Agricultural productivity in the Flinders and Gilbert catchments

A technical 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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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 Government.

(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.

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

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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
DEM	digital elevation model
GCMs	global climate models
GCM-ES	global climate model output empirically scaled to provide catchment-scale variables
IPCC AR4	the Fourth Assessment Report of the Intergovernmental Panel on Climate Change
IQQM	Integrated Quantity-Quality Model – a river systems model
Landsat TM	Landsat Thematic Mapper
MODIS	Moderate Resolution Imaging Spectroradiometer
NQIAS	North Queensland Irrigated Agriculture Strategy
NRM	natural resource management
ONA	the Australian Government Office of Northern Australia
OWL	the Open Water Likelihood algorithm
PAWC	plant available water capacity
PE	potential evaporation
RCP	representative concentration pathway
Sacramento	a rainfall-runoff model
SALI	the Soil and Land Information System for Queensland
SLAs	statistical local areas
SRTM	shuttle radar topography mission
TRaCK	Tropical Rivers and Coastal Knowledge Research Hub
WRON	CSIRO's Water Resource Observation Network

Units

MEASUREMENT UNITS	DESCRIPTION
GL	gigalitres, 1,000,000,000 litres
keV	kilo-electronvolts
kL	kilolitres, 1000 litres
km	kilometres, 1000 metres
L	litres
m	metres
mAHD	metres above Australian Height Datum
MeV	mega-electronvolts
mg	milligrams
ML	megalitres, 1,000,000 litres

Preface

The Flinders and Gilbert Agricultural Resource Assessment (the Assessment) aims to provide information so that people can answer questions such as the following in the context of their particular circumstances in the Flinders and Gilbert catchments:

- 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 questions – and the responses to the questions – are highly interdependent and, consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports must be read as a whole if they are to reliably inform discussion and decision making on regional development.

The Assessment is producing a series of reports:

- Technical reports present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the 12 research activities (outlined below) has a corresponding technical report.
- Each of the two catchment reports (one for each 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 of these reports are available online 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.

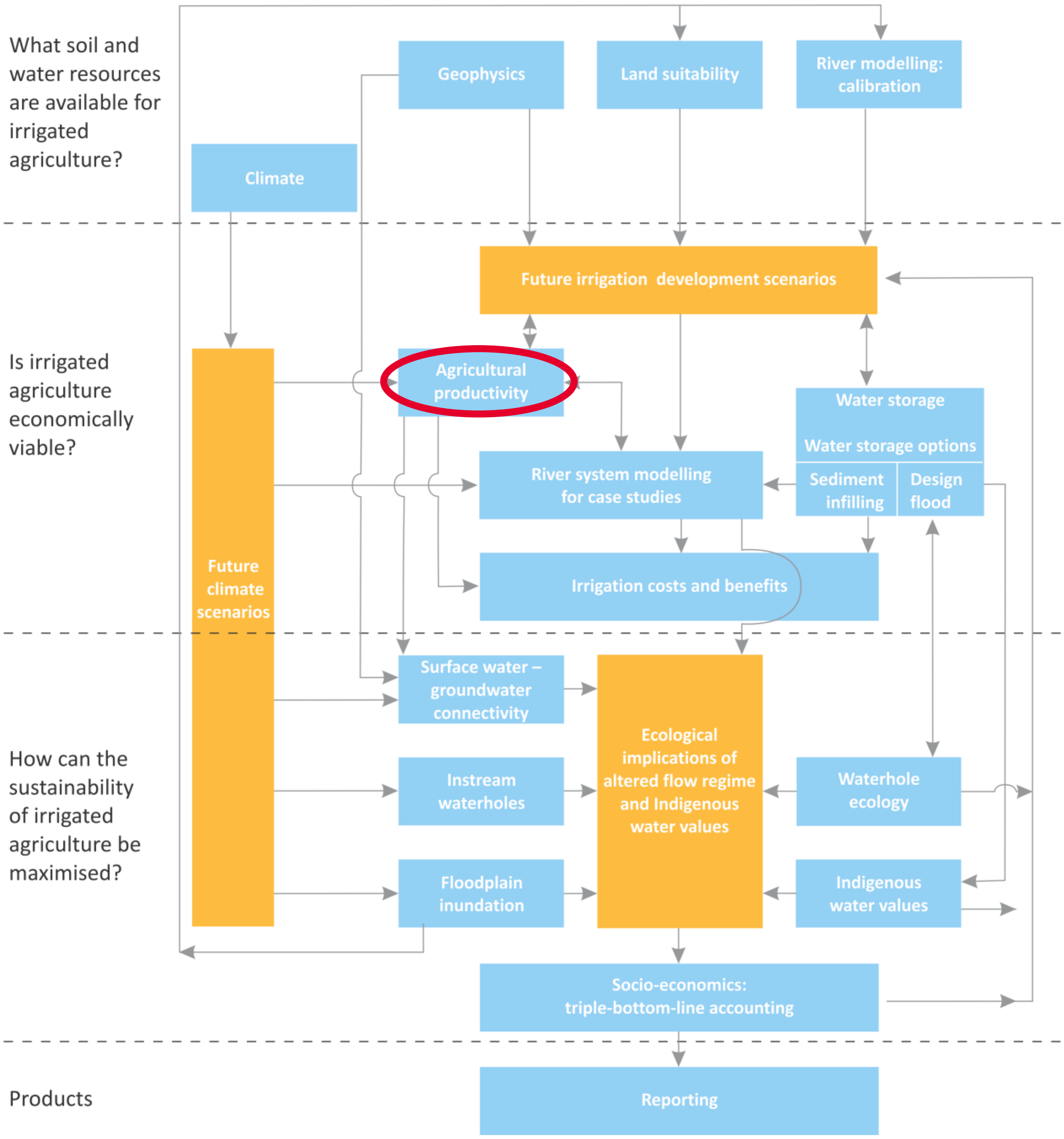
The Assessment is divided into 12 scientific activities, each contributing to a cohesive picture of regional development opportunities, costs and benefits. Preface Figure 1 illustrates the high-level linkages between the 12 activities and the general flow of information in the Assessment. Clicking on an ‘activity box’ links to the relevant technical report.

The Assessment is designed to inform consideration of development, not to enable particular development activities. As such, the Assessment informs – but does not seek to replace – existing planning processes. Importantly, the Assessment does not assume a given regulatory environment. As regulations can change, this will enable the results to be applied to the widest range of uses for the longest possible time frame. Similarly, the Assessment does not assume a static future, but evaluates three distinct scenarios:

- 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.

The approaches and techniques used in the Assessment have been designed to enable application elsewhere in northern Australia.



Preface Figure 1 Schematic diagram illustrating high-level linkages between the 12 activities (blue boxes)

This report is a technical report. The red oval in Preface Figure 1 indicates the activity (or activities) that contributed to this report.

The orange boxes indicate information used or produced by several activities. The red oval indicates the activity (or activities) that contributed to this technical report. Click on a box associated with an activity for a link to its technical report (or click on ‘Technical reports’ on <http://www.csiro.au/FGARA> for a list of links to all technical reports). Note that the Water storage activity has multiple technical reports – in this case the separate reports are listed under the activity title. Note also that these reports will be published throughout 2013, and hyperlinks to currently unpublished reports will produce an ‘invalid publication’ error in the CSIRO Publication Repository.

Executive summary

Agricultural productivity for a range of crops is considered for the Flinders and Gilbert catchments, based on the climate and soils of the Assessment area. Agriculture in the Flinders and Gilbert catchments is currently dominated by extensive dryland beef grazing. There is a very small area of irrigated cropping in the Flinders and Gilbert catchments, and about half of this area is providing feed for the beef cattle industry. Of the area in the Flinders and Gilbert catchments currently irrigating crops, a proportion is irrigation mango trees, with the rest used for opportunity cropping and on-farm experimenting with cropping systems.

Given the limited experience of crop growing seasons, yields, water requirements and farming systems in the Flinders and Gilbert catchments the Agricultural Production Systems Simulator (APSIM) crop model was employed to estimate potential agricultural productivity and irrigation water requirements. APSIM was parameterised using climate locations from the Flinders and Gilbert catchments, and modelled soils that represent the most common soils found in the Assessment area. APSIM was run using unlimited water for irrigation. The yields presented are optimum yields, where the crop was modelled without abiotic stress, and represent the upper limit of yield potential for the Assessment area. Actual yields are likely to be lower.

Modelled potential productivity for a number of crops, particularly summer cereals, fodder crops (grasses and legumes), some pulses and peanuts is promising, with modelled yields that are comparable with other areas of Australia.

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1 Introduction

This technical report describes irrigated agricultural production potential on a per hectare basis for a range of crops in the Flinders and Gilbert catchments of north Queensland. The technical report briefly discusses irrigated agriculture in northern Australia in the context of the Flinders and Gilbert catchments, describes the methods used to estimate potential production, summarises key principles of crop production and describes characteristics of a number of crops that could be considered in the Flinders and Gilbert catchments. Estimates of production potential, and irrigation water requirements on a per hectare basis are made.

1.1 Current scale of irrigated agriculture in the Flinders and Gilbert catchments

Agriculture in the Flinders and Gilbert catchments is currently dominated by extensive dryland (without irrigation water) beef cattle production. Rainfall is used to grow extensive pastures, which are grazed by cattle. Some enterprises also plant forage crops that are either fed directly to cattle, or are cut and baled as hay to be fed to cattle at a later date. There is virtually no dryland cropping for human food or fibre production.

There are approximately 500 hectares and 360 hectares of irrigated agriculture in the Flinders and Gilbert catchments respectively. In the Flinders catchment this comprises several enterprises irrigating hay crops with both sprinkler and flood irrigation systems, and a flood irrigated farm that has tried several cropping systems recently including cotton, rice and mungbean. In the Gilbert catchment there is some significant irrigated horticulture (mango) irrigated by under tree sprinklers, and hay production enterprises irrigated by overhead sprinkler. One farm in the Gilbert catchment has trialled cotton, peanut, sorghum for seed production, guar and a number of other crops.

The Flinders and Gilbert catchments are dominated by beef cattle production enterprises, and about half of the current irrigation activities across the Flinders and Gilbert catchments are directly related to supporting beef cattle production through production of hay and forage. Irrigated hay and forage production can be used for drought feed, supplementary feeding of weaners at weaning or for times when cattle are in yards or being worked. Supplementary feeding of beef cattle can allow cattle to be turned off earlier (through faster weight gain) or increase the number of calves produced.

The soils of the Flinders and Gilbert catchments affect the type of irrigation system possible. The Flinders catchment is dominated by heavy cracking clay soils, that are well suited to flood irrigation systems due to their moderately low permeability. The soils in the Gilbert catchment are generally more sandy, and not as well suited to flood irrigation. Overhead sprinkler irrigation systems are more suited to the Gilbert catchment.

1.2 Assessment of potential agricultural productivity

There is currently limited irrigated cropping in the Flinders and Gilbert catchments. Consequently there is limited experiential knowledge of crop growing seasons, yields, water requirements or farming systems. 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). 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.

Climate is a significant determinant of the type of crops that can be grown, and the methods by which they are grown. Temperature, rainfall and radiation are prime determinants of crop growth and physiological development. Climate (primarily rainfall and temperature) influences crop type, when they can be grown, and how they need to be managed. The climate in the Flinders and Gilbert catchments differs significantly from that in

most irrigated agricultural areas in Australia, and is detailed in the companion technical report about climate (Petheram and Yang, 2013).

To investigate the potential agricultural productivity of the Flinders and Gilbert catchments the nature and extent of the soils needs to be understood. Soil type will also influence the type of irrigation system that can be used, and the amount of irrigation water needed. The companion technical report about land suitability (Bartley et al. 2013) details the location of different soil types in the Flinders and Gilbert catchments, and describes those soils.

The agricultural system modelling reported in this technical report outlines potential agriculture productivity on a per hectare basis. Potential yields are not limited by availability of irrigation water; unlimited irrigation is assumed, and the irrigation water required to achieve maximum yield is reported. To determine regional agricultural potential for the Flinders and Gilbert catchments it is necessary to understand the total amount of water that is available for irrigation. Water from the rivers must be captured, stored and transported to fields, which results in losses of water through the system. The companion technical report on river modelling (Holz et al. 2013) details how much water may be available to irrigated agriculture in the Flinders and Gilbert catchments. These figures can be used to aggregate potential agricultural productivity in combination with the per hectare yields reported in this technical report.

Not all crops are suited to the environments found in the Flinders and Gilbert catchments. Some crops will perform better than others, and a number that are not suited may be unlikely to produce a marketable yield. Because there is limited cropping experience in the Flinders and Gilbert catchments, and indeed in northern Australia, crop agronomic management cannot follow an established 'recipe'. It is very important to recognise that 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. Management must account for multiple decisions including nutrition, watering, sowing time, plant population, rotations, pests, diseases, weeds, climate stresses such as wind and flooding, supply chain issues all the while working on the underlying assumption that a profit will be made. Management skill grows with experience and, until it reaches a high level, the challenges associated with the relative lack of cropping experience in the Flinders and Gilbert catchments 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 crop modelling reported in this technical report assumes optimum management, and represents the high end of achievable yields. APSIM modelling has provided highly accurate estimates of crop and pasture yield potential for a wide range of environments around the world. It is, however, 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. The modelling assumes optimum agronomic management and there is no impact of pests, diseases or any abiotic stress. Major episodic events such as cyclones and flooding are not accounted for. The irrigated crops are 'produced' under unlimited water, with no periods of water stress during crop establishment or growth.

1.3 Potential crops

The companion technical report on land suitability (Bartley et al. 2013) evaluated thirteen land use categories for irrigated agriculture in the Flinders and Gilbert catchments (Table 1). The categories were derived following consultation with agronomists, knowledge of what crops have grown in similar tropical regions and an understanding of the commercial aspirations of local land-holders in the region.

Table 1 List of 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, orange
Food legume (pulse crop)	Chickpea, mungbean (black), navy bean, soybean
Non-leguminous forage, 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 land use categories were used in the assessment because the crops within each category will generally respond similarly to climate, soils and management action. Section 1.3.1 to section 1.3.13 provides a brief summary of the cropping requirements of each land use category in the Flinders and Gilbert catchments.

1.3.1 CEREAL CROP

Dryland and irrigated cereal production are well established in Australia. Around 20 Mha of land is devoted to grain (wheat, barley, grain, sorghum, oats, triticale, maize, etc) production each year, yielding an average of approximately 35 Mt pa. Domestic markets demand all cereals. Significant export markets exist for wheat, barley and grain sorghum and there are niche export markets for grains such as maize and oats.

Amongst the cereals, the 'summer crops' such as grain sorghum and maize are the most prospective for the Flinders and Gilbert catchments. These could be grown opportunistically using dryland production or more continuously using irrigation. The 'winter cereals' such as wheat and barley are not well adapted to the climate of the Flinders and Gilbert catchments. 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.

1.3.2 CITRUS

Citrus crops – such as lemon, lime, mandarin and orange – are marginally suited to the climate of the Flinders and Gilbert catchments. While some citrus species can grow well in tropical areas such as Dimbulah, the temperatures in the Flinders and Gilbert catchments makes citrus less prospective.

Most citrus grown in Australia is for fresh fruit markets, with some juicing also conducted. Citrus fruit is harvested over a prolonged period, generally from January to October, with the bulk harvested in March to July. This long season presents some, but possibly limited, opportunities for the Flinders and Gilbert catchments to produce fruit 'out of season', thus commanding higher market prices. The citrus market rewards high quality fruit with higher

market prices, and carful management including nutrition, pest and disease control as well as harvesting, packaging and transport is needed to ensure blemish free fruit.

Citrus demands well drained soils, with an assured water supply, so water supply to the crop can be closely managed. Citrus would generally not be well suited to cracking clay soils of the Flinders catchment, but may perform better on the lighter soil in the Flinders and Gilbert catchments.

1.3.3 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 Flinders and Gilbert catchments 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. Not all pulse crops are likely to be suited to the Flinders and Gilbert catchments. Those that are ‘tender’ such as field peas and beans may not be well suited to the highly desiccating environment and periodically high temperatures. Direct field experimentation in the catchment is required to confirm this, for these and other species.

Pulses are often advantageous in rotation with other crops because they provide a disease break and, being legumes, often provide nitrogen for subsequent crops. Even where this is not the case, their ability to meet their own nitrogen needs can be beneficial. This may be a distinct advantage the Flinders and Gilbert catchments 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.

1.3.4 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 during 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 Flinders and 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 amongst the most promising opportunities for dryland and irrigated agriculture. There is potential for farmers primarily engaged in extensive cattle production to use irrigated forage, hay and silage to increase the carrying capacity of their enterprise.

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 grain sorghum 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.

1.3.5 FORAGE LEGUME

The use of forage legumes is similar to that of forage grasses, described in section 1.3.4. They are generally grazed by animals, but can also be cut for silage or hay. Some forage legumes are very well suited to the Flinders and Gilbert catchments, and would be considered among the more promising opportunities for irrigated agriculture.

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 Flinders and Gilbert catchments.

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.

1.3.6 INDUSTRIAL

Industrial crops in the Assessment are those crops that require post harvest processing, usually straight after harvest, and usually in a proximate facility. Examples of industrial crops in Australia are cotton and sugarcane.

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).

Sugar production is well established in Queensland, which produces approximately 95% of the Australian crop. Sugarcane was grown in the Ord River until 2007. There is approximately 380,000 hectares of cane grown annually, supplying 24 mills that produce approximately 4.4 Mt of sugar. The gross value of production is approximately $1,400 million.

Other industrial crops such as tea and coffee are unlikely to yield well in the Flinders and Gilbert catchments, 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 Flinders and Gilbert catchments, 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.

Industrial crop production is highly dependent on access to processing plants (such as cotton gins or sugar mills). There are no processing facilities in the Flinders and Gilbert catchments, which is likely to decrease the attractiveness of industrial crop production compared with other cropping options, particularly those that can service a local regional market. The economics of establishing processing plants generally requires that they continuously operate at or near capacity; it is therefore critical that the area and yield of crops meets this need.

Industrial crops such as cotton requires access to suitable picking and module or baling equipment as well as transport to processing facilities. Sugarcane requires specialised planting, row formation, and harvesting equipment, however most farmers use contract harvesting, and many also use contract planters.

1.3.7 INTENSIVE HORTICULTURE (VEGETABLES)

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 (out of a total of about $22 billion for all Australian crops) (ABARES, 2012).

Production is highly seasonal and often involves the growth on a particular farm of a wide range of crops. The importance of freshness in many horticultural products means seasonality of supply is important in the market. The Flinders and Gilbert catchments 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 2011-12, compared with a total value of imports of these products of $2.1 billion (DAFF 2013). Potential yields for horticultural crops are not modelled as there are no simulation models that have been calibrated for the environment in the Flinders and Gilbert catchments. 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.

1.3.8 OILSEED CROP

Winter grown oilseed crops, such as canola, are not well suited to the Flinders and Gilbert catchments. Summer oilseed crops such as sunflower are more suited to the environment. Australia produces around 2 to 3 million tonnes of oilseed crop annually, about half from canola and a third from cottonseed.

1.3.9 ROOT CROP

Root crops – such as peanut, sweet potatoes and cassava – are potentially well suited to the lighter soils found in some alluvial stretches of the Flinders and Gilbert catchments. Root crops are not suited to growing on heavier clay soils because they need to be 'pulled' from the ground for harvest, and the heavy clay soils, such as cracking clays, are not conducive to easy pulling.

Peanuts are a crop that has been well established in Queensland. They can be planted in summer or winter. Peanuts grown in the Flinders and Gilbert catchments would probably be summer-grown, with supplementary irrigation required as the crop entered the dry season.

The most widely grown root crop in Australia, peanut, is a legume crop that therefore requires little or no nitrogen fertiliser, and is 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 root crop production, but a specialised digger is required to remove the roots from the ground prior to harvest. Hay-making equipment is also an advantage, as the residue makes good-quality hay that can be sold locally to the cattle industry.

1.3.10 SILVICULTURE (PLANTATION)

Of the potential plantation tree species available to be grown in the Flinders and Gilbert catchments, African Mahogany and Indian Sandalwood are considered most likely to be economically feasible. Many other plantation species could be grown; however, returns are much lower than for these two crops.

The cracking clay soils found in parts of the Flinders and Gilbert catchments are not considered highly suited to perennial crops such as silviculture due to potential for root shear. Cracking clay soils shrink and swell with wetting and drying, potentially breaking roots as they move. It is possible to successfully grow perennial crops on cracking clay soils with well managed irrigation practices. By keeping the soil wet enough, shrink swell action can be minimised. A water limited environment increases the associated risk. Plantation species require greater soil depth than most other crop species.

Plantation timber species require over 15 years to grow, but once established can tolerate prolonged dry periods. Irrigation water is critical in the establishment and first two years of a plantation.

1.3.11 TREE CROP/HORTICULTURE (FRUIT)

Some fruit tree crops – such as mango – are demonstrably well suited to the climate of the Flinders and Gilbert catchments. Other species – such as avocado, and lychee – are not likely to be well adapted to the climate and are less prospective. Perennial crops are generally not suited to cracking clay soils of the Flinders catchment, however with careful irrigation management can be successfully grown.

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 Flinders and Gilbert catchments 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 approximately from August up to November through to February, depending on the species. This is a period in the Flinders and Gilbert catchments when very little rain falls, and farmers would need to have a system in place to access irrigation water during this time.

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.

1.3.12 TREE CROP (NUTS)

Some nut tree crops – such as cashew – are well suited to the climate of the Flinders and Gilbert catchments. Other species – such as macadamia – are not likely to be well adapted to the climate and are less prospective. Perennial crops are generally not suited to cracking clay soils of the Flinders catchment, however with careful irrigation management can be successfully grown. Nut crops such as cashew are highly susceptible to frost.

The perenniality of tree crops makes a reliable year-round supply of water essential. However, many species can survive under mild water stress from the end of the wet season through to flowering (August to October). It is critical for optimum production that trees are not water stressed from flowering through to harvest. This is the period approximately from August up to November through to February, depending on the species. This is a period in the Flinders and Gilbert catchments when very little rain falls, and farmers would need to have a system in place to access irrigation water during this time.

1.3.13 VINE

Vine crops in this Assessment refers to table grapes. Table grapes are grown for the fresh fruit market, with harvest from November (in warmer northern climates) through to March/April. There is a niche opportunity to grow table grapes in the Flinders and Gilbert catchments to produce fruit ‘out of season’ and command higher market prices, however this brings higher risk.

Table grapes are a perennial crop, and not suited to cracking clay soils which could induce root sheer with their shrink and swell action. Table grapes grow best in well drained soils with adequate irrigation water available so that water can be easily managed in the root zone.

1.4 Requirements / Considerations for irrigated agriculture development

Irrigated agricultural precincts tend to have different physical and socio-economic infrastructure than currently exists in the Flinders and Gilbert catchments. Development of irrigated agriculture in the Flinders and Gilbert catchments will require infrastructure, additional to the crop specific machinery and skills needed on-farm to produce an irrigated crop. This could include on-farm developments such as roads, sheds, pumps, power, water storage and transport and off-farm developments such as water storage and metering, handling facilities for grains or fodder and roads. Irrigated agricultural development will likely provide a need for additional labour on-farm to maintain irrigation activities. These skills are currently locally limited, so expansion of irrigation will require a combination of migration of skills into the region or training of local labour. Farmers who decided to irrigate for opportunistic cropping will benefit from developing marketing skills such as crop and market forecasting and forward selling.

Hay and fodder production is either eaten *in situ* or cut and stored on-farm for later consumption. In either case reliance on markets is not an issue when consumption is on-farm. Where irrigation is for opportunistic cropping or fodder production for off-farm consumption, farmers will need to know the cost of getting their produce to a receiving facility (or market), and the risks associated with market pricing (which is based on supply and demand, often on a worldwide scale) and factor this into their costs of production and risk management strategies.

Private agricultural service consultants are usually present in established agricultural regions, especially in irrigation areas. Irrigation infrastructure often needs servicing and maintenance and advice on agronomy is often needed by farmers. It is unlikely these services exist in the Flinders and Gilbert catchments, however if irrigated agriculture develops, then these services will be desirable.

Advice and sales of agricultural chemical and fertiliser inputs is often a prerequisite for cropping and fodder production. In established agricultural areas these services are supplied by agricultural companies who employ sales agronomists to provide advice and generate sales. Attracting these skills and services to a region requires that the market reaches a critical mass. Establishing this during the development phase can prove a challenge for individual producers who for some time may be required to solve issues ‘on their own’.

Support for research and development from government departments will be valuable to the Flinders and Gilbert catchments, particularly in the development phase of irrigated agricultural development. Extension of knowledge from government departments to farmers can be wide-ranging, including agronomy, market identification and risk management, economics, pest and disease control options, market access and environmental impact minimisation. In addition, government departments may be able to offer advice on how to comply with regulations.

Research into specific issues associated with agricultural development in the Flinders and Gilbert catchments will benefit the region. Cropping systems, soils and climate differ significantly from southern Australia, and research on the specifics of cropping and fodder production in northern Australia will facilitate successful agricultural development.

2 Review of agriculture in Northern Australia

2.1 Current agriculture in northern Australia

Beef cattle production from extensive native pastures is the dominant agricultural industry in northern Australia. In the northern draining catchments, the beef cattle industry utilises 60% of the land, accounts for around 5% of the jobs, and contributes around $1 billion to the northern Australian economy annually. Northern Australia carries around 30% of Australia's cattle and accounts for 80% of Australia's live cattle exports, generating about $300 to $400 million annually.

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 per cent of the regional total economic activity. Employment currently generated by irrigated agriculture, directly and indirectly, is estimated to be approximately 1,700 full-time equivalents. This represents around 1.3 per cent 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 (*ca* 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.

2.2 Historical agricultural developments in northern Australia

The irrigated agriculture development ambition for northern Australia has been a policy agenda for over a century. From about 1880 a wide range of crops has been tested under irrigation in northern Australia, with many showing promise, but few persisting. Peanuts were the biggest success prior to World War II, occupying some 600 hectares prior to the outbreak of war (Christian, 1977). Immediately after World War II there was a strong political will to "develop the north", and a review of previous cropping failures identified the causes as environmental (a formidable climate, unsatisfactory soils, floods and droughts, widely varying topography), economic (isolation from markets, transport costs, the lack of marketing) and social (unattractive social and living conditions) (Christian and Stewart, 1953).

From the end of World War II there have been six large scale agricultural developments in northern Australia that have failed to meet the expectations of the time. Reasons for this have included ill-fitted agronomic practices, poor administration, severe climatic hazards, inadequate 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, over capital expenditure, use of unsuitable soils and unrealistic expectations for market price (Chapman et al. 1996).

Socio-economic limitations to agricultural developments in northern Australia are a result of the current population being small, dispersed, and with little traditional agricultural knowledge. Agriculture in northern Australia has a dependence on external, often distant, markets. The current workforce in northern Australia has limited experience in irrigation and there are currently limited agribusiness support services. Additional to these

factors are incompletely developed communications and agricultural transport infrastructure, fluctuating political support for northern industries, poor social facilities, and a hot climate which is difficult to live in (Chapman et al. 1996).

The post World War II review of agricultural development in northern Australia suggested success would come about through demonstration of stable production, adequate and regular markets, organisation of transport and marketing and government assistance to provide a standard of living to sustain a virile population (Christian and Stewart, 1953). 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).

2.3 Lessons from northern Australia

The agronomic challenges posed by climate and soil constraints are becoming more manageable as technology and experience grows. For example it is much easier today to identify salinisation risk in soils (Petheram et al. 2008). Pest and disease risks remain, with some new technological advances such as transgenic crop varieties able to militate against some insect pests, such as BT cotton making it easier to grow cotton in northern Australia (Yeates 2009).

Proponents of irrigated agricultural development are often tempted to rapidly scale-up to increase returns on investment. This rapid development does not allow experience of a new environment to be gained, increasing the risk of the operation (Thorburn 2012).

When the characteristics of successful irrigation developments in northern Australia are looked at, for example the Burdekin River Irrigation Area, the Mareeba-Dimbulah Irrigation Area, the Ord River Irrigation Area or Katherine, key success points can be identified. Soils in these regions are generally good for the crop they are growing, for example the cracking clays are suited to irrigated sugarcane production in the Burdekin or the rich volcanic soils in Mareeba-Dimbulah are highly suited to intensive horticulture. Irrigation water supply in these regions is also highly reliable, allowing continuous cropping, even in drought periods. There are marketing advantages in these regions; the Burdekin and Mareeba-Dimbulah areas are close to significant ports and Katherine and the Ord are highly successful in producing ‘out of season’ produce that commands price premiums.

The lessons from historical irrigated agricultural developments in northern Australia for the Flinders and Gilbert catchments are discernible; choose the best soils, ensure there is a reliable supply of irrigation water, grow marketable crops, gain experience meticulously, take advantage of the best available agronomic advice and expand prudently. While there is no absolute formula for success, the lessons from historical developments, both success and failure, will help plan future development.

3 Methods

This technical report presents the production potential for a range of agricultural crops in the Flinders and Gilbert catchments (Figure 1). The Flinders catchment has an area of approximately 109,000 km^2 and the Gilbert catchment 46,354 km^2. The combined population of the Assessment area is 7200 people with the Flinders catchment serviced by Hughenden, Richmond, Julia Creek, Cloncurry and Mount Isa (outside of the Assessment area) and the Flinders catchment serviced by Georgetown and Croydon (outside the Assessment area). Townsville and Cairns are the two closest major cities and Port facilities.

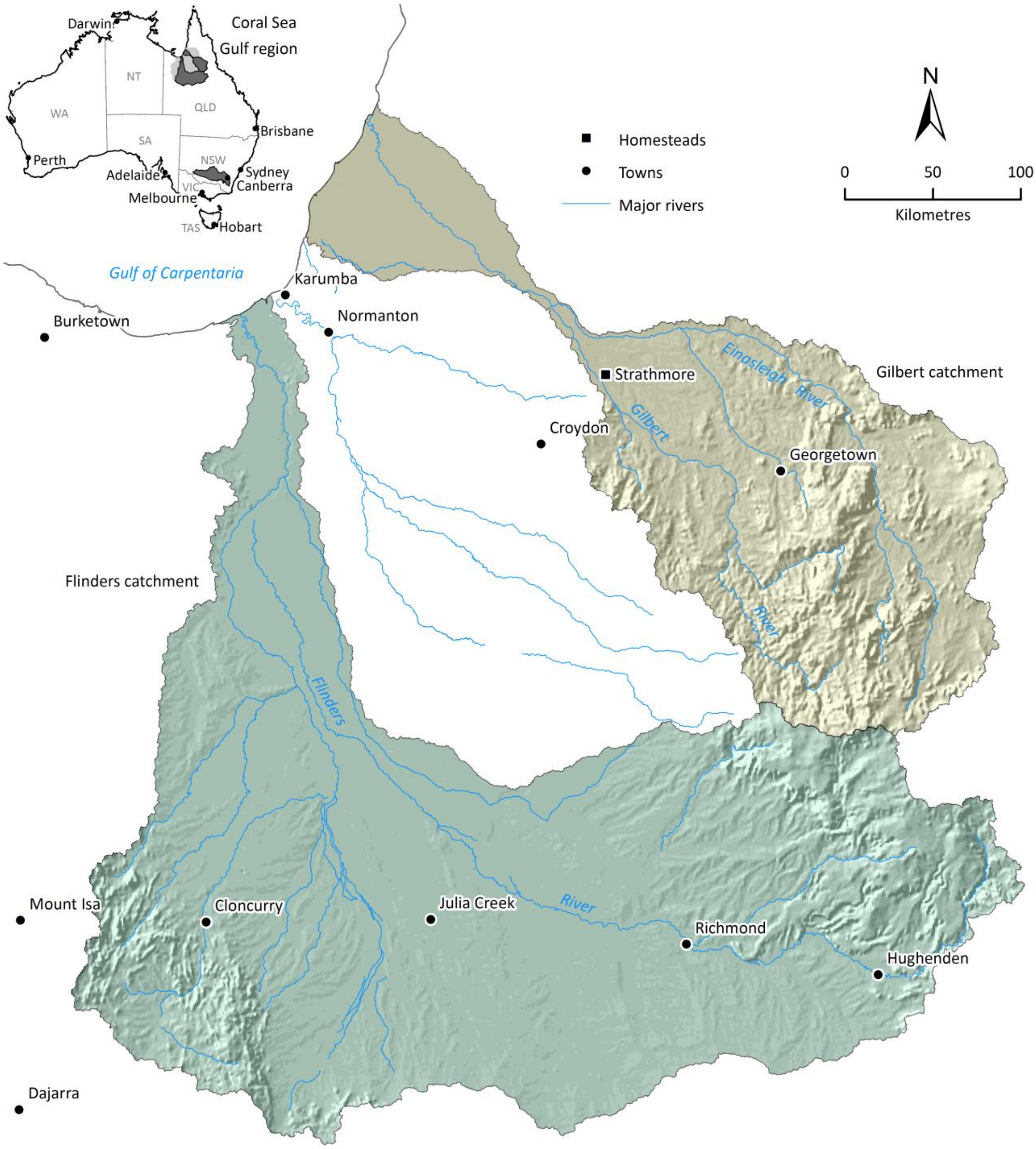


Figure 1 Shaded relief map of the Flinders and Gilbert catchments. The Flinders and Gilbert catchments, the Gulf region and the Murrumbidgee catchment in south-eastern Australia are shown in the thumbnail in the top left

To estimate the production potential for a range of crops in the Flinders and Gilbert catchments the climate and soils of the region need to be understood. The climate in the Flinders and Gilbert catchments is described in the companion technical report about climate (Petheram and Yang, 2013) and soil in the Flinders and Gilbert catchments are described in the companion technical report about land suitability (Bartley et al. 2013). The production potential of a number of crops can be estimated using cropping system modelling. Crop modelling is also used to estimate the irrigation water requirements to produce the estimated potential production. For crops where there is no modelling capability, estimates of production potential and irrigation water requirement are made through expert knowledge and analysis of crop yields and irrigation water requirements in similar climates.

3.1 Modelling agricultural production potential

Agricultural systems can be described as complex physical processes of crop growth, soil water and nutrient dynamics and decomposition in continuous interaction with each other and the local climate. Farmers traditionally learn through continual practise and seasonal experience, while researchers undertake experiments to explore and understand these interactions. The complexity of agricultural systems can surpass our ability to guess future outcomes when considering the constraints to exploration and experience in time and space. Simulation models using long-term historic climate data are suitable tools for exploring these interactions and provide a time efficient method for gaining learning experiences. The Agricultural Production Systems Simulator (APSIM) is a modelling framework that has been developed to simulate biophysical process in farming systems, in particular where there is interest in the economic and ecological outcomes of management practice in the face of climatic risk (Keating et al, 2003). The APSIM modelling framework has been employed in evaluation of a broad range of applications including; on-farm decision making, seasonal climate forecasting, risk assessment for government policy making (Keating et al. 2003); impact of changes to cropping systems and agronomic practices on the water balance of dryland regions (Verburg and Bond, 2003) and has demonstrated utility in predicting performance of commercial crops providing soil properties are well characterized (Carberry et al, 2009). Validated crop models have been used in previous assessments of the cropping potential for a range of prospective crops in Northern Australia (Carberry et al, 1991; Yeates, 2001; Pearson and Langridge, 2008). Models have been developed to capture cropping potential only limited by water, nutrients and seasonal climate variability. The predictive capacity of simulation models is subject to the accuracy of the input data used as a basis for each simulation scenario. The key inputs required by APSIM are long-term daily climate records, characterized soils describing Plant Available Water Capacity (PAWC) and agronomic practice for managing irrigation and crop agronomy. The model assumed best practice in weed and insect pest management and in this analysis assumed 100% irrigation efficiency in application of surface irrigation.

3.1.1 DATA INPUT

Soil

The companion technical report on land suitability identified eight generic soil groups (Table 2), and their locations (Bartley et al. 2013). Four of those identified soil types are deemed to be not suitable for agriculture, and the remaining four have been parameterised for modelling in the Assessment. The four generic soils were developed from soil assessment and digital soil mapping and specified for use with APSIM. These soils can be described for modelling purposes as, (i) Sandy silt-loam (90 mm PAWC to 100 cm), (ii) Brown Dermosol (107 mm PAWC to 100 cm), (iii) Gey Vertosol (149 mm PAWC to 100 cm) and (iv) Black Vertosol (204 mm PAWC to 150 cm). These four soils respectively represent four modelled Soil Generic Groups from the companion technical report on land suitability (Bartley et al, 2013), namely; (i) Sand or loam over relatively friable clay subsoils, (ii) Red, yellow or grey loamy soil, (iii) Friable non-cracking clay or clay loam soils and (iv) Cracking clay soils (Table 2).

Climate

The companion technical report on climate (Petheram and Yang, 2013) provides a comprehensive overview of the climate of the Flinders and Gilbert catchments. Long-term climatic data used by APSIM in simulation analysis is based on historic daily climate data sourced from the SILO data drill database and derived from 0.05° x 0.05° (~5 km x 5 km) resolution grids spanning the 121 year period 1 July 1890 to 30 June 2011. A full description is

included in the companion technical report about climate (Petheram and Yang, 2013). Climate locations were selected to capture climatic gradients occurring north to south and east to west in both catchments and identified as Hughenden, Richmond, Cloncurry, Einasleigh, Georgetown and Croyden. Climatic variables used by APSIM include total solar radiation (Mj/day), maximum and minimum air temperature (°C) and rainfall (mm/day).

Crop

Of the thirteen land use categories identified (Table 1) as potential areas for agricultural investment only the cereal, pulse, root, forage and industrial crop classes can be specified in the current version of APSIM. These modelled crops include maize, wheat, rice, sorghum, mungbean, chickpea, soybean, peanut, bambatsi-panic, forage sorghum, lablab, sugarcane and cotton. A range of horticulture and tree crops were identified as having potential for development under irrigation in both catchments but are currently outside the scope of simulation models such as APSIM and can only be assessed on the basis of availability of industry production and water use data.

Management

Models such as APSIM assume best practice for managing a crop in the absence of any pest and disease related stress. Simulations were undertaken to achieve crop growth in non-limiting soil water and nutrient environments. Applied irrigation was triggered in the model using soil water deficit and the potential root zone of each crop. Natural reset points at the end of winter (September) when the soil profile is normally dry were selected to initialize the soil water, soil nitrogen and surface cover each year so as to only capture the effect of seasonal climate and applied irrigation on crop production. Irrigation management assumed 100 % efficiency in applying irrigation to the crop regardless of availability of supply. Irrigation inefficiencies are discussed in section 4.4.2 but in this analysis not implemented in the simulation results. Simulated water use should be considered a minimum value achievable for given crop and seasonal conditions, to achieve maximum yield.

3.1.2 MODEL OUTPUTS

Annual output from APSIM for a range of variables has been used as the basis for production and water use values reported for the modelling and economics sections reported. Crop or forage production is presented as either kg ha^{-1} or t ha^{-1} (cotton as bales ha^{-1}) in all tables and figures. Probability of exceedance graphs present the probability of exceeding the 20^{th}, 50^{th} and 80^{th} percentile yield or applied irrigation amount for a selected management scenario.

3.2 Determining potential regional agricultural productivity

The outputs used in this technical report are potential productivity and irrigation water use on a per hectare basis. To determine the potential regional agricultural production for a crop the amount of available water needs to be well understood. The amount of water that can be used for irrigation reliably is not easily predicted from rainfall as much of the water in the Flinders and Gilbert catchments is discharged during large flood events. The companion technical report on river modelling uses crop production model outputs, irrigation water requirements and water yields attainable from rivers to predict regional agricultural productivity (Holz et al. 2013).

4 Principles to consider for irrigated agriculture in the assessment area

Before a new irrigated agricultural scheme or enterprise is to be established there are a number of principles, both biophysical and social, that it may be useful to consider. The following principles are fundamental to crop production, and therefore understanding them in the context of the Flinders and Gilbert catchments will help determine the irrigated agriculture crops suited to the scheme or enterprise under consideration. In this section principles that are directly related to irrigated agricultural production are discussed. Information from companion reports in the Assessment are drawn on and discussed in the context of the Flinders and Gilbert catchments. There are a number of limitations to irrigated agricultural productivity, and here we discuss what some of the major limitations are, and managers may account for those limitations in the Flinders and Gilbert catchments.

The greatest influences on potential agricultural productivity in the Flinders and Gilbert catchments are climate, soils and use of irrigation water.

4.1 Climate

The climate has a major influence on crop yield and irrigation water requirements. The climate of the Assessment area is discussed in detail in the companion technical report about climate (Petheram and Yang, 2013).

4.1.1 RAINFALL

Rainfall averages 492 mm and 775 mm in the Flinders and Gilbert catchments respectively, however there is variability across both catchments, with rainfall average increasing generally in each catchment towards the coast (Figure 2). The average rainfall varies between 350 mm and 800 mm in the Flinders catchment and 650 mm and 1050 mm in the Gilbert catchment. In the Flinders catchment 88% of the rainfall falls in the wet season and 90% of that evaporates, so that only 7% of the rainfall makes its way to streamflow. In the Gilbert catchment 93% of the rainfall falls in the wet season and 84% of that evaporates, so that only 13% of the rainfall makes its way to streamflow. The balance is stored in the soil and used by plants.

Rainfall has a very high inter-annual variability; for a region with low annual rainfall, the Flinders and Gilbert catchments have amongst the most variable rainfall in the world (coefficient of variation = 0.5 in the Flinders catchment and 0.4 in the Gilbert catchment). 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 Flinders and Gilbert catchments than in most of Australia’s other cropping regions but they are, because of high evaporation rates and markedly seasonal rainfall, significantly more intense. The Flinders and Gilbert catchments are, for crops, a water-limited environment in which water stored in dams and soils is at a premium.

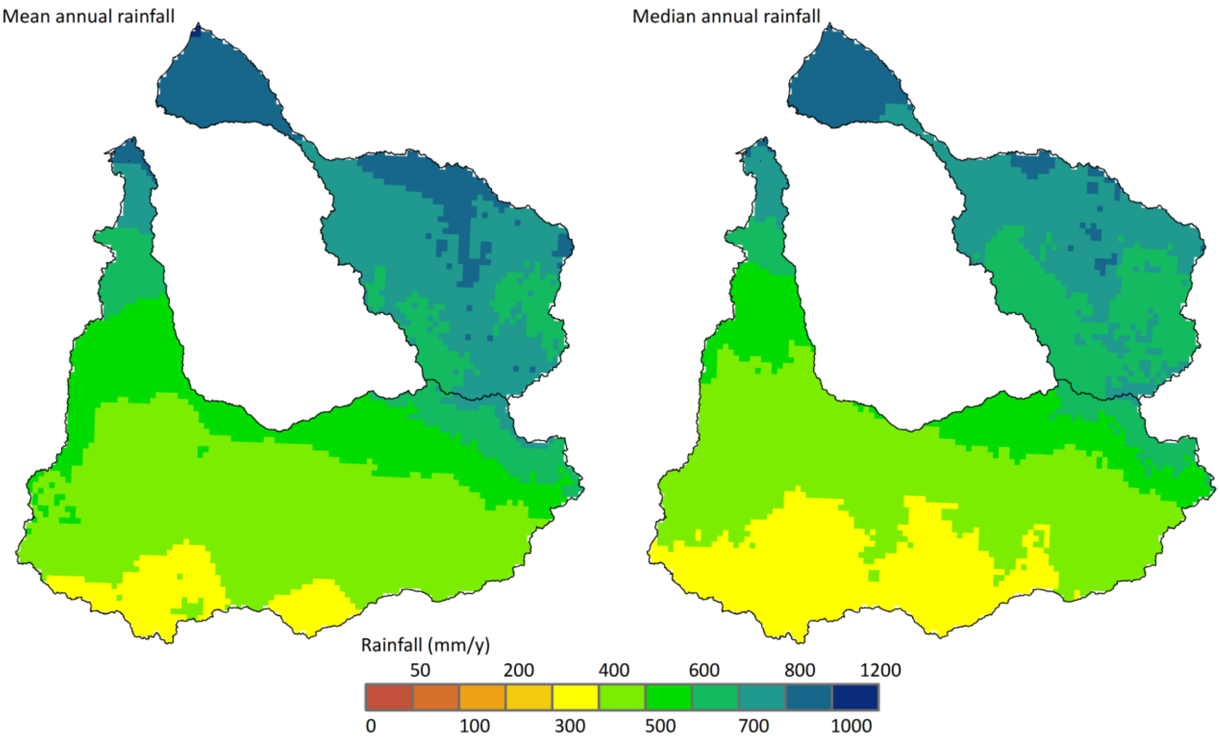


Figure 2 Historical mean annual rainfall (left) and median annual rainfall (right) in the Flinders and Gilbert catchments

Rainfall intensity is high in northern Australia in comparison to southern Australia. High intensity rainfall can have erosion consequences and can render rainfall ineffective by running off before being able to infiltrate into the soil. Different soils exhibit different rates of permeability, and the higher intensity rainfall may result in water not permeating into the soil. Soils also have an ability to store water, where it may be utilised by a growing crop. In water limited environments like the Flinders and Gilbert catchments the more water that can be stored in soil prior to planting, the less is required to be delivered by irrigation. Rainfall intensity generally increases closer to the coast in the Flinders and Gilbert catchments.

Rainfall distribution through the year has a major influence on irrigation water requirements for crops, because when there is no rainfall all of the water requirements must be met by irrigation water. The distribution of rainfall also determines when water is potentially available to be extracted from rivers (discussed further in the companion technical report about river modelling (Holz et al. 2013). In the Flinders and Gilbert catchments the distribution of rainfall is strongly seasonal, with 88% and 93% falling in the wet season in the Flinders and Gilbert catchments respectively (Figure 3).

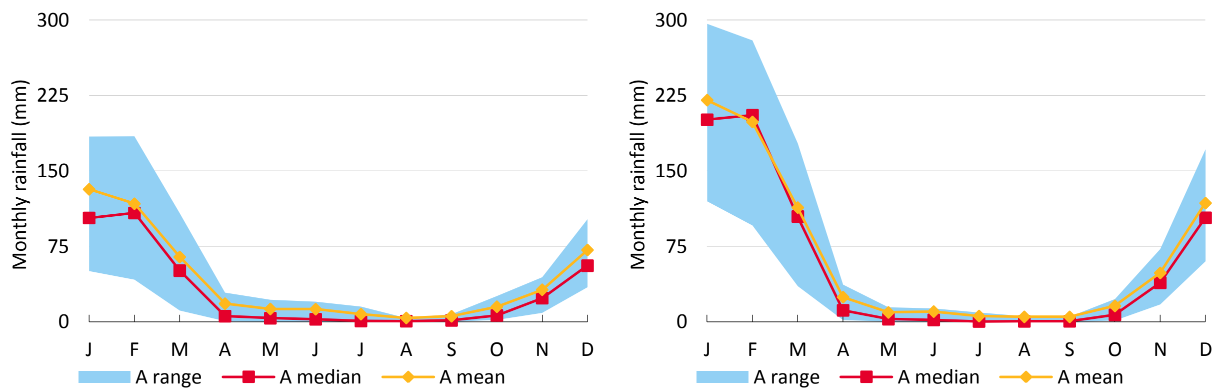


Figure 3 Historical monthly rainfall averaged over the Flinders (left) and Gilbert (right) catchments (A range is the 20th to 80th percentile monthly rainfall)

Interannual variability is the difference between very wet and very dry years. In the dry years more irrigation water is needed to grow crops, but water may not be available. The companion technical report about river

modelling details how much water may be reliably extracted in the Flinders and Gilbert catchments (Holz et al. 2013). In the very wet years radiation may become limiting and crops may experience yield losses through water logging. On heavy clay soils excessive rainfall also reduces trafficability of farm paddocks, possibly making farming operations that require tractor passes difficult to achieve. The Flinders and Gilbert catchments experience irregular periods of consistently low rainfall when successive wet seasons fail, as well as periods of consistently high rainfall when successive wet seasons are above average (Figure 4). These wet or dry spells provide a risk to the farming business, and make securing a reliable supply of irrigation water challenging.

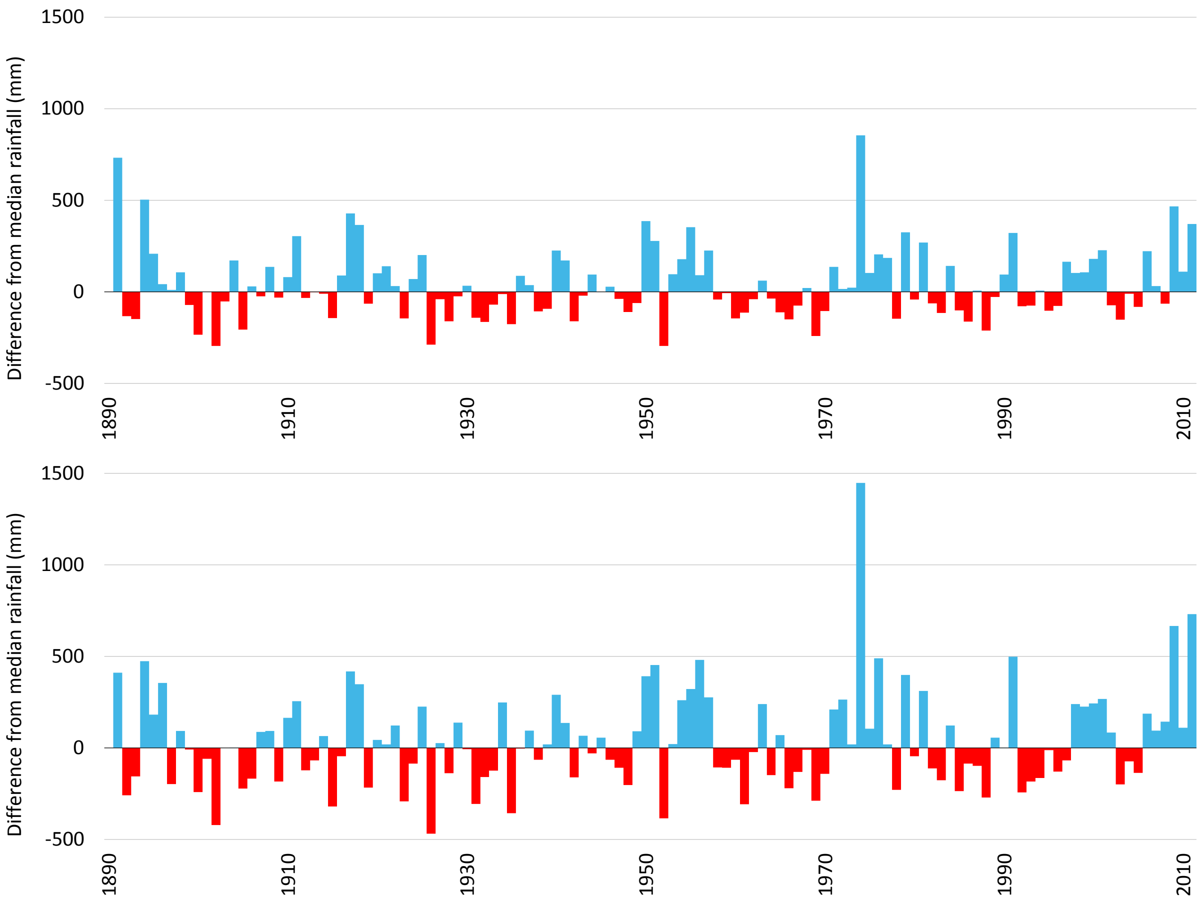


Figure 4 Rainfall variation from the long term median in the Flinders (top) and Gilbert (bottom) catchments

4.1.2 EVAPORATION

Evaporation is "the rate of liquid water transformation to vapour from open water, bare soil, or vegetation with soil beneath", while transpiration is "that part of the total evaporation that enters the atmosphere from the soil through the plants" (Shuttleworth, 1993*)*.

For agricultural productivity, evaporation has an influence on crop water requirements. In the Flinders and Gilbert catchments potential evaporation can be very high, especially in the October to January period. There is generally low variability of evaporation and it is similar across the two catchments.

Evaporation can be a major loss of water within an irrigation scheme before it gets to the crop. Transmission losses from transporting stored water through evaporation are discussed further in section 4.4.2.

4.1.3 TEMPERATURE

Plants are sensitive to temperature, and have different tolerances depending on crop type and crop stage. High temperatures in particular can have a negative impact on crop yields, for example causing seedling death, or reducing seed set. In the Flinders and Gilbert catchments, maximum temperature can adversely impact crop

growth and development (Figure 5). Management practices (such as mulch) have been successfully employed in northern Australia to reduce high temperature effects on crop establishment (Abrecht and Bristow, 1996).

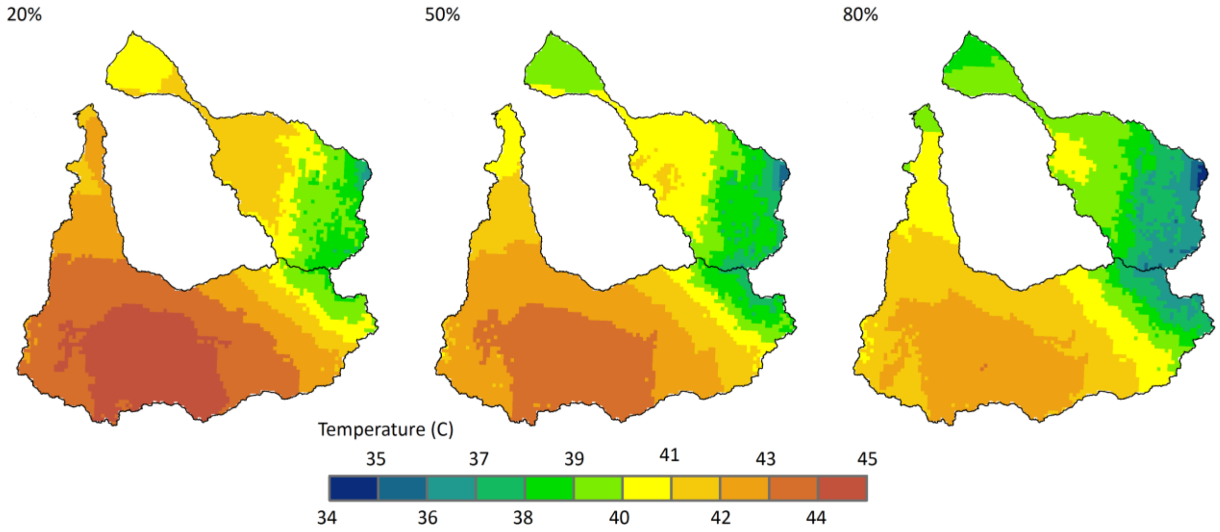


Figure 5 The maximum annual temperature that is exceeded 20%, 50% and 80% of years in the Flinders and Gilbert catchments

Frost risk

There is a frost risk, particularly in the Flinders catchment, when temperature falls below 2°C. In the Richmond climate 45% of years have days when the minimum recorded temperature is below 2°C. This can have implications for some crops, including widespread death of some crops. Manipulating planting time of frost susceptible crops is a suitable way to militate against frost risk.

4.1.4 RADIATION

Short wave radiation from sunlight is used by crops to photosynthesise, converting atmospheric carbon dioxide into carbohydrates. Crops essentially 'harvest' short wave radiation with their leaves, and the more short wave radiation they intercept, the more they grow. The amount of short wave radiation that can potentially reach crops is dictated by latitude and time of year, both of which determine the number of daylight hours and angle of the sun in the sky. Cloud cover is effective at reducing the amount of short wave radiation that reaches crops, and even though cloud cover is highest in the wet season, this period has higher short wave radiation than the dry season in the Flinders and Gilbert catchment due to longer day length and a higher angle of the sun. Sowing time is a management tool that is successfully employed by farm managers to manipulate the amount of short wave radiation that a crop may be exposed to.

4.1.5 RELATIVE HUMIDITY

Relative humidity can affect the economic yield of a crop principally through disease incidence, but can also play a role by affecting crop water use, leaf growth and may affect pollination when very high.

4.1.6 IMPACT OF CLIMATE VARIABILITY ACROSS THE ASSESSMENT AREA

The climate in the Flinders and Gilbert catchments varies in space (Petheram and Yang, 2013). To investigate the impact this variable climate has on yield and required irrigation water, fifteen climate locations were chosen in each catchment (Figure 6) and each site was modelled over the 121 year historical climate record (climate file generation is discussed in the companion technical report about climate (Petheram and Yang, 2013)). All Flinders sites had soil as Mod Grey Vertisol 149 PAWC, crop was sorghum, sowing on 15 Feb, irrigation unlimited on deficit and all Gilbert sites had soil as Tonks Camp Sandy Loam 122 PAWC, crop was sorghum, sowing on 15 Mar, irrigation unlimited on deficit (modelling details are provided in section 3.1).

Average, median, 20th and 80th percentile and minimum and maximum yield and irrigation water required for each of the fifteen climate locations are plotted in Figure 7 to Figure 10. Modelled mean yield of sorghum does not differ substantially in the Flinders catchment (Figure 7), and mean required irrigation water only varies 1.5 ML/ha between the highest (F9) and lowest (F15) modelled locations (Figure 8). The Richmond climate (F11) is used in most of the modelling reported in this section of the technical report to represent the Flinders catchment. Modelled mean yield differs across the Gilbert catchment, being lowest between Strathmore Station and Georgetown (Figure 9) with the maximum difference of about 2 t/ha between G7 and G14 climates. Modelled mean irrigation water required is steady across the entire catchment (Figure 10). The Georgetown climate (G8) is used in most of the reported modelling in this technical report to represent the Gilbert catchment.

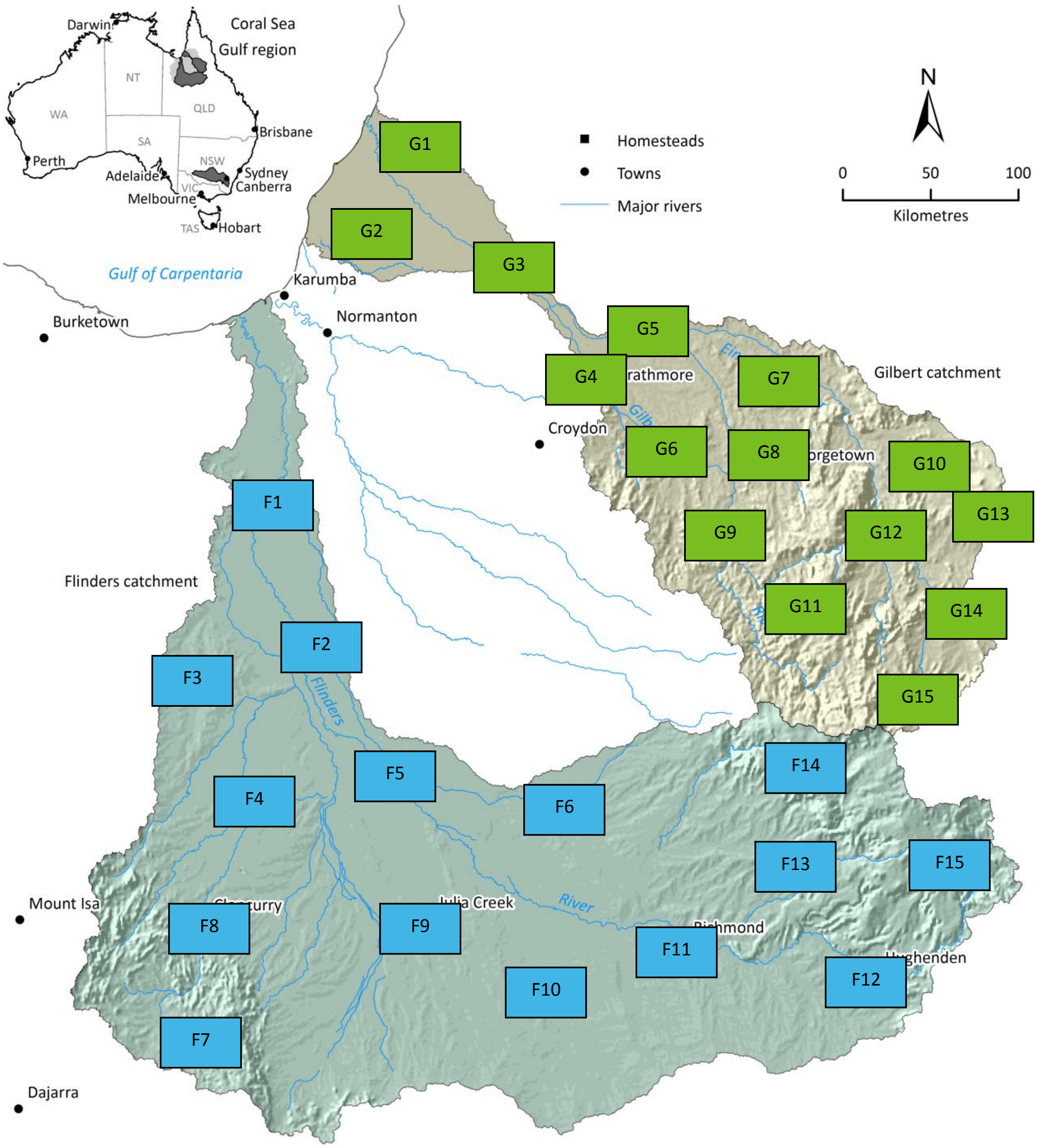


Figure 6 Climate locations used in analysis of climate in the Flinders and Gilbert catchments

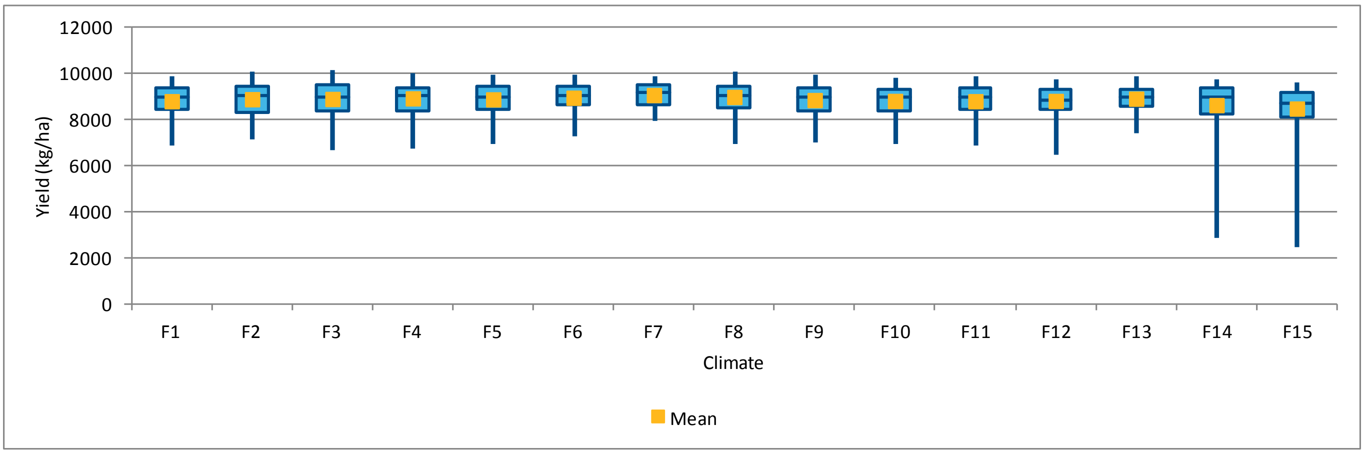


Figure 7 Modelled average (yellow square), median (blue line), 20th to 80th percentile (shaded blue box) and minimum and maximum (extent of vertical bars) yield for fifteen climates located in the Flinders catchment. Climate locations are located in Figure 6

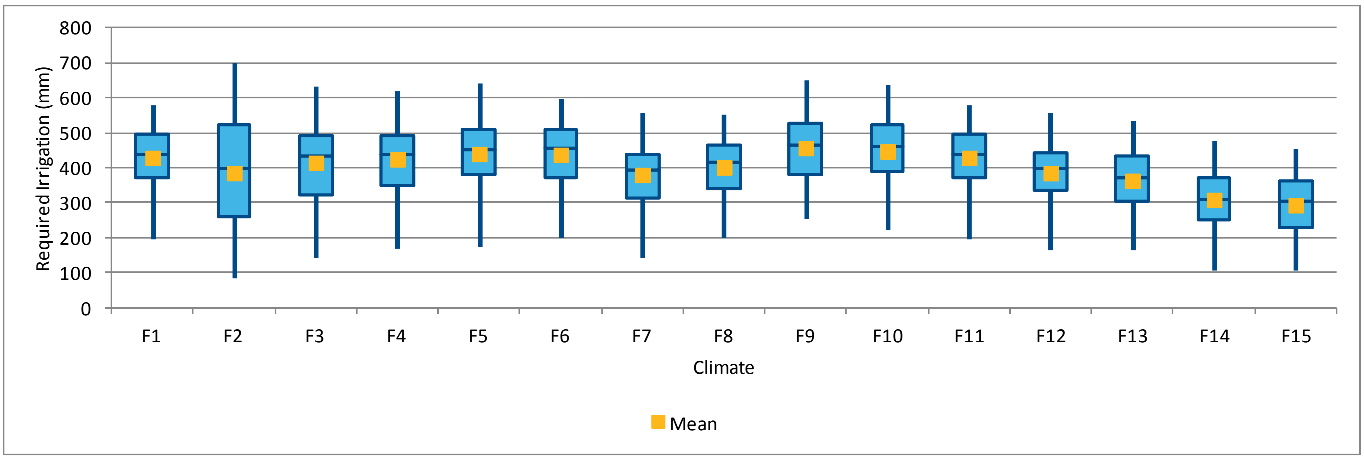


Figure 8 Modelled average (yellow square), median (blue line), 20th to 80th percentile (shaded blue box) and minimum and maximum (extent of vertical bars) irrigation water required for fifteen climates located in the Flinders catchment. Climate locations are located in Figure 6

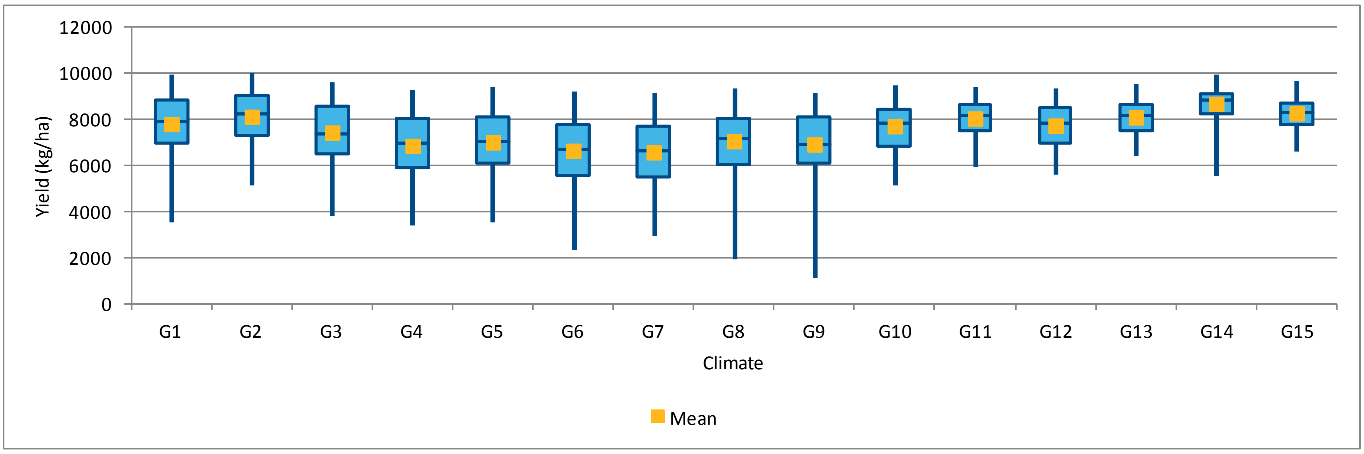


Figure 9 Modelled average (yellow square), median (blue line), 20th to 80th percentile (shaded blue box) and minimum and maximum (extent of vertical bars) yield for fifteen climates located in the Gilbert catchment. Climate locations are located in Figure 6

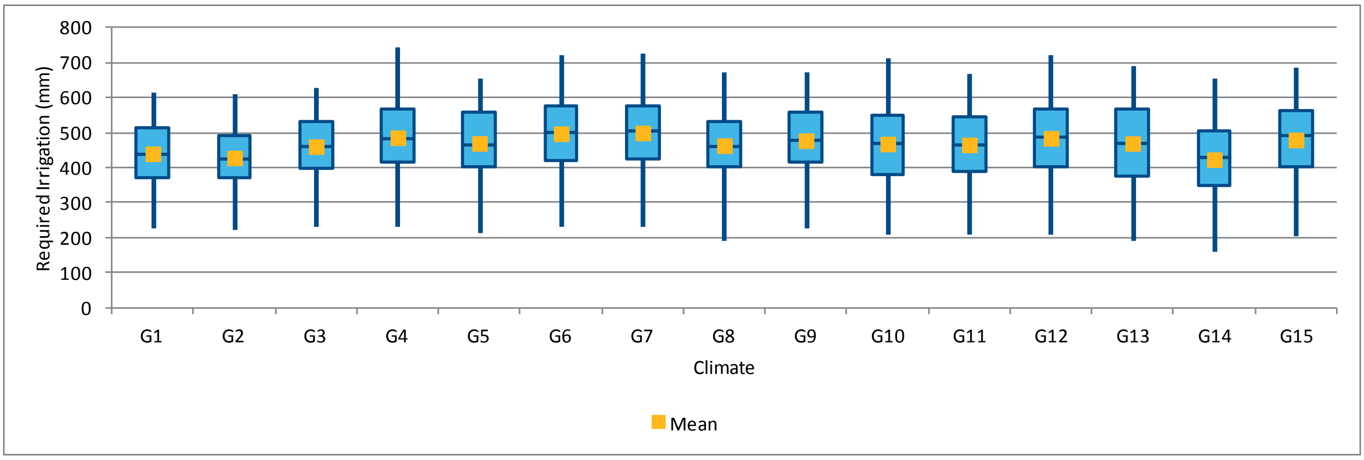


Figure 10 Modelled average (yellow square), median (blue line), 20th to 80th percentile (shaded blue box) and minimum and maximum (extent of vertical bars) irrigation water required for fifteen climates located in the Gilbert catchment. Climate locations are located in Figure 6

4.2 Soil

Soils have a number of characteristics that combine to influence crop growth. Soil type varies depending on parent material. Soils have physical, biological and chemical properties, and these properties combine to give a soil function attributes that influence potential productivity and irrigation water requirements. The companion technical report about land suitability (Bartley et al. 2013) identified eight primary ‘Soil Generic Groups’ in the Flinders and Gilbert catchments. Four of these soils were deemed unsuited to irrigated agriculture (Figure 2), leaving four soils suited to irrigated agriculture, namely: Sand or loam over relatively friable clay subsoils; Friable non-cracking clay or clay loam soils; Red, yellow or grey loamy soils; cracking clay soils (Table 2).

Table 2 Soil Generic Group (SGG) classes and description

Concept	General description	Landform	Major management considerations	ASC orders used to generated SGGs
Sand or loam over relatively friable clay subsoils	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.	The non-acid soils are widely used for agriculture; the strongly acid soils are generally used for native and improved pastures.	Chromosols and Kurosols except those with strongly bleached A horizons (the AT, AV, AY, AZ, BA or BB subgroups)
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.	Generally high agricultural potential because of their good structure, and their moderate to high chemical fertility and water holding capacity. Ferrosols on young basalt landscapes may be shallow and rocky.	Dermosols, Ferrosols and deeper Calcarosols
Seasonally or permanently 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.	Require drainage works before development can proceed. Acid sulfate soils and salinity are associated problems in some areas	Hydrosols and Aquic Vertosols
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.	Moderate to high agricultural potential with spray or trickle irrigation due to their good drainage. Low to moderate water holding capacity, often hard setting.	Kandosols
Deep sandy soils	Moderately deep to deep sands. May be gravelly.	Sandplains and dunes; aeolian and fluvial siliceous sediments.	Low agricultural potential due to excessive drainage and poor water holding capacity	Rudosols, Tenosols
Shallow sandy and stony soils	Very shallow to shallow <0.5m. 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 or eroding lateritic scarps.	Negligible agricultural potential due to lack of soil depth and presence of rock.	Rudosols and Tenosols (shallow occurrences) and Calcarosols (shallow)
Sand or loam over intractable clay subsoils	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.	Generally 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.	Sodosols; bleached Chromosols and Kurosols (those with AT, AV, AY, AZ, BA or BB subgroups)
Cracking clay soils	Clay soils with shrink-swell properties that cause cracking when dry. Usually alkaline and deep to very deep.	Floodplains and other alluvial plains. Undulating to rolling Mitchell Grass Downs country (formed on Cretaceous sedimentary rock). Minor occurrences in basalt landscapes.	Generally a moderate to high agricultural potential. The flooding limitation will need to be assessed locally. Many soils are high in salt (particularly those associated with the Rolling Downs). Gilgai and coarse structured surfaces may occur.	Vertosols

4.2.1 SOIL DEPTH

Soil depth is important because it helps determine the Plant Available Water Capacity (PAWC) of the soil. Shallow soils (where rooting depth is limited) will have a lower PAWC and a smaller area that roots can explore for nutrients. If nutrients are leached below the rooting depth, then the nutrients are lost from the cropping system. Large areas of the Flinders catchment have a soil depth greater than 1 metre, which is good for potential crop production (Figure 11). Much of the Gilbert catchment has soil depth less than 1 metre, however the soils close to the alluvial plains of the rivers have deeper soils conducive for cropping (Figure 12).

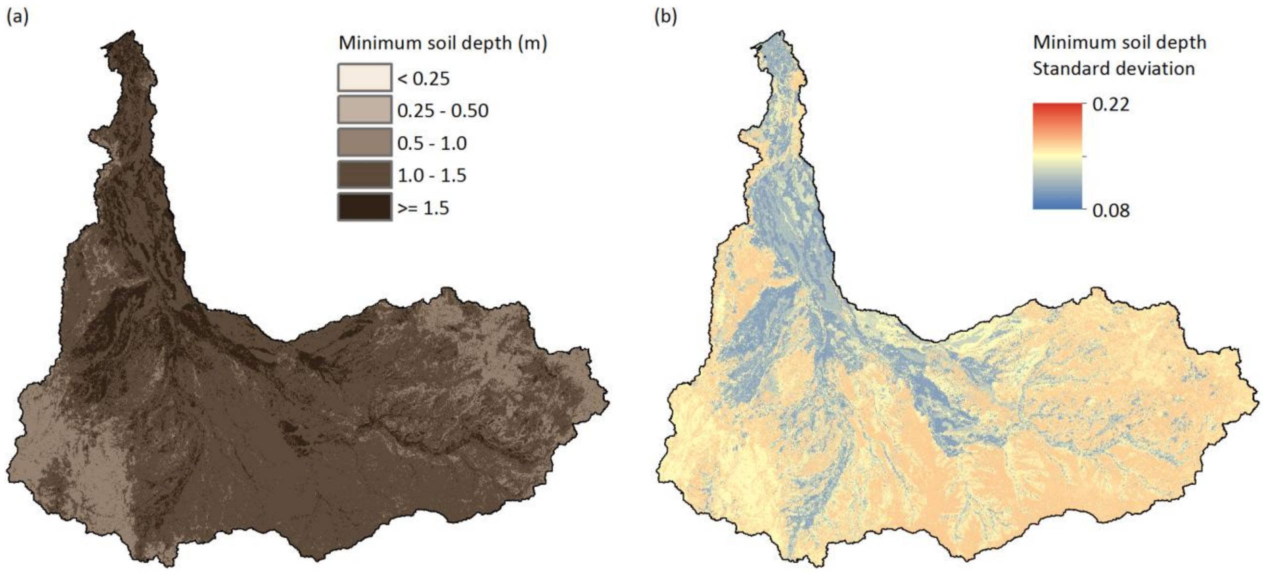


Figure 11 Digital soil mapping predicted surfaces for (a) minimum soil depth and (b) the standard deviation around the prediction in the Flinders catchment
Source: Land suitability companion report

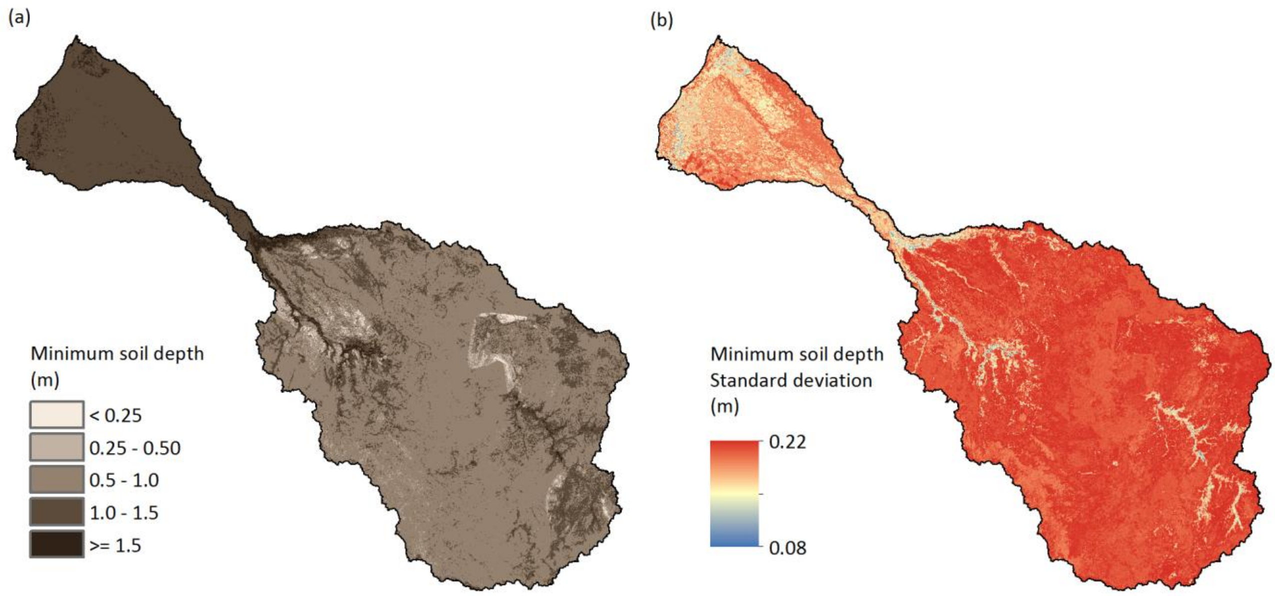


Figure 12 Digital soil mapping predicted surfaces for (a) minimum soil depth and (b) the standard deviation around the prediction in the Gilbert catchment

4.2.2 PERMEABILITY

Permeability of the soil affects the rate that water that can enter the soil. When rainfall intensity is greater than the infiltration rate of the soil, the water will runoff, contributing to river flow. Rainfall entering the soil is stored (up to the PAWC) and will be available for crops to extract. This is important in water limited environments like the Flinders and Gilbert catchments, particularly for dryland cropping. The Flinders and Gilbert catchments have high rainfall intensities, so soils with low permeability are less likely to be able to store rainfall.

Highly permeable soils are less conducive to being irrigated using surface irrigation, because that type of irrigation relies on the soil infiltration rate being low enough so that water applied can laterally along bunded crop rows. With surface irrigation the higher the soil permeability, the shorter the row need to be to ensure applied water reaches all parts of the irrigated paddock.

Deep impermeable layers in a soil can create barriers to water, not allowing water to drain through. During high rainfall events these impermeable layers can contribute to water logging. Highly permeable soils can also drain so quickly they take water and nutrients with it below the root zone.

Soils in the flinders are generally slowly permeable (Figure 13) compared to the moderately permeable soils in the Gilbert catchment (Figure 14). The highly permeable soils in the Gilbert catchment are associated with alluvial sands.

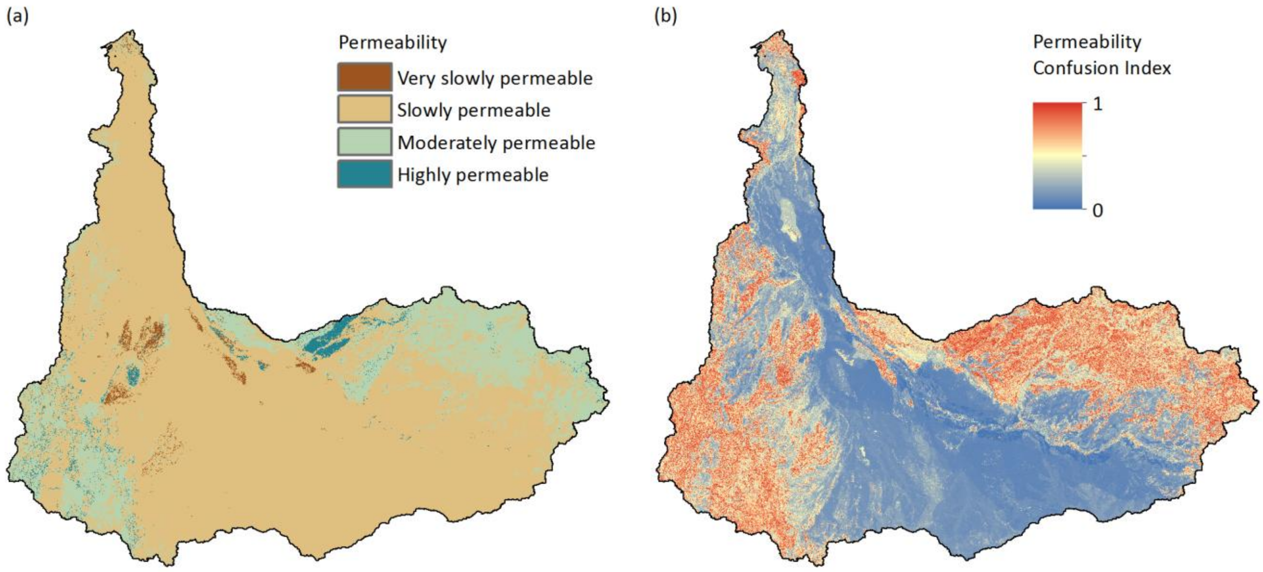


Figure 13 Digital soil mapping predicted surfaces for (a) permeability and (b) the confusion index which represents the reliability of the prediction (see the companion technical report about land suitability (Bartley et al. 2013)) in the Flinders catchment

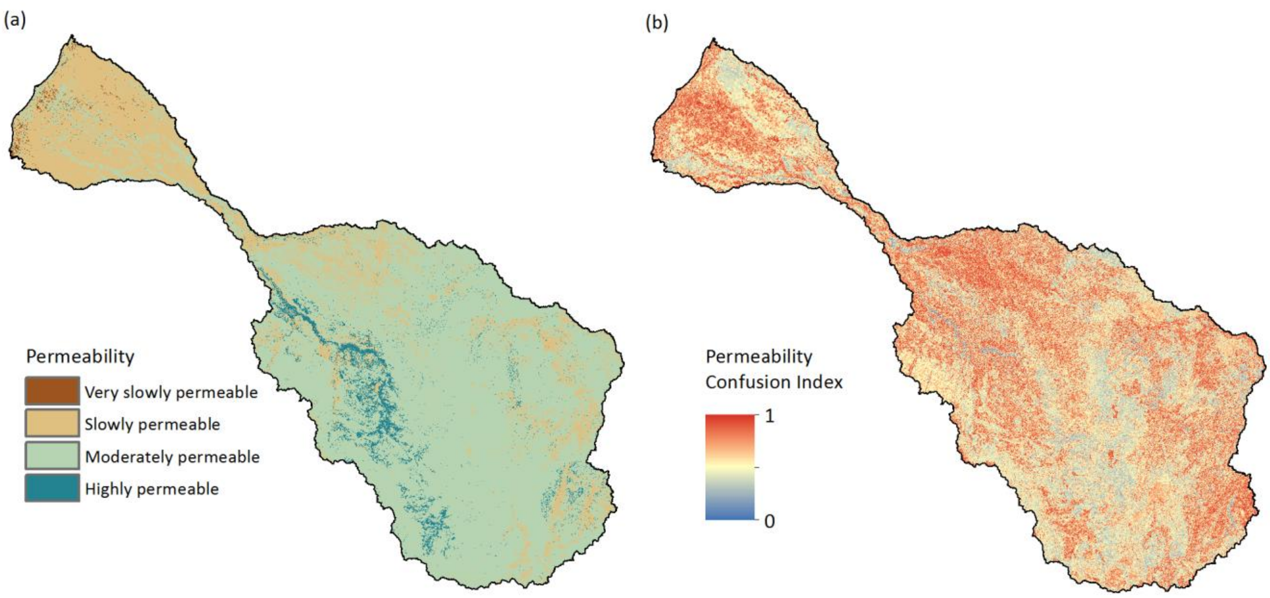


Figure 14 Digital soil mapping predicted surfaces for (a) permeability and (b) the confusion index which represents the reliability of the prediction (see the companion technical report about land suitability (Bartley et al. 2013)) in the Gilbert catchment

4.2.3 PLANT AVAILABLE WATER CAPACITY (PAWC)

The PAWC of a soil is very important. Soils with low PAWC do not store as much water, requiring more frequent irrigation or rainfall events to ensure a ready supply of water to a crop. All soils have an upper limit on the amount of water that can stored, referred to as the 'drained upper limit'. Water entering the soil above this limit will either run off, or drain through the soil, rendering it unavailable to plants. There is a lower extent to which crops can extract water from the soil. This is referred to the 'crop lower limit' and depends on crop and soil characteristics. Deeper rooting crops (e.g. cotton) will be able to extract more water than a shallow rooted crop (e.g. peanut) and hence the PAWC on the same soil will be more for

cotton than for peanut. Soil depth influences PAWC by restricting rooting depth, as do physical and chemical barriers, such as salt. Soils with higher PAWC are better suited to dryland cropping especially in environments like the Flinders and Gilbert catchments where rainfall events are episodic.

Much of the Flinders catchment has a predicted PAWC greater than 100 mm to 1 metre depth (Figure 15) which is adequate for cropping soil, especially considering the soil depth is generally greater than 1 metre (Figure 11), and therefore PAWC of the whole crop root zone would be higher. The predicted PAWC in the Gilbert catchment ranges between 50 and 100 mm to 1 metre depth for much of catchment (Figure 16). The soils with higher PAWC (and greater depth) are the better cropping soils in the Gilbert catchment.

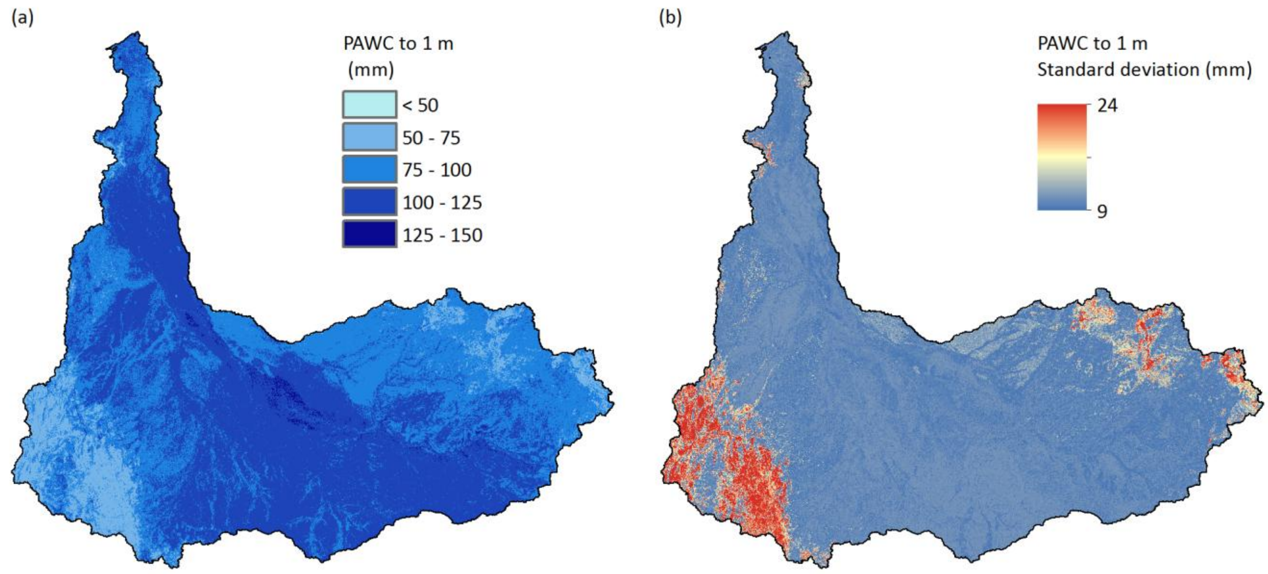


Figure 15 Digital soil mapping predicted surfaces for (a) PAWC and (b) the standard deviation around the prediction in the Flinders catchment

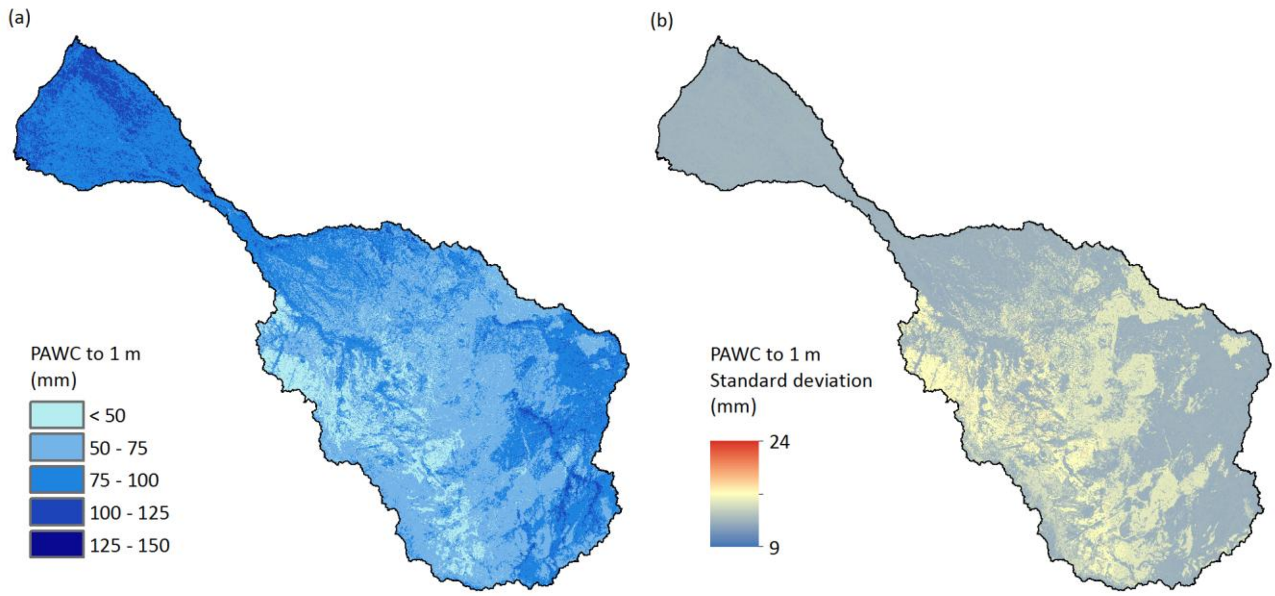


Figure 16 Digital soil mapping predicted surfaces for (a) PAWC and (b) the standard deviation around the prediction in the Gilbert catchment

Soil PAWC impacts both yield and irrigation water requirements. Figure 17 shows the influence of PAWC on modelled yield and irrigation water requirements for maize grown in Richmond over the 121 year historical climate record. Crop management was the same for each scenario, with soil PAWC varying between 54 and

204 mm in steps of approximately 50 mm. Yield increased steadily as PAWC increased from 54 mm to 102 mm, at which it reached a maximum. The influence of PAWC on irrigation requirements was less marked, and showed a much more gradual approach to the maximum occurring at around 147 mm. The below scenario is for a March planting, when most rainfall in the Flinders catchment has ceased.

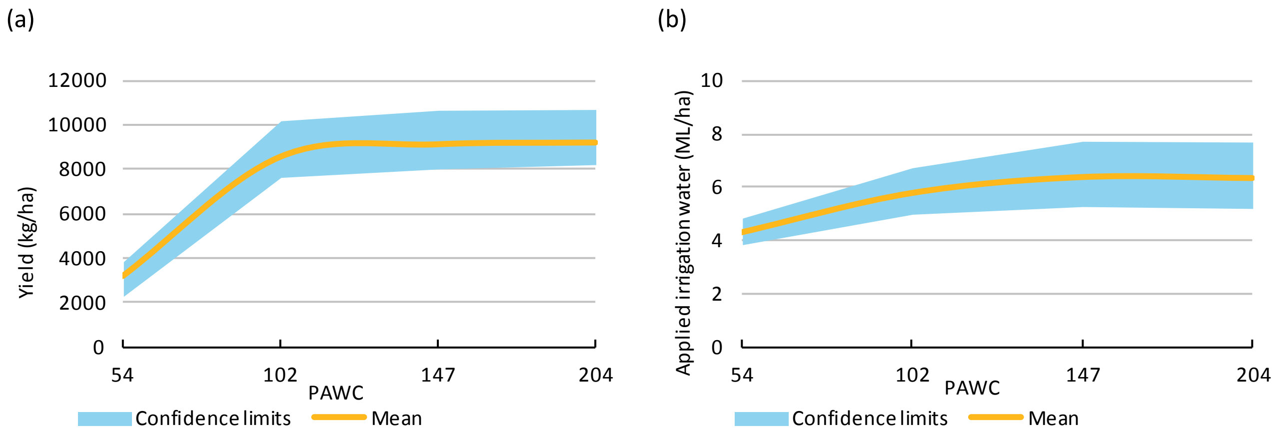


Figure 17 Modelled (a) yield and (b) applied irrigation water for maize in a Richmond climate where only soil Plant Available Water Content (PAWC) varies. Confidence limits are the 20th to 80th percent exceedence values

4.2.4 NUTRIENT STATUS

A soil's nutrient status is important for agricultural production as there are thirteen essential nutrients that must be supplied to the crop through the soil. The primary macronutrients, nitrogen, phosphorous and potassium are usually supplemented using fertiliser, but often a soil is naturally high enough in the secondary macronutrients (calcium, magnesium and sulphur) and micronutrients (boron, copper, iron, chloride, manganese, molybdenum and zinc) that fertilising with these nutrients is not required annually. Complete agronomic testing of soils for nutrients is a basic agronomic recommendation prior to cropping to determine which nutrients are required. During the Assessment it was not feasible to test all soils for all nutrients; however there was some testing conducted for some soil nutrient characteristics. Soil organic carbon in the surface layer of the soil can be used as a surrogate (because organic carbon has an impact on soil nitrogen cycling, and indirectly soil physical properties). In the Assesment area soil organic carbon in the surface layer ranged from 0.36% to 1.32%. The majority of the tested soil values (less than 1.0%) reflect the lower end of the range of agricultural soils, but is not unexpected given the harsh climate and lack of carbon cycling. In all probability soils in the Flinders and Gilbert catchments are low to moderate in soil nutrient status and soil testing prior to cropping would identify amelioration needs through fertilisation.

4.2.5 SALINITY AND SODICITY

Salt is a common feature of the soils in inland Australia, especially in semi-arid to arid areas. This salt is derived from the weathering of rocks and deposition in the landscape by hydrologic processes (rainfall or water movement below the land surface). Agricultural development, especially irrigation, disturbs the natural hydrologic equilibrium in the landscape. Increased access to groundwater results in raised water-tables, which may be saline. Saline water tables my result in the accumulation of soluble salt at or near the soil surface in discharge areas (secondary salinity). The rolling downs landform in the Flinders catchment (Figure 18) has been identified as vulnerable to secondary salinisation, and caution would be required when managing soils on this landform. More information is provided in the companion technical report about land suitability (Bartley et al. 2013).

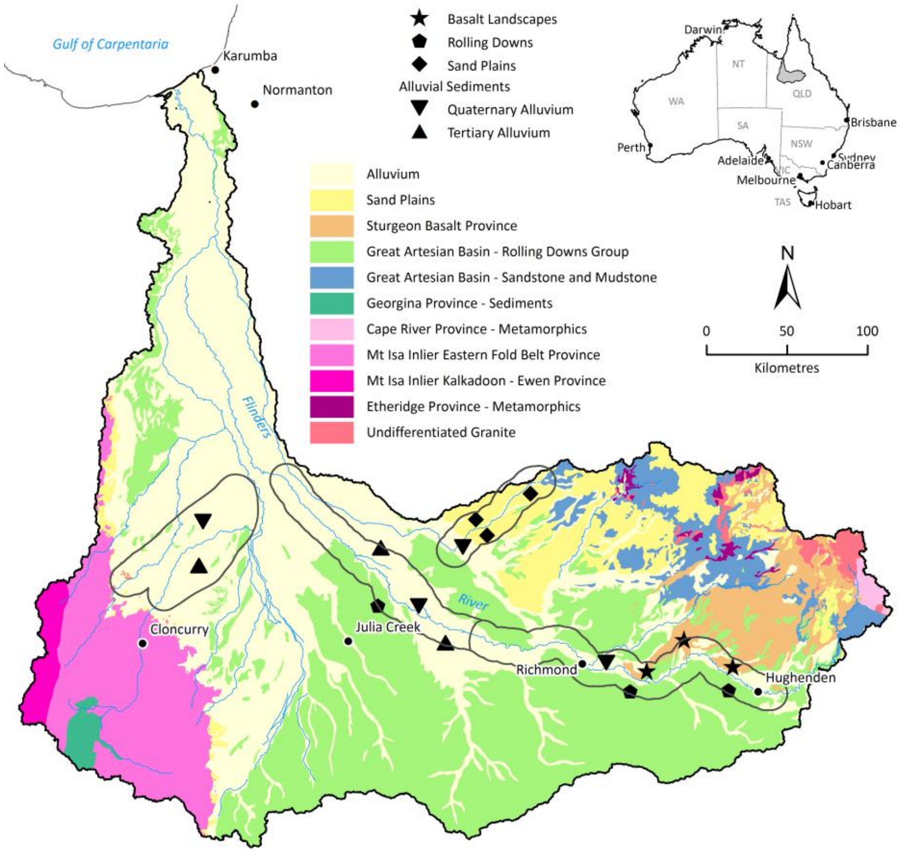


Figure 18 Landform in the Flinders catchment showing the location of the 'rolling downs' landform, which may have a salinity hazard

4.2.6 LOCATIONS OF SOIL GENERIC GROUPS

The companion technical report about land suitability (Bartley et al. 2013) modelled eight soil generic groups across the Flinders and Gilbert catchments (Figure 19 and Figure 20). The Flinders catchment is overwhelmingly dominated by cracking clay soils (68% see Table 3), which almost completely dominate the centre of the catchment (Figure 19). However, at the mouth of the catchment the soils are dominated by seasonally and permanently wet soils (<1%), reflecting the influence of ocean tides. Loamy soils dominate in the upper relief positions. To the east in the uplands, loamy soils dominate. The basalt areas are dominated by cracking clays on the elevated plains, and flanked by clay loams and non cracking clay soils (~15%). The distribution of Soil Generic Group classes in the Gilbert catchment show that the lower catchment below the confluence is dominated by clays (e.g. coarse textures over friable clay soils and cracking clay soils), with lesser though significant areas of seasonally or permanently wet soils (~2%) (Figure 20 and Table 4). Above the confluence, the soils strongly reflect the parent materials in the in situ soils. Here shallow sandy soils are common (~24%) as well as clay loam and non-cracking clay soils (24%). Areas of cracking clays are locally dominant in the alluvial areas in valleys in the eastern upland area, and in the lower catchment of the Einasleigh River (<10%). Small pockets of sands or loams over sodic clay soils are restricted to soils in or downstream from granite areas.

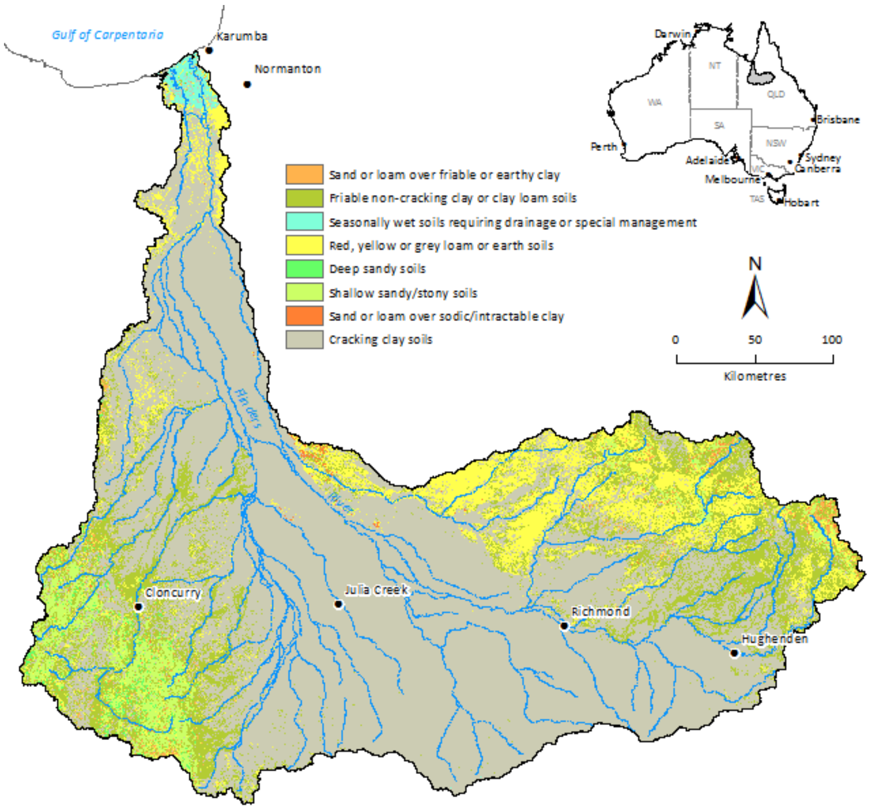


Figure 19 Soil generic group modelled classes for the Flinders catchment

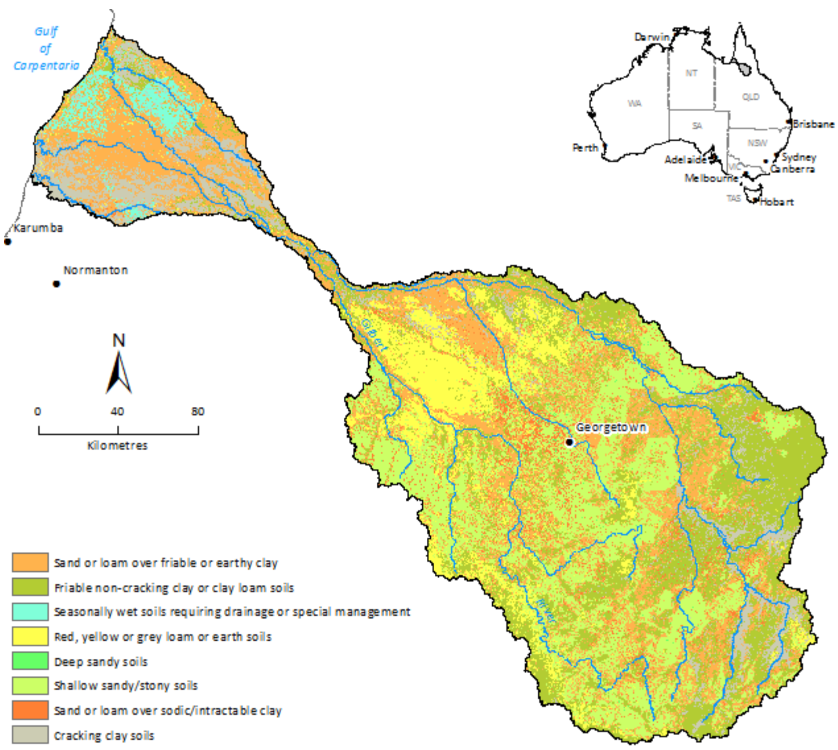


Figure 20 Soil generic group modelled classes for the Gilbert catchment

Table 3 Percentage area of each of the Soil Generic Group (SGG) classes predicted for the Flinders catchment

Soil generic group description	% SGG soil type in Flinders catchment*
Sand or loam over relatively friable clay subsoils	1
Friable non-cracking clay or clay loam soils	15
Seasonally or permanently wet soils	0.75
Red, yellow or grey loamy soils	10
Deep sandy soils	0.75
Shallow sandy and stony soils	4
Sand or loam over intractable clay subsoils	0.5
Cracking clay soils	68

Table 4 Percentage area of each of the Soil Generic Group (SGG) classes predicted for the Gilbert catchment

Soil generic group description	% SGG soil type in Gilbert catchment*
Sand or loam over relatively friable clay subsoils	27
Friable non-cracking clay or clay loam soils	24
Seasonally or permanently wet soils	2
Red, yellow or grey loamy soils	10
Deep sandy soils	0.25
Shallow sandy and stony soils	24
Sand or loam over intractable clay subsoils	4
Cracking clay soils	8.75

4.3 Land suitability

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).

Soils receive 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 in Table 5. Note that a large proportion of Australia's agricultural soils are classified as class 3.

Table 5 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.

The land use suitability scores were used for several purposes. They were applied across the whole Assessment area 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 Flinders catchment (>8 million ha) and the Gilbert catchment (1-2 million ha) are moderately suitable (class 3) for a wide range of crops and irrigation methods (Figure 21 and Figure 22). The companion technical report about land use suitability provides land use suitability estimates for a greater range of crop type by irrigation method (Bartley et al. 2013). It should be noted the land suitability assessment does not take into consideration flooding, risk of secondary salinisation or availability of water.

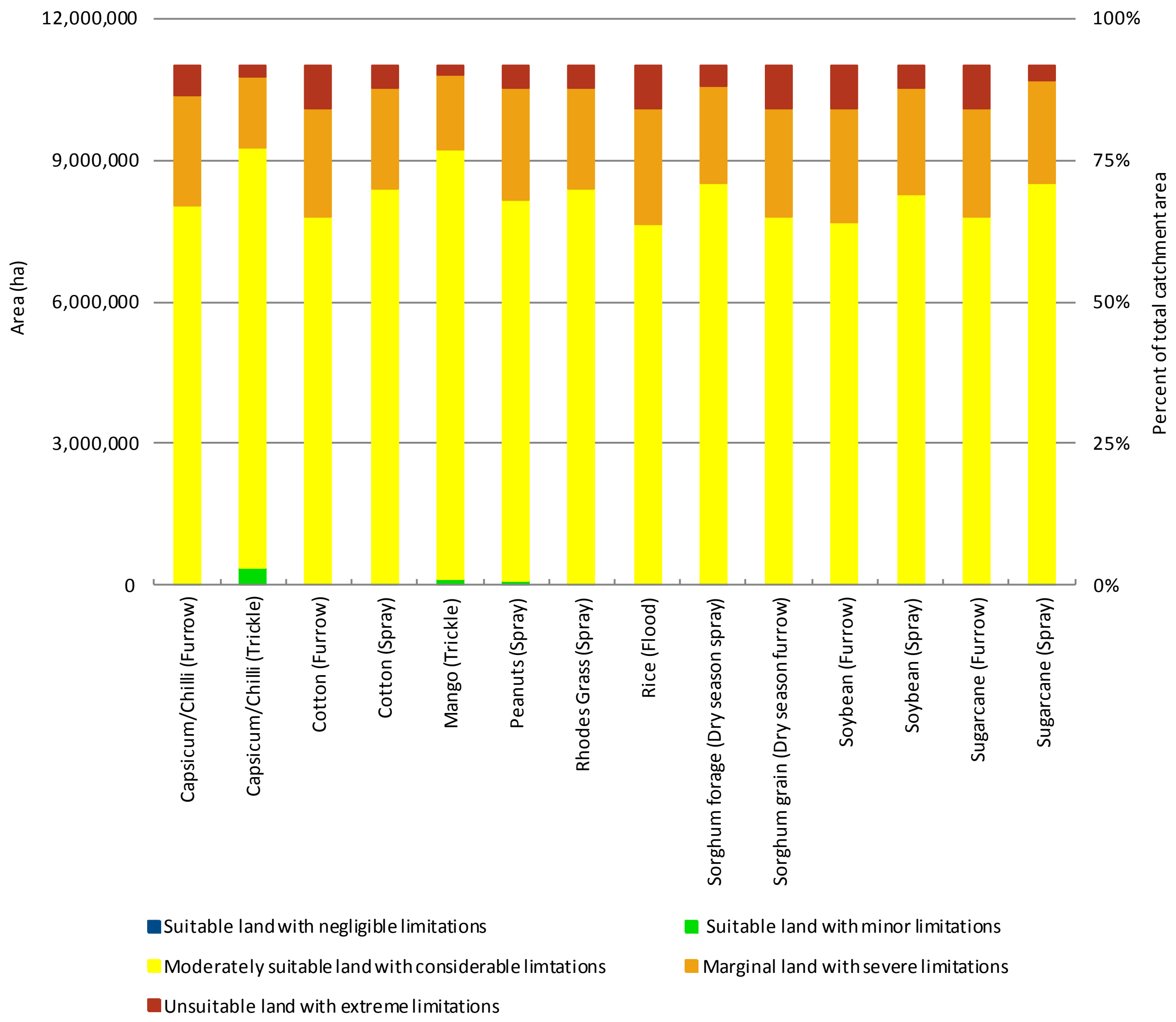


Figure 21 The area associated with each land suitability class for a selection of 14 crops in the Flinders catchment

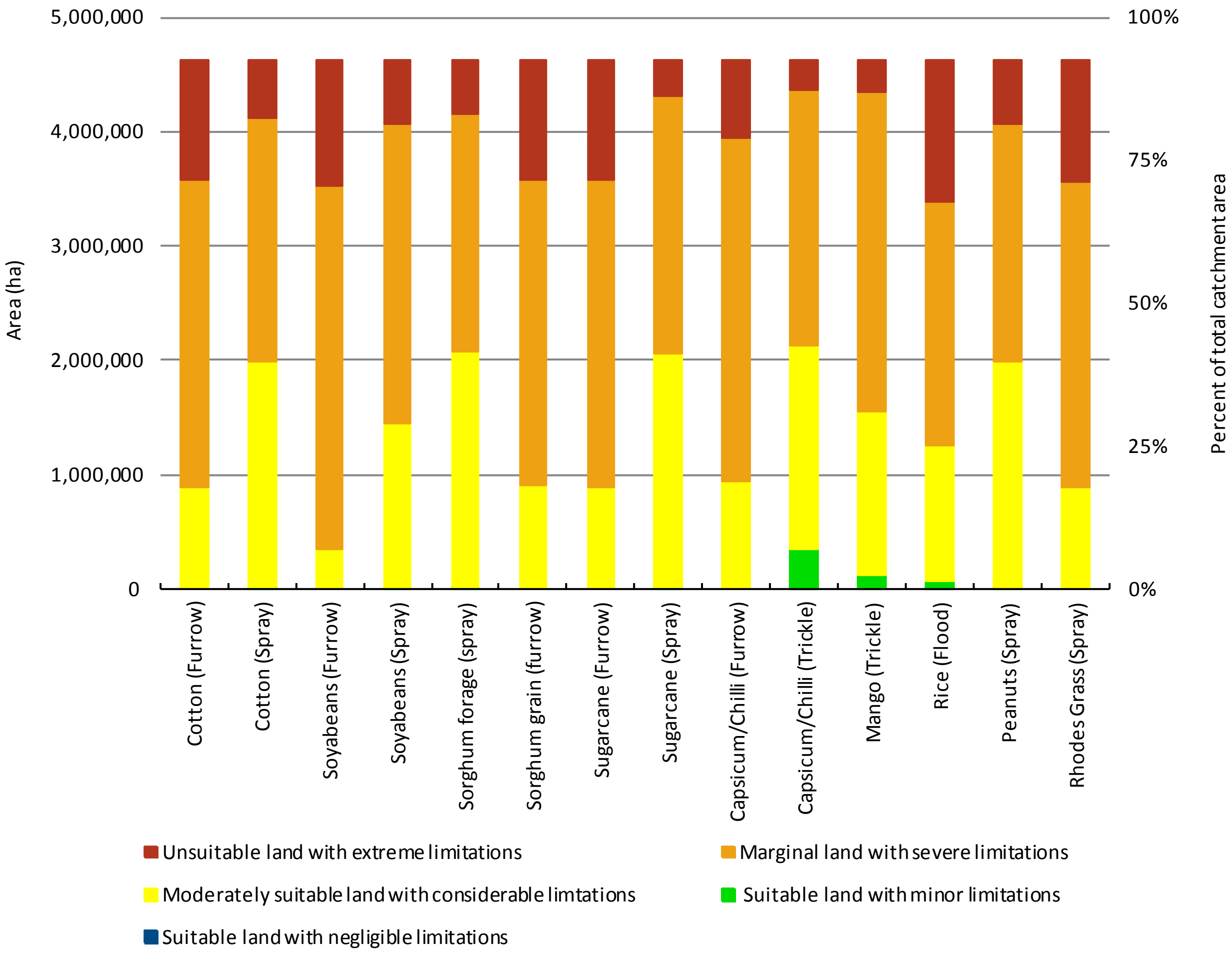


Figure 22 The area associated with each land suitability class for a selection of 14 crops in the Gilbert catchment

4.4 Irrigation

4.4.1 NEED FOR IRRIGATION

The Flinders and Gilbert catchment will be limited in the amount of irrigation water that can reliably be supplied from each catchment. The companion technical report about river modelling provides an overview of reliable yields (Holz et al. 2013). There are opportunities for dryland cropping in the Flinders and Gilbert catchments (see section 4.4.4), however these opportunities are limited, and irrigation will produce more reliable crop yields. The amount of irrigation required per hectare is related to the crop grown, the soil type and crop management such as time of planting. Generally the required irrigation is related to the amount of rainfall received; more irrigation water is required during years when in-crop rainfall is lower (Figure 23).

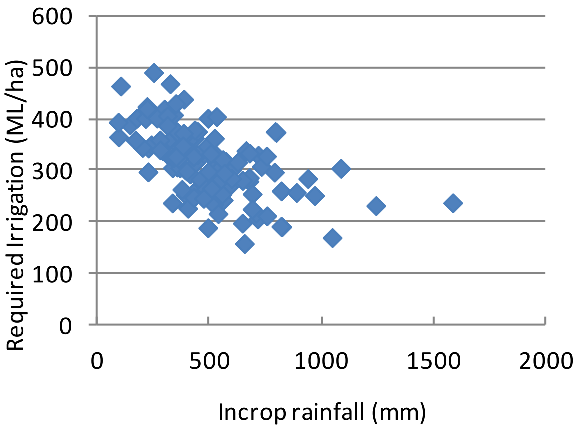


Figure 23 Modelled irrigation water required compared to in-crop rainfall. Each data point represents one season of data from the 121 year historical climate record for a peanut crop sown on the 15th January in a Georgetown climate

4.4.2 IRRIGATION EFFICIENCY

Water that is captured and stored from rivers needs to be transported to and applied in the field where it is needed. Losses occur along the system, and across Australia the average water conveyance efficiency from the river to the farm gate has been estimated to be 71% (Marsden Jacobs Associates, 2003). Losses are from leakage, seepage, evaporation, outfalls, unrecorded usage and system filling.

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. 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 measured channel seepage was less than 5% (Akbar 2000).

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 Flinders and Gilbert catchments: surface irrigation, spray irrigation and micro irrigation (Figure 24). Irrigation systems applied in the Flinders and Gilbert catchments need to be tailored to the soil, climate and crops that may be grown in and matched to the availability of water for irrigation. System design will also need to consider investment risk in irrigation systems as well as likely returns, degree of automation, labour availability, and maintenance and operation costs (e.g. the cost of energy). Generally speaking the more permeable soils are better suited to spray and micro irrigation systems and heavier soils are more suitable for surface systems.

(a) (b) (c)

Figure 24 Types of different irrigation systems (a) bankless channel surface irrigation systems, (b) spray irrigation systems, (c) pressurised drip irrigation system on polymer-covered beds

Surface irrigation systems

Surface irrigation encompasses basin, border strip and furrow irrigation, as well as variations on these themes such as bankless channel systems. In surface irrigation, water is applied directly to the soil surface with check structures (banks or furrows) used to direct water across a field. Control of applied water is dictated by the soil properties, soil uniformity and the design characteristics of the surface system. Generally, fields are prepared by laser levelling to increase the uniformity of applied water and allow ease of management of water and adequate surface drainage from the field. The uniformity and efficiency of surface systems are highly dependent on the system design and soil properties, timing of the irrigation water, and the skill of the individual irrigator in operating the system. Mismanagement can severely degrade system performance and lead to systems that operate at poor efficiencies.

Surface irrigation has the benefit that it can generally be adapted to almost any crop and 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 as high as 85%. On poorly designed and managed systems on soil types with high variability, efficiencies can be below 60% (Table 6).

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 7).

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.

Spray irrigation systems

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 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 6). 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 7).

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 Flinders and Gilbert catchments, 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 climatic conditions found.

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 6). 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.

Table 6 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 skills needed for successful operation

Adopted from Hoffman et al. (2007), Raine and Bakker (1996) and Wood et al. (2007)

Table 7 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

4.4.3 LIMITED WATER

The crop yields presented in this technical report are modelled with unlimited irrigation water. Unlimited irrigation water will not always be available to farm managers, or necessarily most economical. In situations where water availability is limited, the crop will respond by yielding higher with more applied irrigation until a yield plateau is reached (Figure 25). Understanding the shape of the crop yield response to increasing irrigation allows better risk and financial management in water limited environments.

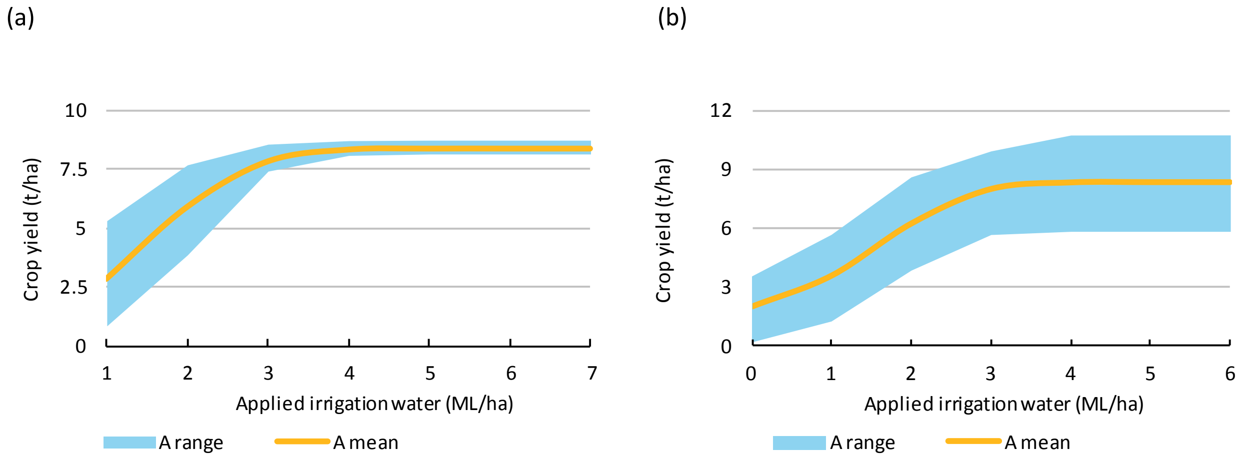


Figure 25 Crop yield plotted against applied irrigation water in Richmond climate.
Modelled range (20th to 80th percentile) and mean crop yields for (a) sorghum (grain) and (b) cotton

4.4.4 DRYLAND

The extreme of limited irrigation water is when crops are grown without any applied irrigation water, or dryland. Dryland crops rely on rainfall (stored in the soil or received during crop growth) for all of their water requirements. The more rainfall that is received, the better dryland crop yields (Figure 26). Generally dryland yields are lower than irrigated yields, but in a very few years dryland yields can match irrigated crop yields (Figure 27).

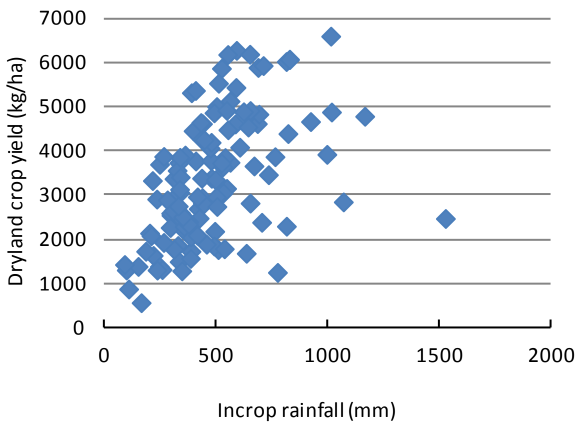


Figure 26 Modelled dryland crop yields compared to in-crop rainfall for the 121 year historical record of sorghum sown on 15th January in a Georgetown climate

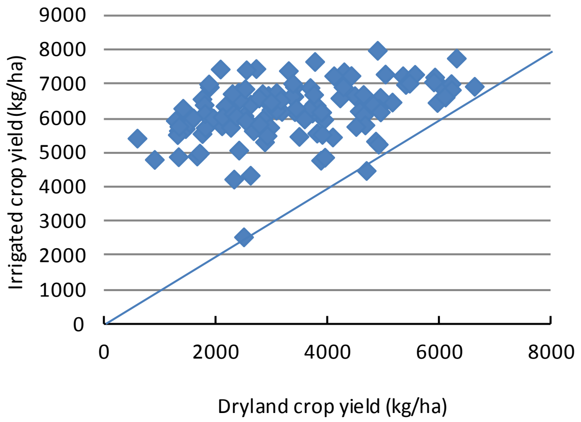


Figure 27 Comparison of modelled dryland and irrigated crop yields for the 121 year historical record of sorghum sown on 15th January in a Georgetown climate

Dryland production (farming without irrigation) comprises virtually all of the agriculture currently practised in the Flinders and Gilbert catchments. Specifically, 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 virtually no dryland cropping for human food or fibre production in the Flinders and Gilbert catchments.

Dryland farming is wholly dependent on water stored in the soil and rainfall occurring during crop growth. The low annual rainfall, and high variability of rainfall means that continuous year-on-year dryland cropping is unlikely to be possible in the Flinders and Gilbert catchments. 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 Flinders and Gilbert catchments is likely to make it possible to readily identify the years in which conditions are favourable.

Table 8 shows how soil water content at sowing and rainfall in the 90 days after sowing are likely to vary for three different sowing dates in Richmond. As sowing is delayed (March), it is more likely that soil has stored water, although soil water storage can still be low (less than 70 mm is stored in 20% of the years). The earlier the sowing date, the more rainfall is received in the following 90 days, however rainfall is not guaranteed. Combining the median soil water content at sowing, and the median rainfall received in the 90 days following sowing, provides totals of 230, 190 and 180 mm for the January, February and March sowing dates respectively in Richmond. Given there is no guarantee all rainfall gets into the soil, the amount of water available to a crop is likely to be even less. This median amount of water is not sufficient to successfully grow most crops. Even the highest amounts of water available (the 20th percentile exceedance figures) are not sufficient to achieve break even yields for many crops. This simple analysis suggests that fewer than 1 in 5 years may be suited to dryland cropping in the Richmond climate.

Table 8 Soil water content at sowing and rainfall for the 90 day period following sowing for three sowing dates (Richmond)

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	120	70	30	240	160	90
28 February	180	110	50	140	80	40
31 March	205	140	70	80	40	10

4.5 Crop type

When considering an irrigated agricultural enterprise an important consideration is what crop or mix of crops will be grown. Different crops need different management, have different markets, and require different expertise. There are thirteen land use categories used in this Assessment, and each land use category has a number of example crops listed in Table 1. An overview of cropping requirements in each land use category is given in section 1.3.

The approximately 40 crop examples listed in Table 1 were subsequently analysed in more detail to identify critical environmental requirements and management considerations. Information about optimum sowing times is given in section 4.6.2 and achievable yields and irrigation water required to produce those yields in the Flinders and Gilbert catchments are provided in section 5.

4.6 Crop Management

The limited historical cropping in the Flinders and Gilbert catchments means that there is a paucity of recorded crop yields and management actions that were used to generate those 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 section 3.1).

4.6.1 IRRIGATION

In the Flinders and Gilbert catchments, 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. Analysis of the 'applied irrigation water' exceedance values in shows that the difference in the volume water required to fully irrigate a crop in the wettest and driest 20% of years was in the order of 25% and 35% in the Flinders and Gilbert catchments respectively. This highlights the impact of inter-annual variability on irrigation requirements.

In the Flinders and Gilbert catchments fully irrigated crops of outperform those of dryland crops, most often by a factor of two to three (Figure 28). Additionally, the yield of irrigated crops is much less variable than that of dryland crops, there being a much lower variation in crop yield between the 20^{th} and 80^{th} percentile exceedence values for irrigated crops than dryland crops (Figure 28). More detailed discussion about irrigation is provided in section 4.4.

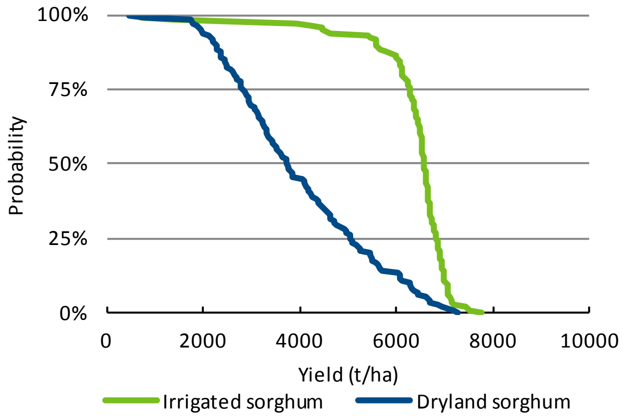


Figure 28 Cumulative probability of yield potential for dryland and fully irrigated grain sorghum sown in Georgetown climate on 15 January.

4.6.2 SOWING TIME

The time of year a crop is sown can have a major influence on achievable yield and irrigation water requirements. Many crops will fail to produce any yield at all if sown during the wrong time of year due to factors such as the wrong day length requirements to induce flowering or heat or cold stress.

The inter-annual variation in climate experienced in the Flinders and Gilbert catchments (section 4.1) has a profound effect on crop performance and irrigation water requirements. Figure 29 shows that sorghum crops planted in Richmond during the winter months will not yield as well as crops planted at other times of year. Crops planted in winter are flowering during the very hot September to November months, with heat stress at flowering reducing seed number. When irrigation water required to achieve these yields is investigated (Figure 29), the greatest requirements for irrigation water coincide with planting dates that would have the bulk of the growing season during the hot, dry Spring months. 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 planting at this time of year. The area of crop that can be reliably irrigated must be carefully assessed each year, with reference to the available stored soil moisture, 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 Assessment’s Case Studies. 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.

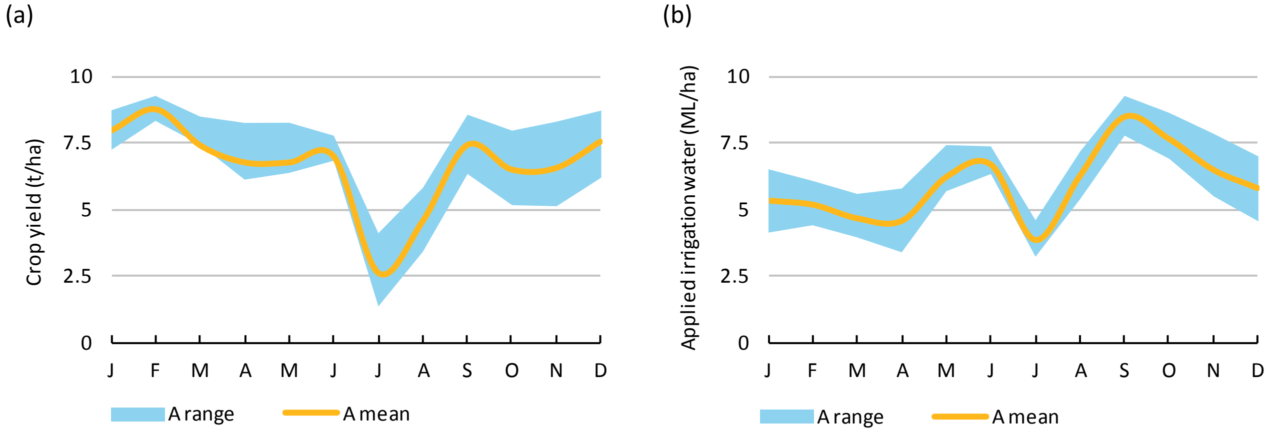


Figure 29 Effect of sowing date on the (a) yield and (b) irrigation water required to achieve that yield for grain sorghum in a Richmond climate

Crop sown on the 15th of each month using modelling from historical climate (1890 to 2011). A range is the 20th to 80th percentile exceedance and A mean applied irrigation water under optimum management.

Cropping calendars are a useful tool to 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 Flinders and Gilbert catchments.

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 amongst crops and regions. Table 9 and provides a cropping calendar for approximately 40 crops that are broadly adapted to the Flinders and Gilbert catchments respectively. Perennial crops are grown throughout the year, and consequently have a less well defined growing season or planting window. Generally, perennial tree crops are transplanted as small plants (not seeds), and in the tropical north this is usually timed towards the beginning of the wet season to take advantage of wet season rainfall.

These cropping calendars were developed based on knowledge of these crops derived from elsewhere in the tropics combined with an understanding of plant physiology, which enables crop response to differences in local climate to be anticipated. The optimum planting window and growing season were further refined through local experience and through use of the APSIM crop model.

The sowing windows identified in Table 9 and correspond with the times of sowing that are likely to maximise crop yield in the Flinders and Gilbert catchments. 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 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.

Table 9 Annual cropping calendar for potential agricultural options in the Flinders catchment

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 (dryland), Supplementary irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Fallow	Fallow	Fallow	
	Rice	Supplementary irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Sorghum (grain)	Rainfed (dryland), Supplementary irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Wheat	Fully irrigated	Growing period	Growing period	Growing period	Growing period	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Outside climatic zone
Citrus	Lemon	Fully irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Lime	Fully irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Orange	Fully irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
Food legume	Chickpea	Fully irrigated	Fallow	Fallow	Fallow	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Fallow	Potentially outside climatic zone
	Mungbean	Rainfed (dryland), Supplementary irrigated, Fully irrigated	Fallow	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Fallow	Fallow	
	Soybean	Rainfed (dryland), Supplementary irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Fallow	Fallow	Fallow	Fallow	Fallow	
Forage, hay, silage	Bambatsi	Rainfed (dryland), Supplementary irrigated	Growing period	Growing period	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Maize	Rainfed (dryland), Supplementary irrigated	Fallow	Fallow	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Fallow	Fallow	Fallow	
	Millet (forage)	Rainfed (dryland), Supplementary irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Rhodes grass	Rainfed (dryland), Supplementary irrigated	Growing period	Growing period	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Sorghum (forage)	Rainfed (dryland), Supplementary irrigated, Fully irrigated	Growing period	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
Forage legume	Cavalcade	Rainfed (dryland), Supplementary irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Fallow	Fallow	Growing period	Growing period	Growing period	
	Lablab	Rainfed (dryland), Supplementary irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Fallow	Fallow	Fallow	Growing period	Growing period	
	Lucerne	Rainfed (dryland), Supplementary irrigated	Growing period	Growing period	Growing period	Growing period	Growing period	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	

Sowing window | Growing period | Fallow | Sowing window for perennial crops

Rainfed (dryland) | Supplementary irrigated | Fully irrigated

Table 9 Annual cropping calendar for potential agricultural options in the Flinders catchment (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														Better suited to lighter soils
Silviculture (plantation)	African mahogany														
	Indian sandalwood														
Tree crop (fruit)	Avocado														
	Banana														
	Lychee														
	Mango														
Tree crop (nuts)	Cashew														
	Macadamia														Outside recommended climatic zone
Vine	Grape														

Table 10 Annual cropping calendar for potential agricultural options in the Gilbert catchment

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 irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Fallow	Fallow	Fallow	
	Rice	Supplementary irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Permeable soils unsuitable for flooded rice
	Sorghum (grain)	Rainfed, Supplementary irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Wheat	Fully irrigated	Growing period	Growing period	Growing period	Growing period	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Outside climatic zone
Citrus	Lemon	Fully irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Lime	Fully irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Orange	Fully irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
Food legume	Chickpea	Fully irrigated	Fallow	Fallow	Fallow	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Fallow	Potentially outside climatic zone
	Mungbean	Rainfed, Supplementary irrigated, Fully irrigated	Fallow	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Fallow	Fallow	
	Soybean	Rainfed, Supplementary irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Fallow	Fallow	Fallow	Fallow	Fallow	
Forage, hay, silage	Bambatsi	Rainfed, Supplementary irrigated	Growing period	Growing period	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Maize	Rainfed, Supplementary irrigated	Fallow	Fallow	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Fallow	Fallow	Fallow	
	Millet (forage)	Rainfed, Supplementary irrigated, Fully irrigated	Sowing window	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Rhodes grass	Rainfed, Supplementary irrigated	Growing period	Growing period	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
	Sorghum (forage)	Rainfed, Supplementary irrigated, Fully irrigated	Growing period	Sowing window	Sowing window	Sowing window	Sowing window	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	Growing period	
Forage legume	Cavalcade	Rainfed, Supplementary irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Fallow	Fallow	Growing period	Growing period	Growing period	
	Lablab	Rainfed, Supplementary irrigated	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	Fallow	Fallow	Fallow	Growing period	Growing period	
	Lucerne	Rainfed, Supplementary irrigated	Growing period	Growing period	Growing period	Growing period	Growing period	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Sowing window for perennial crops	Growing period	Growing period	Growing period	

Sowing window · Growing period · Fallow · Sowing window for perennial crops

Rainfed (dryland) · Supplementary irrigated · Fully irrigated

Table 10 Annual cropping calendar for potential agricultural options in the Gilbert catchment (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	●													

4.6.3 NUTRITION

Adequate crop nutrition is essential for achieving marketable yields of crops. The primary macronutrients, nitrogen, phosphorous and potassium are usually provided through fertiliser, but often a soil is naturally high enough in the secondary macronutrients (calcium, magnesium and sulphur) and micronutrients (boron, copper, iron, chloride, manganese, molybdenum and zinc) that fertilising with these nutrients is not required annually. The best way for farm managers to militate against nutritional risk is to consult an agronomist and conduct thorough soil testing of paddocks to be farmed. Because soil can be variable over relatively short distances, it may be necessary to sample soil for testing in a number of locations.

4.6.4 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. The north’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 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 the north 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 4-6 million is found in tropical north Queensland. Pigs can cause indirect damage for example by carrying weed seed such as parthenium (*Parthenium hysterophorus*) from watercourses to open country, and can cause direct and major physical damage to a wide range of crops and even to cultivated ground. Pigs have a daily water requirement which means that during the dry season their range is generally restricted to watercourses and man-made water supplies (McGaw and Mitchel 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 Flinders and Gilbert catchments.

4.6.5 WEED MANAGEMENT

All of the management of soil, water and plant nutrition conducted to grow a crop will also grow weeds. Weeds left unchecked have the potential to cause severe economic damage to cropping operations. To militate against weeds farm managers can conduct regular inspection of growing crops and spray appropriate herbicides to control weeds.

4.7 Risk

There are a number of risk factors, and mitigation options, when considering irrigated agriculture in the Flinders and Gilbert catchments. The management options discussed in section 4.6 provide a tangible way of managing risk.

There is the possibility of risk from the climate not being conducive in any year to good crop production. This could come about through heavy rain causing flooding, from not enough rain meaning there is limited irrigation water available, extremes of temperature both hot and cold at unexpected times or strong winds (including from cyclones). Over the long term each of the observed extremes from the historical record will likely be observed again, and individual farm managers will have their own appetite for risk, and strategies to manage it. Planting time, crop selection and seasonal climate forecasting are methods that can be used to manage climate risk.

Prices that farm managers expect for their produce can vary dramatically over short time periods, especially for horticultural crops exposed to the fresh food market. Choice of crops to grow, and the prices received for those crops has a large impact on the viability of an agricultural enterprise. Especially when starting out a 'run' of poor prices can have a devastating effect on the viability of a farming operation. Farm managers can mitigate against price fluctuations through forward selling (when available), entering into supply contracts with buyers, and growing a number of different crops each season.

The Flinders and Gilbert catchments are sparsely populated, with limited facilities, and a challenging environment for people to live in. Agricultural industries such as horticulture have a high demand for labour at critical times such as harvest (for picking and packing) and irrigation farms need farm labour. There is a risk that not enough people will be available to fill job vacancies on-farm in the Flinders and Gilbert catchments.

Another risk associated with the remoteness of the Flinders and Gilbert catchments is farmers need the ability to move produce to market. Fresh produce is time critical to get to a market, with Sydney, Melbourne and Brisbane being the main fresh food markets for horticulture produce. Townsville and Cairns ports are possible export points for the Flinders and Gilbert catchments. A critical mass of farm production, that can only come from a reliable irrigation water supply, can help mitigate against supply chain risk by creating opportunities for the private sector.

4.7.1 CLIMATE CHANGE

The future climate may be different to the current climate, and the possible future climate could have different effects on crop production. To determine if future climate may affect crop production in the Flinders and Gilbert catchments the Agricultural Production System Simulator crop model was used to simulate sorghum production for three possible future climates (details of climates used and how they were generated are in the companion technical report about climate (Petheram and Yang., 2013)). All the future climates modelled have an atmospheric CO_2 concentration 100 ppm higher than current (480 ppm) and are either dry, wet, or mid range of the predicted future rainfall patterns. Table 11 summarises the modelled yield and irrigation water use for the current, and future climates for grain sorghum sown on the 15th March at Cloncurry. The 20th, 50th and 80th percentile exceedance values are reported.

Table 11 20th, 50th and 80th percentile exceedence values for yield and irrigated water use for grain sorghum sown at Cloncurry under current and future climates. Future climates are modelled at atmospheric CO2 at 480 ppm and dry, wet and average rainfall patterns.

Climate scenario	Yield			Irrigation		
	20th	50th	80th	20th	50th	80th
Current	8806	8632	8204	482	428	358
Dry	8890	8639	8237	480	423	362
Mid	8925	8673	8271	455	399	337
Wet	8727	8483	8085	432	373	313

There is not much difference in crop yield between the current and future climates, with the wetter climate being slightly lower. There is very little difference between the modelled crop irrigation requirement between the current and future dry climate, and only slight decreases in irrigation water demand for the mid and wet future climate.

4.8 Economics

As with any business the goal of irrigated agriculture is to make a profit. There are many opportunities in the Flinders and Gilbert catchment to be profitable, and this technical report is not the forum for picking winners among the options available.

Indicative crop gross margins for crops are provided in section 5 and more details are provided in the companion technical report about irrigation costs and benefits (Brennan McKellar et al. 2013). 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. To reiterate the crop yields reported in this technical report, and used to calculate gross margins, are modelled potential yields that do not account for a range of biophysical stresses. Actual yields will often be lower and careful consideration of assumptions used in gross margin analysis is recommended.

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.

The gross margins are provided merely as an indication of the cash flow that might be generated by established irrigated cropping enterprises in the Flinders and Gilbert catchments. 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 $ 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, 2012 a, b; Queensland Department of Agriculture, Fisheries and Forestry staff, 2013, pers. comm.; DEEDI, 2011 a, b, c; Mason, 2011). Full details are provided in the companion technical report about irrigation costs and benefits (Brennan McKellar et al. 2013).

5 Results

Figure 30 to Figure 41 presents cumulative distribution functions for eleven crops modelled over the 121 year climate record (Petheram and Yang, 2013) at three climate locations in each of the Flinders and Gilbert catchments. The probability (y axis) of exceeding yield (x axis) is plotted for four soils representing the four likely agricultural soils from the modelled Soil Generic Groups (Table 2 and Bartley et al, 2013) for fully irrigated cropping.

Table 12 to Table 19 presents the 20th, 50th and 80th percentile exceedance values of irrigation water required to achieve the modelled results in Figure 30 to Figure 41.

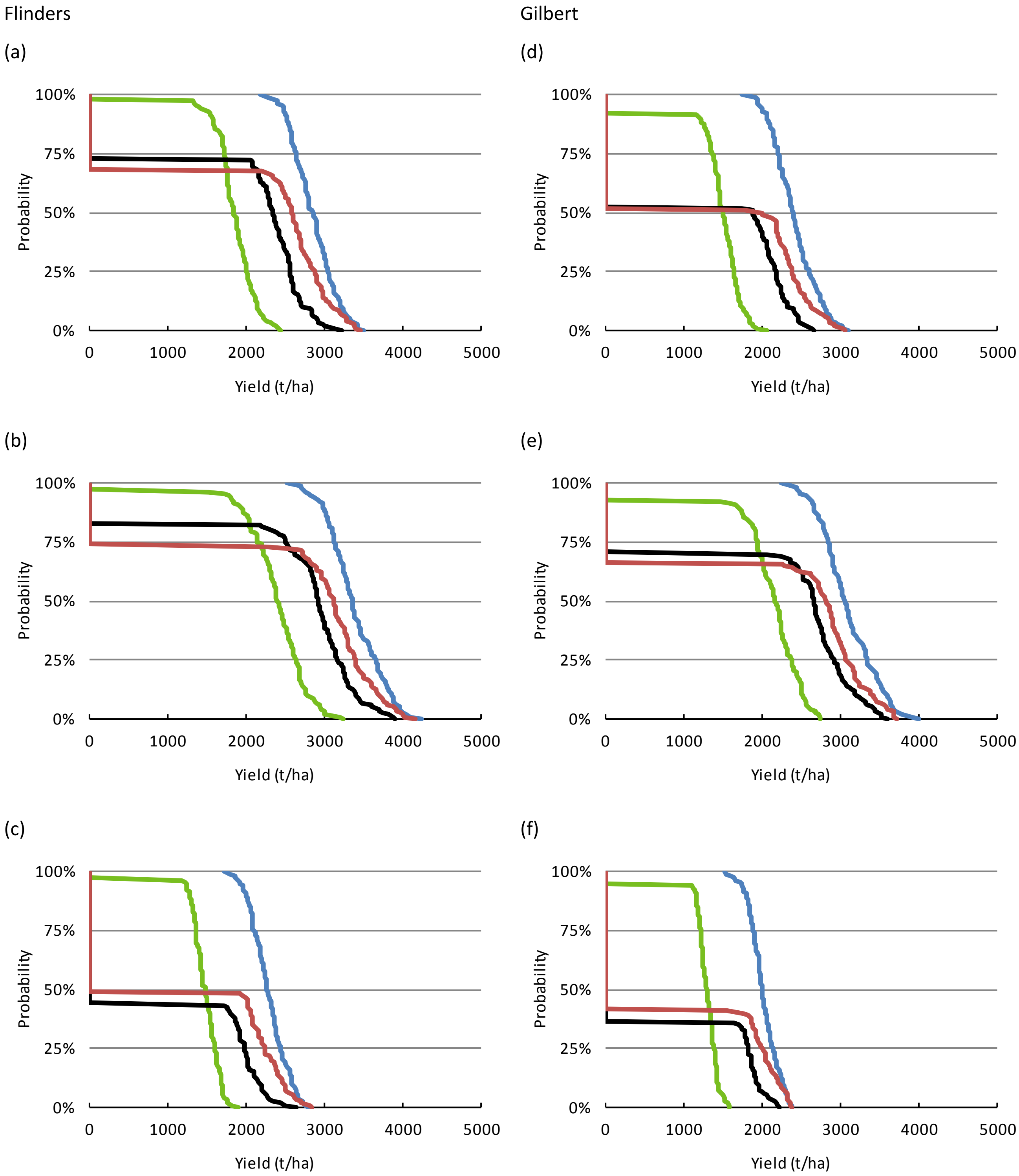


Figure 30 Cumulative probabilities of irrigated chickpea yield for three climate locations in each of the Flinders and Gilbert catchments and four soil types. Climates are (a) Richmond, (b) Eastern Flinders, (c) Northern Flinders, (d) Georgetown, (e) Einasleigh and (f) northern Gilbert. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013)

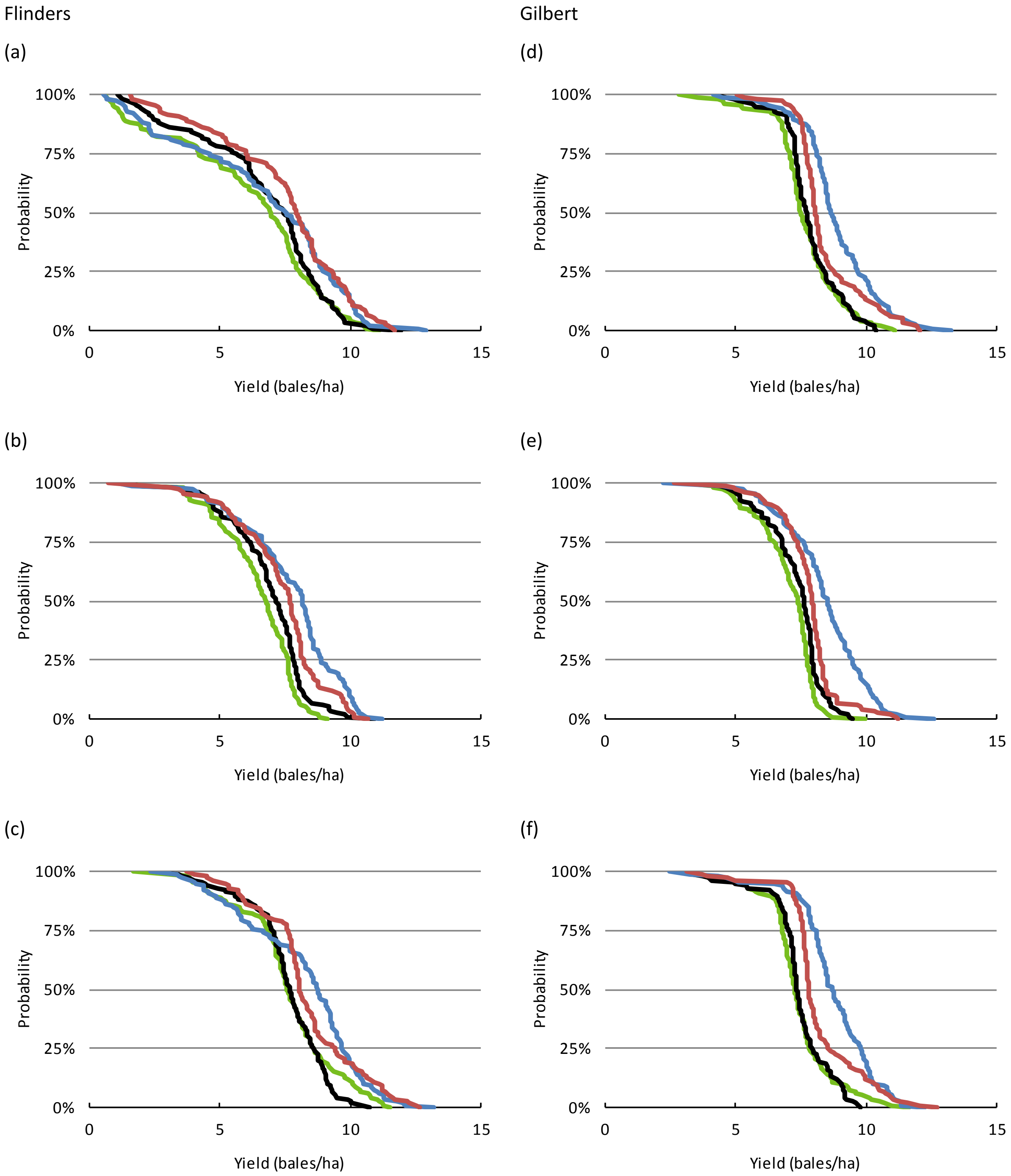
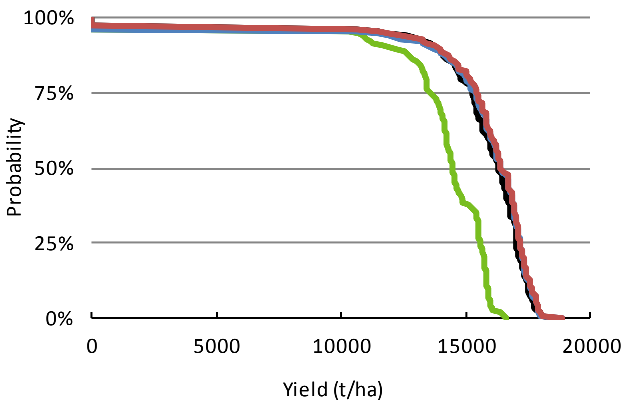


Figure 31 Cumulative probabilities of irrigated cotton yield for three climate locations in each of the Flinders and Gilbert catchments and four soil types. Climates are (a) Richmond, (b) Eastern Flinders, (c) Northern Flinders, (d) Georgetown, (e) Einasleigh and (f) northern Gilbert. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013)

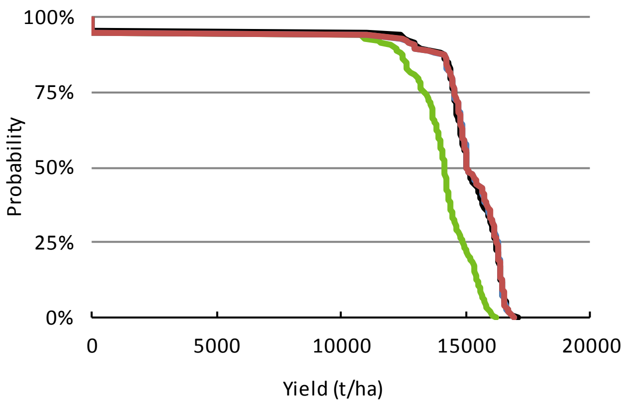
Flinders

Gilbert

(d)



(e)



(f)

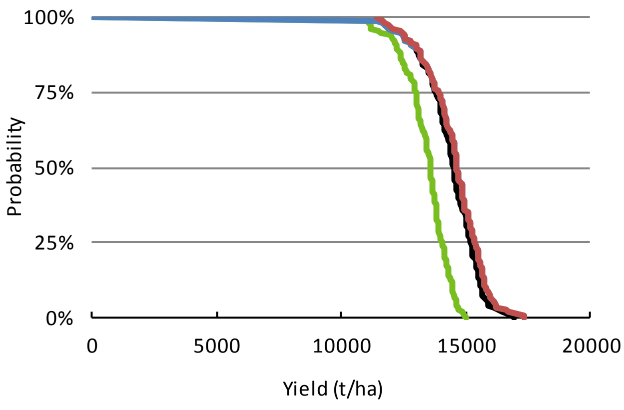


Figure 32 Cumulative probabilities of irrigated forage sorghum yield for three climate locations in the Gilbert catchment and four soil types. Climates are (d) Georgetown, (e) Einasleigh and (f) northern Gilbert. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013). Note forage sorghum was not modelled in the Flinders climates

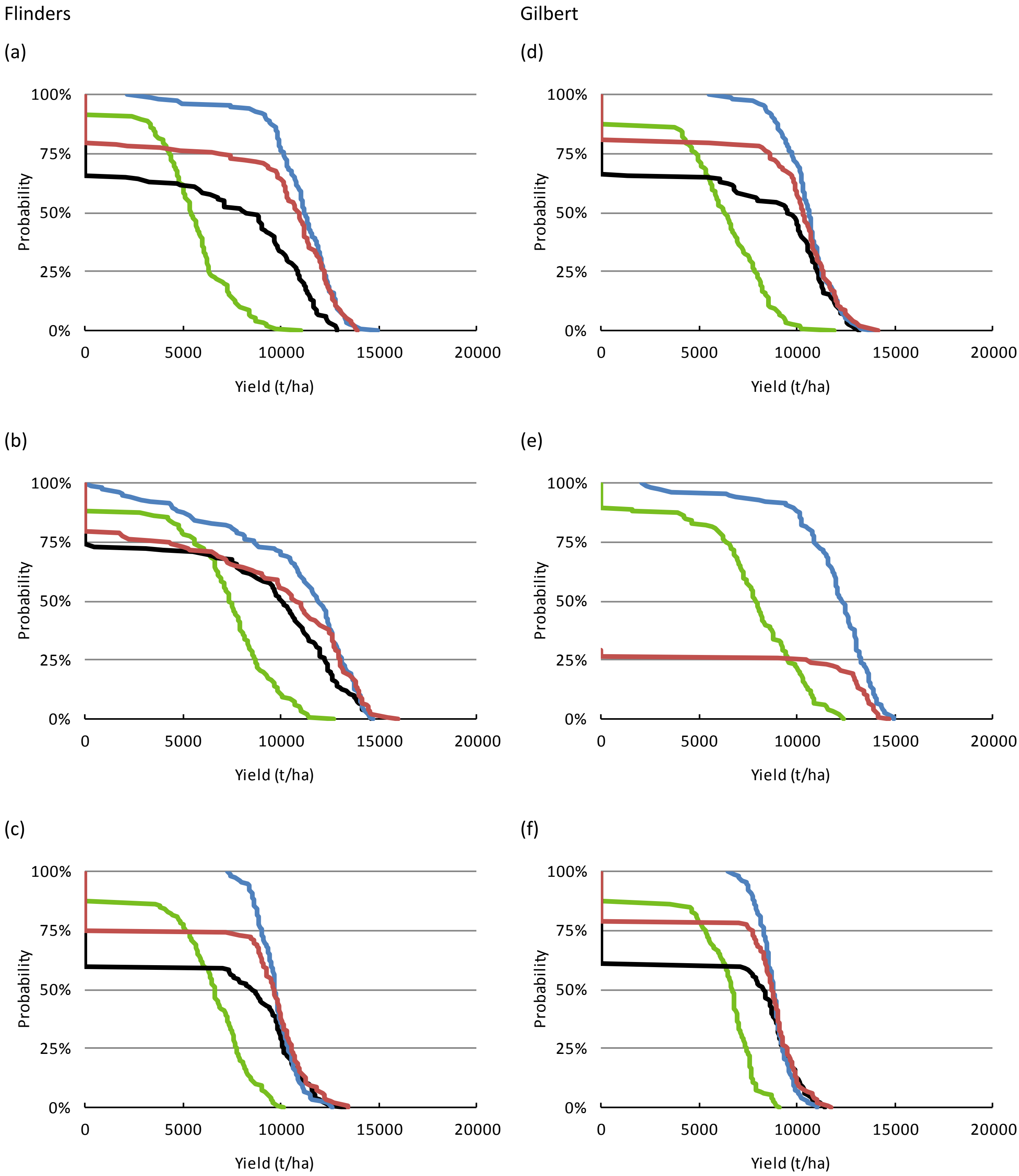


Figure 33 Cumulative probabilities of irrigated maize yield for three climate locations in each of the Flinders and Gilbert catchments and four soil types. Climates are (a) Richmond, (b) Eastern Flinders, (c) Northern Flinders, (d) Georgetown, (e) Einasleigh and (f) northern Gilbert. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013)

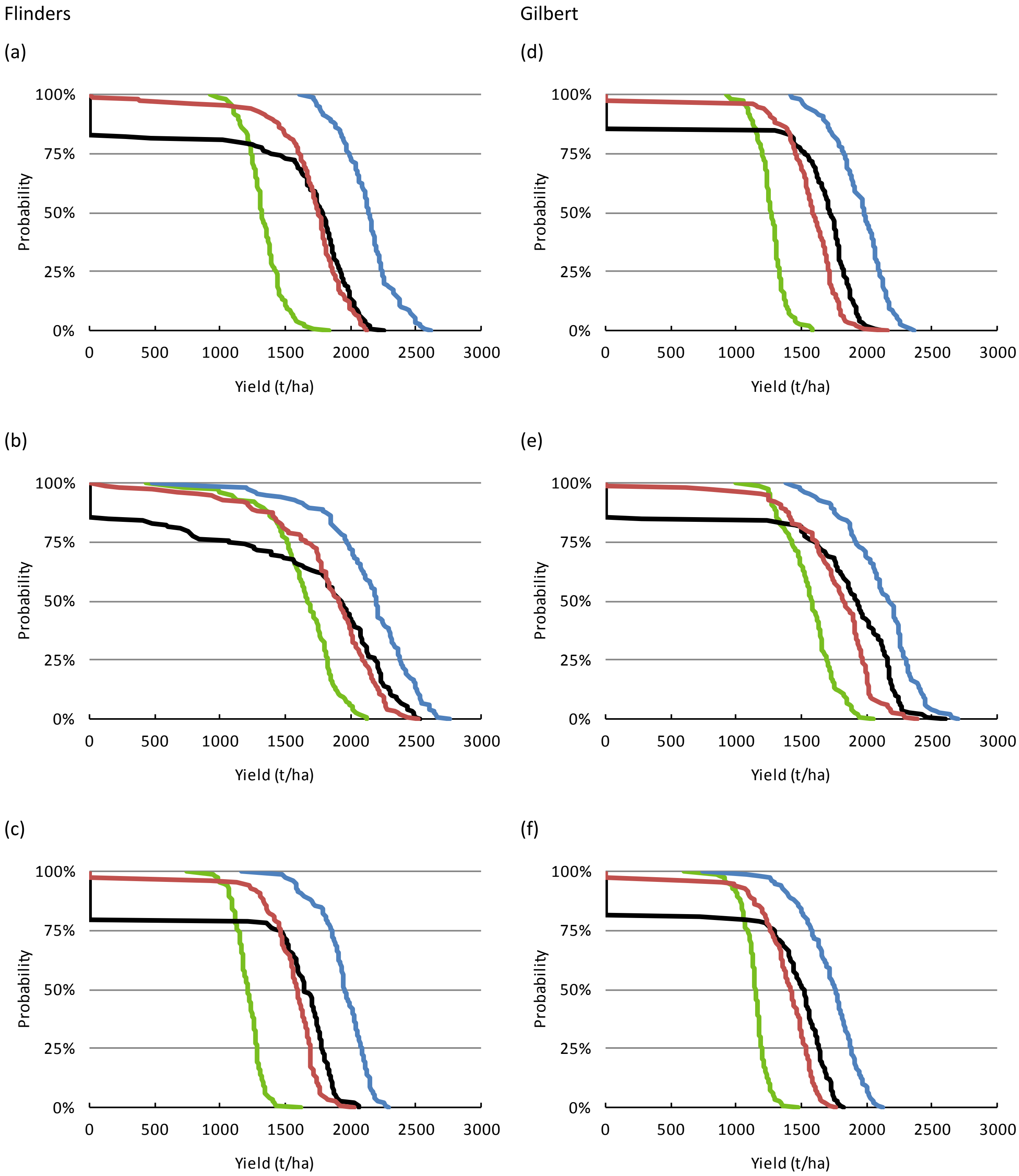
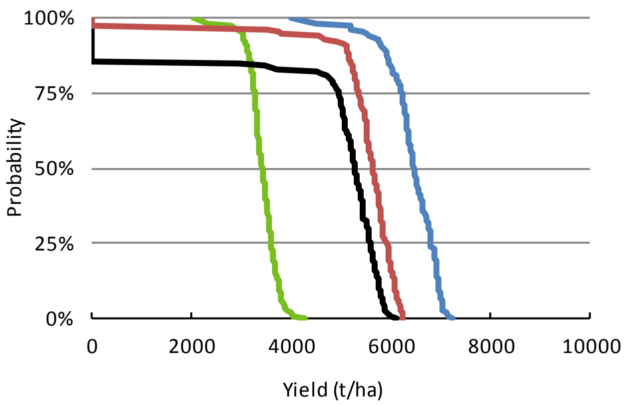


Figure 34 Cumulative probabilities of irrigated mungbean yield for three climate locations in each of the Flinders and Gilbert catchments and four soil types. Climates are (a) Richmond, (b) Eastern Flinders, (c) Northern Flinders, (d) Georgetown, (e) Einasleigh and (f) northern Gilbert. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013)

Flinders

Gilbert

(d)



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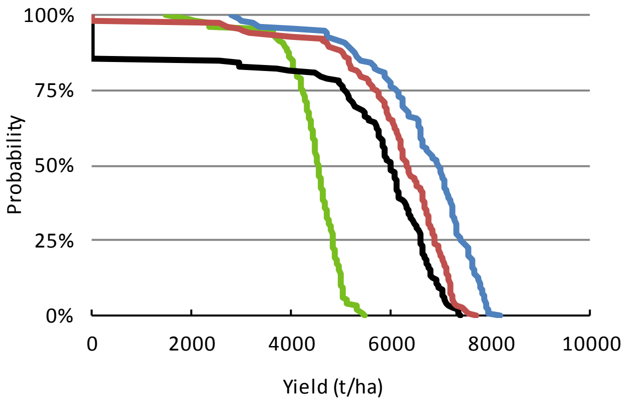

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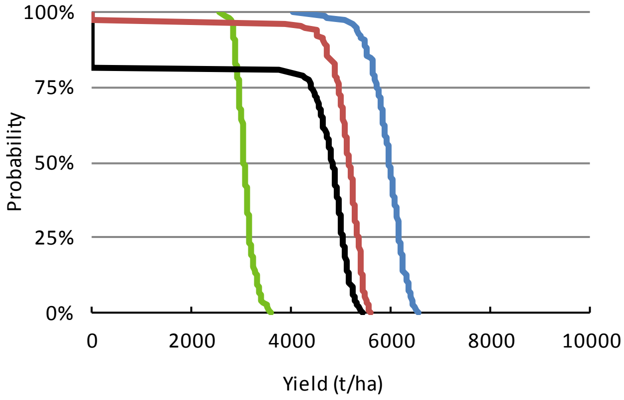


Figure 35 Cumulative probabilities of irrigated peanut yield for three climate locations in the Gilbert catchment and four soil types. Climates are (d) Georgetown, (e) Einasleigh and (f) northern Gilbert. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013). Note peanut was not modelled in the Flinders catchment

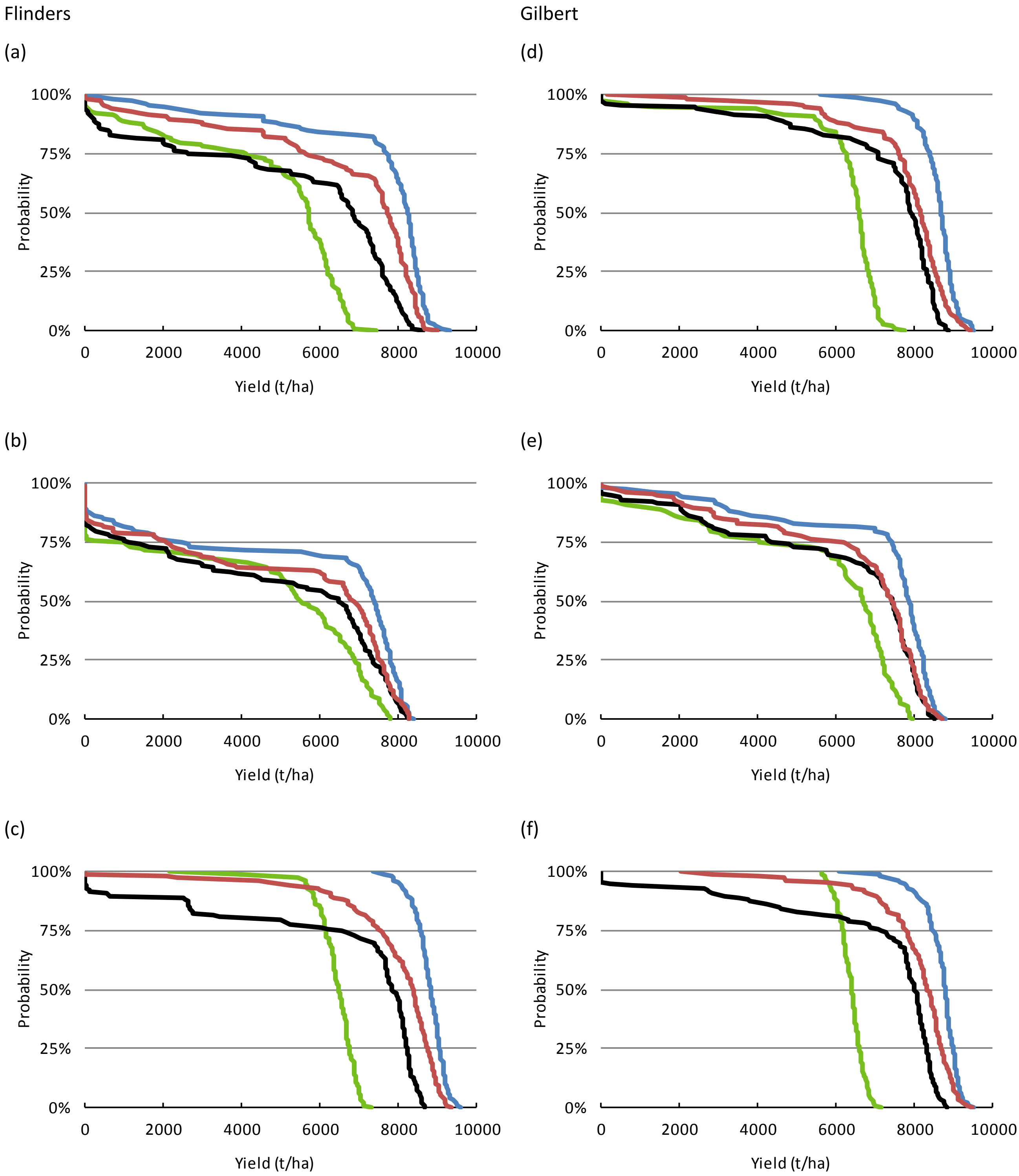


Figure 36 Cumulative probabilities of irrigated sorghum yield for three climate locations in each of the Flinders and Gilbert catchments and four soil types. Climates are (a) Richmond, (b) Eastern Flinders, (c) Northern Flinders, (d) Georgetown, (e) Einasleigh and (f) northern Gilbert. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013)

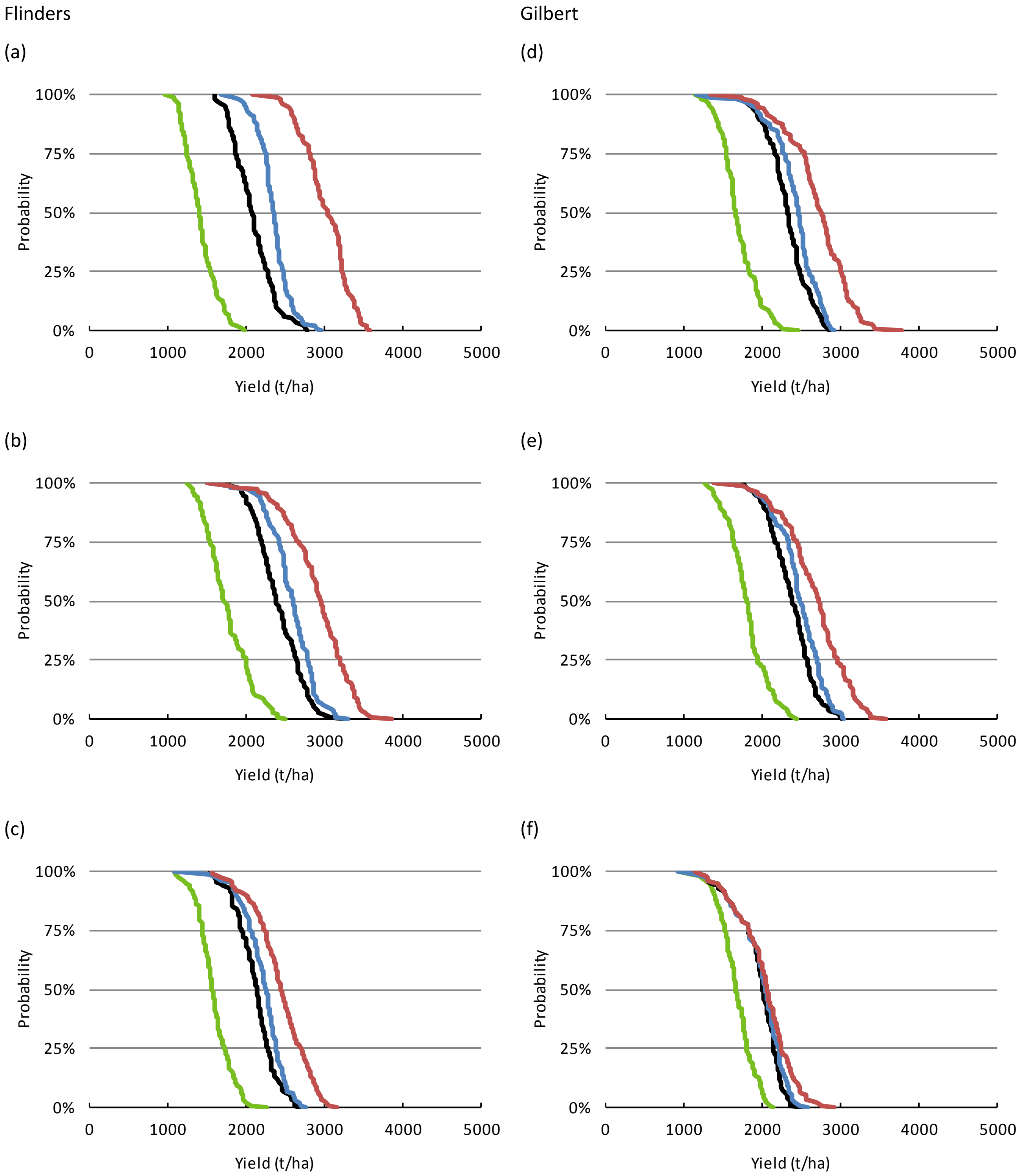
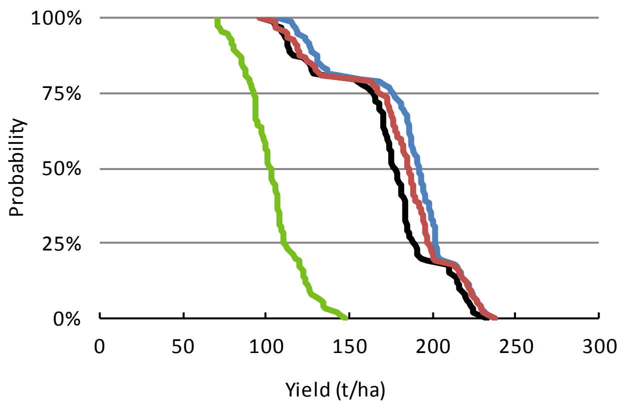


Figure 37 Cumulative probabilities of irrigated soybean yield for three climate locations in each of the Flinders and Gilbert catchments and four soil types. Climates are (a) Richmond, (b) Eastern Flinders, (c) Northern Flinders, (d) Georgetown, (e) Einasleigh and (f) northern Gilbert. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013)

Flinders

Gilbert

(d)



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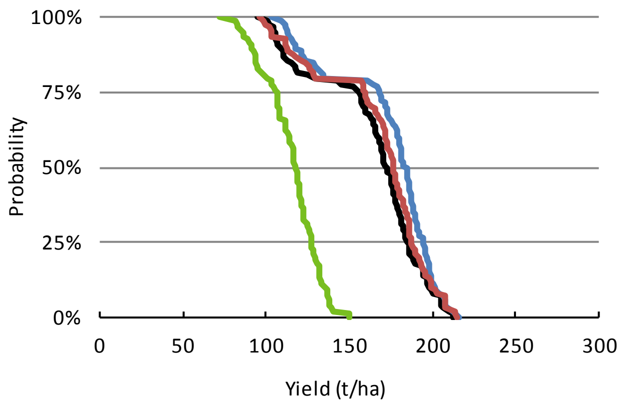

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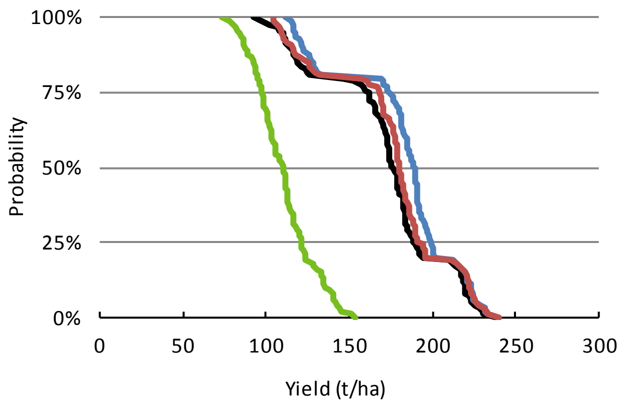
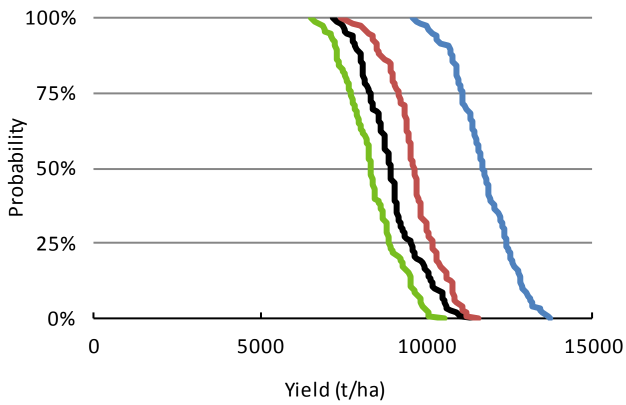


Figure 38 Cumulative probabilities of irrigated sugarcane yield for three climate locations in the Gilbert catchment and four soil types. Climates are (d) Georgetown, (e) Einasleigh and (f) northern Gilbert. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013). Note sugarcane was not modelled in the Flinders catchment

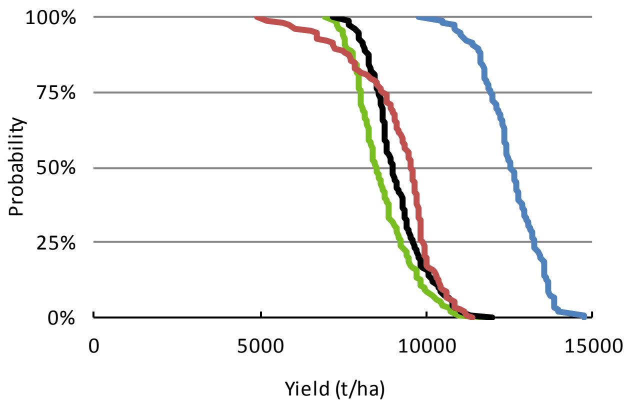
Flinders

Gilbert

(a)



(b)



(c)

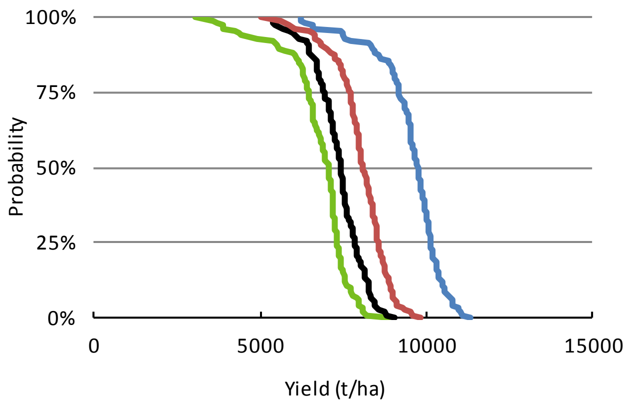
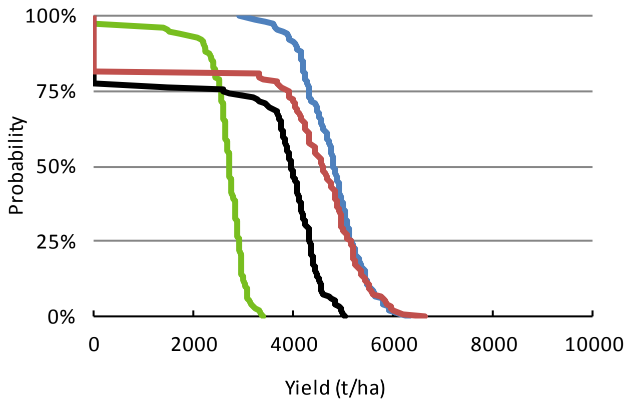


Figure 39 Cumulative probabilities of irrigated rice yield for three climate locations in the Flinders catchment and four soil types. Climates are (a) Richmond, (b) Eastern Flinders, and (c) Northern Flinders. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013). Note rice was not modelled in the Gilbert catchment

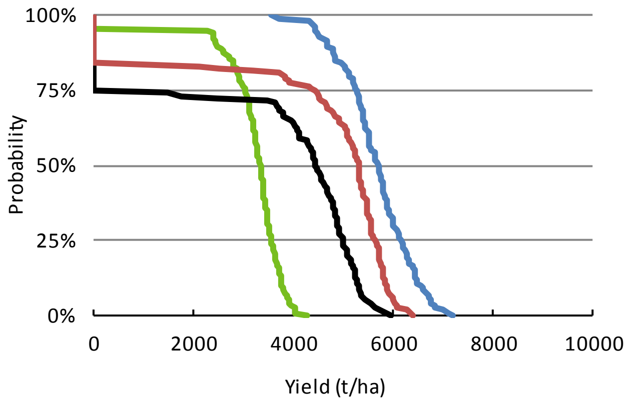
Flinders

Gilbert

(a)



(b)



(c)

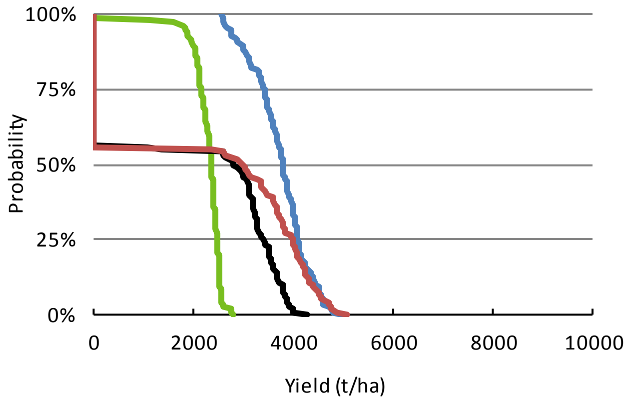
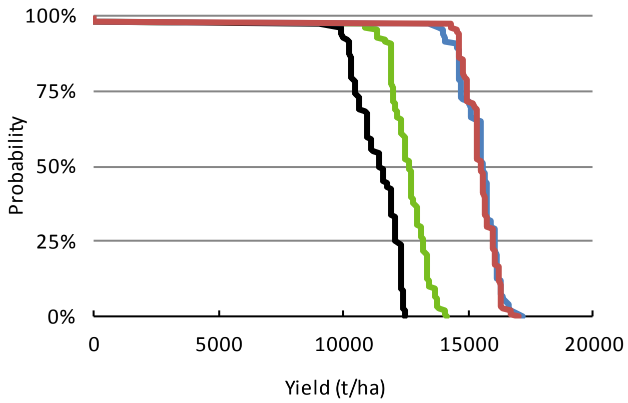


Figure 40 Cumulative probabilities of irrigated wheat yield for three climate locations in the Flinders catchment and four soil types. Climates are (a) Richmond, (b) Eastern Flinders, and (c) Northern Flinders. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013). Note wheat not modelled in the Gilbert catchment

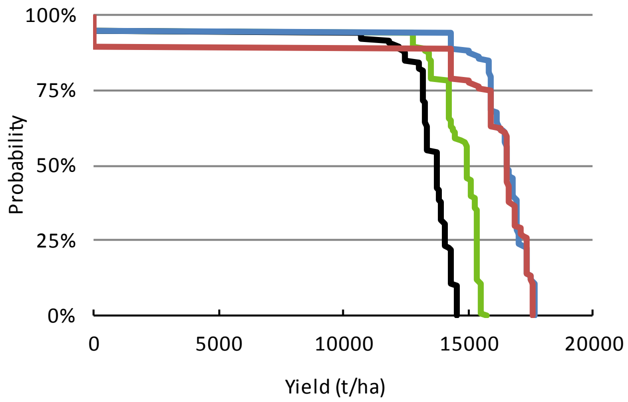
Flinders

Gilbert

(a)



(b)



(c)

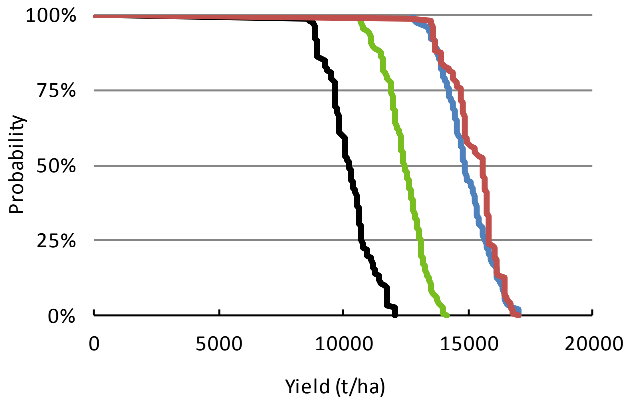


Figure 41 Cumulative probabilities of irrigated lablab yield for three climate locations in the Flinders catchment and four soil types. Climates are (a) Richmond, (b) Eastern Flinders and (c) Northern Flinders. Soil types are Green = Sand or loam over relatively friable clay subsoils, Black = Red, yellow or grey loamy soil, Blue = Friable non-cracking clay or clay loam soil and Red = Cracking clay soils (Bartley et al. 2013). Note lablab not modelled in the Gilbert catchment

Table 12 20th, 50th and 80th percentile exceedance values for required irrigation water in the Flinders catchment soil type is Sand or loam over relatively friable clay subsoils for three climate locations

Climate	Richmond			Eastern			Northern		
Crop	20th	50th	80th	20th	50th	80th	20th	50th	80th
Maize	5.3	4.7	3.8	4.9	4.2	3.5	4.7	4.0	3.1
Wheat	3.4	2.1	1.8	3.3	3.0	2.6	2.3	2.3	2.0
Rice	9.0	8.0	6.6	7.7	6.9	6.0	7.1	6.4	5.6
Sorghum	4.0	3.3	2.1	3.7	2.5	1.3	3.5	3.2	2.7
Mungbean	2.2	2.0	1.7	1.9	1.6	1.3	1.8	1.2	0.8
Chickpea	3.1	2.7	2.2	3.0	2.3	1.8	2.4	2.0	1.8
Soybean	3.2	2.7	2.0	2.5	2.0	1.5	2.3	1.7	1.3
Cotton	3.8	3.0	2.0	4.0	3.3	2.7	4.2	3.5	2.6
Lablab	5.3	2.7	1.1	2.9	1.1	0.6	5.8	5.5	5.0

Table 13 20th, 50th and 80th percentile exceedance values for required irrigation water in the Flinders catchment soil type is Red, yellow or grey loamy soil for three climate locations

Climate	Richmond			Eastern			Northern		
Crop	20th	50th	80th	20th	50th	80th	20th	50th	80th
Maize	5.9	4.7	1.0	5.6	4.6	2.1	4.8	3.8	1.3
Wheat	4.3	3.1	2.2	4.3	3.7	3.4	3.4	2.6	2.2
Rice	8.7	7.5	6.1	7.3	6.4	5.6	6.6	5.9	5.1
Sorghum	5.0	3.7	2.2	4.2	2.5	1.2	4.7	3.5	2.8
Mungbean	2.4	1.9	1.4	1.7	1.4	0.9	1.7	1.0	0.7
Chickpea	4.2	3.2	2.5	3.7	2.8	2.2	2.6	2.2	1.9
Soybean	4.0	3.4	2.6	3.2	2.5	1.7	2.8	2.1	1.5
Cotton	3.7	2.8	2.0	3.8	3.2	2.3	4.1	3.2	2.4
Lablab	4.4	1.2	0.3	3.2	0.9	0.3	4.4	0.3	0.3

Table 14 20th, 50th and 80th percentile exceedance values for required irrigation water in the Flinders catchment soil type is Friable non-cracking clay or clay loam soil for three climate locations

Climate	Richmond			Eastern			Northern		
Crop	20th	50th	80th	20th	50th	80th	20th	50th	80th
Maize	5.9	4.9	4.3	5.0	3.8	3.2	4.8	3.8	3.2
Wheat	5.2	2.7	2.2	5.1	4.6	4.0	3.0	2.7	2.2
Rice	6.6	5.7	4.4	5.8	5.0	4.2	5.2	4.5	3.8
Sorghum	4.9	4.2	3.2	3.7	2.7	1.7	4.4	3.8	3.2
Mungbean	2.7	2.3	1.8	1.9	1.5	0.8	1.5	0.8	0.4
Chickpea	4.3	3.8	2.8	3.2	2.7	2.1	2.7	2.2	1.6
Soybean	5.1	4.3	3.5	3.9	3.3	2.2	3.5	2.8	1.8
Cotton	3.4	2.7	1.8	3.7	3.0	2.2	3.7	3.0	2.3
Lablab	15.7	7.0	4.8	4.5	1.1	0.5	6.6	6.0	5.5

Table 15 20th, 50th and 80th percentile exceedance values for required irrigation water in the Flinders catchment soil type is Cracking clay soils for three climate locations

Climate	Richmond			Eastern			Northern		
Crop	20th	50th	80th	20th	50th	80th	20th	50th	80th
Maize	6.3	4.8	2.7	5.4	3.9	2.2	4.8	3.9	2.6
Wheat	5.0	3.2	2.2	4.6	4.1	3.3	4.1	3.1	2.2
Rice	6.2	5.6	4.4	4.9	4.1	3.6	5.0	4.3	3.7
Sorghum	5.3	3.9	2.6	4.0	2.6	1.3	4.5	3.1	2.6
Mungbean	2.6	2.1	1.7	1.9	1.5	1.2	1.5	0.9	0.9
Chickpea	4.4	3.5	2.6	3.7	2.6	2.0	2.8	2.2	1.7
Soybean	6.2	5.2	3.8	4.5	3.4	2.3	3.7	2.8	1.8
Cotton	3.6	2.9	2.0	3.9	3.2	2.2	4.1	3.3	2.6
Lablab	6.2	5.8	4.6	1.7	0.8	0.4	5.8	0.5	0.4

Table 16 20th, 50th and 80th percentile exceedance values for required irrigation water in the Gilbert catchment soil type is Sand or loam over relatively friable clay subsoils for three climate locations

Climate	Georgetown			Einasleigh			Northern		
Crop	20th	50th	80th	20th	50th	80th	20th	50th	80th
Maize	5.1	4.3	3.4	4.9	4.2	3.7	4.3	3.6	2.7
Sorghum	3.6	3.0	2.7	3.7	2.9	1.8	3.2	2.9	2.6
Mungbean	2.0	1.2	0.8	1.9	1.5	1.2	1.2	1.0	0.7
Chickpea	2.5	2.2	1.8	3.0	2.4	2.0	2.5	2.1	1.8
Soybean	2.0	1.4	0.9	2.1	1.6	1.1	1.4	0.9	0.4
Cotton	3.8	3.3	2.6	3.8	3.3	2.6	4.0	3.4	2.6
Forage sorghum	6.3	5.7	5.0	6.1	5.6	4.5	6.1	5.7	5.2
Peanut	5.2	4.9	4.5	5.7	5.1	4.5	4.9	4.5	4.2
Sugarcane	14.3	12.1	10.5	12.9	11.4	9.3	13.7	11.2	9.4

Table 17 20th, 50th and 80th percentile exceedance values for required irrigation water in the Gilbert catchment soil type is Red, yellow or grey loamy soil for three climate locations

Climate	Georgetown			Einasleigh			Northern		
Crop	20th	50th	80th	20th	50th	80th	20th	50th	80th
Maize	5.1	3.8	1.0	4.6	4.6	4.6	3.8	3.1	1.0
Sorghum	4.6	3.5	2.8	4.1	2.8	1.9	4.1	3.2	2.8
Mungbean	1.8	1.0	0.7	1.7	1.4	1.0	0.9	0.7	0.5
Chickpea	2.7	2.3	1.9	3.6	2.5	1.9	2.6	2.2	1.9
Soybean	2.4	1.9	1.3	2.6	2.0	1.2	1.7	0.9	0.6
Cotton	3.7	3.2	2.6	3.8	3.2	2.4	4.0	3.2	2.3
Forage sorghum	5.5	4.9	4.3	5.2	4.6	3.7	5.3	4.9	4.3
Peanut	5.7	5.3	4.7	6.1	5.5	4.7	5.1	4.8	4.2
Sugarcane	14.7	12.1	10.4	13.1	11.1	8.8	13.8	11.1	8.8

Table 18 20th, 50th and 80th percentile exceedance values for required irrigation water in the Gilbert catchment soil type is Friable non-cracking clay or clay loam soil for three climate locations

Climate	Georgetown			Einasleigh			Northern		
Crop	20th	50th	80th	20th	50th	80th	20th	50th	80th
Maize	4.9	4.3	3.3	4.9	4.3	3.2	3.8	3.3	3.2
Sorghum	3.9	3.3	3.2	3.7	2.7	2.1	3.8	3.3	2.7
Mungbean	1.9	0.8	0.4	1.9	1.5	1.1	0.8	0.7	0.4
Chickpea	2.2	2.1	1.6	3.3	2.7	2.2	2.2	2.2	2.1
Soybean	3.2	2.5	1.6	3.4	2.8	1.8	2.3	1.4	0.9
Cotton	3.7	2.9	2.3	3.6	3.0	2.2	3.9	3.3	2.3
Forage sorghum	5.0	4.5	3.5	4.5	4.0	3.4	4.5	4.0	3.9
Peanut	6.5	5.8	5.3	6.6	5.8	4.7	5.8	5.4	5.0
Sugarcane	16.9	14.7	12.5	14.7	12.6	10.2	16.3	13.5	10.3

Table 19 20th, 50th and 80th percentile exceedance values for required irrigation water in the Gilbert catchment soil type is Cracking clay soils for three climate locations

Climate	Georgetown			Einasleigh			Northern		
Crop	20th	50th	80th	20th	50th	80th	20th	50th	80th
Maize	4.8	3.9	2.6	5.3	4.4	3.8	3.9	3.0	2.2
Sorghum	3.9	3.0	2.6	3.6	2.6	1.7	3.5	2.7	2.6
Mungbean	2.1	0.9	0.6	1.9	1.5	1.2	0.9	0.9	0.6
Chickpea	2.6	1.8	1.7	3.7	2.6	2.2	2.2	2.1	1.7
Soybean	3.6	2.7	1.4	3.6	2.6	1.4	2.3	1.3	0.8
Cotton	4.1	3.1	2.7	4.0	3.2	2.3	4.4	3.6	2.7
Forage sorghum	5.4	4.9	4.1	5.3	4.5	3.6	5.3	4.9	4.1
Peanut	6.4	5.8	5.3	6.8	6.2	5.2	5.8	5.5	4.9
Sugarcane	16.9	14.5	11.8	14.6	12.5	9.2	16.3	12.8	10.4

Table 20 to Table 23 summarises yieldand economic data for dryland crops in the Flinders and Gilbert catchments. Breakeven yields are based on the yield that will produce a gross margin of $0.

Table 20 Sowing date, crop yield, price, variable cost, gross margin and break even yield for dryland crops in the Flinders 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 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 YIELD
		20th	50th	80th		50th	20th	50th	80th	
Cotton	15 January	3	1.3	0.4	$450/bale	$1,199	–$29	–$726	–$1095	3.1 (local gin) 5.9 (Emerald gin)
Rice	15 January	0.3	0.0	0.0	$320/t	$1,110	– $1,031	– $1,110	–$1,110	4.2
Maize	15 January	4.5	2.1	0.8	$280/t	$1,099	$26	–$511	–$801	4.4
Wheat	15 April	2.2	1.5	0.9	$310/t	$779	–$97	–$314	–$500	2.5
Sorghum	15 January	3.7	1.0	0	$230/t	$978	–$131	–$745	–$978	4.3
Mung-bean	15 February	0.9	0.6	0.4	$1,000/t	$450	$404	$150	–$20	0.4
Soybean	15 January	1.0	0.4	0.2	$500/t	$694	–$227	–$494	–$583	1.5
Chickpea	15 April	1.3	0.9	0.4	$500/t	$617	$11	–$167	–$390	1.3
Lablab	15 February	6.5	4.8	3.7	$160/t	$285	$755	$483	$307	1.8
Sugarcane	15 May	26	13	4	$409/t sugar	$1,041	–$161	–$470	–$700	32

Table 21 Sowing date, crop yield, price, variable cost, gross margin and break even 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 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

Table 22 Sowing date, applied irrigation water, crop yield, irrigation type, price, variable cost and gross margin for irrigated crops in the Flinders 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 yield and water use values. Gross margins for the 20th, 50th and 80th percentile are calculated using 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 process crops (cotton, sugarcane) assume delivery to a (currently non-existent) processing plant

CROP	SOWING DATE	APPLIED IRRIGATION WATER (ML/ha)			CROP YIELD (t/ha)*			IRRIGATION TYPE	PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)			BREAK EVEN YIELD
		20th	**50th**	**80th**	**20th**	**50th**	**80th**			**50th**	**20th**	**50th**	**80th**	
Bambatsi	Perennial	14.1	12.7	10.7	14.4	12.7	11.7	S	$150/t	$1332	$827	$566	$428	8.9
Chickpea	1 May	4.4	3.5	2.6	3.0	2.7	2.5	S	$500/t	$953	$530	$397	$308	1.8
Cotton	1 January	5.3**	3.9**	2.6**	10.6 bale	8.7 bale	5.7 bale	F	$450/bale	$1341	$3193	$2387	$1116	3.2 bales (local gin) 6.1 (Emerald gin)
Guar			1.9			2.0			$625/t	$423				
Lablab	1 March	6.3	5.8	4.8	13.4	12.7	12.0	S	$160/t	$678	$1466	$1354	$1242	4.2
Maize	15 March	6.3	4.8	2.7	12.5	11.3	10.1	S	$280/t	$1943	$1489	$1221	$952	5.8
Mango									$2.71/kg	$23,201				
Melon									$0.93/kg	$34,080				
Mungbean	15 March	2.6	2.1	1.7	1.9	1.8	1.6	S	$1000/t	$776	$1108	$1024	$854	0.6
Rice	15 January	6.2	5.6	4.4	10.3	9.6	9.0	F	$320/t	$1704	$1554	$1368	$1209	4.4
Sorghum (forage)	15 August	6.2	5.8	4.5	17.7	16.5	15.2	S						
Sorghum (grain)	15 March	5.3	3.9	2.6	8.3	7.7	5.4	S	$230/t	$1255	$652	$516	($8)	5.4

CROP	SOWING DATE	APPLIED IRRIGATION WATER (ML/ha)			CROP YIELD (t/ha)*			IRRIGATION TYPE	PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)			BREAK EVEN YIELD
Soybean	1 January	6.2	5.2	3.8	3.3	3.0	2.7	S	$500/t	$1189	$444	$311	$177	2.3
Sugarcane	15 May	19	17	14	161	139	119	F	$409/t sugar	$2069	$3183	$2663	$2148	32
Wheat	15 June	5.0	3.2	2.2	5.3	4.8	4.2	S	$310/t	$995	$648	$493	$307	3.2

* 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 and the model outputs are likely to be underestimated. For this reason, the applied irrigation water values for cotton have been based on similar summer-grown crops (sorghum (grain)).

Table 23 Sowing date, applied irrigation water, crop yield, irrigation type, price, variable cost, gross margin and break even 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. Variable costs reflect those for the 50th percentile yield and water use values. Gross margins for the 20th, 50th and 80th percentile are calculated using 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 process crops (cotton, sugarcane) assume delivery to a (currently non-existent) processing plant.

CROP	SOWING DATE	APPLIED IRRIGATION WATER (ML/ha)			CROP YIELD (t/ha)			IRRIGATION TYPE	PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)			BREAK EVEN YIELD
		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	$1317	$2791	$2321	$2108	3.2 (local gin) 7.3 (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	$1400	$1132	$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	$3195	$1076	$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	$1927	$3033	$2415	$2043	30

CROP	SOWING DATE	APPLIED IRRIGATION WATER (ML/ha)	CROP YIELD (t/ha)	IRRIGATION TYPE	PRICE ($/unit)	VARIABLE COST ($/ha)	GROSS MARGIN ($/ha)	BREAK EVEN YIELD
Sweet corn				M	$0.6/kg	$12,845	$10,805	
Rice								4.2

6 Summary remarks

This report details crop modelling using APSIM undertaken as part of the Assessment. APSIM modelling has provided highly accurate estimates of crop and pasture yield potential for a wide range of environments around the world. It is, however, 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. The modelling assumes optimum agronomic management and there is no impact of pests, diseases or any abiotic stress.

A wide range of crops could be grown in the Flinders and Gilbert catchments. However, some crops will perform better than others, and a number of crops that are marginally suitable may not produce a marketable yield. Because there is limited cropping experience in the Flinders and Gilbert catchments, and indeed in northern Australia, crop agronomic management cannot follow an established 'recipe'. It is very important to recognise that 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. Management must account for multiple decisions including nutrition, watering, sowing time, plant population, rotations, pests, diseases, weeds, climate stresses such as wind and flooding, supply chain issues all the while working on the underlying assumption that a profit will be made. Management skill grows with experience and, until it reaches a high level, the challenges associated with the relative lack of cropping experience in the Flinders and Gilbert catchments 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.

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Appendix A

Sorghum

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 Assessment area is marginal (class 4) or unsuitable (class 5) for cereal cropping. These limitations are caused by rockiness, potential erosion (slope) and soil moisture storage capacity (due to shallow and/or lightly textured soils). More land is suitable to spray irrigation than furrow primarily due to the lightly textured soils being unsuitable to furrow irrigation. The Flinders and 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 (Flinders median)	3.9 ML/ha (March sowing)
Applied irrigation water (Gilbert median)	3.5 ML/ha (March sowing)
Crop yield (Flinders median)	Dryland: 1.0 t/ha (January sowing). Break-even yield 4.3 t/ha Irrigated: 7.7 t/ha (March sowing). Break-even yield 5.4 t/ha
Crop yield (Gilbert median)	Dryland: 3.8 t/ha (March sowing). Break even yield 4.9 t/ha Irrigated: 8.0 t/ha (March sowing). Break even 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 $150-300 /t
Opportunities and risks under a changing climate	More tolerant of drought and temperature stress than maize
Further reading	DAFF (2011a)

Photo: CSIRO

Mungbean

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	Part of the Flinders catchment is marginal (class 4) or unsuitable (class 5) for pulse cropping. Limitations in these areas are caused by rockiness, and low soil moisture storage capacity (due to shallow and/or lightly textured soils). About the same amount of land is suitable to spray and furrow irrigation primarily due to the heavier textured soils being suitable to furrow irrigation. A small area of the Flinders delta is seasonally wet and/or poorly drained and generally unsuited for cereal production. 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 moisture 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 (Flinders median)	2.1 ML/ha (March sowing)
Applied irrigation water (Gilbert median)	1.2 ML/ha (March sowing)
Crop yield (Flinders median)	Dryland: 0.6 t/ha (January sowing). Break-even yield 0.4 t/ha Irrigated: 1.8 t/ha (March sowing). Break-even yield 0.6 t/ha
Crop yield (Gilbert median)	Dryland: 0.7 t/ha (March sowing). Break even yield 0.4 t/ha Irrigated: 1.3 t/ha (March sowing). Break even 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

PARAMETER	DESCRIPTION
	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)

Photo: CSIRO

Bambatsi

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 level s 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	Part of the Flinders catchment is marginal (class 4) or unsuitable (class 5) for hay cropping. Limitations in these areas are caused by rockiness, and low soil moisture storage capacity (due to shallow and/or lightly textured soils). About the same amount of land is suitable to spray and furrow irrigation primarily due to the heavier textured soils being suitable to furrow irrigation. A small area of the Flinders delta is seasonally wet and/or poorly drained and generally unsuited for bambatsi production. 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 moisture 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 moisture 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 (Flinders median)	12.7 ML/ha (March sowing)
Applied irrigation water (Gilbert median)	11.8 ML/ha (March sowing)
Crop yield (Flinders median)	Irrigated: 12.7 t/ha (March sowing). Break-even yield 8.9 t/ha
Crop yield (Gilbert median)	Irrigated: 12.6 t/ha (March sowing). Break even 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

PARAMETER	DESCRIPTION
Opportunities and risks under a changing climate	Drought tolerant, with some tolerance of moderate soil salinity (when established)
Further reading	DAFF (2013a)


Photo: CSIRO

Lablab

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	Part of the Flinders catchment is marginal (class 4) or unsuitable (class 5) for forage legume cropping. Limitations in these areas are caused by rockiness, and low soil moisture storage capacity (due to shallow and/or lightly textured soils). About the same amount of land is suitable to spray and furrow irrigation primarily due to the heavier textured soils being suitable to furrow irrigation. A small area of the Flinders delta is seasonally wet and/or poorly drained and generally unsuited for cereal production. 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 moisture 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 moisture 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 (Flinders median)	5.8 ML/ha (March sowing)
Applied irrigation water (Gilbert median)	4.5 ML/ha (March sowing)
Crop yield (Flinders median)	Dryland: 4.8 t/ha (January sowing) Irrigated: 12.7 t/ha (March sowing). Break-even yield 4.2 t/ha
Crop yield (Gilbert median)	Dryland: 6.2 t/ha (March sowing). Break even yield 1.8 t/ha Irrigated: 9.1 t/ha (March sowing). Break even 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

PARAMETER	DESCRIPTION
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)

Photo: CSIRO

Cotton

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 moisture 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	Part of the Flinders catchment is marginal (class 4) or unsuitable (class 5) for cotton cropping. Limitations in these areas are caused by rockiness, and low soil moisture storage capacity (due to shallow and/or lightly textured soils). About the same amount of land is suitable to spray and furrow irrigation primarily due to the heavier textured soils being suitable to furrow irrigation. A small area of the Flinders delta is seasonally wet and/or poorly drained and generally unsuited for cereal production. 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 moisture 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 moisture 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 (Flinders median)	2.9 ML/ha (January sowing)
Applied irrigation water (Gilbert median)	3.2 ML/ha (January sowing)
Crop yield (Flinders median)	Dryland: 1.3 bales/ha (January sowing). Break-even yield 3.1 bales/ha (local gin), 5.9 bales/ha for Emerald gin Irrigated: 8.7 bales/ha (January sowing). Break-even yield 3.2 bales/ha (local gin), 6.1 bales/ha for Emerald gin
Crop yield (Gilbert median)	Dryland: 1.8 bales/ha (January sowing). Break even yield 3.1 bales/ha (local gin);7.3 bales/ha for Emerald gin Irrigated: 8.5 bales/ha (January sowing). Break even 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

PARAMETER	DESCRIPTION
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.
Prices	Currently approx. $450/bale
Opportunities and risks under a changing climate	Seasonal climate variability, water availability for irrigation
Further reading	DAFF (2012a)

Photo: CSIRO

Sugarcane

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 grow 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	Part of the Flinders catchment is marginal (class 4) or unsuitable (class 5) for sugarcane cropping. Limitations in these areas are caused by rockiness, and low soil moisture storage capacity (due to shallow and/or lightly textured soils). About the same amount of land is suitable to spray and furrow irrigation primarily due to the heavier textured soils being suitable to furrow irrigation. A small area of the Flinders delta is seasonally wet and/or poorly drained and generally unsuited for cereal production. 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 moisture 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 moisture 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 moisture storage capacity and potential for erosion largely driven by slope.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (Flinders median)	17 ML/ha (May sowing, September harvest)
Applied irrigation water (Gilbert median)	12 ML/ha (May sowing, September harvest)
Crop yield (Flinders median)	Dryland: 32 t/ha (May planting, September harvest). Break-even yield 32 t/ha, assuming local processing. Note that break-even yield does not occur with sufficient frequency to make local processing of dryland sugarcane viable. Irrigated: 139 t/ha (May planting, September harvest). Break-even yield 32 t/ha, assuming local processing
Crop yield (Gilbert median)	Dryland: 31 t/ha. Break even yield 26 t/ha. Note that break even 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 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.

PARAMETER	DESCRIPTION
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
Opportunities and risks under a changing climate	Reduced water availability in a drier climate will reduce yields.
Further reading	Canegrowers (2013), DAFF (2012b)


Photo: CSIRO

Sweet corn

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 moisture 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 Assessment area unsuitable for trickle irrigation due to the slope, rockiness, shallow soils and low soil moisture storage capacity. A small area of the Flinders delta is seasonally wet and/or poorly drained and generally unsuited for cereal production.
Irrigation system requirements	Micro
Applied irrigation water (Flinders median)	4.0 ML/ha, based on maize
Applied irrigation water (Gilbert median)	3.8 ML/ha, based on maize
Crop yield (median)	Irrigated: 8.5 t/ha (fresh weight) based on DPI Agrilink
Salinity tolerance	Moderately sensitive – EC_e threshold for yield decline 1.7 dS/m
Downstream processing	Requires local processing soon after harvest. Rapid transport and cooling of fresh market crops is important to maintain quality. 80% of sweet corn goes to the processing sector rather than the fresh food market.
By-products	Stubble can be grazed by livestock.
Production risks	Late sowings risk high temperature stress during flowering. Sweet corn is very prone to pest damage. Complete crop losses do occur.
Rotations	The plant grows quickly and is considered a valuable rotation crop, 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.

PARAMETER	DESCRIPTION
Further reading	NSW Department of Primary Industries (2007), DAFF (2013b)

Photo: CSIRO

Peanut

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 moisture 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 moisture management as root crops have shallower rooting depths than other crop groups.
Irrigation system requirements	Spray, surface, micro
Applied irrigation water (Gilbert median)	4.9 ML (March sowing)
Crop yield (Gilbert median)	Dryland: 1.2 t/ha (March sowing). Break even yield 3.0 t/ha Irrigated: 4.8 t/ha (March sowing). Break even 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 moisture 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)


Photo: CSIRO

Indian Sandalwood

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 moisture storage capacity for optimum production. Soils with loamy textures have better soil moisture 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. Cracking clay soils need to be carefully managed with irrigation to prevent root shear.
Irrigation system requirements	Surface
Irrigation demand	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
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 moisture at any time of year. Planting several species of sandalwood and host plants together makes the plantation more resilient to climate change. Sandalwood trees are not fire tolerant.
Further reading	Forest Products Commission Western Australia (2008), Clarke (2006)

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Mango

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 extends 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 moisture storage capacity. The marginal (class 4) and unsuitable (class 5) areas largely have shallow or rocky soils. The Flinders and 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)


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