-ha farm
Farm-scale costs: operation	Overheads	1	$660	ha		Includes maintenance costs, employee costs, land lease, and other additional business overheads

NA = not applicable
* These fixed costs are independent of the size of the irrigation development.
** Operation and maintenance costs are captured in farm-scale cost overheads

Critical infrastructure

Critical infrastructure can enable greenfield irrigation developments. Investment can be limited by the absence of hard infrastructure (such as roads and energy) and community infrastructure (such as schools and housing), which are required to support large irrigation developments and the people who work there. Table 10.5 summarises features of infrastructure in the Einasleigh/Georgetown area.

Table 10.5 Critical infrastructure in the Einasleigh and Georgetown area

ITEM		COMMENT
Community infrastructure	General	The main town serving the irrigation developments is Georgetown, which currently has fewer than 300 residents. Small-scale production of fodder is unlikely to impact significantly on Georgetown population. The status of community infrastructure is summarised below.
	Schools	A primary school at Georgetown currently has 47 enrolments, and hard infrastructure (classrooms) can be added if needed.* Additional staffing needs, if any, would be expected to depend on the number and composition of new enrolments.
	Hospital	Georgetown does not have a hospital. It has a clinic and the Georgetown area is serviced by a flying doctor. Facilities could be expected to require expansion under population growth.*
	Housing	Georgetown currently has a supply of unoccupied dwellings; however, the quality of available housing, and whether new construction is required, would require further assessment.
	Water	Water for the town is currently sourced from bedsands of the Etheridge River. It is treated and then gravity-fed to the town. There are concerns whether the bedsand aquifers could support a larger population. The Etheridge Shire Council has commissioned the construction of a small dam at Forsyth to secure town water supplies. However, the dam can only service small increases in demand, and would be unlikely to be sufficient if the population reached, for example, 2500 residents. There is no sewerage treatment plant in Georgetown – a septic system is used. If there was a large increase in population a sewerage treatment plant would need to be installed[1].
	Other	Georgetown is close to rivers and the town centre is vulnerable to flooding. It has been proposed that further commercial and residential development would be more appropriately sited a few kilometres west from the current town centre[1].
Hard infrastructure	Roads	The shire has a network of gravel roads – the imperative for road upgrades is unlikely to be as strong as for other irrigation development options (e.g. sugar).
	Rail	None
	Energy	The electricity network is maintained by Ergon Energy. The Georgetown area is serviced by feeders from the Georgetown 66 kV zone substation. The projected maximum demand growth (9.4 MVA in 2020) is significantly less than the rated capacity (44 MVA). However, dependent on location of the facilities some infrastructure upgrade to SWER may be required.
	Port	Not applicable as it assumed that fodder will be sold within the region and/or consumed on-farm by the existing beef cattle operation.
Processing infrastructure	Hay	Hay is baled on-farm using on-farm equipment or contractors.

* Sourced from discussions with elected members and staff of Etheridge Shire Council.

10.6.3 APPLIED IRRIGATION WATER, CROP YIELD AND PRODUCTION RISKS

In this case study, the bambatsi module of APSIM was used with a soil representative of the Einasleigh area to simulate the crop water use and crop yield data for Rhodes grass. Figure 10.10 shows the relationship between different application volumes of water and crop yield, assuming ideal irrigation timing (i.e. no losses to deep drainage or overland flow). As the Rhodes grass becomes increasingly water stressed, crop yield decreases because the volume of water applied is insufficient to meet the crop water requirements. The APSIM results presented in Figure 10.10 are representative of the production potential (i.e. nutrients are not limiting, and there is no damage to the crop due to disease, pests, poor irrigation management or farming practices).

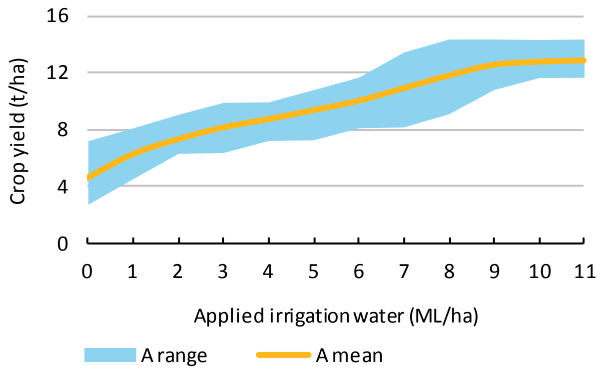


Figure 10.10 Crop yield versus applied irrigation water under Scenario A for Rhodes grass hay in the Einasleigh area
Planted 15 March. Figures are representative of the production potential (i.e. assumes no nutrient limitations or pest damage). Scenario A is the historical climate (1890 to 2011). The range is the 20th to 80th percentile exceedance.

Production risks

It is very important to recognise that actual on-farm crop yields are highly dependent on the critically important – yet difficult to define – trait of 'management skill', the process by which the best decisions and actions occur at the best times. This grows with experience and, until it reaches a high level, the challenges associated with the relative lack of cropping experience in the Assessment area should not be underestimated. Until a pool of expertise develops and builds over several years, with the growing ability to anticipate challenges that first need to be experienced (such as pest and disease pressures), actual crop yields would be expected to be significantly lower than potential crop yields. The difference between actual and potential crop yields, often referred to as the 'yield gap', usually closes slowly over time, and this needs to be factored into individual enterprise and regional development plans.

10.7 Financial analysis

This section addresses crop yields, crop gross margins (based on feed grain sales), and financial analysis at both farm scale and scheme scale.

The analysis assumes that the whole scheme is funded and operated by a single developer who incurs all the costs and receives all the benefits of development. The question asked is: are the projected revenues sufficient to cover all expenditures? The strong possibility of different funding and operation models is recognised, but is beyond the scope of this case study.

The farm-scale analysis considers the net benefits after only farm-scale costs are deducted from gross margins. This analysis assumes that the investor purchases irrigation water from a third-party scheme water supplier who bears the scheme's capital and operating costs. Water prices are initially set at zero, but the farm-scale investor's capacity to pay for water is also estimated. This provides an estimate of the extent to which a scheme developer may recoup operation and maintenance costs or capital costs through water charges.

All financial analyses in this section are reported in 30-year windows, as this was the selected investment time frame (see the companion technical report about cost–benefit analysis (Brennan et al., 2013) for a discussion on the choice of investment planning period). Using the 121 years of historical data, the total number of 30-year windows is 92. For example, the first 30-year window is 1891 to 1920, and values are calculated over this window. The second window is 1892 to 1921, and a second set of values is calculated over this window. This sampling – and subsequent calculating – was repeated 92 times, with the final window corresponding to the period from 1981 to 2011. The median value from calculations for each of the 92 windows is presented. A straight-line depreciation approach was used to calculate the residual value of long-life infrastructure (i.e. infrastructure with a service life of more than 30 years). This is a generous assumption over the alternative, which is to assume that the infrastructure has no value at the end of the investment period.

A commonly used term in this section is scheme area. Scheme area refers to the maximum area that is planted to Rhodes grass at any one time.

Two financial analyses are presented. The first analysis (in Section 10.7.1) explores an appropriate scheme area for the irrigation development. The results are presented as column charts of scheme area (see Section 10.7.1). It is assumed that land is not a constraint and that all capital costs were incurred in the first year.

In the second analysis (in Section 10.7.2), a single scheme area is selected, based on scheme- or farm-scale profitability or the availability of suitable land.

10.7.1 DIFFERENT SCHEME AREAS

Water supply, reservoir characteristics and changes in downstream flow

The larger the scheme area, the larger the total volume of water supplied to and used by the irrigation development, up until about 2000 ha (Figure 10.11a). Thereafter, the mean applied irrigation water does not increase above 7500 ML. Figure 10.11b shows that mean applied irrigation water per hectare decreases with increasing scheme area.

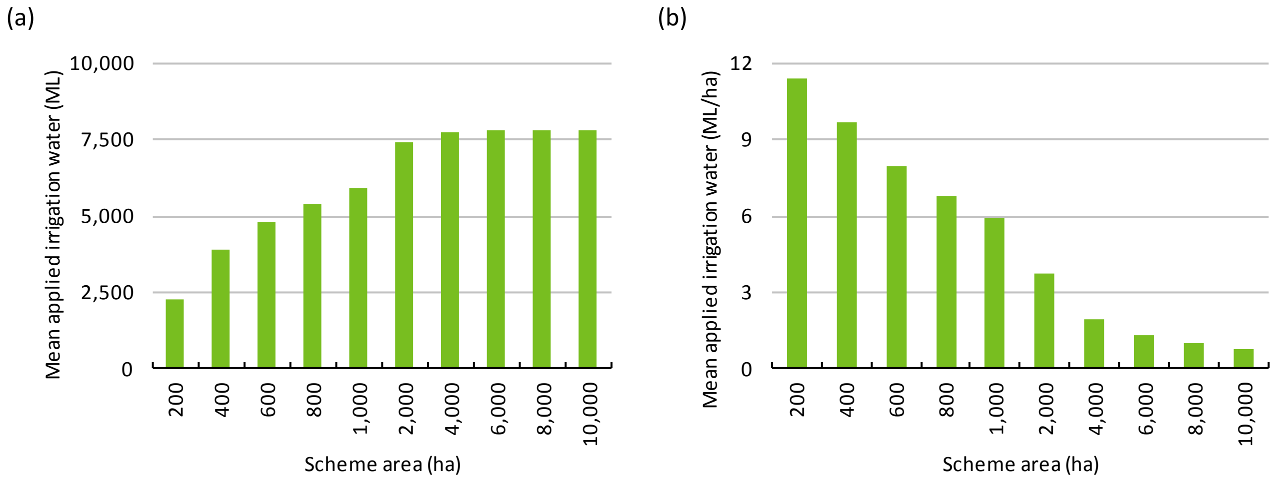


Figure 10.11 Mean annual applied irrigation water supplied to the crop in (a) ML and (b) ML/ha equivalent under Scenario B for the irrigation development associated with the Kidston Dam
Applied irrigation water is the water supplied from the dam, with the losses from river conveyance, channel distribution and field application removed. Scenario B is the historical climate (1890 to 2011) with irrigation development.

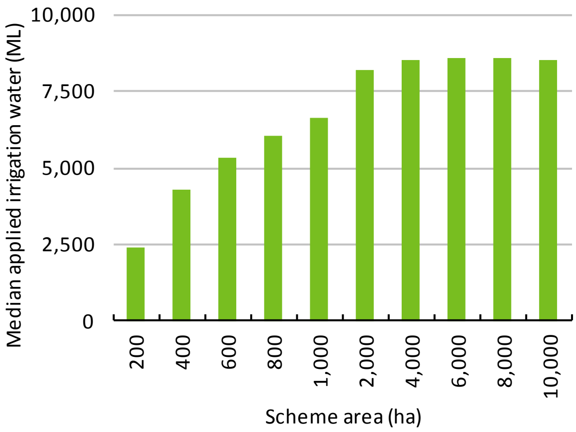


Figure 10.12 Median annual applied irrigation water supplied to the crop under Scenario B for the irrigation development associated with the Kidston Dam
Applied irrigation water is the water supplied from the dam, with the losses from river conveyance, channel distribution and field application removed. Scenario B is the historical climate (1890 to 2011) with irrigation development.

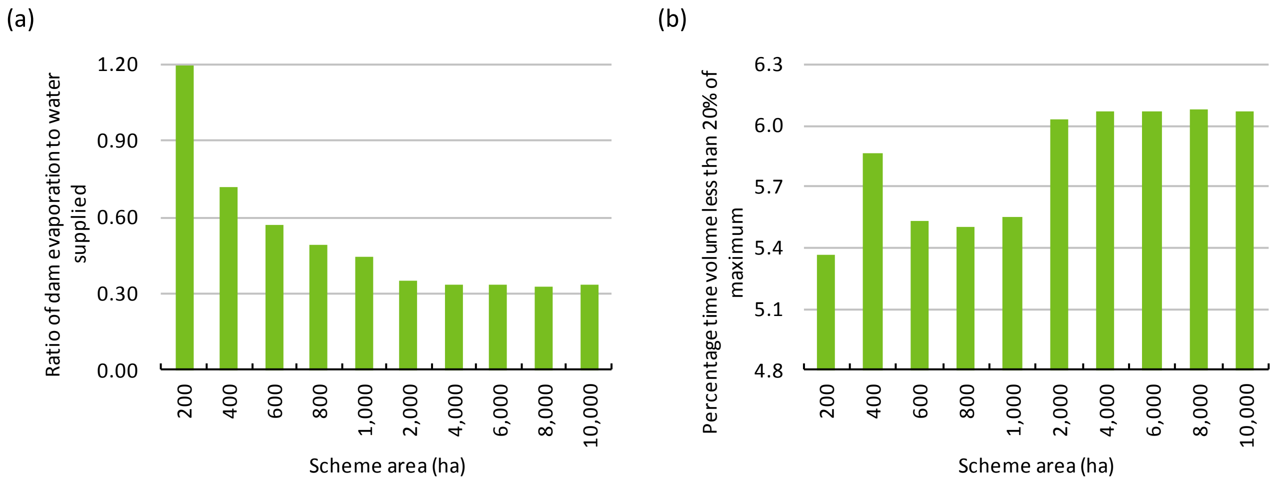


Figure 10.13 (a) Ratio of evaporation from the reservoir to the applied irrigation water and (b) percentage of time the volume of the reservoir is less than 20% of the full supply level volume under Scenario B for the irrigation development associated with the Kidston Dam
Scenario B is the historical climate (1890 to 2011) with irrigation development.

Figure 10.12 illustrates the change in median applied irrigation water. It follows a similar pattern to the mean applied irrigation water.

Figure 10.13a presents the ratio of water lost to evaporation by water supplied at the dam wall. At low scheme areas, water is not fully used, and a large amount of water is lost to evaporation when water is carried over into the following year. At high scheme areas the ratio of evaporation to supply is low because all available water is used every year (i.e. reservoir is treated as within-year storage). Figure 10.13b shows the percentage of time that the Kidston Dam reservoir is less than 20% of its full supply level (FSL) volume.

Figure 10.14 illustrates the median annual streamflow quotient at a streamflow gauge below both the dam and the irrigation development (915203A) and near the mouth of the Gilbert River (915003A). This provides an indication of the extent to which the median annual streamflow would change under irrigation development for different combinations of scheme area and crop area decision. For all scheme areas only a small change in the flow regime occurs at gauge 917106A, and effectively no change occurs at the lowest gauge on the Gilbert River (917009A). The reason there is very little change is that the Kidston Dam was an existing dam and under this case study the only thing that changes is its operation.

Crop yield

Total crop yields from a scheme area are highest for larger scheme areas (Figure 10.15a). This is because, in the years the reservoir is full or nearly full, the planted area is less constrained by the scheme area and more biomass can be produced in wet years under effectively dryland conditions. However, the variability in the 30-year crop yields is high at large scheme areas (Figure 10.15b).

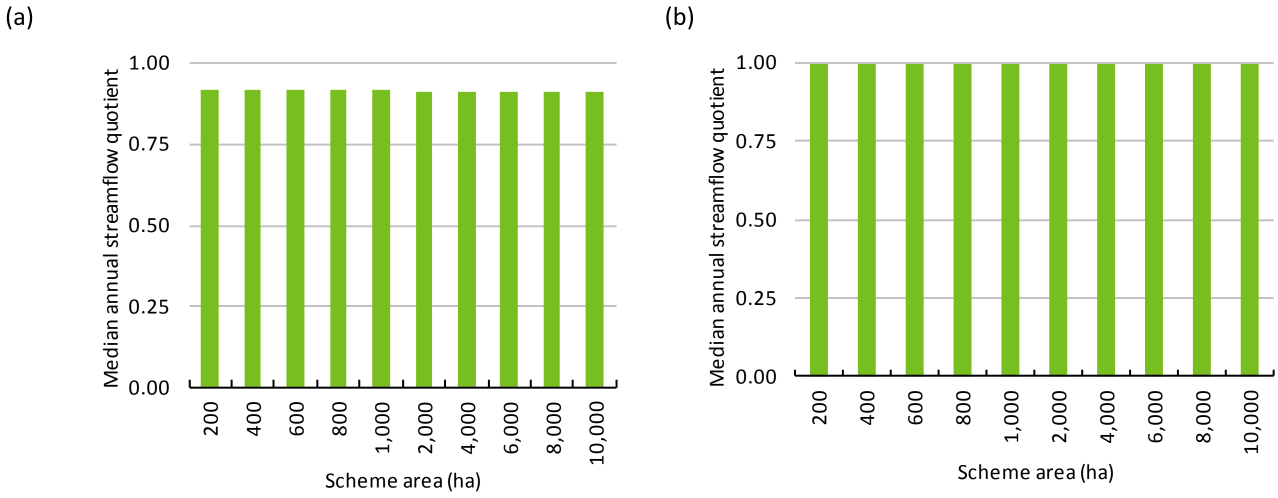


Figure 10.14 Median streamflow quotient at (a) gauge 917106A and (b) gauge 917009A under or the irrigation development associated with the Kidston Dam
Median streamflow quotient is the median annual streamflow under Scenario B divided by the median annual streamflow under Scenario A. Scenario A is the historical climate (1890 to 2011) and current development. Scenario B is the historical climate (1890 to 2011) with irrigation development. Location of streamflow gauging stations shown on Figure 10.2.

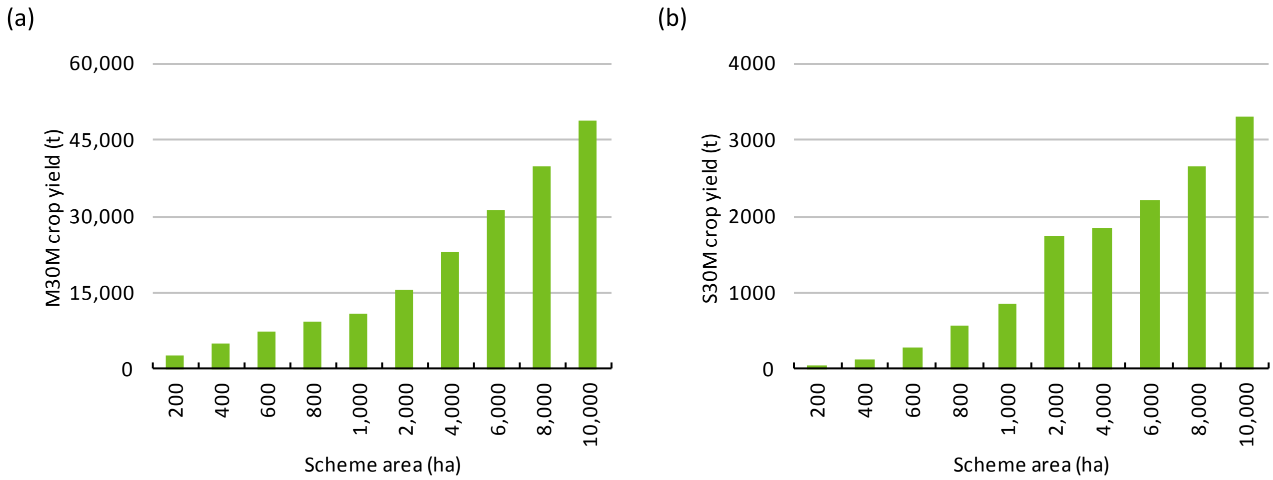


Figure 10.15 (a) Median of the 30-year mean values (M30M) for crop yield and (b) standard deviation of the 30-year mean values (S30M) for crop yield under Scenario B for the irrigation development associated with the Kidston Dam
Scenario B is the historical climate (1890 to 2011) with irrigation development. Median values are calculated for 30-year windows in the period 1890 to 2011. Both the median and the standard deviation of the mean values for each of the 92 windows are presented.

The higher crop yields and higher variability for larger scheme areas are illustrated in Figure 10.16. Although the 400-ha scheme area has the lowest total crop yield, there is always sufficient water in the dam to ensure that there is not a complete crop failure.

The crop yield per hectare planted (specific yield) decreases with increasing scheme area because Rhodes grass is more often under water stress, resulting in lower yields per hectare (Figure 10.17a). The variability in specific yield is highest for scheme areas of 1000 and 2000 ha (Figure 10.17b) because at smaller areas sufficient water is supplied in most years, and at larger areas, even when the Kidston Dam is full, the crop yields are severely reduced due to water stress.

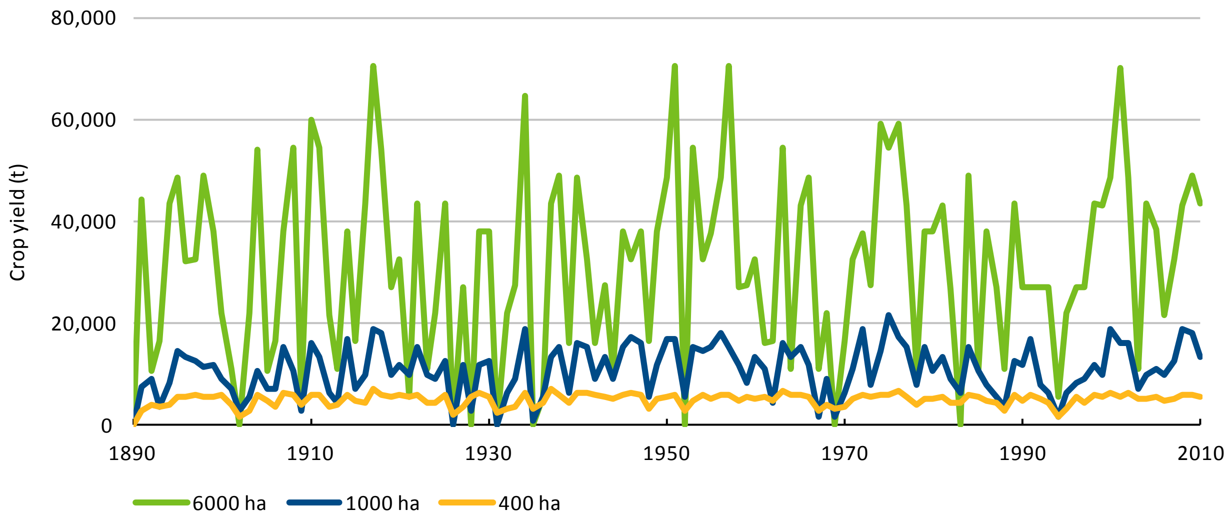


Figure 10.16 Crop yield from the total scheme area under Scenario B for three different scheme areas

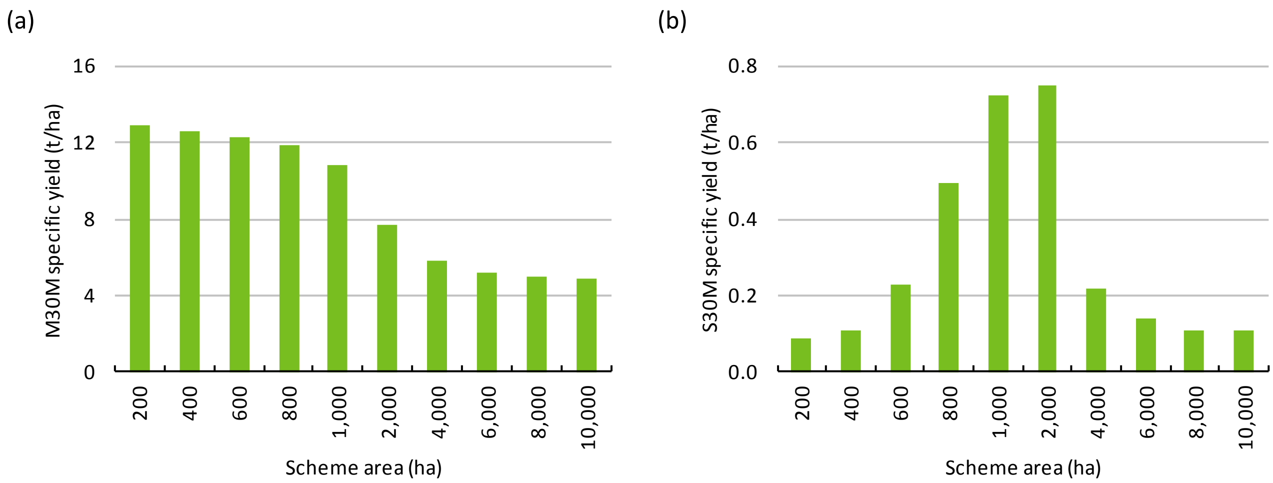


Figure 10.17 (a) Median of the 30-year mean values (M30M) for specific yield and (b) standard deviation of the 30-year mean values (S30M) for specific yield under Scenario B for the irrigation development associated with the Kidston Dam

Specific yield is crop yield per hectare planted. Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows in the period 1890 to 2011. The median of the mean values for each of the 92 windows is presented.

Crop gross margins

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

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

Water charges are also a variable cost when charged on a $/ML basis, but are omitted from the gross margin calculations here (pumping costs, however, are included). Instead, as part of this financial analysis, farmers' capacity to pay a water charge is determined. The crop gross margin is calculated using simulated crop yield and water use. Table 10.6 lists the key assumptions in the gross margin calculations for Rhodes grass used in this analysis. For details on crop gross margin calculations, see the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013).

Low crop yields per hectare result in low gross margins per hectare (Figure 10.18a). However, low gross margins per hectare over a large planted area (e.g. scheme area of 10,000) can result in higher total scheme gross margins than a high gross margin per hectare occurring over a smaller planted area (e.g. scheme area of 400 ha).

Scheme-scale gross margins increase with scheme area (Figure 10.18b). At higher scheme areas, however, the gross margins per hectare will be smaller because the specific yield will be smaller. Variability in scheme-scale gross margins increases with larger scheme areas, because a higher proportion of the crop does not receive its full water requirement.

Table 10.6 Key assumptions in the gross margin calculations for Rhodes grass for irrigation development associated with the Kidston Dam

KEY ASSUMPTIONS	VALUE	COMMENTS
Price	$150/t or $250/t	$250/t is a high price
Variable costs		
Freight to depot	$0/t	Assumes local delivery
Pumping cost	$58.90/ML	Spray irrigation, diesel
Other	$469/ha	In a planting year, otherwise other variable costs are $303 per year. Details provided in Brennan McKellar et al. (2013)

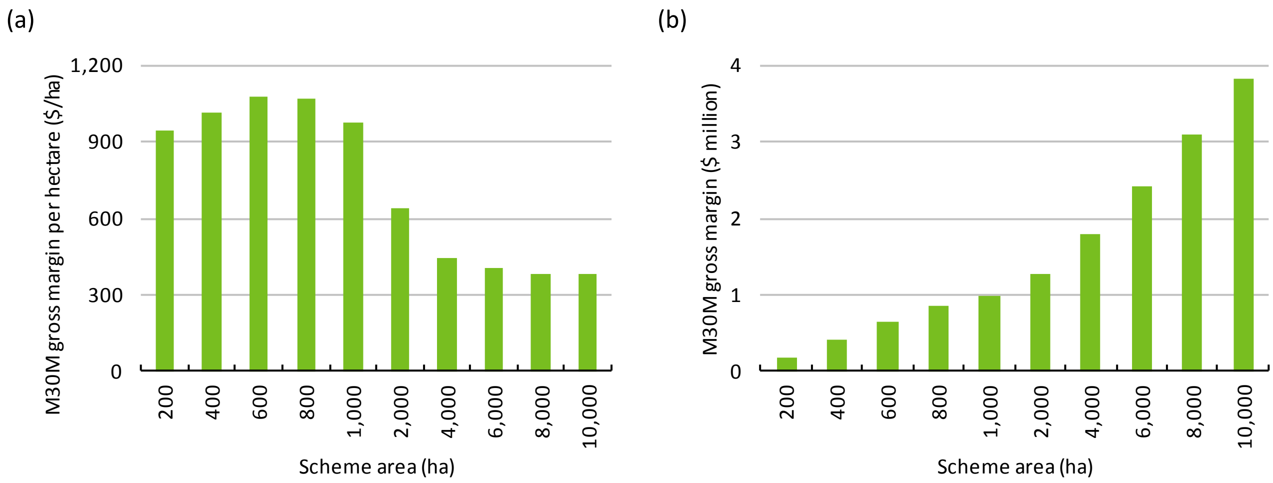


Figure 10.18 (a) Median of the 30-year mean values (M30M) for gross margin per hectare and (b) median of the 30-year mean values (M30M) for gross margin under Scenario B for the irrigation development associated with the Kidston Dam
Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows within the period from 1890 to 2011. Both the median and the standard deviation of the mean values for each of the 92 windows are presented.

Whole-of-scheme net present value

As a new capital project requiring investment in equipment and infrastructure, the irrigation development is assessed for the costs expended and benefits incurred over a 30-year project life. When the costs over this period are subtracted from the benefits to give a net benefit stream, a discount rate of 7% is applied to yield an NPV for the development. A zero or positive NPV value indicates that the scheme is profitable at the specified discount rate.

The whole-of-scheme NPV calculation takes into consideration the scheme- and farm-scale capital, operation and maintenance costs, and scheme-scale gross margins. Asset replacement and residual values are considered within the 30-year project period. Further details on the framework for discounted cash flow financial analysis and assumptions are presented in the companion technical report about irrigation costs and benefits (Brennan McKellar et al., 2013).

The scheme-scale NPV is negative under all scheme areas, because the revenue generated from the scheme (total crop gross margins) does not offset the capital, operation and maintenance costs of the scheme-scale and on-farm infrastructure over the life of the investment (Figure 10.19). Losses are minimised by not undertaking an irrigation development.

Figure 10.19 (a) Median of the 30-year mean values (M30M) for net present value and (b) standard deviation of the 30-year mean values (S30M) for net present value under Scenario B for the irrigation development associated with the Kidston Dam

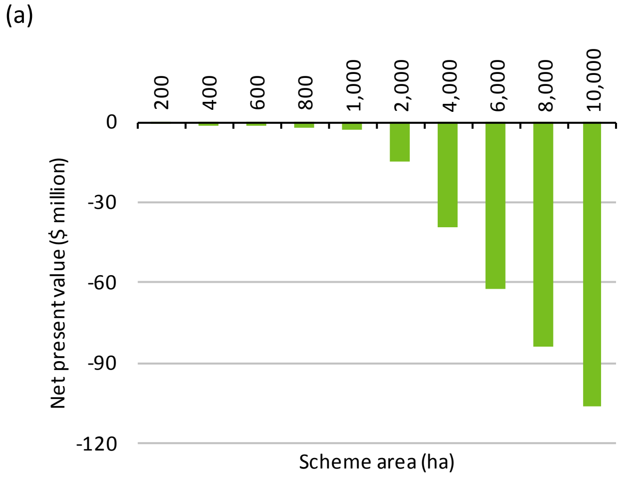
Results are presented as a function of scheme area and annual crop area decision. Scenario B is the historical climate (1890 to 2011) with irrigation development. Mean values are calculated for 30-year windows in the period 1890 to 2011. The median and the standard deviation of the mean values for each of the 92 windows are presented.

Farm-scale net present value

A situation may arise involving independent funding and ownership of off-farm (water storage and transmission) and on-farm (land, equipment) development capital.

In these circumstances, investment decisions made by irrigators could be confined to consideration of on-farm costs only. For this purpose, the NPV of an on-farm investment is calculated. This calculation considers the capital, annual operating and maintenance (overhead) costs of on-farm infrastructure. The capacity to contribute to scheme-scale operation and maintenance costs, and possibly capital costs, through a water price depends on the extent to which the farm-scale NPV is positive.

In this case study, the total crop gross margin is not sufficient to cover the capital and overhead costs over the duration of the investment period, for any combination of scheme areas (Figure 10.20).



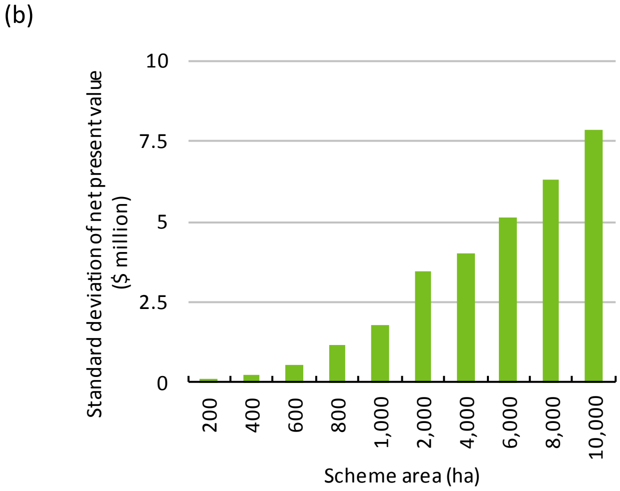


Figure 10.20 (a) Median of the 30-year mean values (M30M) for net present value and (b) standard deviation of the 30-year mean values (S30M) for net present value under Scenario B for the irrigation development associated with the Kidston Dam

10.7.2 DETAILED ANALYSIS FOR A GIVEN SCHEME AREA

For this more detailed investigation, a scheme area of 1000 ha was selected. Construction costs were staged over the first three years of the 30-year investment period (Table 10.7). This is likely to be a more realistic assumption than assuming that all costs are incurred and full revenue is attained in the first year. In this case study, staging construction costs is about 1% less profitable than not staging.

Table 10.7 Staging of construction, farm development and crop production

YEAR	CONSTRUCTION PROGRAM	FARM DEVELOPMENT	CROP PRODUCTION
Year 1	50% diversion and area works and 100% approvals and legal costs		
Year 2	50% diversion and area works	50% farm development	
Year 3		50% farm development	50% revenue
Year 4			100% revenue
Year 16			100% pasture renewal

Gross margins

Figure 10.21a is a time series of annual gross margins ($/ha) simulated using APSIM for each year of the 121-year climate record, assuming various market prices for Rhodes grass. In Figure 10.21b, the range of gross margins for each hay price assumption is indicated by a black vertical line, and the median (50th percentile) is indicated by the black horizontal line. The top and bottom of the coloured box indicates the gross margin at the 25th and 75th percentile, respectively. The large difference between the 75th percentile and the minimum gross margin indicates that a relatively small number of very low gross margins were simulated. At the $150/t price for hay, the gross margins exceed $539/ha in 75% of the years, $987/ha in half of the years and $1502/ha in 25% of the years. At the $250/t hay price, the gross margins exceed $1336/ha in 75% of the years, $2071/ha in half of the years and $3033/ha in 25% of the years.

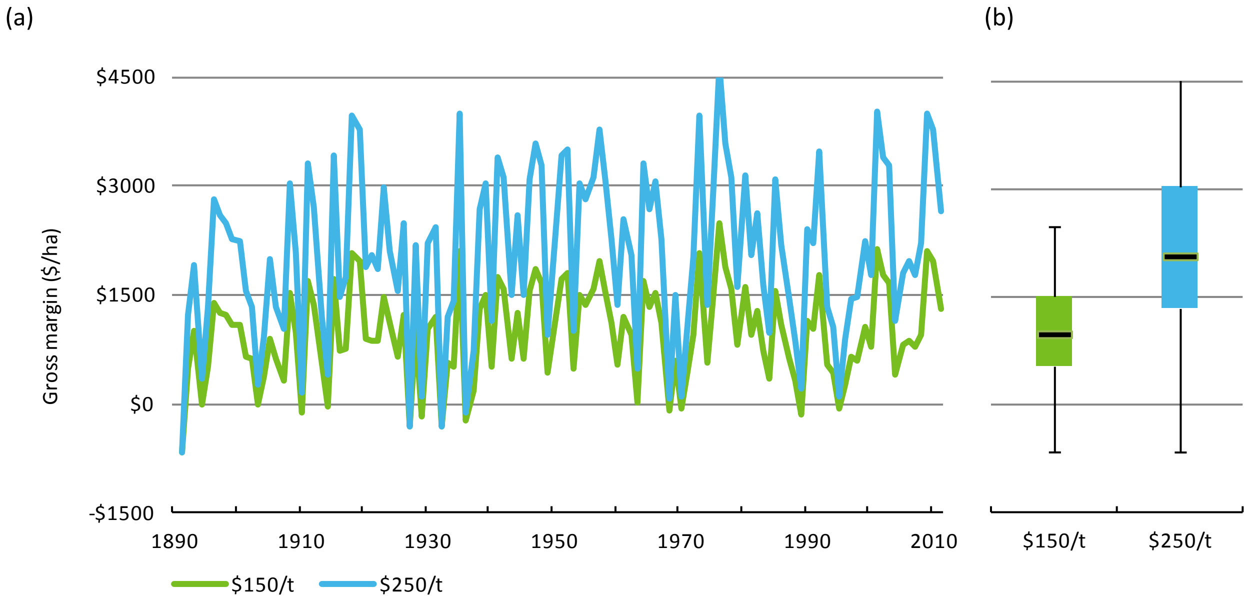


Figure 10.21 Gross margins for Rhodes grass under Scenario B for the irrigation site associated with the Kidston Dam, with a scheme area of 1000 ha: (a) time series and (b) box plots
Scenario B is the historical climate (1890 to 2011) with irrigation development. Results are shown for both the default price of Rhodes grass ($150/t) and a high price ($250/t). In (b), the mean for each price is indicated by a black horizontal line and the range is indicated by the black vertical line. The top and bottom of the coloured boxes indicate the 25th and 75th percentile, respectively.

Variability is a notable feature of this analysis, and this takes on further importance because the analysis used a constant commodity price and the variability is yield driven due only to variations in climate and water availability (i.e. through streamflow). In reality, the effect of variability in commodity prices and production risks (e.g. pests, disease, flooding, access), combined with yield variability (due to variations in climate and water availability), is to increase the modelled variability in gross margin in Figure 10.21. Like all crops the gross margin of hay, in particular, is sensitive to price movements. The 66% increase in price from $150/t to $250/t (Figure 10.21) results in the median gross margin more than doubling. It should also be noted that the gross margins presented in Figure 10.21 do not include a water charge. This is, however, another cost that would be expected to be reflected in the gross margin.

A range of other costs could also affect the gross margin. For example, if there is a drought in the Gulf region, the demand for and hence price of hay would increase dramatically. This is not reflected in this simple analysis, which assumes a uniform price. Likewise, in very good rainfall years, when wet seasons are extended and green pasture is available into the dry season, there will be less demand for hay and prices would drop. These wet years are also likely to interfere with growing and making hay.

Scheme-scale analysis

Using the 121-year distribution of simulated gross margin outcomes presented in Figure 10.21, it was possible to sample 30-year gross margin windows and calculate the NPV of the income stream after accounting for scheme-scale and on-farm capital and annual operating costs in a 30-year investment planning period. In addition to NPV, internal rate of return (IRR) was calculated. The IRR represents the break-even discount rate – that is, the discount rate that will bring the NPV to zero. A viable investment has an IRR higher than the discount rate.

The purpose of sampling from the 121-year distribution is to show how the overall investment performance is sensitive to the particular set of underlying climate conditions during the 30-year investment period.

The ninety-two 30-year NPV and IRR values are presented in Figure 10.22 as percentage exceedance plots. All of the NPVs are negative (Figure 10.22a), ranging from –$27 million to –$32 million for the $150/t Rhodes hay price, and from –$13 million to –$22 million for the $250/t hay price. In other words, the cost of the investment exceeds the income over the 30-year investment period, for all 92 investment periods.

Likewise, in none of the investment periods does the IRR reach a rate that indicates a viable investment. To generate a positive NPV, at the specified discount rate of 7%, the price of Rhodes grass would need to be $400/t.

The only difference between any of the NPV (and IRR) results is the sampled 30-year window of gross margins. In turn, the year-to-year variation in gross margins reflects the climate-driven year-to-year variability in crop yield and water availability. For any given price, the difference between the highest and lowest NPV (and IRR) is therefore driven by the underlying climate conditions. In the case of the $150/t Rhodes hay price, the maximum NPV is 18% higher than the lowest NPV. Discounting increasingly degrades the value of net benefits the further into the future they are received; therefore, the timing of high- and low-yielding years can have a notable effect on the NPV and IRR (Section 6.3).

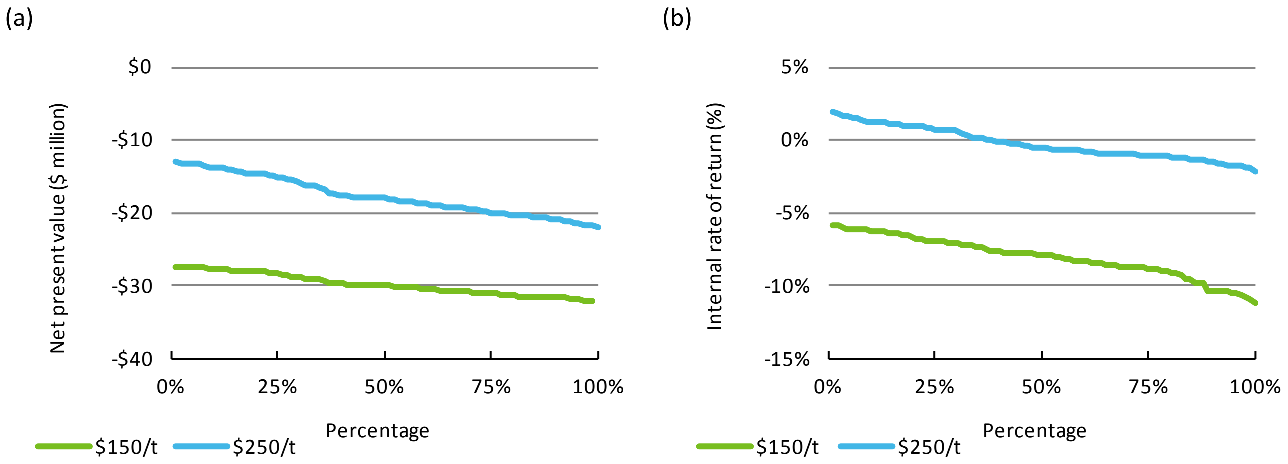


Figure 10.22 Percentage exceedance plots for (a) net present value and (b) internal rate of return under Scenario B for the scheme-scale irrigation development of 1000 ha associated with Kidston Dam
This financial analysis includes all scheme-scale and farm-scale capital and operating costs and income from crop gross margins. Values are for a 30-year investment period. Net present values are calculated using a 7% discount rate, and internal rate of return is calculated using a 7% discount rate.

Farm-scale analysis

In the farm-scale analysis, all capital, operation and maintenance costs associated with the scheme-scale infrastructure are excluded from the analysis. Similar to the scheme-scale analysis, financial assessments use 30-year windows.

The results in Figure 10.23a show that investment at this scale is not viable under the $150/t Rhodes hay price because all NPVs are negative. Under a hay price of $250/t, all of the 92 NPVs generated are positive. This can be interpreted to mean that investors are likely to experience climate conditions that will generate yield and water use outcomes capable of generating a gross margin stream able to offset costs. For the high hay price, all IRRs are greater than 10% (Figure 10.23b).

At the $150/t Rhodes hay price and for the median 30-year NPV, the investor would require a payment of $49/ML to break even (i.e. an NPV of zero) and could pay up to $136/ML at the $250/t hay price, respectively. At a hay price of $177/t, the investment would break even. Therefore, investors have no capacity at the default $150/t hay price to pay a water charge to help offset operation and maintenance of the scheme. Figure 10.23 shows the NPV exceedance plot under a 7% discount rate.

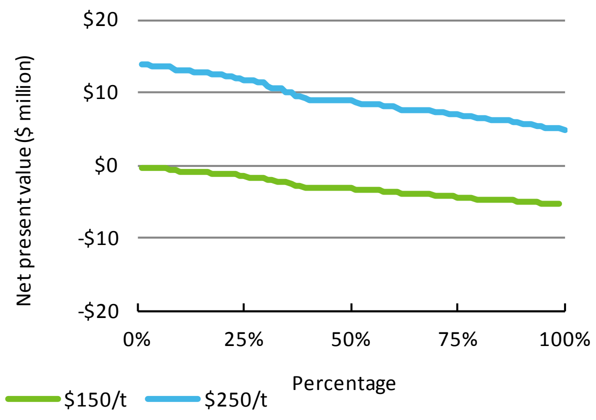


Figure 10.23 Percentage exceedance plots of net present value under Scenario B for the farm-scale irrigation development of 1000 ha associated with the Kidston Dam
This financial analysis includes all farm-scale capital and operating costs and income from crop gross margins. Values are for a 30-year investment period.

10.8 On-site and off-site impacts

Prior to irrigation development, the area would require more intensive assessment of any ecological impacts. This section provides an overview of some of the potential on-site and off-site impacts that may result from the 1000-ha irrigation development analysed in Section 10.7.2.

10.8.1 RISK OF RISE IN WATERTABLE LEVEL AND SECONDARY SALINISATION

Based on the best available information, it is estimated that the watertable level under a 1000-ha irrigation development is likely to rise to within 2 m of the ground surface within 10 to 40 years. Rise in watertable level is likely to mobilise soluble salts in the substrate and clay subsoils, which could cause secondary salinisation when the watertable level rises within 2 m of the ground surface.

The rise in groundwater levels under the 1000-ha irrigation development was assessed using an analytical groundwater model developed as part of the Assessment. The irrigation development is assumed to commence 100 m from the river. Recharge is calculated using annual simulated irrigation and rainfall data under Scenario B (see Jolly et al. (2013)). The parameters and their values used in the analytical model are listed in Figure 10.10. No field-based measurements of aquifer parameters were available for this part of the Gilbert catchment. The values used in Table 10.8 are considered a likely range, based on bore log information. For more detail, see the companion technical report about surface water – groundwater connectivity (Jolly et al., 2013).

Table 10.8 Range of parameter values used in analytical groundwater model for the irrigation development associated with the Kidston Dam

AQUIFER PARAMETER	UNIT	VALUE	COMMENT
Aquifer thickness	m	12	
Depth to groundwater	m	9	
Distance of edge of irrigation development to river	m	100	
Recharge rate	mm/year	136, 214	Lower (heavy soils) and higher (metamorphic and sandy/loamy alluvium) estimate
Saturated hydraulic conductivity (k)	m/day	1, 10, 100	Lower, middle and higher estimate
Specific yield		0.2	Only has bearing on rate of rise, not maximum rise

Figure 10.24 indicates that under the lower (1 m/day) saturated hydraulic conductivity values, the watertable level under the 1000-ha irrigation development will reach within 2 m of the ground surface in 10 to 40 years, depending on the recharge rate. The relatively long time taken for the watertable level to rise to the surface is due to proximity of the irrigation development to the river.

The proximity of the irrigation development to the river makes the prediction of rise in watertable level sensitive to saturated hydraulic conductivity. Based on the bore logs in the area, it is likely that the saturated hydraulic conductivity of the Einasleigh area would be relatively low (i.e. 1 to 10 m/day).

The clay plains in the confluence of the Einasleigh and Copperfield rivers are relatively narrow and adjacent to incised river channels; therefore, a rise in watertable level close to the surface is unlikely.

(a) (b)

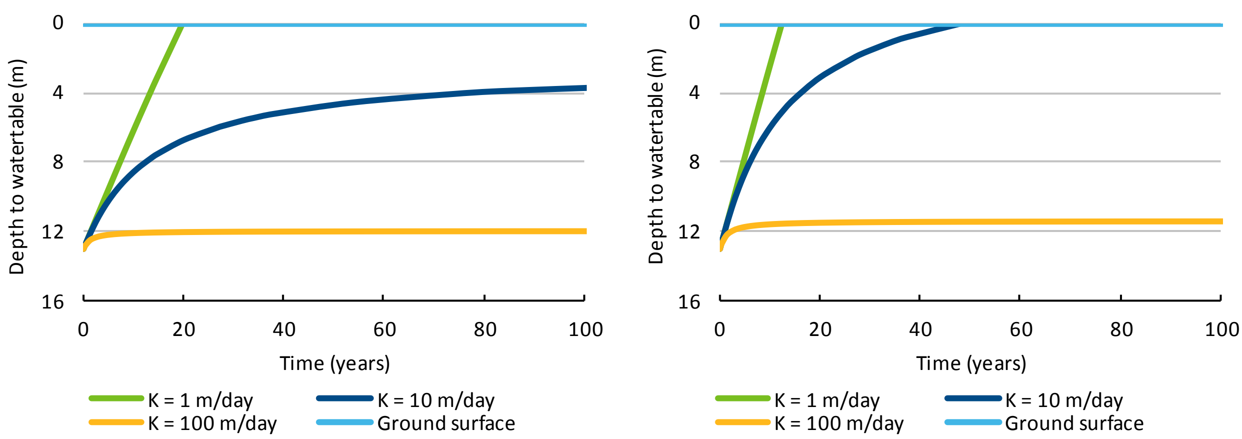


Figure 10.24 Change in depth to watertable for different values of saturated hydraulic conductivity (K): (a) low recharge rate of 135 mm/year and (b) high recharge rate of 215 mm/year

Based on the results from the airborne geophysical investigation of selected areas (Section 10.4), there is a high likelihood of the irrigated area contributing to a rising saline watertable, if poor irrigation practices are used. Previous ground-based studies by Enderlin (2000) have shown that soil profiles for the area on the heavier soils are generally saline with depth. Recharge from the irrigation development has the potential to cause build up of a saline groundwater mound, which would need to be carefully managed to ensure it does not adversely affect the irrigation development or surrounding environment. Additionally, irrigation will need to be carefully managed to prevent salts within the deeper soil profile being mobilised into the plant root zone through capillary rise. For irrigation to proceed, modern, well-designed irrigation systems operating on best-practice principles would minimise the risk of secondary salinisation.

10.8.2 ECOLOGICAL, SOCIAL AND CULTURAL CONSIDERATIONS

Table 10.9 provides a summary of some potential ecological, social and cultural considerations with respect to the 1000-ha irrigation development associated with the Kidston Dam.

Table 10.9 Summary of potential ecological, social and cultural considerations with respect to the 1000-ha irrigation development associated with Kidston Dam

ECOLOGICAL AND SOCIAL CONSIDERATIONS	COMMENT
Vegetation at reservoir and irrigation development	The area inundated at full supply level will not affect regional ecosystems that are 'Of concern' or 'Endangered' (Petheram et al., 2013). The site also contains riverine wetland or fringing riverine wetland vegetation that will be lost to inundation (Petheram et al., 2013).
Sediment infill of reservoir	It is predicted that about 6% (range between 1 and 17%) of the storage volume of Kidston reservoir will infill with sediment after 30 years, and 21% (range between 4 and 56%) of the storage volume will infill with sediment after 100 years (Tomkins, 2013).
Reservoir water quality	The risk of blue-green algal blooms is high. The dam is predicted to have a permanently thermally stratified water column that will have a bloom-supporting light climate from September to May. Because of the development of permanent stratification, downstream delivery of water needs to be carefully managed to avoid delivery of cold, oxygen-depleted water. Thermal impacts associated with release of such water are likely to be limited spatially during periods of warm weather but may be spatially extensive during the cooler months and at night.
Sediment, nutrient and pesticide loads	Suspended sediment load in the Gilbert River are not predicted to increase to a large extent under 1000 ha of irrigated Rhodes grass. Nitrogen and phosphorus loads are predicted to increase moderately (<20%) and are likely to result in some downstream impact (Waltham et al., 2013). It is not possible to model likely losses of pesticides given lack of pesticide data for this land use type (Waltham et al., 2013). If Kidston Dam remains persistently turbid for a long period of the year, at least well into the dry season (as suggested below), there exists the potential for water releases to be turbid. Ecological investigations of waterholes in the Gilbert catchment reveal them to be very sensitive to small increases in turbidity. Such an impact is probably limited to the river reach between Kidston Dam and the irrigation development, given that the re-regulation weirs near Einasleigh trap all available flow; therefore, no turbid water should pass.
Fish passage	Raising the dam wall height does not change existing fish passage status, whereby the existing dam presently is a local fish passage barrier. This dam is beyond the maximum upstream extent of key fish species of high conservation value - freshwater sawfish, barramundi and giant whipray. Downstream barrier effects are likely due to the series of re-regulating weirs on the lower Copperfield River. Although this location is above the maximum upstream limit for the species listed above, most riverine fish species in this region make migratory movements for reproduction or to access newly inundated habitat. Failure to provide passage past these structures is likely to impact on upstream fish communities.
Freshwater and coastal aquatic ecology in response to flow alteration	The proposed enlargened dam would trap an extra 5 GL of water in the upper Copperfield River, potentially including ecologically important early wet-season first flush inflows. The degree of change to flow regime immediately below the dam is difficult to quantify in the absence of gauging station data within a short distance downstream. Because raising the Kidston Dam wall by 2 m would only increase the storage capacity by about 5 GL the changes to flow are unlikely to be large. Dry-season water releases from the dam to the re-regulating weirs near Einasleigh may alter seasonal patterns of river flow and its water quality along the affected reach. Although unnatural, these releases may extend the persistence of instream aquatic habitats, providing some benefit to aquatic productivity. In other irrigation developments, such dry-season releases have, when in large volumes, greatly altered instream ecology, including connecting otherwise isolated waterholes and allowing the development of instream vegetation and weed communities that would normally perish in the dry season. Reproduction of freshwater crocodiles and turtle species in the Copperfield River may be impacted by elevated dry-season flows if such flows inundate otherwise exposed sandbars used as oviposition (nesting) sites. The irrigation development is near the Copperfield River Gorge at Einasleigh township, an important regional scenic attraction and permanent waterhole. Slight reductions in modelled dry-season flows and trapping of any dry-season flushing events in either the re-regulating weirs or Kidston Dam may impact on water levels within the gorge.

Table 10.9 Summary of potential ecological, social and cultural considerations with respect to the 1000-ha irrigation development associated with Kidston Dam
(continued)

ECOLOGICAL AND SOCIAL CONSIDERATIONS	COMMENT
Freshwater and coastal aquatic ecology in response to flow alteration (continued)	Modelling of the flow downstream of the dam has been completed for scenarios before and after development of the dam (Holz et al., 2013). This development results in only very minor changes to mean and median annual flow, or seasonal flow regimes, at all gauging stations downstream of Kidston Dam. Ecological impacts below the confluence of the Einasleigh and Copperfield Rivers are likely to be minimal.
Terrestrial ecology	The effect on terrestrial ecology requires site-based assessment, including examination of existing terrestrial flora and fauna databases. methods. In the event of salinisation it is likely to impact on vegetation communities and ultimately on nearby freshwater habitats.
Impoundment ecology	The enlarged impoundment will offer similar aquatic habitat as the existing impoundment. Colloidal sedimentary material washed into Kidston Dam during rain/flow events can reportedly remain in suspension until August (Tait, 1998), creating elevated turbidity. Where such turbid water is released for irrigation, it will impact on downstream waterholes whose ecology is based on their high water clarity and depth of sunlight penetration. Because the area is upstream of the normal distribution of barramundi, a popularly stocked predatory species that is not currently present in the dam, careful consideration needs to be given to any proposal to stock the dam with fish suitable for recreational fishing. Stocking with barramundi will give them access to an extensive length of river from which they are currently absent. This large predator has significant effects on other fish species and invertebrates. Sooty grunter (also called black bream) occurs in the dam and is a popular angling species. The genetic structure of sooty grunter stocks in the dam needs to be considered, if the fishery was to be enhanced through stocking.
Human ecology	The expansion of the existing body of water may have a marginal effect on human behaviour and human use of the landscape. Recreational and subsistence opportunities, including fish stocking, may be increased depending on how often low water levels prevail. Altered or diminished downstream flow may impact on economic, recreational, subsistence, amenity and cultural values downstream (Barber, 2013). Any potential impacts on Copperfield Gorge due to a reduction in flows below the re-regulating structures or elevation in turbidity may impact on the amenity value of this important tourist destination.
Cultural heritage considerations	Construction and use of the existing dam is likely to have resulted in the destruction of Indigenous archaeological sites within the current footprint. Previous preliminary assessments of the area (Bird and Lovell-Pollok, 1998) have concluded that it has high archaeological potential and is likely to contain a range of sites outside the existing footprint. Further field surveys are required to assess the potential Indigenous archaeological impact of works in this case study area. Any such investigation should be undertaken in consultation with the registered Aboriginal Party, the Ewamian people (McIntyre-Tamwoy et al., 2013).

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Appendixes

Appendix A

Assessment products

More information about the Flinders and Gilbert Agricultural Resource Assessment can be found at <http://www.csiro.au/FGARA>. The website provides readers with a communications suite including factsheets, multimedia content, FAQs, reports and links to other related sites, particularly about other research in northern Australia.

In order to meet the requirements specified in the contracted 'Timetable for the Services', the Assessment provided the following key deliverables:

- Technical reports present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the activities of the Assessment has a corresponding technical report.
- Each of the two catchment reports (i.e. this report and another for the Flinders catchment) synthesises key material from the technical reports, providing well-informed but non-scientific readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture.
- Two overview reports – one for each catchment – are provided for a general public audience.
- A factsheet provides key findings for both the Flinders and Gilbert catchments for a general public audience.

This appendix lists all such deliverables.

Please cite as they appear.

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FACTSHEET ON KEY FINDINGS

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Appendix B

Shortened forms

AEM	airborne electromagnetics
AHD	Australian Height Datum
APSIM	Agricultural Production Systems Simulator
AWRC	Australian Water Resources Council
CGE	Computable General Equilibrium
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSO	community service obligations
DEM	digital elevation model
DSM	digital soil mapping
EC	electrical conductivity
EM	electromagnetic
ENSO	El Niño – Southern Oscillation
FSL	full supply level
FTEs	full-time equivalents
GAB	Great Artesian Basin
GCM-ES	global climate model output empirically scaled to provide catchment-scale variables
GCMs	global climate models
IDAS	Integrated development assessment system
IPCC AR4	the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
IQQM	Integrated Quantity-Quality Model – a river systems model
IRR	internal rate of return
Landsat TM	Landsat Thematic Mapper
mEGM96	Earth Gravitational Model 1996
MODIS	Moderate Resolution Imaging Spectroradiometer
NABSA	North Australia Beef System Analysis
NPV	net present value
NQIAS	North Queensland Irrigated Agriculture Strategy
NRM	natural resource management
ONA	the Australian Government Office of Northern Australia
OWL	the Open Water Likelihood algorithm

PAWC	plant available water capacity
PE	potential evaporation
Sacramento	a rainfall-runoff model
SALI	the Soil and Land Information System for Queensland
SGG	soil generic group
SLAs	statistical local areas
SRTM	shuttle radar topography mission
Zeu	euphotic depth
Zsml	surface mixing layer

Geological timeline

Eon	Era	Period	Epoch	Age (Ma)
PHANEROZOIC	CENOZOIC	Quaternary	Holocene	0.01
			Pleistocene	2.6
		Neogene	Pliocene	5.3
			Miocene	23
		Paleogene	Oligocene	34
			Eocene	56
			Paleocene	66
	MESOZOIC	Cretaceous		145
		Jurassic		201
		Triassic		252
	PALAEOZOIC	Permian		299
		Carboniferous		359
		Devonian		419
		Silurian		444
		Ordovician		485
		Cambrian		541
Supereon	**Eon**	**Era**		**Age**
PRECAMBRIAN	PROTEROZOIC	Neo		1000
		Meso		1600
		Paleo		2500
	ARCHAEAN			4000

Major events

- Major glaciations
- Man
- Eruption of basalt in North Queensland
- Karumba Basin deposited
- Deep weathering in North-Eastern Australia
- Rise of East Australian highlands
- Marine inundation of Eastern and Central Australia
- Great Artesian Basin deposited
- Last major episode of orogenic mountain building (Eastern Australia)
- Intrusion of granite and deposition of volcanic rocks in Kennedy Province
- First land plants
- Marine inundation of Northern and Central Australia
- Georgina Basin deposited
- Oxygen rich atmosphere
- Deposition then deformation of Mt Isa and Georgetown Inliers
- Oxygen poor atmosphere

Units

MEASUREMENT UNITS	DESCRIPTION
BP	before present
GL	gigalitres, 1,000,000,000 litres
keV	kilo-electronvolts
kL	kilolitres, 1000 litres
km	kilometres, 1000 metres
kPa	kilopascal
L	litres
m	metres
Ma	million years
MB	megabyte
mAHD	metres above Australian Height Datum
mEGM96	Earth Gravitational Model 1996 geoid heights in metres
MeV	mega-electronvolts
mg	milligrams
ML	megalitres, 1,000,000 litres

Data sources and availability

The Flinders and Gilbert Agricultural Resource Assessment obtained a range of data for use under licence from a number of organisations, including the following:

- State of Queensland (Department of Natural Resources and Mines)
  - Groundwater database, data dictionary and standards. Version 7. Revision Date: 13/12/2011
  - Attributable acknowledgement: Based on or contains data provided by the State of Queensland (Department of Natural Resources and Mines), 2012. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for direct marketing or be used in breach of the privacy laws.
- State of Queensland (the Department of Science, Information Technology, Innovation and the Arts ; Queensland Herbarium)
  - Queensland's *Regional Ecosystem Description Database*
  - Conditions of use statement: Technical descriptions have been developed from information published by the State of Queensland (acting through the Department of Science, Information Technology, Innovation and the Arts) and remain the property of the State of Queensland. While every effort has been made to ensure the information presented is as reliable as possible, the State of Queensland accepts no liability and gives no assurance in respect of its accuracy and shall not be liable for any loss or damage arising from its use. Technical descriptions are based on a combination of quantitative and qualitative information and should be used as a guide only. Technical descriptions are not to be used as a substitute for reference sites. Descriptions are subject to review and are updated as additional data becomes available.
  - <http://www.ehp.qld.gov.au/ecosystems/biodiversity/re_introduction.html>
- Geoscience Australia
  - *GEODATA Topo 250K Series 3* – spatial data for mapping
  - Attributable acknowledgement: This Assessment report (*Agricultural resource assessment for the Flinders catchment*) incorporates Product which is © Commonwealth of Australia 2006. The Product has been used in *Agricultural resource assessment for the Flinders catchment* with the permission of the Commonwealth. The Commonwealth has not evaluated the Product as altered and incorporated within *Agricultural resource assessment for the Flinders catchment*, and therefore gives no warranty regarding its accuracy, completeness, currency or suitability for any particular purpose.
  - <https://www.ga.gov.au/products/servlet/controller?event=GEOCAT_DETAILS&catno=63999>
- Science Delivery Division of the Department of Science, Information Technology, Innovation and the Arts (DSITIA)
  - SILO climate data – an enhanced climate data bank containing datasets which are based on historical climate data provided by the Bureau of Meteorology. SILO contains Australian climate data from 1889 (current to yesterday), in a number of ready-to-use formats, suitable for research and climate applications. In addition, SILO provides users with access to climate change projections data for 2030 and 2050 in a daily format.
  - Attributable acknowledgement on any created products or images: Based on or contains data provided by the State of Queensland (Department of Science, Information Technology, Innovation and the Arts) [2013]. In consideration of the State permitting use of this data you acknowledge and agree that the State gives no warranty in relation to the data (including accuracy, reliability, completeness, currency or suitability) and accepts no liability (including without limitation, liability in negligence) for any loss, damage or costs (including consequential damage) relating to any use of the data. Data must not be used for direct marketing or be used in breach of the privacy laws.

- <http://www.longpaddock.qld.gov.au/silo/>

- Esri
  - *World Imagery Map Service* – map service of satellite imagery for the world and high-resolution imagery for the United States and other areas around the world. Imagery is sourced from GeoEye IKONOS, Getmapping, AeroGRID, IGN Spain, IGP Portugal, i-cubed, USGS, AEX, Aerogrid, Swisstopo and by the GIS User Community.
  - <http://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9>

Glossary and terms

Anthropogenic: a human impact on the environment.

Aquifer: a permeable geological material that can transmit significant quantities of water to a bore, spring, or surface water body. Generally, ‘significant’ is defined based on human need, rather than on an absolute standard.

Aquitard (confining layers): a saturated geological unit that is less permeable than an aquifer, and incapable of transmitting useful quantities of water. Aquitards often form a confining layer over an artesian aquifer.

Artesian: a general term used when describing certain types of groundwater resources. Artesian water is underground water confined and pressurised within a porous and permeable geological formation. An artesian aquifer has enough natural pressure to allow water in a bore to rise to the ground surface. Sub-artesian water is water that occurs naturally in an aquifer, which if tapped by a bore, would not flow naturally to the surface. Artesian conditions refer to the characteristics of water under pressure.

Basement: the crust below the rocks of interest. In hydrogeology it means non-prospective rocks below accessible groundwater. Commonly refers to igneous and metamorphic rocks which are unconformably overlain by sedimentary beds or cover material, and sometimes used to indicate ‘bedrock’ (i.e. underlying or encasing palaeovalley sediments).

Benthic: the ecological region at the lowest level of a body of water such as an ocean or a lake, including the sediment surface and some sub-surface layers.

Current development: the level of surface water, groundwater and economic development in place as of 1 July 2013. The Assessment assumes that all current water entitlements are being fully used.

Development: see entries for ‘current development’ and ‘future irrigation development’.

Drainage division: the area of land where surface water drains to a common point. There are 12 major drainage divisions in Australia. At a smaller scale, surface water drainage areas are also referred to as river basins, catchments, or watersheds.

Drawdown: the lowering of groundwater level resulting from the extraction of water, oil or gas from an aquifer.

Ecosystem services: the contributions that ecosystems make to human wellbeing.

Eutrophication: the ecosystem response to the addition of artificial or natural substances, such as nitrates and phosphates, through fertilizers or sewage, to an aquatic system. One example is an ‘algal bloom’ or great increase of phytoplankton in a water body as a response to increased levels of nutrients.

Environmental flows: describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well being that depend on these ecosystems.

Flow regime: the entire pattern of flow in a river – from how long it lasts, to how frequently it flows and how large it is.

Fecundity: the potential reproductive capacity of an individual or population.

Future irrigation development: is described by each case study storyline (see chapters 8 to 10); river inflow and agricultural productivity are modified accordingly.

Geological basin: layers of rock that have been deformed by mega-scale geological forces to become bowl-shaped. Often these are round or oblong with a depression in the middle of the basin.

Geological formation: geological formations consist of rock layers that have common physical characteristics (lithology) deposited during a specific period of geological time.

Groundwater (hydrogeology): water that occurs within the zone of saturation beneath the Earth's surface. The study of hydrogeology focuses on movement of fluids through geological materials (e.g. layers of rock).

Groundwater basin: a groundwater basin is a non-geological delineation for describing a region of groundwater flow. Within a groundwater basin, water enters through recharge areas and flows toward discharge areas.

Groundwater divide: a divide that is defined by groundwater flow directions that flow in opposite directions perpendicular to the location of the divide.

Groundwater flow (hydrodynamics): within a groundwater basin, the path from a recharge area to a discharge area is referred to as a groundwater flow system, where travel time may be as short as days or longer than centuries, depending on depth. The mechanics of groundwater flow – the hydrodynamics – are governed by the structure and nature of the sequence of aquifers.

Groundwater flow model: a computer simulation of groundwater conditions in an aquifer or entire groundwater basin. The simulations are representations based on the physical structure and nature of the sequence of aquifers and rates of inflow – from recharge areas – and outflow – through springs and bores.

Groundwater level: in this report refers to the elevation of equivalent freshwater hydraulic head at 25 °C

Groundwater recharge and discharge: recharge occurs where rainfall or surface water drains downward and is added to groundwater (the zone of saturation). Discharge occurs where groundwater emerges from the Earth, such as through springs or seepage into rivers.

Hydrodynamics: the study of liquids in motion

Lithology: the character of a rock; its composition, structure, texture, and hardness.

Net present value: a standard method for using the time value of money to appraise long-term projects by measuring the differences between costs and revenues in present value terms.

Palaeochannel: refers to the main channel of ancient rivers, sometimes called the 'thalweg', the lowest point of incision along the river bed where coarser sediments are commonly deposited. Former river channels that are recognised in the surface (from aerial or satellite images) or subsurface (typically in aerial electromagnetic surveys or drilling).

Permeability: a measurement describing the ability of any fluid (water, oil) to pass through a porous material. Values vary widely, with higher values corresponding to aquifers (i.e., highly permeable) and lower values corresponding to aquitards (i.e. less permeable).

Refugia: habitat for species to retreat to and persist in.

Regolith: weathered upper layer.

Riparian: of, on, or relating to the banks of a watercourse. A riparian zone is the area of land immediately adjacent to a stream or river. Plants found within this zone are collectively known as riparian vegetation. This vegetation frequently contains large trees that stabilise the river bank and shade part of the river.

River reach: an extent or stretch of river between two bends.

Streamflow: is the flow of water in rivers and other channels (creeks, streams etc.). Water flowing in channels comes from surface runoff, from groundwater flow, and from water discharged from pipes. There are a variety of ways to measure streamflow – a gauge provides continuous flow over time at one location for water resource and environmental management or other purposes; it can be estimated by mathematical equations. The record of flow over time is called a hydrograph. Flooding occurs when the volume of water exceeds the capacity of the channel.

Triple-bottom-line: an accounting framework that incorporates three dimensions of performance: social, environmental and financial.

Watertable: the surface where the groundwater level is balanced against atmospheric pressure. Often, this is the shallowest water below the ground.

Appendix C

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