Financial and socio-economic viability of irrigated agricultural development in the Victoria catchment, Northern Territory

A technical report from the CSIRO Victoria River Water Resource Assessment for the National Water Grid

Anthony Webster[1], Diane Jarvis[2], Shokhrukh Jalilov[1], Seonaid Philip[1],Yvette Oliver[1], Ian Watson[1], Tiemen Rhebergen[1], Caroline Bruce[1], Di Prestwidge[1], Stephen McFallan[1], Matt Curnock[1], Chris Stokes[1]

[1]CSIRO, [2]James Cook University

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Important disclaimer

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Aspects of the Assessment have been undertaken in conjunction with the NT Government.

The Assessment was guided by two committees:

i. The Assessment's Governance Committee: CRC for Northern Australia/James Cook University; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Agriculture and Fisheries; Queensland Department of Regional Development, Manufacturing and Water

ii. The Assessment's joint Roper and Victoria River catchments Steering Committee: Amateur Fishermen's Association of the NT; Austrade; Centrefarm; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Cattlemen's Association; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; NT Farmers; NT Seafood Council; Office of Northern Australia; Parks Australia; Regional Development Australia; Roper Gulf Regional Council Shire; Watertrust

Responsibility for the Assessment's content lies with CSIRO. The Assessment's committees did not have an opportunity to review the Assessment results or outputs prior to their release.

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Acknowledgement of Country

CSIRO acknowledges the Traditional Owners of the lands, seas and waters, of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture and pay our respects to their Elders past and present.

Photo

Cotton under centre pivot spray irrigation in northern Australia. Source: CSIRO – Nathan Dyer

Director’s foreword

Sustainable development and regional economic prosperity are priorities for the Australian and Northern Territory (NT) governments. However, more comprehensive information on land and water resources across northern Australia is required to complement local information held by Indigenous Peoples and other landholders.

Knowledge of the scale, nature, location and distribution of likely environmental, social, cultural and economic opportunities and the risks of any proposed developments is critical to sustainable development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpin the resource security required to unlock investment, while at the same time protecting the environment and cultural values.

In 2021, the Australian Government commissioned CSIRO to complete the Victoria River Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to generate data and provide insight to support consideration of the use of land and water resources in the Victoria catchment. The Assessment focuses mainly on the potential for agricultural development, and the opportunities and constraints that development could experience. It also considers climate change impacts and a range of future development pathways without being prescriptive of what they might be. The detailed information provided on land and water resources, their potential uses and the consequences of those uses are carefully designed to be relevant to a wide range of regional-scale planning considerations by Indigenous Peoples, landholders, citizens, investors, local government, and the Australian and NT governments. By fostering shared understanding of the opportunities and the risks among this wide array of stakeholders and decision makers, better informed conversations about future options will be possible.

Importantly, the Assessment does not recommend one development over another, nor assume any particular development pathway, nor even assume that water resource development will occur. It provides a range of possibilities and the information required to interpret them (including risks that may attend any opportunities), consistent with regional values and aspirations.

All data and reports produced by the Assessment will be publicly available.

Chris Chilcott

Project Director

The Victoria River Water Resource Assessment Team

Project Director	Chris Chilcott
Project Leaders	Cuan Petheram, Ian Watson
Project Support	Caroline Bruce, Seonaid Philip
Communications	Emily Brown, Chanel Koeleman, Jo Ashley, Nathan Dyer

Activities

Agriculture and socio-economics	Tony Webster, Caroline Bruce, Kaylene Camuti[1], Matt Curnock, Jenny Hayward, Simon Irvin, Shokhrukh Jalilov, Diane Jarvis[1], Adam Liedloff, Stephen McFallan, Yvette Oliver, Di Prestwidge[2], Tiemen Rhebergen, Robert Speed[3], Chris Stokes, Thomas Vanderbyl[3], John Virtue[4]
Climate	David McJannet, Lynn Seo
Ecology	Danial Stratford, Rik Buckworth, Pascal Castellazzi, Bayley Costin, Roy Aijun Deng, Ruan Gannon, Steve Gao, Sophie Gilbey, Rob Kenyon, Shelly Lachish, Simon Linke, Heather McGinness, Linda Merrin, Katie Motson[5], Rocio Ponce Reyes, Nathan Waltham[5]
Groundwater hydrology	Andrew R. Taylor, Karen Barry, Russell Crosbie, Geoff Hodgson, Anthony Knapton[6], Shane Mule, Jodie Pritchard, Steven Tickell[7], Axel Suckow
Indigenous water values, rights, interests and development goals	Marcus Barber/Kirsty Wissing, Peta Braedon, Kristina Fisher, Petina Pert
Land suitability	Ian Watson, Jenet Austin, Bart Edmeades[7], Linda Gregory, Jason Hill[7], Seonaid Philip, Ross Searle, Uta Stockmann, Mark Thomas, Francis Wait[7], Peter L. Wilson, Peter R. Wilson, Peter Zund
Surface water hydrology	Justin Hughes, Matt Gibbs, Fazlul Karim, Steve Marvanek, Catherine Ticehurst, Biao Wang
Surface water storage	Cuan Petheram, Giulio Altamura[8], Fred Baynes[9], Kev Devlin[4], Nick Hombsch[8], Peter Hyde[8], Lee Rogers, Ang Yang

Note: Assessment team as at September, 2024. All contributors are affiliated with CSIRO unless indicated otherwise. Activity Leaders are underlined. For the Indigenous water values, rights, interests and development goals activity, Marcus Barber was Activity Leader for the project duration except August 2022 – July 2023 when Kirsty Wissing (a CSIRO employee at the time) undertook this role.

[1]James Cook University; [2]DBP Consulting; [3]Badu Advisory Pty Ltd; [4]Independent contractor; [5]Centre for Tropical Water and Aquatic Ecosystem Research. James Cook University; [6]CloudGMS; [7]NT Department of Environment, Parks and Water Security; [8]Rider Levett Bucknall; [9]Baynes Geologic

Shortened forms

SHORT FORM	FULL FORM
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
AE	adult equivalent
ALR Act	*Aboriginal Land Rights (Northern Territory) Act 1976* (Cth)
ANCOLD	Australian National Committee on Large Dams
APSIM	Agricultural Production Systems sIMulator
AWC	available water capacity
CBA	cost–benefit analysis
CBD	central business district
BCR	benefit–cost ratio (present value of benefits/present value of costs for a project)
CCS	commercial cane sugar (percentage of extractable raw sugar in harvested cane)
CGE	computable general equilibrium (model)
CLEM	Crop Livestock Enterprise Model
CO2CRC	a Cooperative Research Centre (CRC) investigating carbon capture and storage technologies
CPI	consumer price index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCF	discounted cashflow
DIDO	drive-in drive-out (applied to type of workforce)
DKIS	Darwin–Katherine Interconnected System (electricity distribution)
DOI	digital object identifier
DS	dry season
EBITDA	earnings before interest, taxes, depreciation and amortisation
EIS	environmental impact statement
EPRI	Electric Power Research Institute
FIFO	fly-in fly-out (applied to type of workforce)
FTE	full-time equivalent
FWPA	Forest and Wood Products Australia
GCM	global climate model
GCM-PS	global climate model - pattern scaled
GDP	gross domestic product
GFA	gross floor area
GM	gross margin
GSP	gross state product

SHORT FORM	FULL FORM
GVAP	gross value of agricultural production (an ABARES statistic)
GVIAP	gross value of irrigated agricultural production (an ABARES statistic)
HSD	Health Service District
HV	high voltage (electricity transmission lines)
ILUA	Indigenous land use agreement
I–O	input–output
IRR	internal rate of return
KP	Kensington Pride (mango variety)
LCOE	least cost of energy
NABSA	Northern Australia Beef Systems Analyser
NPF	Northern Prawn Fishery
NPV	net present value
NSW	New South Wales
NT	Northern Territory
O&M	operation and maintenance (type of recurring cost)
PAW	plant available water
PAWC	plant available water capacity
PCA	Peanut Company of Australia
PCR	post-completion review
PE	potential evaporation
PHN	primary health network
PVR	plant variety rights
Qld	Queensland
RH	relative humidity
SA	South Australia
SA1 to SA4	ABS Statistical Area (spatial boundary for data collection), number indicates hierarchy level SA1s are the smallest unit for general release of Census data (and are aggregated into larger units)
SEIFA	Socio-Economic Indexes for Areas (published by ABS)
SGG	soil generic group
TERN	The Enormous Regional Model
TDH	total dynamic head (1 m TDH = 9.8 kPa)
TraNSIT	Transport Network Strategic Investment Tool
USC	University of the Sunshine Coast
VPD	vapour pressure deficit
VRD	Victoria River District
WA	Western Australia
WACC	weighted average cost of capital
WS	wet season

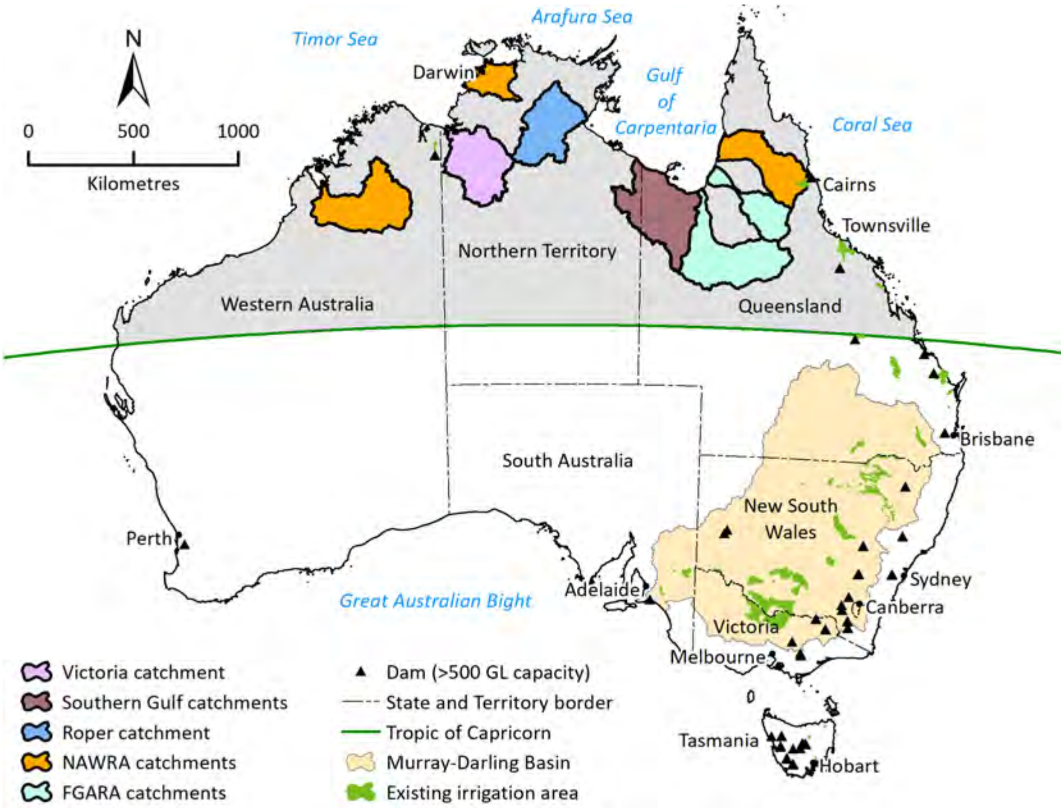
Units

UNITS	DESCRIPTION
$	Australian dollars, at constant December 2023 value
°C	degree Celsius
cm	centimetre
AE	animal equivalent (cattle)
bale	bale of processed cotton lint (227 kg)
FTE	full-time equivalent
g	gram
GL	gigalitre
GWh	gigawatt hour
ha	hectare (= 10,000 m^2)
kg	kilogram
km	kilometre
kPa	kilopascal
kV	kilovolt
kVA	1000 volt amps
kW	kilowatt
kWh	kilowatt hour
L	litre
m	metre
MJ	megajoule
ML	megalitre
mm	millimetre
MVA	megavolt amp (1 MVA = 1 MW)
MW	megawatt
MWh	megawatt hour
ppm	parts per million
t	metric tonne
y	year

Preface

Sustainable development and regional economic prosperity are priorities for the Australian and NT governments and science can play its role. Acknowledging the need for continued research, the NT Government (2023) announced a Territory Water Plan priority action to accelerate the existing water science program 'to support best practice water resource management and sustainable development.'

Governments are actively seeking to diversify regional economies, considering a range of factors. For very remote areas like the Victoria catchment (Preface Figure 1-1), the land, water and other environmental resources or assets will be key in determining how sustainable regional development might occur. Primary questions in any consideration of sustainable regional development relate to the nature and the scale of opportunities, and their risks.



Preface Figure 1-1 Map of Australia showing Assessment area (Victoria catchment and other recent CSIRO Assessments

FGARA = Flinders and Gilbert Agricultural Resource Assessment; NAWRA = Northern Australia Water Resource Assessment.

How people perceive those risks is critical, especially in the context of areas such as the Victoria catchment, where approximately 75% of the population is Indigenous (compared to 3.2% for Australia as a whole) and where many Indigenous Peoples still live on the same lands they have inhabited for tens of thousands of years. About 31% of the Victoria catchment is owned by Indigenous Peoples as inalienable freehold.

Access to reliable information about resources enables informed discussion and good decision making. Such information includes the amount and type of a resource or asset, where it is found (including in relation to complementary resources), what commercial uses it might have, how the resource changes within a year and across years, the underlying socio-economic context and the possible impacts of development.

Most of northern Australia's land and water resources have not been mapped in sufficient detail to provide the level of information required for reliable resource allocation, to mitigate investment or environmental risks, or to build policy settings that can support good judgments. The Victoria River Water Resource Assessment aims to partly address this gap by providing data to better inform decisions on private investment and government expenditure, to account for intersections between existing and potential resource users, and to ensure that net development benefits are maximised.

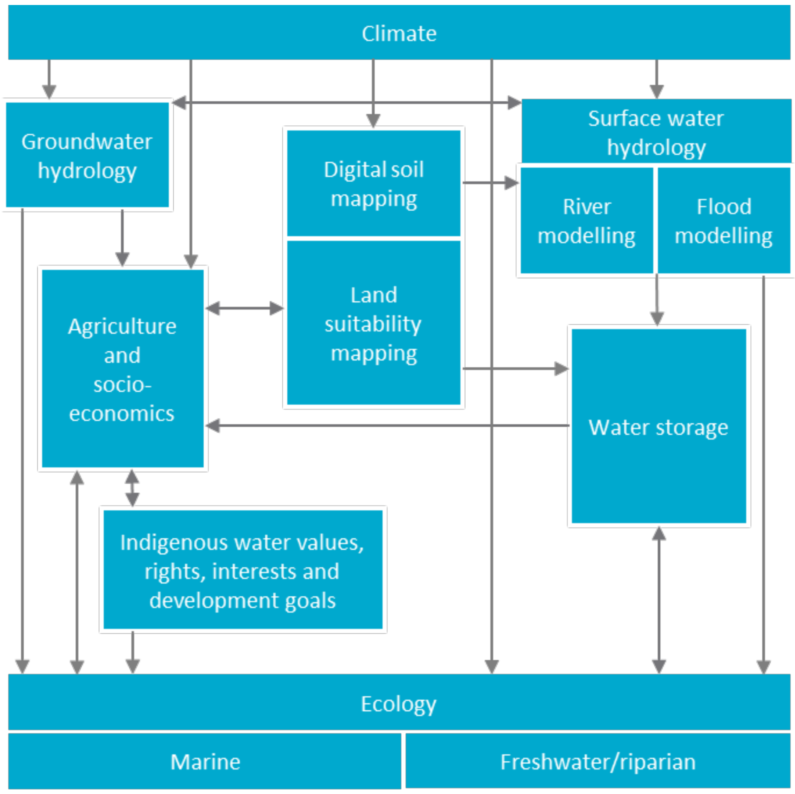
The Assessment differs somewhat from many resource assessments in that it considers a wide range of resources or assets, rather than being a single mapping exercise of, say, soils. It provides a lot of contextual information about the socio-economic profile of the catchment, and the economic possibilities and environmental impacts of development. Further, it considers many of the different resource and asset types in an integrated way, rather than separately. The Assessment has agricultural developments as its primary focus, but it also considers opportunities for and intersections between other types of water-dependent development.

The Assessment was designed to inform consideration of development, not to enable any particular development to occur. The outcome of no change in land use or water resource development is also valid. As such, the Assessment informs – but does not seek to replace – existing planning, regulatory or approval processes. Importantly, the Assessment does not assume a given policy or regulatory environment. Policy and regulations can change, so this flexibility enables the results to be applied to the widest range of uses for the longest possible time frame.

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

CSIRO has strong organisational commitments to reconciliation with Australia's Indigenous Peoples and to conducting ethical research with the free, prior and informed consent of human participants. The Assessment consulted with Indigenous representative organisations and Traditional Owner groups from the catchment to aid their understanding and potential engagement with its fieldwork requirements. The Assessment conducted significant fieldwork in the catchment, including with Traditional Owners through the activity focused on Indigenous values, rights, interests and development goals. CSIRO created new scientific knowledge about the catchment through direct fieldwork, by synthesising new material from existing information, and by remotely sensed data and numerical modelling.

Functionally, the Assessment adopted an activities-based approach (reflected in the content and structure of the outputs and products), comprising activity groups, each contributing its part to create a cohesive picture of regional development opportunities, costs and benefits, but also risks. Preface Figure 1-2 illustrates the high-level links between the activities and the general flow of information in the Assessment.



Preface Figure 1-2 Schematic of the high-level linkages between the eight activity groups and the general flow of information in the Assessment

Assessment reporting structure

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

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

- Technical reports present scientific work with sufficient detail for technical and scientific experts to reproduce the work. Each of the activities (Preface Figure 1-2) has one or more corresponding technical reports.
- A catchment report, which synthesises key material from the technical reports, providing well-informed (but not necessarily scientifically trained) users with the information required to inform decisions about the opportunities, costs and benefits, but also risks associated with irrigated agriculture and other development options.
- A summary report provides a shorter summary and narrative for a general public audience in plain English.
- A summary fact sheet provides key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable users to better access information that is not readily available in print format. All of these reports, information tools and data products are available online at https://www.csiro.au/victoriariver. The webpages give users access to a communications suite including fact sheets, multimedia content, FAQs, reports and links to related sites, particularly about other research in northern Australia.

Executive summary

The purpose of this report is to provide information on the costs, risks and benefits of new irrigated development in the catchment of the Victoria River, at farm to scheme and regional scales, and supply chains beyond. The overall conclusion is that large public dams would be marginal, but on-farm water sources, suitably sited, could provide good prospects for viable new enterprises.

Farming options for the Victoria catchment

- Amongst the range of irrigated cropping options suited to Victoria catchment environments, those that are most likely to be profitable (if development costs can be kept low enough) are annual horticulture, cotton, forages, and, in suitable locations, peanuts. Most broadacre cropping is best suited to dry-season planting (late March to August), but this requires more irrigation. Wet-season planting (December to early March) would be possible on well-drained soils, particularly for annual horticulture (targeting harvests for winter gaps in supply in southern markets). The amount of irrigation required depends on a number of factors, but as an example, cotton planted at the end of the wet season would need about 4 to 6 ML/ha while the perennial forage crop Rhodes grass would require up to 25 ML/ha each year.
- Sequential cropping systems present opportunities for generating additional net revenue from the same capital investment. Sequential cropping can reduce risk through diversifying income streams and has potential pest and disease mitigation benefits through reducing pest and disease host continuity. There are many potential cropping sequences (more than one crop per year in the same field) that show agronomic potential for matching back-to-back crop requirements with Victoria catchment growing conditions, particularly on well-draining loamy soils (Kandosols in the southern Victoria catchment) and soils with good structure, moderate to high chemical fertility and water-holding capacity (Dermosols scattered throughout the Victoria catchment), but these would need to be developed and proven locally.
- Trafficability constraints and poor drainage on some areas of finer-textured clay soils (Vertosols on flood and alluvial plains) would make scheduling crop sequences in the same year more difficult, and so would restrict the choice of crops to those with shorter growing seasons.
- The farm-scale performance of cropping systems will be determined by: (i) finding markets and supply chains that can provide a sufficient price, scale and reliability of demand; (ii) the skill of farmers in managing the operational and financial complexity of adapting crop mixes and production systems to Victoria catchment environments; (iii) the nature of water resources in terms of their costs to develop, the volume and reliability of supply, and the timing of when water is available relative to optimal planting windows and crop needs; and (iv) the nature of the soil resources in terms of their scale and distribution, proximity to water sources and supply chains, farming constraints, the crops they can support with viable yields, and costs to develop.
- There are natural synergies in growing irrigated forages and hay to integrate with existing beef enterprises in the Victoria catchment. This intensification can increase the amount of beef turned-off from the property and the amount of income, however gross margins and NPV

analysis suggest that this kind of intensification may not be viable due to the higher costs involved. Rhodes grass may be an option where development costs can be kept low and beef prices are high.

Economic considerations beyond the farm gate

- A review of recent public dams built in Australia highlighted some areas where cost–benefit analyses (CBAs) for water infrastructure projects could be improved, particularly regarding more realistic forecasting of demand for water. This report provides information for benchmarking a range of assumptions commonly used in such CBAs, including demand forecasting, that can be used to check when proposals for new dams are being unrealistically optimistic (or pessimistic).
- Financial analyses indicated that large dams in the Victoria catchment are unlikely to be viable (if governments required full cost recovery at a 7% internal rate of return (IRR) and provided no assistance). Irrigators could afford to contribute at most $20,000 to $30,000/ha towards the cost of new *off-farm* water infrastructure (before accounting for risks), whereas the more cost-effective potential large dam developments would likely cost about $125,000/ha of new irrigated farmland (e.g. capital cost of $510 million to build a dam and supporting backbone infrastructure that could irrigate about ~4,000 ha).
- *On-farm* water sources provide better prospects and, where sufficiently cheap water development opportunities can be found, these could likely support viable broadacre farms and horticulture with low development costs. Horticulture with high development costs (like fruit orchards with modern packing facilities) in the Victoria catchment would be more challenging unless farm financial performance could be boosted by finding niche opportunities for premium produce prices, or savings in production and marketing costs.
- For broadacre crops, gross margins of the order of $4000 per hectare per year (before accounting for the costs of water or risks) are required to provide a sufficient return on investment. Those crops likely to achieve such a return (under current conditions, in 2023) include Rhodes grass hay and wet-season cotton.
- Horticultural gross margins would have to be higher (of the order of $7,000 to $11,000 per hectare per year) to provide an adequate return on the higher capital costs of developing this more intensive type of farming (relative to broadacre). Profitability of horticulture is extremely sensitive to prices received, so the locational advantage of supplying ‘out-of-season’ (winter) produce to southern markets is critical to viability. Wet-season planted annual horticultural row crops would be the most likely to achieve these returns in the Victoria catchment. Horticultural investments will need to fully assess the high costs of transporting produce to market from the Victoria catchment region and the availability and cost of labour in the region.
- Farm performance can be affected by a range of risks, including water reliability, climate variability, price fluctuations, and learning to adapt farming practices to new locations. Setbacks that occur early on after an irrigation scheme is established have the largest effect on scheme viability. There is a strong incentive to start any new irrigation development with well-proven crops and technologies, and to be thoroughly prepared for the anticipatable agronomic risks of establishing new farmland. Risks that cannot be avoided need to be managed, mitigated where possible, and accounted for in determining the realistic returns that may be expected from a farm/scheme and the capital buffers that would be required.

- Any development of new irrigated agriculture and supporting infrastructure would have knock-on benefits to the regional economy beyond the direct economic growth from the new enterprises and construction. During the ongoing production phase of a new irrigation development, there could be an additional \$0.46 to \$1.82 million of indirect regional benefits for each million dollars of direct benefits from increased agricultural activity (gross farm revenue net of any payments for water), depending on the type of agricultural industry. Each net \$100 million increase in agricultural activity could create about 100 to 825 jobs, depending on the agricultural industry.

Identifying investment opportunities

As market, regulatory, infrastructure and other conditions in the Victoria catchment change from those prevailing at the time this report was written, investors/farmers would be expected to adapt and respond to opportunities and challenges accordingly. Ultimately, to establish and sustain new irrigated developments in the Victoria catchment, investors will need to identify opportunities that simultaneously solve all three of the following questions:

- Markets: Where is the investor going to sell their produce and how are they going to set up the supply chains to get their products, at low-enough cost, from the Victoria catchment to those who want to buy them?
- Production systems: What is the investor going to grow and do they understand how this needs to be grown differently in tropical Australia (and the soils, water resources and climates of Victoria catchment environments specifically) to where they have gained their previous experience?
- Competition: Why is it better to grow the chosen product(s) in tropical Australia, relative to alternative options of growing the same product elsewhere, or growing different products in the chosen location?

There is a wide variety of potential investors in northern Australia agriculture, each of whom will come with different strengths regarding the above three criteria but will also likely have blind spots where they are not initially completely aware of the full scale of the challenges involved. Successful investments have typically been able to find comprehensively planned answers to all three of these questions, while failures have not.

This Assessment (including Victoria River Water Resource Assessment companion technical reports) has focused primarily on ‘production system’ challenges by filling knowledge gaps on the land and water resources in the Victoria catchment. This report evaluated the farming options that could be sustainably and profitably developed on that resource base, and it provides additional supporting information for overcoming the competitive disadvantages and market constraints for northern Australia. Widespread expansion of agriculture in the Victoria catchment is unlikely to occur in the near term. However, smaller-scale opportunities will continue to emerge for those able to find niches for cost savings and suitable markets, and who have the capital and capacity to persist through the challenging establishment years.

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Part I Background context

Part I provides the background information and context to support the analyses in Parts II and III.

Chapter 1 summarises the main principles governing successful irrigated development in northern Australia and describes the structure of this report.

Chapter 2 describes the current social and economic characteristics of the Victoria catchment and the existing agriculture and infrastructure base, as background context for the chapters that follow, and the foundation from which any new development would build.

Part II analyses the farm-scale performance of potential irrigated agricultural development options and covers the agronomic principles that determine the types of cropping systems that could be sustainably and profitably implemented.

Part III analyses the scheme-scale viability of irrigated development options and economic considerations beyond the farm gate that would be required for those developments to succeed in the Victoria catchment.

Mango fruit

Source: CSIRO – Nathan Dyer

1 Introduction

1.1 Rationale and approach

Large infrastructure projects, such as new irrigation developments, can deliver substantial social and economic benefits to the regions in which they are built, but are complex and costly investments. The difficulty in accurately estimating costs and the chance of incurring unanticipated expenses during construction, or not achieving projected benefits when completed, mean that there are risks to the viability of developments if they are not thoroughly planned. For example, large water (and other) infrastructure projects routinely cost more and deliver less benefit than originally planned (see review in Chapter 6). In recent decades there has been growing emphasis in Australia on greater accountability and transparency in how water resources are managed and priced (e.g. Infrastructure Australia, 2021a, 2021b; NWG, 2022, 2023), and part of this shift has involved greater scrutiny of the viability of potential new water infrastructure. Similar issues arise, at smaller scale, for on-farm water sources for irrigated development.

Past work has examined the factors that contribute most to whether greenfield (mainly irrigated) agricultural developments succeed or fail; this includes lessons from historical farming experiences in northern Australia (Ash et al., 2014; Ash and Watson, 2018), analyses of potential new development options in other northern Australian catchments (Stokes et al., 2023), and a financial evaluation of the Bradfield Scheme and more cost-effective water infrastructure alternatives (Stokes and Jarvis, 2021). The broad principles emerging from that work highlight the most important determinants of success for greenfield agricultural development in locations like the catchment of the Victoria River:

- Although northern Australian environments are challenging for agriculture, the main historical factors determining the success of farming ventures have been management, planning and finances.
- By their nature, greenfield developments in new farming locations lack the strong support networks of peers for sharing experiences and learning together, which makes overcoming the initial challenges of adapting farming systems to local conditions more difficult.
- It is inevitable that greenfield farms in locations without an established history of farming will initially perform below their long-term potential and allowance needs to be made for a period of learning-by-doing. Staging developments, where possible, allows making mistakes at a small scale, where risks are contained and rectified, before expanding.
- Blind overoptimism is unhelpful; it ignores anticipatable risks that otherwise could have been mitigated or avoided (including unrealistic assumptions about productivity, sizes of markets and prices), and wastes time and resources pursuing options long after they should be abandoned.
- The rate at which water resources are developed (especially large public water infrastructure investments) needs to be scaled to realistic expansion rates for agriculture and associated trajectories of demand for new water. Building oversized infrastructure that can't be fully utilised shortly after development is very cost inefficient.

- Long supply chains and distant processing and phytosanitary (plant health) facilities often put northern agriculture at a competitive disadvantage. Economies of scale are required to support viable local processing and shortened supply chain routes, which often creates a chicken-and-egg dilemma.
- Given the competitive disadvantages of farming in northern Australia (versus established southern farming areas), there is a greater imperative for finding the most cost-effective development opportunities, that is, good soils in close proximity to good water resources, both of which can be developed at affordable expense.
- Agricultural industries that have succeeded in northern Australia have often done so by finding niche opportunities for cost savings and markets (such as out-of-season production), but these usually come at the expense of scalability, limiting the rate at which expansion can occur.
- Historically, the NT's successful agricultural industries have started with small-scale trials and grown to relatively large industries. Starting small and increasing in size has allowed producers to test markets and growing conditions, and develop supply chains without risking large upfront capital investments.

All the above themes are strongly echoed and reinforced throughout this report. The report aims to provide information that can assist in planning and evaluating the viability of investments in irrigated development, and quantifying the costs, benefits and risks involved. The intention is to provide a generic information resource that is broadly applicable to a wide range of irrigated agriculture development options, rather than being prescriptive about how future development (if any) in the Victoria catchment (Figure 1-1) should proceed, or examining specific proposals in detail.

1.2 Structure of this report

This report complements the overall assessment of potential opportunities and constraints for new irrigated agriculture in the Victoria catchment by conducting a multi-scale analysis (from farm to scheme, region and markets) that identifies the agronomic, social and economic conditions required for potential new developments to succeed. The chapters of this report are structured into three main parts as follows:

Part I provides the background information for the analyses in the later parts of the report.

Chapter 1 is this introduction.

Chapter 2 describes the current social and economic characteristics of the Victoria catchment and the existing agriculture and infrastructure base, as background context for the chapters that follow, and the foundation from which any new development would build.

Part II analyses the farm-scale performance of potential irrigated agricultural development.

Chapter 3 provides background information on tropical agronomy including the environmental factors affecting crop performance (climate, soils, land suitability and water resources), the range of potential crop options, and crop management considerations.

Chapter 4 describes the approach used for crop modelling and other quantitative analyses of a set of 19 possible crop options for the Victoria catchment and the methods used to estimate their potential performance (in terms of yields, water use and farm gross margins).

Chapter 5 presents the results of the farm-scale analyses, uses narrative risk analyses to illustrate opportunities and challenges for establishing viable new enterprises, and interprets the practical implications of the farm-scale information provided for the types of cropping systems that could be fine-tuned to Victoria catchment environments.

Part III analyses the scheme-scale viability of irrigated development options and economic considerations beyond the farm gate.

Chapter 6 reviews recent large dam projects in Australia for how well proposed benefits were realised in practice to elicit lessons for future developments and to provide context for the financial analyses that follow.

Chapter 7 provides indicators of the demand trajectories for new water (and other) infrastructure from growth in agriculture in the NT and describes the types of infrastructure that would be required to support large-scale irrigated development, together with indicative costs and options for building that infrastructure.

Chapter 8 uses a generic financial analysis approach to demonstrate the key determinants of irrigation scheme viability that investors need to balance.

Chapter 9 quantifies the regional costs and benefits of irrigated development using regional input–output (I–O) analysis. It also includes estimates of the proportions of those benefits that are likely to flow to Indigenous Australians, and an environmental I–O analysis of how increased agricultural water use would stimulate additional demand from other water users.

Part IV concludes by summarising key principles for identifying agricultural investment opportunities in the Victoria catchment.

Part V is the appendices.

Appendix A reviews aquaculture opportunities and their potential viability (mainly summarising previous work).

Appendix B presents the current mining and petroleum industry setting in the Victoria catchment, commodities' water use, critical minerals and strategic materials occurrences, and regulatory frameworks.

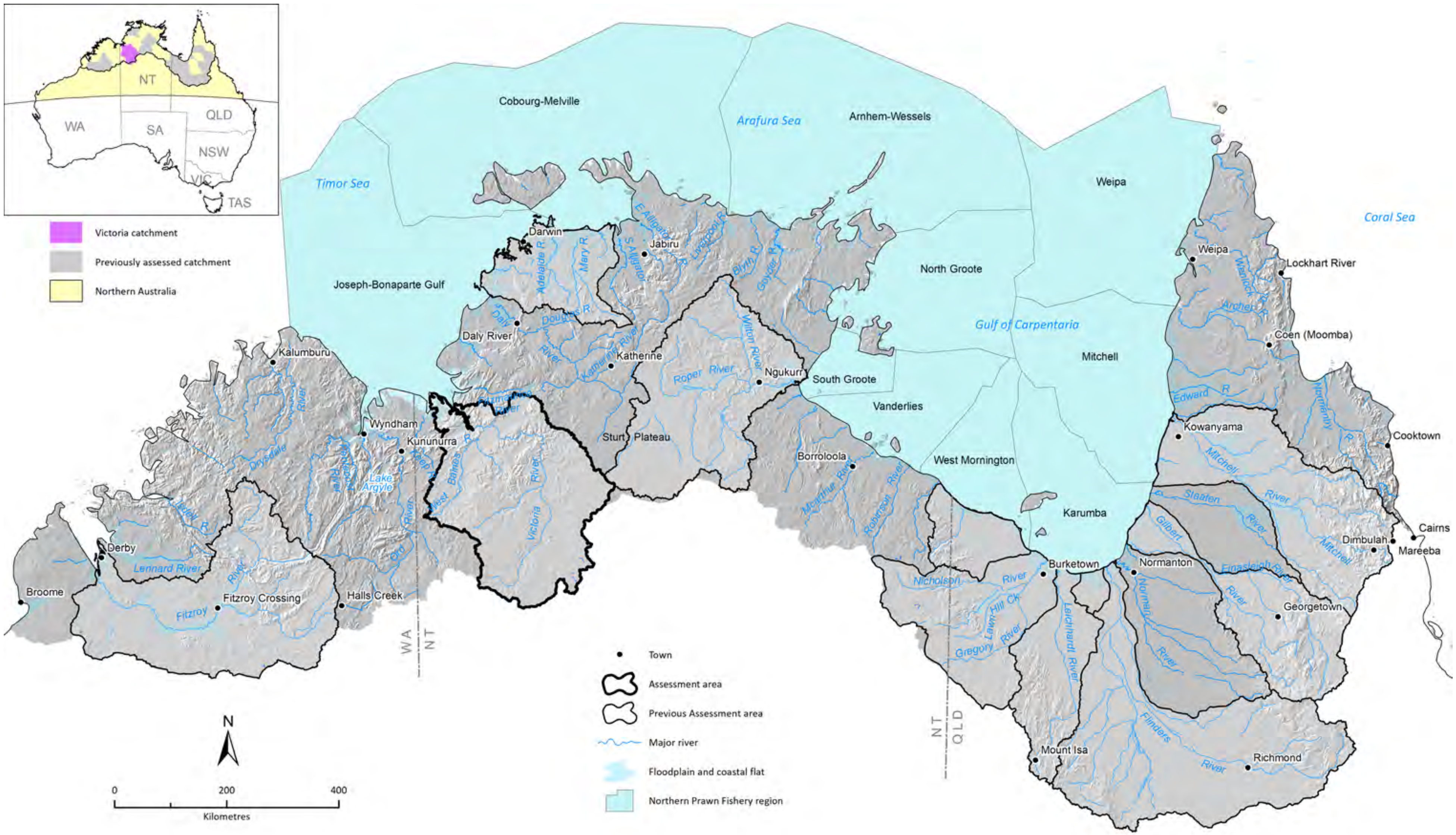


Figure 1-1 Map of the Assessment area showing the Victoria catchment and catchments from previous related assessments of land and water resources in northern Australia

2 Socio-economic context

This chapter begins with a general overview of current agricultural industries in the NT (Section 2.1) and the market opportunities and challenges involved in expanding agriculture in the NT (Section 2.2), before providing more specific details on the demography, economy and existing infrastructure in the catchment of the Victoria River (Section 2.3).

2.1 Agricultural industries of the Northern Territory

The economy of the NT has experienced significant growth over the past decade, with a gross state product (GSP) of $26.2 billion in 2020–21 that is forecast to continue growing at an average rate of 2.9% over the five years to 2025−26 (NT Economy, 2022). The agricultural sector, which accounts for over 45% of the NT's land, produced a gross commodity value of $925.7 million in 2020 (ABS, 2021c). The agricultural, forestry and fishing sector of the NT made up 3.6% of the NT's GSP as compared to 2.3% nationally, according to the NT Economy report (2022). Despite its relatively small contribution to the GSP, this industry plays a crucial role in generating economic activity and employment opportunities in regional areas. In contrast to the boom-and-bust cycles of the mining sector in the NT, long-term economic output from the agricultural sector has been a relatively stable and constant contributor to the economy.

According to Australian Bureau of Statistics (ABS, 2021c), the noteworthy economic contributions in terms of value were $605.1 million from livestock and $141.1 million from plant-based agricultural and horticultural crops (ABS, 2021c). It is worth noting, however, that the agriculture sector's production value is subject to variability due to seasonal conditions and changes in global and domestic commodity price and demand for NT commodities (NT Department of Treasury and Finance, 2022) (Figure 2-1). The ABS data is based on information collected from farms with an estimated value of agricultural output of $40,000 or more (ABS, 2023e), and therefore the actual gross value of NT agriculture may be higher, especially for cropping, due to many small farms producing horticulture in the NT. For example, horticultural production from the NT has been estimated as having a net value of $291 million per year (Sangha et al., 2022). Although the agricultural industry in the NT is diverse, its primary subsectors consist predominantly of cattle grazing and horticulture.

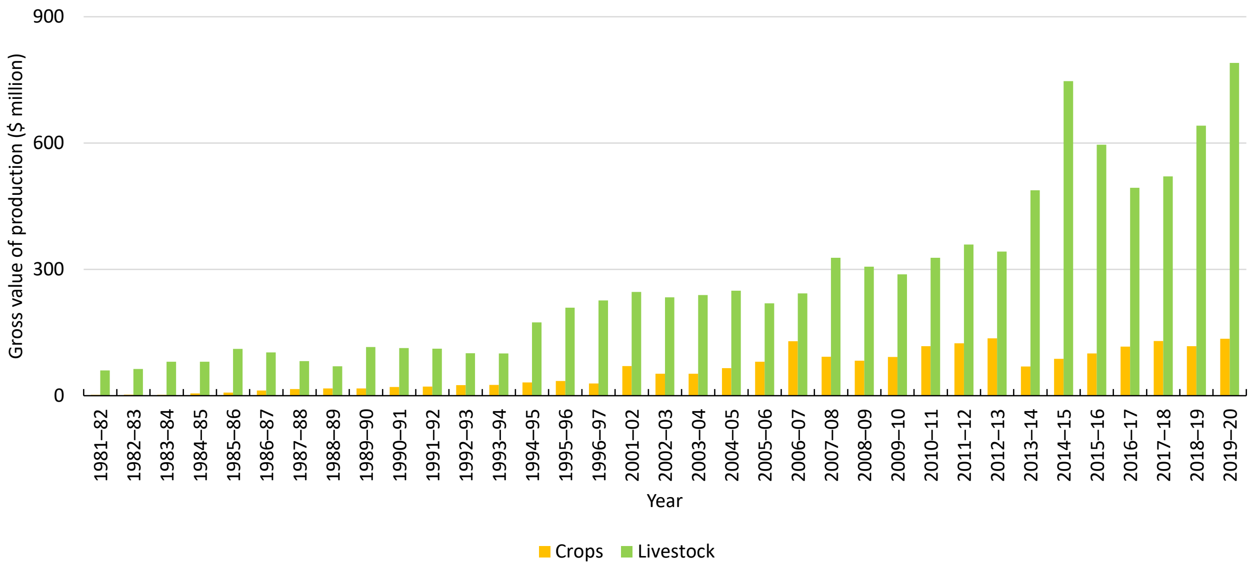


Figure 2-1 Trends in gross value of agricultural production for crops and livestock in the Northern Territory over 40 years (1981–2020)

Source: ABS (2022b)

The agriculture, forestry and fishing industry of the NT supports a significant number of jobs and contributes to economic activity in the rural and remote regions of the NT, as stated in the NT Department of Treasury and Finance report (2022). This sector accounted for 1.8% of the NT's workforce in 2020–21, compared to the national rate of 2.6%, and is linked to other sectors of the NT's economy, such as wholesale and retail sale, manufacturing, and transport.

The NT's agricultural sector is divided into four major subsectors: broadacre crops, horticultural crops, forestry and livestock (cattle grazing). Mangos (*Mangifera indica*) (accounting for half of Australia's total production), melons (Cucurbitaceae family), Asian vegetables, grapes (*Vitis* spp.), tropical fruit, ornamental plants, pastures and fodder crops are grown in the NT. Although current NT crop production is mainly focused on domestic markets (with limited export), there is a growing interest in broadacre crops for food or fibre, such as rice (*Oryza sativa*), peanuts (*Arachis hypogaea*), cotton (*Gossypium* spp.) and industrial hemp (*Cannabis sativa* ssp. *Sativa*). Additionally, forestry is the second-largest user of land in the NT after cattle grazing, with stands of acacia (*Acacia mangium*) for wood chips, African mahogany (*Khaya* spp.) for cabinet timber, and Indian sandalwood (*Santalum album*) for a range of wood and oil products (NT Government, 2022). The vast coastline of the NT offers numerous sites suitable for fishing and aquaculture, with substantial opportunities to participate directly in wild catch fisheries, aquaculture, fish processing and value-adding operations. The estimated value of fisheries production in 2020 was $124.0 million (NT Department of Industry, Tourism and Trade, 2021).

2.1.1 Broadacre crops

Broadacre cropping is a significant agricultural activity in northern Australia that has been successfully integrated with existing agribusiness enterprises to support, enhance and diversify beef production (CRCNA, 2020). Although the capacity to produce a variety of crops in the north is well-established, tropical broadacre cropping faces several barriers, costs and risks, making it a challenging enterprise for farmers in the region. Consequently, the agricultural community is exploring ways to leverage crop production as part of a more comprehensive business value proposition, which promotes the profitability and sustainability of the enterprise (CRCNA, 2020).

The viability of single broadacre crops can be marginal, and therefore, farmers often have to develop farming systems that maximise the synergies of multiple crops to establish viable new businesses. For example, an irrigated farm could cultivate various irrigated crops in rotation such as melons, hay, cotton, mungbean (*Vigna radiata*) and maize (*Zea mays*) that could be delivered to both domestic and export markets (CRCNA, 2020).

While broadacre cropping is not yet widely established in the NT, investments in crop trials and processing industries such as cotton ginning could facilitate new farming opportunities in crops such as cotton, rice, peanuts, sorghum (*Sorghum* spp.), sesame (*Sesamum indicum*) and hemp. Large-scale broadacre cropping development attempts in the NT have been more recent than those in southern Australia. While there were earlier endeavours to engage in commercial cropping in the early 1900s, organised research into crops and pastures commenced after World War II. CSIRO founded the Katherine Research Station in 1948, and in 1959, the Coastal Plains Research Station was established to the southeast of Darwin. Additionally, the NT Administration initiated other research facilities at locations such as Tortilla Flats, Berrimah in Darwin, Douglas-Daly, and the Katherine Experimental Farm (O'Gara, 1998). As of 2021–22 there were less than 5000 ha of broadacre cropping in the NT (ABS, 2022b).

Cotton

The Australian cotton industry is renowned for producing high-quality fibre cotton that offers excellent market opportunities. Cotton seed, in addition to lint, is a valuable feed supplement for cattle or can be processed into a range of products such as oil, soaps and cosmetics.

Cotton is a crop that is biophysically suited to a significant proportion of the NT. The NT Farmers Association has identified and proposed the Katherine-Daly basin as a promising region for cotton development including rainfed and irrigated cotton. Cotton needs to be processed after the farm gate, where the lint is removed from the cotton seed in a processed called ginning. For this reason, cotton produced on farms needs shipping to a cotton gin and the distance a farm is to a cotton gin will have a bearing on farm viability. Another implication of the need for ginning is that there is a critical throughput required before a cotton gin is viable. Enough cotton needs to be produced in proximity to a cotton gin for that cotton gin to viably operate. For example, a cotton gin was officially opened just north of Katherine in December 2023. It is estimated to require 55,000 bales per year initially to be financially viable. The development of a 62,000-ha cotton industry with four gins in the NT could cost an estimated $732 million to develop and could support up to 424 jobs (NT Farmers, 2019).

Rainfed cotton will usually result in reduced yields compared to irrigated cotton. This can be offset as rainfed cotton presents a more cost-effective cultivation option with lower establishment and operating costs compared to irrigated cotton. The cultivation of rainfed cotton is often practised in irrigated cotton districts and will contribute to the overall volume of cotton processed by a cotton gin. Opening of a cotton gin will be a driver for increased cotton production, both irrigated and rainfed (DITT, 2023). In the NT, as of 2024, roughly 95% of cotton under production is rainfed. It is expected that irrigated cotton will rise in popularity but rainfed production will very likely remain the dominant production system due to lower capital expenditure and operational costs.

The NT Government has proposed a series of measures aimed at boosting the cotton industry and scaling up the cropping sector (NT Department of Primary Industry and Resources, 2020), with a goal of increasing the industry's value by $700 million within a decade. The strategy includes plans to streamline approval processes for land clearing and water licences, support the construction of new cotton gins, and utilise pastoral leases for crop cultivation. The expansion of the cropping industry, particularly driven by cotton, to 100,000 ha is a key target, with hopes of growing the current $1.3 billion agribusiness sector to $2 billion by 2030. While these proposals present opportunities for economic growth and job creation, concerns have been raised by environmental groups regarding potentially unsustainable land clearing and inadequate regulatory frameworks (ABC News, 2023a; Section 2.2.4). The challenges associated with reaching the targeted cleared land area, as well as the need for responsible water management and irrigation technologies, have been acknowledged. Balancing economic development with environmental considerations and the rights of traditional landholders remains a critical aspect in the cotton industry's expansion in the NT (ABC News, 2023a; Section 2.2.4).

Peanut

The NT presents potential for peanut cultivation due to its high gross margin and suitability to the region, as reported by the NT Farmers (2019). Although peanuts require less water than many other broadacre crops (Zhang et al., 2021), optimal yields and quality require a reliable supply of water through either rain or irrigation. Generally, effective irrigation management is crucial in achieving a high-yielding and economically viable peanut crop.

In Australia, around 120 manufacturers utilise peanuts in snack food, confectionery, and peanut butter production. The market is dominated by seven processors that account for approximately 80% of the total industry share (GRDC, 2017). Domestic consumption of nut-in-shell peanuts amounts to 50,000 t, with an annual growth rate of 2% to 3% (GRDC, 2017). Nevertheless, local production can satisfy less than half of the demand, with the remainder being imported (Bega Peanut Butter, 2022).

The NT represents an attractive opportunity for peanut expansion, given the limited contribution of Australian growers to the local market and stable prices throughout the year (Dowd, 2013). However, all produce must currently be transported to Queensland for processing, as there are no shellers/processors located in the NT. This has historically been a challenging market for NT producers to access.

Over the last century, Queensland has been the primary peanut production region in Australia, focused on the Burnett region and the Atherton Tablelands. Over the past 25 years, decreasing rainfall and limited access to irrigation water in the Burnett region has posed significant challenges for an expansion of the peanut industry there (Marshall et al., 2014). The Peanut Company of Australia (PCA), a leading supplier of peanuts, initiated a transformation in response to perceived climatic risks impacting business sustainability. Starting in 2002, PCA pursued a diversification and vertical integration shift, hoping to establish a peanut industry in Katherine, NT. PCA decided to abandon this strategy, finalising property sales in February 2012 (Jakku et al., 2016). Early production data and a simulation study suggests that expanding the Australian peanut industry into Katherine offered high yield potential (Chauhan et al., 2015), however it also encountered unexpectedly elevated establishment and production expenses complicated by the uncertainties tied to the water allocation planning process (Jakku et al., 2016).

Sorghum

Rainfed grain sorghum has been the predominant broadacre crop cultivated in the NT over the last two decades due to its suitability to the local conditions and stockfeed market. The regions between Daly Waters and Darwin, particularly Douglas-Daly and Katherine, have been successful in cultivating the crop. Rainfed grain sorghum can thrive in areas with average wet-season rainfall between 700 and 1400 mm, with a yield potential of 2.5 to 3.5 t/ha. Sorghum also provides valuable grazing stubble for cattle, with recorded weight gains of up to 1 kg per head per day during the early to mid-dry season (Hausler et al., 2002).

According to the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), the value of sorghum production in Australia is projected to reach $929 million in 2022–23, with China being the dominant market for Australian sorghum, accounting for 83% of exports in 2021–22 (ABARES, 2022).

Hemp

In recent years, the regulations surrounding the cultivation of industrial hemp have been relaxed in all states of Australia, and the NT, where it became legal to grow in August 2019 with a licence. This presents an opportunity for farmers to potentially diversify their crops, given the growing momentum and interest in industrial hemp. Industrial hemp is a fast-growing, annual herbaceous plant with a deep tap root. To achieve a viable gross margin, industrial hemp production would need to be grown at scale, comparable to other broadacre crops such as sorghum, cotton and soybean (*Glycine max*). However, the plant is intolerant to wet, flooded or waterlogged soil. Adequate moisture is also necessary during active growth to obtain an economically viable yield (NT Farmers, 2019).

The NT's climate is potentially well-suited for hemp production, especially if farmers are able to harvest two crops per year. However, one of the most significant challenges facing the northern Australian hemp industry is a lack of market for products and local processing facilities. Nonetheless, there are several options available for marketing hemp, including processing, packaging, and selling products online or joining a company or cooperative that processes and markets grain and products on growers' behalf (Kumar and Telfer, 2022).

Sesame

The cultivation of sesame in northern Australia holds potential for establishing a high-value cropping industry based on recently released, non-shattering varieties (where the seed does not shatter during harvest). Initial effort in the 1990s identified the NT as having potential for a sesame industry, however factors including drought, limited irrigation and insufficient industry funding previously thwarted the industry's potential (Bennett, 2014). Recent trials conducted at six locations in northern Australia revealed promising yields ranging from 1.8 to 2.6 t/ha, exceeding the global average of 0.6 t/ha (CRCNA, 2020, 2021). It is important to note these trials were small research plots and not commercial yields. There are several agronomic challenges to be addressed, including effective weed control strategies, optimisation of mechanical harvesting methods, optimum planting times and density specific to different regions, to provide necessary insights into the performance of sesame varieties and their suitability to northern Australia.

With growing global demand for sesame products, the findings from the sesame trials in northern Australia highlight the immense market opportunities for sesame cultivation in the region. The global black sesame crop market, valued at US$6.5 billion in 2018, is projected to reach US$17.77 billion by 2025, indicating a growing demand for sesame products (Trotter et al., 2020).

2.1.2 Forage

Fodder cropping, producing hay and silage for feeding to livestock, is one of the most important agricultural industries in Australia, producing feed valued at between $800 million to $2 billion each year (AFIA, 2023). Importantly, the availability and distribution of reliable quantities and quality fodder throughout the year is critical for the competitiveness of Australia's multi-billion dollar livestock industries. The Australian livestock industries contributed $17.6 billion to gross domestic product (GDP) in 2018–19, with exports valued at $16.3 billion according to Meat & Livestock Australia's *State of the industry report* (2020).

Droughts naturally drive-up domestic demand for fodder, as well as prices. Many farmers plan ahead with their own fodder production, so they can rely on fodder stored on-farm. The main constraints to fodder production in the NT are climate, weed management and nitrogen deficiency in the soils but they also experience similar issues to any other cropping enterprise such as low rainfall, insects, fire and costs of plant and equipment.

The NT fodder industry plays an important role in supporting the pastoral industry and provides feed for live export. The main fodder products are hay and silage. Most of the hay is used for either feeding cattle destined for live export or as part of a feed pellet used on boats carrying live export cattle. In recent years the live export industry has diversified its feed to include sorghum, rice, maize, peanuts and pulses.

Pelleting of fodder has increased prominence for its handling efficiency and waste reduction attributes. Within the NT, two pellet manufacturing facilities produce approximately 35,000 t of feed pellets using NT-grown hay. Pelleted feed is primarily for use on live cattle vessels (NT Farmers, 2015). There is a market in the NT for superior-quality hay, although it may displace the current production of lower-quality rainfed hay. Rainfed hay production generally has inferior energy, protein and digestibility analysis compared to irrigated hay. Pellets for the live export trade require approximately 10% protein, 9 to 10 MJ/kg energy, and 60% digestibility.

The collective demand for feed pellets in the live cattle trade market spanning from Townsville to Broome is estimated to be approximately 100,000 t (Source: Northern Livestock Solutions). A significant portion of this market, approximately 60,000 t, is currently supplied by pellet producers located in southern Australia. They have the advantage of accessing higher quality hay and shipping it to northern live cattle ports at competitive prices in comparison to feed pellets produced in the NT. If the pellet production capacity increased in the NT, irrigated hay produced in the NT that meets pellet standards could replace pellets produced in southern Australia. To produce 100,000 t of pellets, approximately 85,000 t of high-quality hay would be required, with an average ratio of 850 kg of hay per tonne of pellet.

Hay

Hay is the most common method of fodder conservation. Most crops and pastures can be made into hay of varying quality. Hay production in the NT is primarily focused on supplying the local livestock industry. The NT's tropical climate and seasonal rainfall patterns make it challenging to produce hay year round without irrigation. However, there are examples of irrigated hay being produced throughout the year (NAAM, 2016).

Presently, the NT hay market enjoys a robust supply of rainfed hay, primarily composed of Jarra grass (*Digitaria milanjiana* 'Jarra') and Cavalcade (*Centrosema pascuorum* 'Cavalcade') legume hay blends. The NT hay market is estimated at around 80,000 t, with prices averaging approximately $180 to $200/t for grass hay and $250 to $300/t for higher quality Cavalcade hay (NAAM, 2016).

The integration of hay production into an irrigated cropping system can significantly bolster net cashflow, forming part of a cropping rotation. Irrigated fodder is cultivated during the dry season, from April to early November, in conjunction with a wet-season crop, like mungbeans, which are sown in December or January and harvested in late March (NAAM, 2016). Research conducted by the NT Department of Industry, Tourism and Trade (NT DITT) on irrigated fodder, utilising Sudan grass (*Sorghum* × *drummondii*) and forage sorghum varieties such as Jumbo, reveals the potential for hay yields of 30 t/ha, based on four cuts throughout the dry season, starting from late April with the final cut in early November.

Silage

Silage generally produces better quality feed than hay. This is due to the reduced interval when making silage between cutting and conserving the feed – the longer the time, the more the feed nutrients degrade. Early cut silage will have higher quality, but less quantity. Silage production and storage is reliant on an anaerobic environment to promote fermentation processes that preserve the feed's nutritional value. It is critical that this environment is retained during storage of silage.

Silage production is not as widespread as hay production, however, there are still some areas where silage is made. Irrigated forage crops such as sorghum, maize and millet are commonly used for silage production.

Export

For more than 25 years, the Australian export fodder industry has supplied forage to countries around the world. Key export markets include Japan, China, Korea and Taiwan (AFIA, 2023). According to the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), almost 1.2 million t of hay was exported from Australia in 2020, with exports valued at $584 million in 2019–20. This represents considerable growth in the industry since 2006–07 for example, when fodder exports were valued at $242 million.

2.1.3 Horticulture

The horticulture industry is a significant contributor to agricultural productivity in Australia. Horticulture encompasses four major subindustries, namely fruits, vegetables, nuts and nursery products such as cut flowers and turf (DAFF, 2022). Fruits account for the majority of horticultural production (38%), followed by vegetables (31%), nursery goods and ornamental crops (17%) and nuts (14%) (Hort Innovation, 2023). In the 2019–20 period, horticultural production in Australia was valued at more than $15 billion (DAFF, 2022). Much horticultural produce is a highly perishable commodity, requiring significant investments in storage and transportation. Additionally, strict phytosanitary standards are often imposed on moving fruit and vegetables, in particular interstate or for export, which limits the potential for trade and can add additional compliance costs. The majority of Australian horticultural production is sold domestically, with growth being driven by demand from local consumers. While some produce is exported, fresh exports rarely exceed 15% of Australian production.

Tropical and subtropical fruits are among the key horticultural produce grown in northern Australia, including bananas (*Musa* spp.), citrus (*Citrus* spp.), macadamias (*Macadamia integrifolia*) and mangoes. In addition, there are also plantings of other fruits, such as rambutan (*Nephelium lappaceum*), mangosteen (*Garcinia mangostana*) and durian (*Durio* spp.). Most of the production of tropical and subtropical fruits takes place in Queensland, although the NT does produce smaller volumes. As for vegetables, Australian farmers grow a wide range of produce, including asparagus (*Asparagus officinalis*), zucchini (*Cucurbita pepo*), squash (*Cucurbita* spp.), potatoes (*Solanum tuberosum*), tomatoes (*Solanum lycopersicum*), carrots (*Daucus carota*), mushrooms (e.g. *Agaricus bisporus*), onions (*Allium cepa*) and lettuce (*Lactuca sativa*). The use of greenhouses is also becoming increasingly popular in the horticulture industry, enabling year-round production of various crops.

The horticultural industry in the NT encompasses three main subindustries: fruit, vegetables, and nurseries that grow cut flowers and cultivated turf. The vast majority of horticultural production is sold to other states. In the NT, mangoes and melons are the two primary contributors in terms of both produce volume and value (Figure 2-2). In the 2019–20 season, the total value of horticultural production in the NT was made up of the following components, and shown in (Figure 2-2(b)):

- $128.8 million for mango production
- $69.4 million for melon production
- $61 million for vegetables
- $37.1 million for field crops and fodder
- $22.4 million for other fruits (including citrus, grapes and tropical fruits)
- $15 million for nursery and turf production.

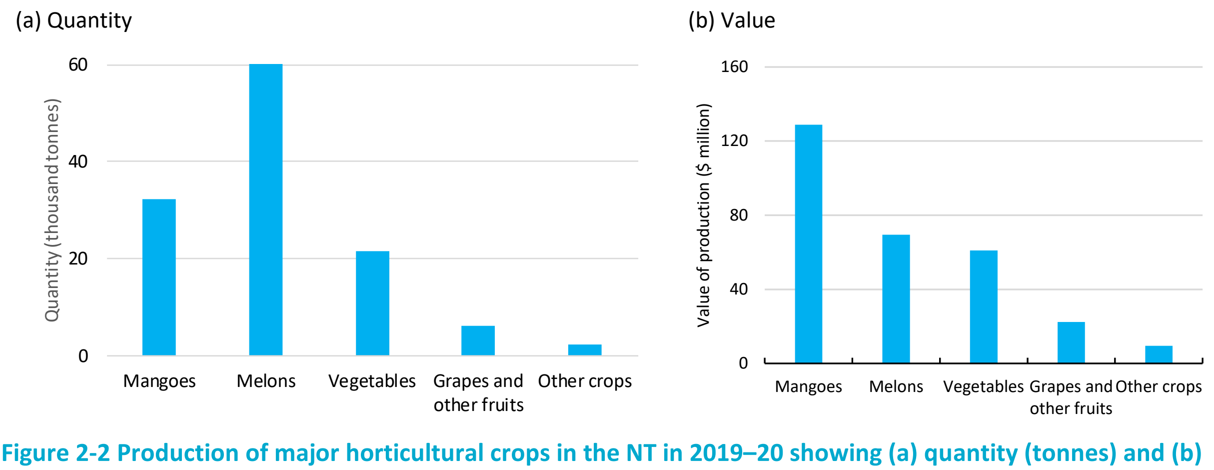


Figure 2-2 Production of major horticultural crops in the NT in 2019–20 showing (a) quantity (tonnes) and (b) economic value of production ($ million)

Source: Sangha et al. (2022)

The market price of horticultural crops is known to be highly elastic. Therefore, any significant increase in seasonal supply of horticultural crops, in comparison to the seasonal market demand, could lead to an oversupply. This, in turn, may cause a decline in the market price and farm gate return for farmers as per NT Farmers (2019).

Figure 2-3 provides a comprehensive overview of the trends in gross value of agricultural production (GVAP) for horticulture compared to other agricultural industries in Australia and the NT over the past 40 years. Horticulture has exhibited a faster increase in value than other agricultural industries during this period, and it now accounts for a larger proportion of total agricultural production in both the NT and Australia as a whole.

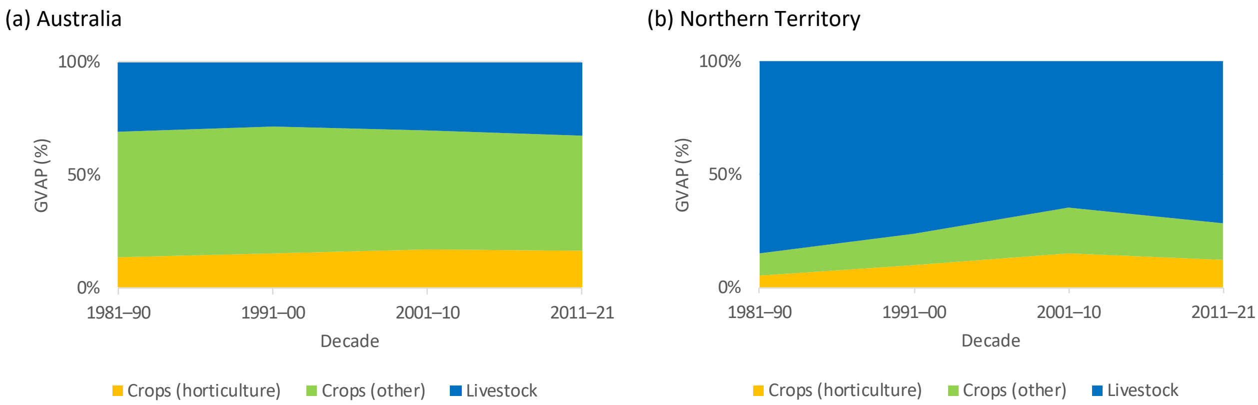


Figure 2-3 Changes in agricultural subsector relative values (GVAP) in (a) Australia and (b) the Northern Territory over 40 years (1981–2021)

Data points are decade averages of annual values.

Source: ABS (2022b)

The major horticulture production regions are situated in Victoria, New South Wales and Queensland. While the NT's contribution to national horticultural production is limited, it has tripled its share from 0.3% in 1981–90 to 1.0% in the last decade (2011–21), as shown in (Figure 2-4).

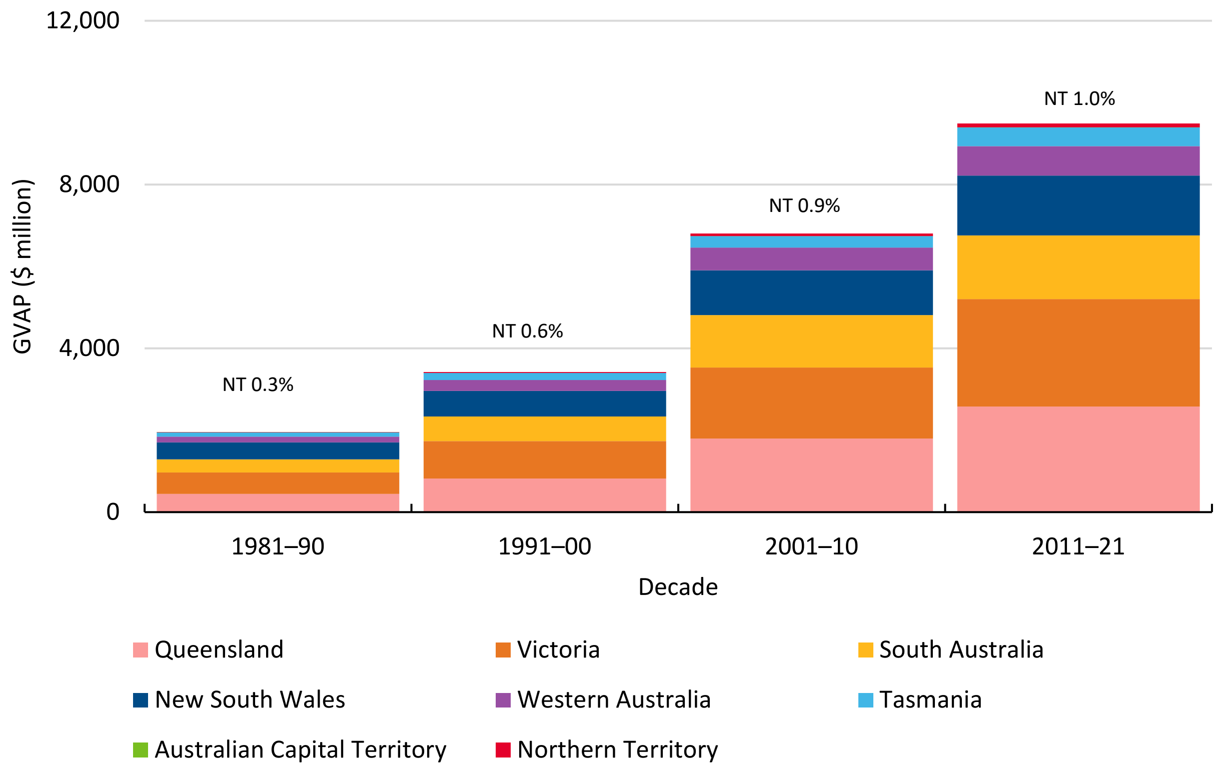


Figure 2-4 Trend in horticultural crop production across Australian states and territories over 40 years (1981–2021)

Data points are decade averages of annual values. The share of the ACT is too small to be visible in the bars above. Numbers above columns show the NT share of total Australian horticultural production. GVAP = gross value of agricultural production.

Source: ABS (2022b)

Mango

The mango industry is a significant contributor to Australia's horticultural sector, valued at over $185 million (AMIA, 2024; OrchardTech, 2023). Mangoes are grown in the northern Australian states, dominated by the NT. Significant production areas include Darwin and Katherine in the NT, Kununurra in WA and Mareeba, Bowen and Bundaberg in Queensland (OrchardTech, 2023). The value of mangoes grown in the NT amounted to $128.8 million in the 2019–20 season. The NT is a key player in the mango industry, producing over four million trays annually, representing greater than half of Australia's total mango crop (Brann, 2021). These mangoes are sold in both domestic and international markets, with north Asian markets showing strong growth potential, aided by the recent completion of a new phytosanitary treatment facility as part of a new export hub at Darwin International Airport. Opportunities for expanding the market for Australian mangoes are also being explored in South-East Asia, China and the United States.

The mango industry in Australia is supported by a proactive peak industry body, which works closely with governments to improve market access and support trade. On an annual basis, about 12% of the Australian crop, equivalent to 7000 t, is exported to key markets such as Hong Kong, New Zealand, Singapore and the United Arab Emirates (AMIA, 2024).

Mango flowering, fruiting and harvesting occur earlier in the year in the NT than in Queensland production regions, meaning NT mangoes reach the domestic market sooner and therefore receive premium prices (Clonan et al., 2020). More than half of mango-producing businesses are located in the Darwin area (Figure 2-5), highlighting the importance of this region to the NT's mango industry.

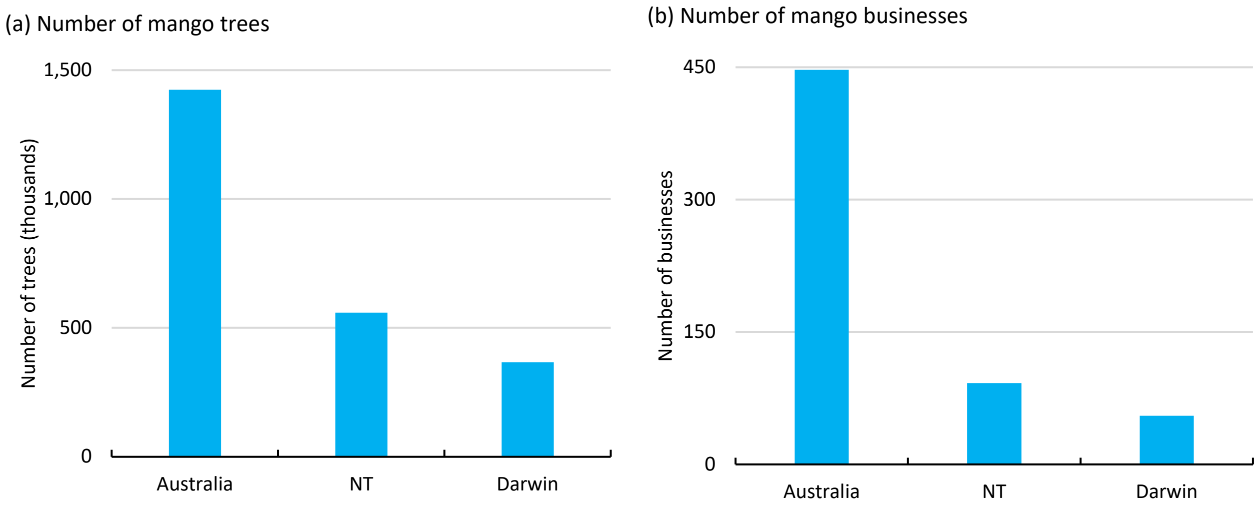


Figure 2-5 Mango production in Australia and the Northern Territory in 2019–20 expressed in terms of (a) the number of trees and (b) the number of businesses

Source: Clonan et al. (2020)

Managing the supply of fruit to market can be a challenging task, particularly when extreme or unusual conditions impact flower initiation and fruit set, which can affect the volume and timing of fruit. Furthermore, mangoes have a short shelf life and are sensitive to prolonged cold storage, which results in highly restricted storage and transport options. Additionally, transport of mangoes overseas to export markets is impacted by biosecurity and export quality demands. The management of the supply of mangoes can be particularly challenging since late harvesting in the NT overlaps with production from regions like Queensland that typically produce most of their fruit slightly later in the season (Clonan et al., 2020). This situation creates regional interactions in seasonal supply that are typical for horticultural products and are exacerbated by highly perishable produce, expensive storage, and inelastic consumer demand, leading to high volatility in the prices paid to growers. Despite these challenges, the high value of horticultural crops, particularly during seasonal windows of unmet demand, means that they can be very profitable for growers who are able to effectively manage this volatility.

Melon

The melon sector in the NT plays a vital role, with an estimated yield of around 75,000 t (NT Department of Industry, Tourism and Trade, 2024), which is approximately 23% of the Australian market (NT Farmers, 2024). The climatic conditions of the NT's dry season offer optimal settings for cultivating high-quality melons during the mild winter months. NT producers capitalise on these favourable conditions to meet the demands of key interstate markets, particularly when colder climates inhibit melon production in southern regions. Primarily focusing on seedless watermelons (*Citrullus lanatus*) alongside some varieties of rockmelon (*Cucumis melo*) and honeydew melons (*Cucumis melo*), NT farmers cultivate melons extensively throughout the Territory, including arid regions south of Tennant Creek. With a contribution of approximately $69.4 million to the local economy, the melon industry serves as a significant economic pillar and employer within the plant-based sector (NT Farmers, 2024; NT Department of Industry, Tourism and Trade, 2024).

The local melon industry encompasses farms scattered across the Big Rivers region to Central Australia. The NT Government's initiatives to support the melon sector have yielded positive outcomes, including the arrival of overseas workers ahead of the harvest season. Approximately 650 workers engage in various tasks such as picking, packing, sorting and logistics during each harvest, with additional workers now joining to bolster the skilled horticultural workforce (NT Department of Industry, Tourism and Trade, 2024).

2.1.4 Plantation forestry

The plantation forestry industry is gaining greater significance in the NT and stands as the second highest user of agricultural land by area, behind cattle grazing, with over 42,000 ha presently dedicated to producing forestry products in managed plantations. The NT currently hosts three significant plantation forestry initiatives.

- Black Wattle (*Acacia mangium*) plantations, managed by Midway Limited on behalf of the Tiwi Plantations Corporation on Melville Island, are grown for woodchip exports. A total of 23,000 t of Black Wattle woodchips were sold from the Tiwi Islands in 2020–21.
- African mahogany is being grown in the Douglas-Daly and Katherine regions by African Mahogany Australia and is the largest plantation estate of this species in the world. It is being grown for a high-value, sawn timber market, which includes veneer boards, floorboards and feature grade timber. These plantations are currently in mid-rotation, with a predicted rotation of 18 to 25 years.
- Indian sandalwood is also grown in the Douglas-Daly and Katherine regions for oil and pharmaceuticals. These plantations are currently in mid-rotation and will not realise the bulk of their value for another 3 to 4 years. In 2022, Indian sandalwood company Quintis sold its sandalwood plantations near Mataranka years before harvesting a single tree. The decision to sell was primarily driven by the underperformance of the sandalwood plantation (ABC News, 2024). In April 2024, Quintis entered into receivership with the receivers looking to either recapitalise or sell the business. The vast majority of Indian sandalwood in the NT was either owned or managed by Quintis (ABC News, 2024).
- The forestry industry in the NT serves various markets, including luxury furniture manufacturers, beauty and fragrance product makers who require oil, and timber mills for logs and woodchips in both domestic and international markets like China. The region presents promising prospects to expand the industry and current plantations, particularly in the Douglas-Daly area with its existing African mahogany plantations, and the Tiwi Islands with their advantages for eucalyptus plantation growth and expanding woodchip industry. Furthermore, potential opportunities for branded products geared toward international markets have been identified (NT Farmers, 2019). Although the plantations are fragmented, capitalising on these prospects could significantly enhance the forestry industry's worth and forest products in the NT (NT Farmers, 2019).

A research initiative, managed by Forest and Wood Products Australia (FWPA) in collaboration with the University of the Sunshine Coast (USC), is set to explore and support the growth of the native forestry harvest industry in NT's East Arnhem Land. The project, funded by industry and the Australian Government through FWPA's matching program, focuses on empowering Indigenous communities to lead the development of sustainable forest-based livelihoods. In partnership with various organisations, including Developing East Arnhem Limited and the Gumatj Corporation, the project aims to provide insights for the long-term commercial viability of Indigenous-led forestry (FWPA, 2024). The development of a forestry industry in the NT will require a potential investment into basic milling facilities and supply chains to support the industry to send timber interstate and overseas.

2.1.5 Beef cattle

Data from the 3-year period ending in 2013–14 indicates that northern Australia was home to over 8500 beef cattle producing farms. Queensland accounted for approximately 97% of these farm enterprises, with the NT and WA comprising 2% and 1%, respectively (Martin, 2015). On average, in most of northern Australia, there is a higher degree of variability in pasture quantity and reduced quality, leading to lower stocking rates and a greater prevalence of extensive production systems compared to southern Australia (Chudleigh et al., 2019).

The NT has a herd size of around 1.7 million cattle, which makes up 7% of the total Australian herd number (Meat & Livestock Australia, 2023). Extensive grazing of beef cattle, valued at $110.2 million in 2020–21 (Table 2-4), dominates agricultural production in the Victoria catchment. According to Cattle Producer NT (2014), for every $1 million the NT beef industry generated in 2012–13 it created another $510,000 within the NT economy; for every 100 jobs held in the NT beef industry another 36 are created in the NT economy alone (Cattle Producer NT, 2014).

Pastoralism is the dominant land use by area in the Victoria catchment, making up 62% of the catchment. This is after land acquisitions by the Australian Department of Defence (Bradshaw Field Training Area in 1996) and NT Government (Judbarra National Park in 1990).

The first pastoral lease assigned in the NT was in 1876, on the Katherine River. Beef cattle were first introduced to the Victoria catchment in about 1878 and by 1882, the pastoral lease Victoria River Downs had been established with an area of 41,154 km^2, with the first cattle arriving there in 1883 (Makin, 1970). *The Big Run* (Makin, 1970) documents the early history of the district, development of the cattle industry and life of pastoral settlers at Victoria River Downs Station, once the world's largest cattle properties.

The first export shipment of live cattle, from Port Darwin to Hong Kong, was in 1885 and included cattle from the Victoria catchment. The shipment turned into an expensive failure. Later attempts to export live cattle (to Singapore and to the Philippines) were also loss-making ventures and the general lack of markets in the early years became a serious impediment to profitability. Local markets were insufficient to underwrite the profitability. The stations were remote, the high cost of stocking them with supplies and equipment and finding suitable staff to work on them provided substantial constraints. Furthermore, the most common market was in Darwin and the cattle lost considerable weight in the overland journey, compounding the cost of droving them there. (Makin, 1970).

A proposal to build the NT's first meatworks in the Victoria catchment in 1901 did not come to fruition. Subsequently, meatworks were built in both Darwin and in Wyndham in WA (Makin, 1970). Both of these are now closed.

The prospect of running sheep was also considered, with the aim of wool production – which, once shorn, is less perishable than meat. One estimate was that the NT had the potential to run 30 million sheep. Indeed, sheep were brought on to Victoria River Downs in 1891 (Makin, 1970). However, within a few years, the sheep were sold on and shortly after there were no sheep in the Victoria catchment.

Many of the constraints to profitability of the early years remain today in the Victoria catchment. It is remote from the large domestic markets in southern Australia. It is better suited to breeding cattle than to fattening, or finishing, them for local slaughter. This limits the number of markets that can be targeted. The long distance to services lends itself to high input costs. Finding skilled staff is difficult. Therefore, the industry continues to seek ways in which to overcome some of these constraints through economies of scale, technical advances in sensor networks and potentially the introduction of on-farm forage and hay supply. More detail on the beef industry characteristics in the Victoria catchment can be found in Section 3.6.

Markets

The beef cattle industry in northern Australia focuses primarily on export markets and on the live cattle export trade. In contrast, production in the southern states is spread more evenly between the beef export market and the domestic beef market (Gleeson, Martin & Mifsud, 2012). Live export was the dominant direct market in the NT, accounting for 55% of turn-off in the Katherine region (Cowley, 2014). While abattoirs were the next most common market, they accounted for a smaller percentage of turn-off compared with backgrounders. Backgrounders commonly included inter-company property transfers and floodplain agistment closer to Darwin, with these cattle typically destined for live export after growing out, bringing the total indirect turn-off to live export to 83%. The most common live export destination was South-East Asia, accounting for 52% of turn-off and 98% of cattle exported. Company supply chains were less commonly used; however, they accounted for 23% of turn-off in the region. Cattle sent to NSW, SA and Victoria were destined for abattoirs.

The NT supplied a total of 444,750 head of live beef cattle to both domestic and overseas markets in 2021, as depicted in Figure 2-6.

The Philippines, Vietnam, Indonesia and Malaysia are the primary markets for live cattle exports from the NT. The present dependence on live export poses significant social licence risk in addition to the industry being susceptible to changes in laws, biosecurity protocols and trade relationships with major export nations, as noted by NT Farmers (NT Farmers, 2019).

The local broadacre and cattle sectors are undergoing a period of rapid development and potential change. The emerging cotton industry could provide the cattle sector with a high-protein feed source further supplemented by improvements in fodder production. These developments, coupled with producers' desire to diversify their markets, may support a local feedlot and boxed-meat industry. Infrastructure investments into feedlots and abattoirs would be required, however it may provide a valuable market opportunity for Top End cattle producers.

There is potential for the feedlot sector to expand into northern Australia (Beef Central, 2021). The Beef Central report highlights the opportunity to increase the national herd size and access key markets by extending feedlot operations in tropical northern Australia. There are challenges posed by the northern Australian climate and housing options suitable for northern conditions, drawing inspiration from experiences in the United States and South America, may need to be investigated prior to widespread adoption. Modifications to feedlot structures are also possible to manage heat stress in animals, including designs featuring raised ridge capping. Opportunities for feedlots include access to local feed sources that may accompany expansion of irrigation areas such as soybeans, tropical grasses and cotton seed. The conclusion drawn (Beef Central, 2021) is that expanding feedlots into northern Australia, supported by improved infrastructure and large-scale irrigation projects, could help mitigate risks and ensure consistent beef supply, thus capitalising on Australia's natural advantages as a global supplier of premium quality beef.

Outlook for Australian cattle

The Australian cattle industry has experienced a drop in prices due to herd restocking, with a 20% decrease in 2023 (AFR, 2023). Prices in 2024 have returned to be closer to where they were prior to the fall through 2023 (MLA, 2023), with more stable market conditions and a positive outlook for exports. The Australian industry has successfully rebuilt its cattle herd, aided by favourable weather conditions, leading to increased supply and a larger national cattle herd. However, the recent high prices for Australian cattle, leading up to 2023, have prompted Indonesia, a major trading partner, to seek alternative supplies, including Brazilian beef. Despite this challenge, experts predict a positive outlook for the industry, with Rabobank forecasting stable prices and strong beef producer margins (AFR, 2023). The anticipated lower United States cattle production, increased demand from Japan and South Korea, and China's economic recovery further contribute to the positive market environment.

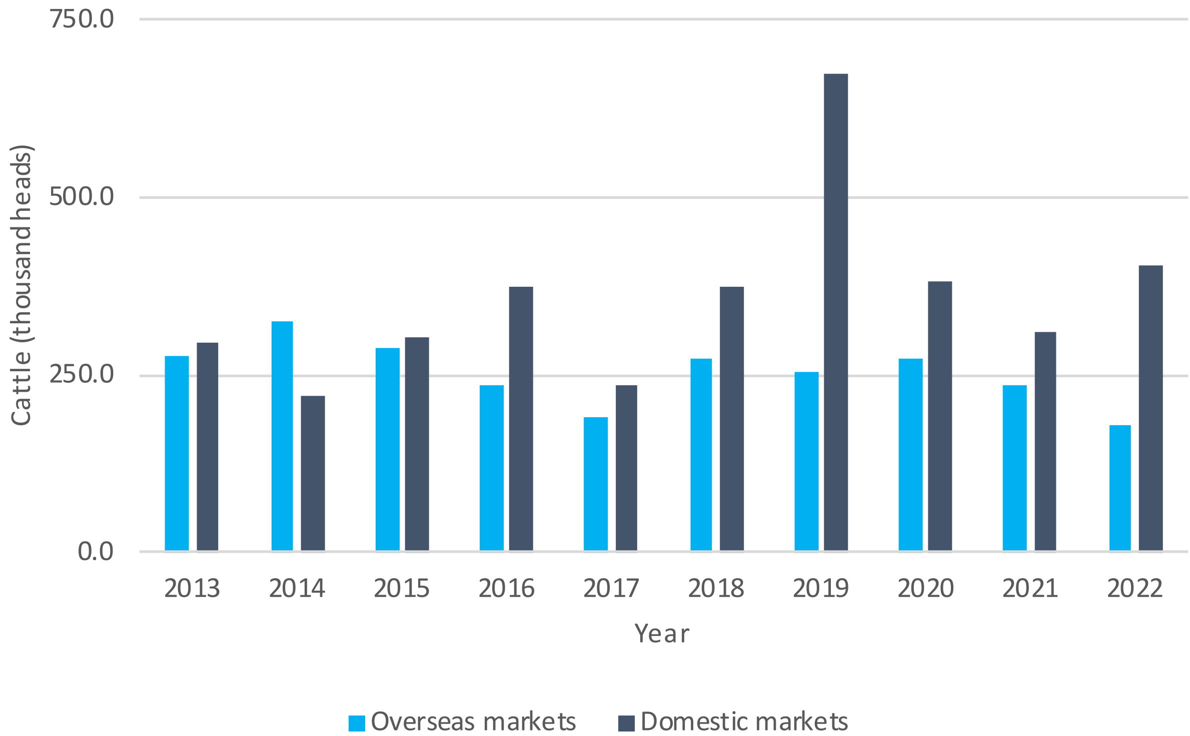


Figure 2-6 Trends in Northern Territory cattle production over the last decade (2012–2021)

Source: ABS (2022a)

There are also natural synergies of new cropping with the established beef industry. For instance, forages are well-suited as a first crop to grow in greenfield locations (they are more forgiving and have a ready local market). There are also opportunities for vertical integration of forages with beef production (both on-farm consumption and in pelleted form for live export cattle). In addition, cotton seed (separated from lint during ginning) is a good dietary supplement for cattle.

2.2 Market opportunities and challenges

2.2.1 Overview

The NT's strategic location near major export markets in Asia, well-established industrial and export infrastructure, rich natural resources, and status as Australia's northernmost jurisdiction and base for defence activities in the Indo-Pacific region, have all historically influenced the Territory's investment landscape. As a result, the mining, defence and agriculture sectors have played a significant role in the NT's economic output, as evidenced by the major projects currently in progress in those areas (NT Economy, 2022). In this section, we will provide an overview of the market outlook for increased agricultural production in the NT, along with an assessment of the potential opportunities and challenges that could arise for future economic development and investment.

2.2.2 Key advantages

The NT offers significant potential for the development of agriculture and related businesses due to its abundant land resources, suitable water and soil resources, and proximity to growing Asian markets. The region has several characteristics that make it attractive for new agricultural investments, including stable growth trends in the production of agricultural products, particularly horticulture. Additionally, the NT has stringent controls over agrichemical use and biosecurity risk management in agri-food industries to maintain a reputation of producing clean, green and safe agricultural produce.

The NT's proximity to large and growing Asian markets, combined with its ability to offer counter-seasonal production domestically, provides opportunities for higher prices and increased demand for fresh produce. The region's favourable climate presents opportunities for horticultural development given climate and land are important determinants for crop selection. The NT's ability to harvest crops earlier than southern Australia also provides a distinct market advantage within Australia and counter-seasonal opportunities for overseas markets.

2.2.3 Risks, challenges and constraints

Farm development and expansion in northern Australia often face regulatory constraints that make it difficult to secure sufficient land and water resources to not only make on-farm investments viable, but also to reach the scale of production necessary to make investments in processing and other steps in new supply chains economically feasible (CRCNA, 2020). This can include investment in facilities like cotton gins and pulse packaging facilities.

Underdeveloped pastoral areas are often difficult to convert to alternative land uses such as horticulture due to the lease conditions on pastoral leases, and a high level of investment required for developing road and other infrastructure on-farm. The process to negotiate land tenure and access to land and water resources can be complex and expensive (Sangha et al., 2022).

Increasing input costs, particularly for fertilisers, pesticides and transport, provide further challenges to the sustainability and profitability of horticultural industries (Sangha et al., 2022). There is little available information on the impacts of pesticides and fertilisers on the environment in northern Australia, outside of the catchments flowing into the Great Barrier Reef. However, offsite impacts from use of fertilisers and pesticides can impact surface water, groundwater and other environmental assets. The companion technical report on agricultural impacts on water quality (Motson et al., 2024) provides a review of available information for northern Australia.

Other key challenges for new agricultural development in the NT are discussed below.

Water

Expanding crop production in northern Australia is significantly limited by the availability of water. In the NT, groundwater is the primary source of irrigation for growers. According to Hu et al. (2022), the northern region of the NT (defined as areas with a latitude above 15°S) exhibits the greatest potential for irrigated agriculture. This is attributed to its significantly higher annual groundwater availability, in contrast to the limited groundwater availability found in the central and southern areas of the NT (Hu et al., 2022). Approximately 21,300 ha of the NT is under irrigation.

Additionally, a lack of understanding about the potential impacts of long-term surface water and groundwater extraction in the NT could further impede efforts to increase water availability for agriculture (Sangha et al., 2022). Moreover, even if new water sources become available, uncertainties about the viability and profitability of different cropping options must be considered before making use of the water (CRCNA, 2020).

Biosecurity

While the Victoria catchment is relatively isolated relative to other regions of Australia, it still has physical connections to the rest of the NT, across northern Australia more broadly, with the rest of the country and with neighbouring countries such as Indonesia. Examples of such connections are the sharing of specialist cropping machinery between agricultural regions, tourist visits into remote areas (which are increasing), international trade and tourism, mining exploration, shifting cattle between pastoral properties, army training exercises and movements between Indigenous communities. These connections can be pathways for entry of new pests, weeds or diseases. Pests, weeds and diseases can spread through human-mediated activities, such as ‘hitchhiking’ on vehicles, machinery, shipping containers and other equipment, or through natural spread, using vectors such as wind, water and animals to facilitate their spread (Stratford et al., 2024a).

In primary industries, pests, weeds and diseases cause economic losses by reducing crop yield and product quality and interfering with farm operations, and in terms of loss of market access and the costs of control measures. The national economic impact of established weeds and vertebrate pests on Australian agriculture has been estimated at over $5.3 billion/year (Hafi et al., 2023). Insect pests are also a substantial economic burden nationally (Bradshaw et al., 2021).

The environmental impacts of pests, weeds and diseases, collectively termed ‘invasive species’, include loss of native plants and animals (from competition, predation and infection), degradation of habitats and disruption of ecosystem processes (e.g. changed fire or moisture regimes). Invasive species are the greatest threat to Australia’s threatened flora and fauna (Ward et al., 2021).

Social impacts of pests, weeds and diseases include loss of public amenity and access to outdoor areas, damage to infrastructure and public safety risks. Cultural impacts include a loss of traditional foods, impaired access for hunting and damage to cultural sites.

Current pest, weed and disease threats to the Victoria catchment are fully explored in the companion catchment Report for the Victoria River (Stratford et al., 2024a).

Labour supply

The NT faces a unique set of challenges when it comes to labour supply. Its vast geographic expanse, coupled with a relatively small population, can lead to labour shortages in various industries, particularly in regional and remote areas. The NT’s economic activities, such as agriculture, horticulture, tourism and hospitality, often rely on seasonal labour to meet the fluctuating demands of these sectors. These labour shortages can hinder business operations and impede the growth potential of these industries. Additionally, the NT’s tropical climate necessitates a flexible and responsive workforce, especially during peak seasons when activities like fruit harvesting and tourism increase demand.

In addressing these labour shortages, the Pacific Australia Labour Mobility scheme plays a pivotal role in the NT’s workforce dynamics. The scheme allows NT employers to access workers from Pacific Island countries and Timor-Leste, providing a regulated and reliable source of labour. This program has direct implications for the NT by mitigating labour deficits in industries such as agriculture and hospitality. It supports the economic activities of local businesses, facilitates cultural exchange, and fosters cross-cultural understanding within the NT community.

The agriculture sector is expected to see increased demand for certain occupations between 2021 and 2025, with many roles related to farming, crop cultivation and livestock production (Australia Industry and Skills Committee, 2022). The plant-based agricultural and horticultural industry in the NT is projected to employ over 3500 full-time equivalents (FTEs) by 2030, requiring an additional 1803 FTEs to meet demand (NT Farmers, 2019).

Market and supply chain

The influence of retailers and supermarkets is strong in the Australian horticultural market, resulting in growers receiving lower (i.e. 9 to 10-fold less) prices than consumers due to market mechanisms (Sangha et al., 2022). This has created concerns among family farm owners as declining marginal profitability puts pressure on small- and medium-scale farms, which may have to sell to larger enterprises or increase in size themselves. The supply chain processes have inflexibilities that pose challenges for growers, such as major retail chains requiring six weeks’ notice of supply and advanced transport bookings before harvest (Clonan et al., 2020).

Horticulture supply chains in Australia face several key issues (LEK Consulting, 2021). These issues include perishability, time-sensitive freight that is vulnerable to long delays, pests, diseases, and contaminants potentially entering the supply chain and damaging the produce. Additionally, the supply chain is dynamic, with farms changing the produce they grow, increasing the reliance on flexible road freight, which is often less efficient than rail. Horticulture production is also highly sensitive to variability in weather, which can affect the production, harvest timing, quality and market timing of the produce, making infrastructure investment decisions challenging.

The timing of harvest for horticultural produce has a significant impact on the entire supply chain, including market prices. Currently, national industry crop forecasts are used to communicate changes in volume or supply to the industry. The national industry body facilitates information supply between growers, marketers, wholesalers and retailers, but new tools could better forecast the impacts from farm level to national supply chains (Clonan et al., 2020).

Demand for beef is likely to continue to increase from South-East Asia. The NT pastoral industry will not have the capacity to meet future demand. However, this prospect is overshadowed by increased competition from India and South America and the push by animal welfare groups to ban live exports.

2.2.4 Social licence considerations

Farmers globally are becoming more aware of the importance of the consumer perception of products they grow. Price, country of origin, health and safety, food integrity and transparency, animal welfare, carbon footprint and people’s diet choices are just a few of the factors that consumers place importance on globally.

Crop production

The revocation of the land-clearing permit for Auvergne Station in the Victoria catchment following challenges by environmental groups and the Northern Land Council illustrates the implications of social licensing (ABC News, 2023b). Opposition from stakeholders, concerns over reputational risks faced by the owner, and the regulatory compliance issues highlight the importance of obtaining social acceptance and transparent decision-making processes.

Another case sheds light on the growing recognition and concern for the preservation of legal rights and cultural interests of Traditional Owners in land-clearing decisions (ABC News, 2023c). The head of the Northern Land Council, aligning with others in urging a federal inquiry into the NT Government’s management of land clearing, asserted that the legal rights and interests of Traditional Owners concerning the land have been disregarded. Stakeholders are increasingly calling for improved consultation and greater protection of sacred sites and customary practices. The expansion of the cotton industry presents opportunities for economic growth, job creation and infrastructure development in the NT. However, there is a shared responsibility to ensure sustainable practices and proper regulation to safeguard the NT’s cultural heritage. Calls from environmentalists for updated environment laws and inquiries reflect general concerns by members of the wider community to development in the region.

Crop and horticulture production systems almost always necessarily involve the use of synthetic chemicals such as fertilisers, herbicides, fungicides and pesticides. The economic gross margin (GM) analysis undertaken in this report assumes all crop production systems evaluated use these chemicals. Even under industry best-management practices these chemicals can leave the cropping system boundary and have off-site impacts. The Victoria River is a relatively undisturbed ecosystem and drains into a highly valuable fishery. Off-site impacts in the Victoria River, groundwater or the fishery from cropping development in the Victoria catchment is undesirable and potential misuse of these chemicals impacts the social licence of these developments. However, there is little available information on the impacts of pesticides and fertilisers on the environment in northern Australia, outside of the catchments flowing into the Great Barrier Reef. The companion technical report on agricultural impacts on water quality (Motson et al., 2024) provides a review of available information for northern Australia.

Beef production

Ethical issues hold significant relevance for the beef industry in Australia, as highlighted in the 2018 Industry Insights report (Industry Insights, 2018). Large export markets for Australian beef, such as Japan and the United States, have similar ethical concerns. A Meat and Livestock Australia report (MLA Industry Insights, 2018) has found that beef producers must focus attention on meeting consumer expectations 'sooner rather than later', which includes Australian consumer expectations that live export of cattle is conducted ethically with high animal welfare standards. With so many international competitors producing and trading beef, Australian beef faces the threat of losing market share. The report outcomes found that the marketing of meat products must start on-farm to ensure long-term viability. Beef producers have a positive story for a global marketplace of consumers. In evolving world markets, beef may struggle to keep a foothold as a protein source compared to other meats such as pork and poultry. As Burnett (2018) highlighted, there is a bigger trend from consumers wanting more organic produce, and produce that complies with ethical concerns.

Water licensing challenges

In the NT, two recent cases underscore the challenges surrounding water licensing and its implications for social licence considerations. The cancellation of a 10,000-ML water extraction licence in Larrimah in 2021 brought to light complexities in the water planning and licensing procedures in the NT and the values of Traditional Owners and environmental groups. The Northern Land Council successfully challenged the initial decision, emphasising the importance of sustainable water resource management and collaboration with Aboriginal communities (NLC, 2021). In another 2022 case, Traditional Owners opposed the NT's largest-ever water licence on Singleton Station, allowing the extraction of 40,000 ML of groundwater. Concerns centred on potential environmental degradation, threats to sacred sites, and the project's massive scale, which prompted legal action by Traditional Owners and environmental groups (ABC News, 2022). These cases collectively highlight the highly contested and often emotive debates and legal proceedings surrounding development and water licences.

Land tenure

In the NT, around 45% of land is held by Aboriginal Land Trusts as Aboriginal freehold land; 43.7% is under pastoral leasehold; 5% is in national parks; and 3.3% is vacant state land. Only 0.8% of the NT is held as freehold land, primarily urban land (Centre for Conservation Geography, 2020).

Aboriginal freehold land is inalienable freehold title, meaning it cannot be sold, and title may only be held by an Aboriginal Land Trust. The *Aboriginal Land Rights (Northern Territory) Act 1976* (Cth) (ALR Act) sets out the process for granting a lease or licence over Aboriginal freehold land. An Aboriginal Land Trust may grant an interest (such as a lease or licence) in the whole or any part of the land vested in it to any person and for any purpose. Land Councils are responsible for negotiating with any person wishing to obtain an estate or interest in land in the area of the Land Council, and an Aboriginal Land Trust may only grant an interest at the direction of the Land Council. Where an interest, such as a lease, is for a period of more than 40 years, then the consent of the Australian Minister responsible for the ALR Act is also required. A Land Council must not agree to the grant of an interest in Aboriginal land unless (i) the Traditional Owners understand the proposed grant and consent to it, (ii) any Aboriginal community or group affected by the grant has been consulted, and (iii) the terms of the grant are reasonable (Speed and Vanderbyl, 2024).

A pastoral lease is a title issued under the Pastoral Land Act to a person or company to lease Crown land for pastoral purposes. 'Pastoral purposes' refers to the commercial pasturing of stock, but also extends to related uses such as the production of agricultural produce to feed stock, carbon farming, and agritourism. Pastoral leases are granted for a specific term (which may include in perpetuity) and are subject to a range of conditions including:

- a reservation of a right of entry and inspection (by the relevant minister or their representative)
- a reservation of all minerals on or in the land
- a requirement to obtain consent to take any timber trees, stone, sand or gravel on the land.

Leases also include a reservation in favour of the Indigenous inhabitants of the NT. This provision entitles Indigenous persons who, by tradition, are entitled to use or occupy the leased land, to enter the land and to take and use water from natural waters and springs, to take or kill wild animals and to take plants, for food or for ceremonial purposes (Speed and Vanderbyl, 2024).

2.2.5 Markets and infrastructure

Due to the low population density in northern Australia (Section 2.3.1), the demand for locally grown produce is minimal. Thus, producers have to concentrate on supply chains and markets in the southern part of the country or export destinations (CRCNA, 2020). Despite this, the NT holds a potential geographical advantage compared to other regions in Australia due to its proximity to Asian and other markets. However, it is also faced with several limitations and constraints.

The availability of supporting facilities plays a crucial role in facilitating export markets. In the case of the cattle industry, the closest large operating abattoirs for the Katherine region are located in Townsville, Queensland (2000 km) and Naracoorte, SA (3000 km). Transport costs and a competitive local live export market through Darwin Port tend to deter producers in the Katherine region from selling to these abattoirs (MLA, 2009). In the case of broadacre crops, container packing for small volumes of non-bulk produce, such pulses, is currently limited to Darwin, Gladstone, Mackay and Townsville, while bulk export of grains is feasible in Wyndham, Darwin, and possibly Townsville, with varying levels of infrastructure primarily designed for non-grains (CRCNA, 2020). Despite the NT's proximity to key markets, most agricultural exports are transported through southern ports, resulting in longer supply chains. For instance, Darwin Port presently lacks the capacity to handle bulk food-grade containers for either import or export, and its container traffic is low in comparison to primary ports such as the Port of Fremantle in WA. To achieve efficient supply chains, it is essential to establish an integrated supply chain that minimises underutilisation of transport capacity on all sectors. Therefore, the challenge is to develop transport and handling capacity for exports and balance that with compatible imports to avoid the additional expense of freighting empty containers (CRCNA, 2020).

One of the challenges faced by growers in the NT is the competition with suppliers from other locations, both domestically and internationally, who tend to have lower production costs. As shown in Figure 2-7, NT growers face higher relative marketing costs, including transportation costs, compared to their counterparts in other parts of Australia. The marketing costs, as reported by the ABS, cover various expenses such as freight, container costs, commissions and other marketing charges, from the farm gate to markets. Although the data may not be entirely comparable between jurisdictions, they provide insight into the supply chain issues that NT growers face compared to the rest of the country. The marketing costs in all three agriculture categories are higher for the NT than the national average, placing NT producers at a competitive disadvantage.

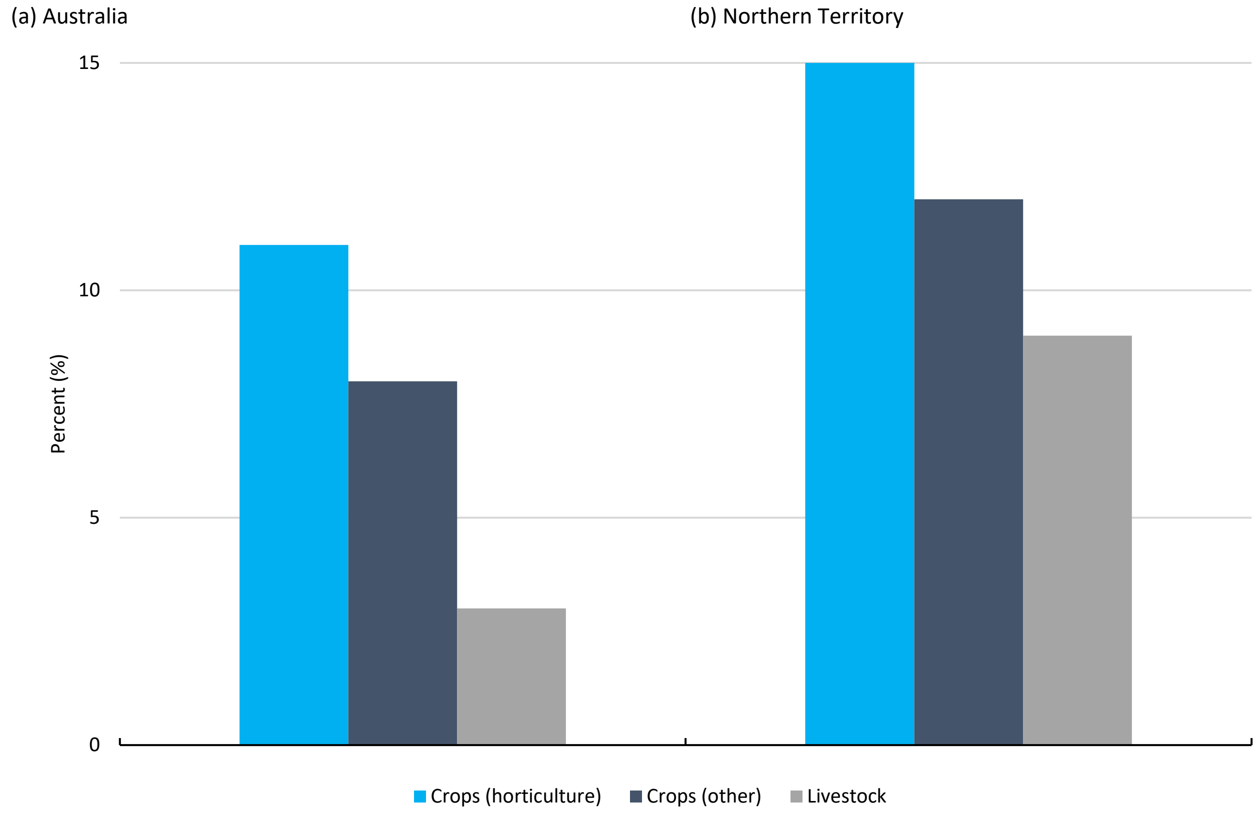


Figure 2-7 Comparison of marketing costs, across three categories of agriculture, relative to gross value of agricultural production (GVAP) for (a) Australia and (b) the Northern Territory (average 2011–12 to 2020–21)

Source: ABS (2022a)

2.2.6 Export opportunities

Asia is a significant market for Australian agricultural exports, representing more than half of the country's total exports (Sefton and Associates, 2013). The region's strong income growth is expected to continue driving demand for food, with projections indicating that Asian agrifood demand will double by 2050 (Hafi et al., 2023). This presents growth opportunities for the Australian food industry, particularly in supplying safe, high-quality meat, dairy, wine, vegetables and branded processed products to the expanding middle class in China, estimated to reach 300 million people in the next decade, with a rapidly westernising diet (KPMG and The University of Sydney China Studies Centre, 2013). According to Lockie (2015), the value of red meat imports into Asia is projected to increase from the current $3 billion to $150 billion by 2050.

The Australian horticulture industry relies heavily on export markets, as approximately $3.4 billion worth of horticultural commodities are exported annually, which accounts for about 25% of the total production in Australia (ABARES, 2022). Horticultural commodities such as oranges (*Citrus* x *aurantium*), mandarins (*Citrus reticulata*), avocados (*Persea americana*), almonds (*Prunus dulcis*) and macadamias have seen significant expansion in the area planted over the last 3 to 5 years. Given the relatively small Australian domestic market, expanding international market access for horticultural commodities is essential for current and future growth. Failure to develop additional markets may result in a price slump on the domestic market, impacting growers' profitability and leading to industry consolidation as less profitable growers leave the market (ABARES, 2022).

The Australian horticulture industry faces challenges in exporting products that require high labour and transportation costs. However, due to product seasonality and Australia's reputation for producing clean and green products, there are profitable market niches and quality lines for fresh produce exports. Over the years, the real value of fresh and processed horticultural exports has been growing at an average annual rate of 5%.

Australia's strategic location close to developing markets in Asia and as a supplier to northern hemisphere markets out of season are key advantages for the horticultural industry (Entegra Signature Structures, 2022). The estimated total value of Australian horticultural exports in 2021–22 was $3.4 billion, with fruits and nuts dominating the market (ABARES, 2022). Oranges, grapes, carrots, mandarins, and almonds were the top five horticultural exports by volume, while almonds, grapes, oranges, macadamias, and mandarins were the top five by value (LEK Consulting, 2021). Asparagus, carrots, and cauliflowers were the most important vegetable exports, and cut flowers, especially to Japan, constituted a significant export market (Entegra Signature Structures, 2022). The majority of Australian horticultural produce is seasonal, except for a few products like potatoes, carrots, cauliflower (*Brassica oleracea*), and broccoli (*Brassica oleracea*) (LEK Consulting, 2021).

The horticultural import market in Australia has demonstrated a steady growth in value over the past decade (2010–11 to 2019–20). South Korea, Mexico and China are the primary vegetable suppliers to Australia, with mushrooms, asparagus, garlic (*Allium sativum*) and onions being the most imported items. New Zealand and the United States are the largest suppliers of imported fruits to Australia, with kiwifruit (*Actinidia deliciosa*), avocados, oranges and table grapes being the most imported. In 2019–20, the value of fresh fruit exports was more than triple that of fresh fruit imports.

In contrast to horticultural crops, bulk broadacre commodities are traded on large global markets with multiple competing international buyers. The vast majority of Australia's broadacre commodities are already exported (82% of cereals, 92% of pulses and 98% of oilseeds by value (ABARES, 2022)). Therefore, export markets have the capacity to absorb potential increases in production. Figure 2-8 illustrates the adaptability of broadacre export markets in accommodating changes in product volumes and market access, even during periods of substantial disruptions to supply chains and market access restrictions before and after the Covid pandemic. Despite these challenges, broadacre commodity exporters easily adapted to available markets and sold all commodities produced each year.

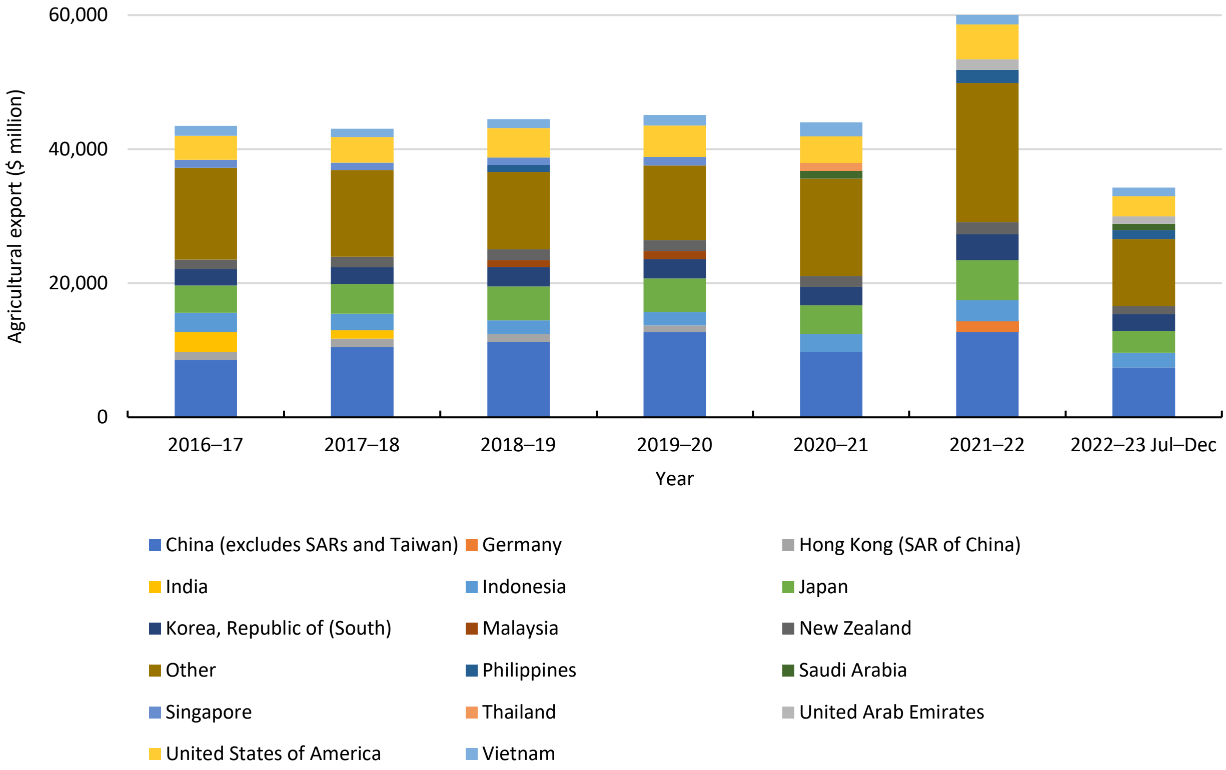


Figure 2-8 Adaptability of Australia's exports of broadacre commodities, as demonstrated by year-to-year variations in export volumes and market mixes before and after the disruptions associated with the Covid pandemic

Only the ten largest export destinations for each year are shown. SAR = special administrative region.

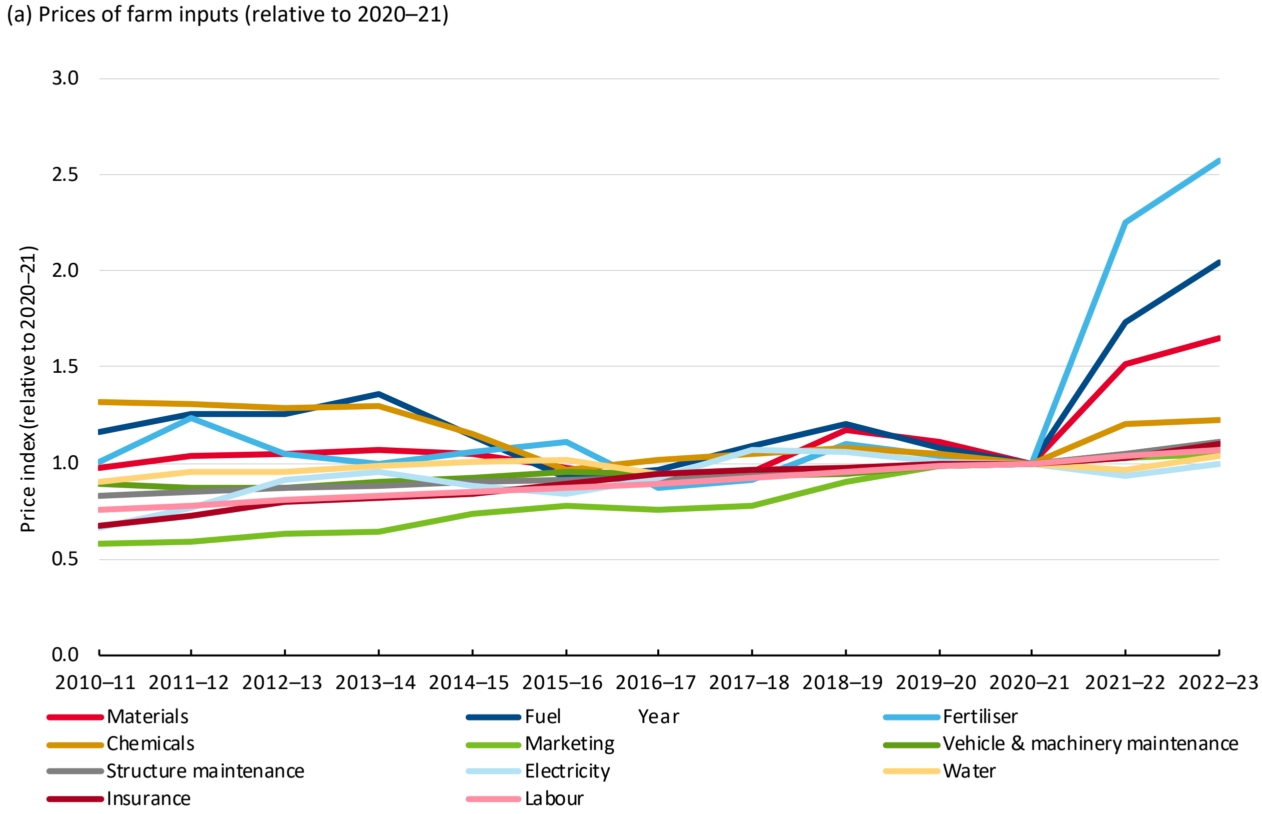
Source: ABARES Trade dashboard (beta) (2022)

2.2.7 Volatility in costs and prices

All costs and prices in this Assessment are standardised in real December 2023 Australian dollars (with inflation adjustments made to older sources when necessary). For agricultural commodity prices, that can fluctuate substantially from year to year; the decade mean (2011 to 2021) was used instead (so as not to be influenced by short-term dips and spikes in prices when comparing alternative cropping options). Historically, many agricultural inputs have experienced more moderate year-to-year price volatility than individual food and fibre commodities. However, over the duration of the Assessment, major global events such as the Covid pandemic, the war in Ukraine and other substantial disruptions to market access and supply chains have introduced a period of higher than normal volatility in agricultural input prices. Recent changes in agricultural terms of trade are therefore presented below as context for interpreting the December 2023 pricing used in this report (Figure 2-9).

The inputs of fertiliser and fuel both more than doubled in price between 2020–21 and 2022–23 (Figure 2-9). Relative changes in the costs of many inputs over the past 2 years exceed those over the previous decade. It should be mentioned that fertiliser prices, though having eased from their early 2022 peaks, remain historically elevated due to weakened demand as farmers reduce field applications for affordability and availability reasons, coupled with supply-side challenges such as a production crunch in Europe, disruptions from sanctions on Russia and Belarus, and trade restrictions in China (Baffes and Koh, 2023). In contrast, the prices that farmers receive for farm produce have not kept pace with increasing input costs (yet), leading to declining terms of trade.

Until increases in the costs of farming inputs flow through to increases in the prices of agricultural commodities, managing farm finances will be more difficult. This includes the irrigated farming options evaluated in this report (using 2021 prices). Until it is clear how recent disruptions to farming terms of trade balance out in the longer term, there will be added risk for investors in the agricultural sector. These risks should be borne in mind when using information in this report, particularly the financial analyses.



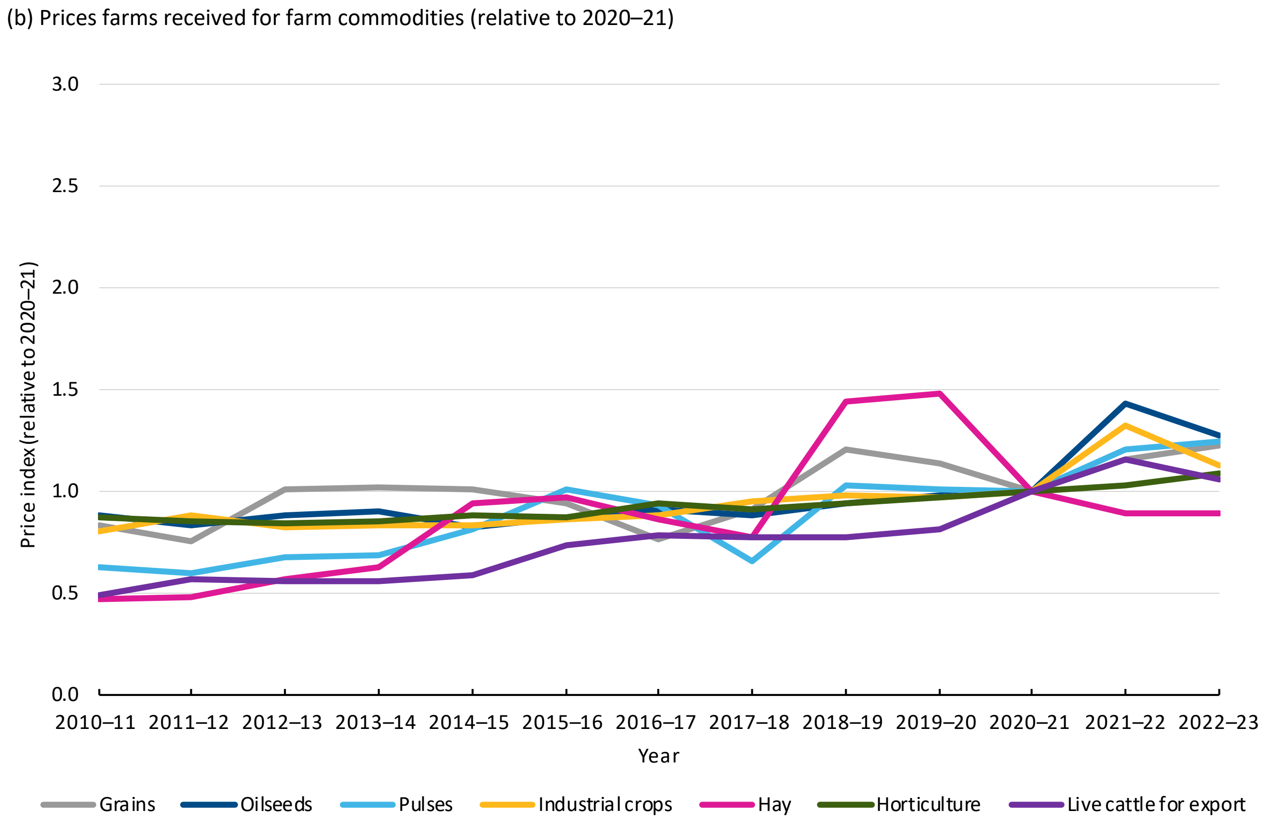


Figure 2-9 Farmers' terms of trade in Australia for (a) input prices and (b) prices received for commodities

ABARES (2022) terms of trade indices have been rebased to 2020–21. Indices for 2021–22 are preliminary, and for 2022–23 are forecasts. Axes are on the same scale for both panels to aid comparison. Price volatility for individual commodities can be much greater than for the aggregated categories displayed (e.g. see Figure 5-3).

2.3 Demography and economy of the Victoria catchment

This section describes the current social and economic characteristics of the Victoria catchment in terms of the demographics of local communities (Section 2.3.1); the current industries and land use (Section 2.3.2); and the existing infrastructure of transport networks, supply chains, utilities and community infrastructure (Section 2.3.3). Together these characteristics describe the built and human resources that would serve as the foundation upon which any new development in the Victoria catchment would be built. Indigenous water values, rights, interests and development goals are explored in the companion technical report on Indigenous aspirations, water values and use options (Barber et al., 2024).

2.3.1 Demographics

The Victoria catchment lies within the NT and comprises around half of the Victoria Daly Regional Council local government area. The northern part of the catchment includes part of the NT electoral division of Daly, and the southern part of the catchment includes part of the NT electoral division of Gwoja. At the federal level, the catchment forms a part of the Division of Lingiari (which encompasses most of the NT, excluding the Division of Solomon that covers an area near Darwin).

Population density of the Victoria catchment is extremely low at one person per 51.4 km^2. This is about one-eighth of the population density of the NT and one-165th of Australia as a whole. The catchment contains no significant urban areas (population >10,000 people), but there are several small towns and communities including Timber Creek (the furthest north in the catchment and regional centre), Victoria River, Yarralin, Daguragu and Kalkarindji, the furthest south. The largest of these settlements is Kalkarindji (population 383 as at the 2021 Census). Katherine (population 6303 in 2016) is the closest urban service centre and is located north-east of the catchment, approximately 290 km from Timber Creek. The nearest major city and population centre is the NT capital of Darwin (population of Greater Darwin area was 136,828 in 2016) approximately 600 km from Timber Creek. The small town of Timber Creek (population 278 as at the 2021 Census). located on the National Highway between Katherine and Kununurra in the north of the Victoria catchment, would be a likely service centre for any cropping expansion in the Victoria catchment. Timber Creek is currently primarily a service centre for tourism, with accommodation, shop, health service, P–9 school, indoor sports centre and police station.

The demographic profile of the catchment, based on data from the 2021, 2016, 2011 and 2006 censuses, is shown in Table 2-1. The ABS reports statistics by defined statistical geographic regions that are classified into a nested hierarchy of statistical areas. The Victoria River ABS Statistical Area Level 2 (SA2) region (702051068) broadly encompasses the Victoria catchment, extending beyond the catchment boundary in most directions (Figure 2-10). Small portions of the catchment reach into two other SA2 regions: Tanami (702011053) and Barkly (702021055). Thus, data are shown for: (i) the Victoria River SA2 region as the single region that most closely approximates the catchment boundary, and (ii) Victoria catchment estimated data based on combining appropriate portions of three ABS regions to best match the actual spatial coverage of the catchment (60.7% of Victoria River SA2 region plus small portions (less than 1%) of Tanami and Barkly SA2 regions).

Table 2-1 Major demographic indicators for the Victoria catchment

INDICATOR	UNIT	VICTORIA RIVER SA2 REGION	VICTORIA CATCHMENT†	NORTHERN TERRITORY	AUSTRALIA
Total population 2021	People	2609	1600	232,605	25,422,788
Total population 2016	People	2489	1527	228,833	23,401,891
Total population 2011	People	2516	1544	211,946	21,507,720
Total population 2006	People	2762	1693	192,899	19,855,287
% change in population, from 2016 to 2021	%	4.82	4.80	1.65	8.64
% change in population, from 2011 to 2021	%	3.70	3.62	9.75	18.20
% change in population, from 2006 to 2021	%	−5.54	−5.49	20.58	28.04
Indigenous population 2021, as % of total	%	74.59	74.68	26.27	3.20
Indigenous population 2016, as % of total	%	73.40	73.53	25.45	2.77
Indigenous population 2011, as % of total	%	75.99	76.06	26.79	2.55
Indigenous population 2006, as % of total	%	76.36	76.46	27.82	2.29
Male population 2021, as % of total	%	50.36	50.35	50.53	49.35
Male population 2016, as % of total	%	50.70	50.68	51.81	49.34
Male population 2011, as % of total	%	49.28	49.29	51.67	49.44
Male population 2006, as % of total	%	50.58	50.57	51.52	49.35
Population density 2021, per 1000 ha	People	0.2	0.2	1.7	33.1
Median age 2021	Years	25	25	33	38
Change in median age, from 2016 to 2021	Years	No change	No change	1	No change
Change in median age, from 2011 to 2021	Years	1	1	2	1
Median weekly household income 2021	$	$1095	$1097	$2061	$1746
Change in median weekly household income, from 2016 to 2021	%	0.18	0.34	3.93	21.42
% of households with weekly household income less than $650/week	%	27.20	27.12	12.40	16.50
% of households with weekly household income more than $3000/week	%	8.70	8.67	28.80	24.30
Mean number of people per household 2021	People	4.1	4.1	2.8	2.5
Change in mean number of people per household, from 2016 to 2021	People	0.3	0.3	−0.1	−0.1

†Weighted averages of scores for SA2 regions falling wholly or partially within the catchment boundary.
Source: ABS (2021a), ABS (2016), ABS (2011) and ABS (2006) Census data

The typical resident of the catchment is younger, has a lower weekly household income, and more likely to identify as Indigenous than the typical resident of the NT and of Australia as a whole. The catchment population is predominantly younger (median age 25 years in 2021) than is typical in the NT (33 years) and the country as a whole (38 years). However, the trend from 2011 to 2016 and to 2021 suggests that the median age is increasing a little. The population in the catchment contains a much larger proportion of Indigenous Peoples (close to 75%) than the NT (26.3%) and the country overall (3.2%). Median household incomes in the catchment were considerably below the average for the NT and the country as a whole in 2021. Furthermore, the proportion of households on low incomes (less than $650/week) was far higher, and the proportion on high incomes (more than $3000/week) far lower, than the proportion for the NT and for the country as a whole (Table 2-1).

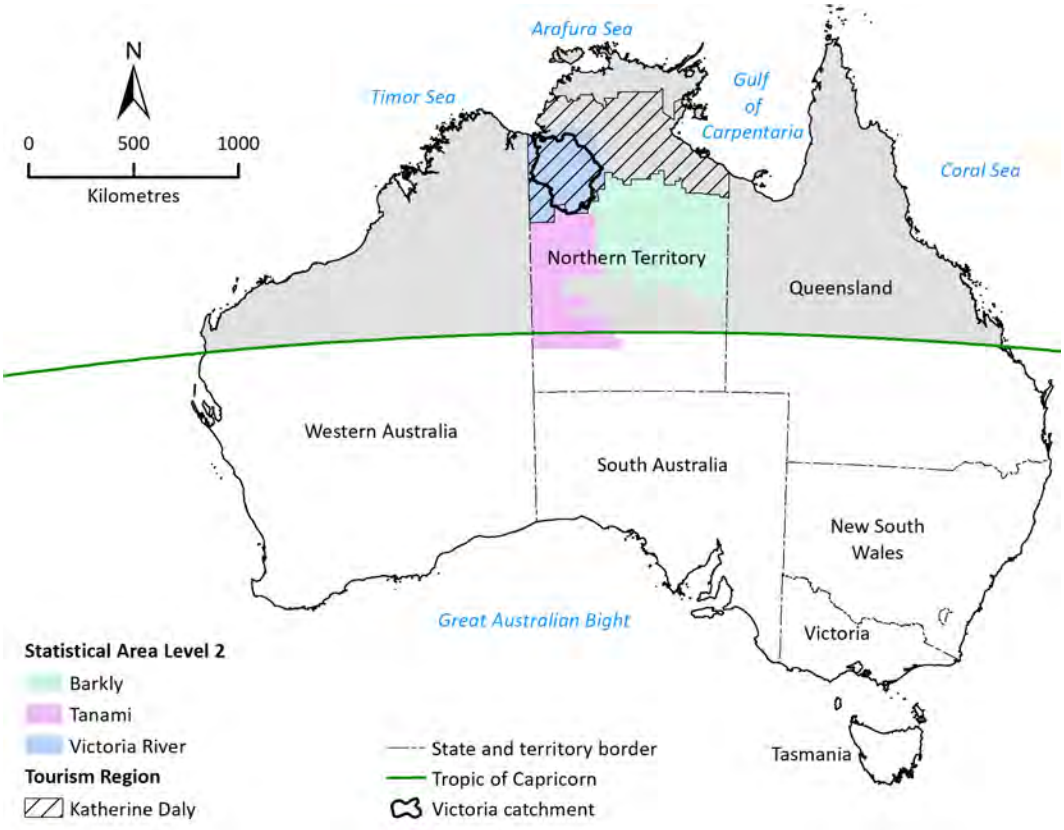


Figure 2-10 Boundaries of the Australian Bureau of Statistics (ABS) Statistical Area Level 2 (SA2) regions used for demographic data in this analysis

The Victoria catchment falls within the first decile for each of the Socio-Economic Indexes for Areas (SEIFA) metrics (Table 2-2), indicating that the catchment scores below 90% of the rest of the country on each measure. For example, the percentage of the population with a bachelor degree or higher is less than 10% compared with a national average of 26%. All three SA2 regions that fall within the catchment boundary (Victoria River, Tanami and Barkly) individually rank within the first decile for all four measures.

Table 2-2 Socio-Economic Indexes for Areas (SEIFA) scores of relative socio-economic advantage for the Victoria catchment

Scores are relativised to a national mean of 1000, with higher scores indicating greater advantage.

INDICATOR	VICTORIA RIVER SA2 REGION		VICTORIA CATCHMENT		NORTHERN TERRITORY	
	SEIFA score	**(Decile)**	**SEIFA score**	**(Decile)**	**SEIFA score**	**(Mean decile)**
Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD)†	501	(1)	501	(1)	904	(5)
Index of Relative Socio-Economic Disadvantage (IRSD)‡	678	(1)	678	(1)	945	(5)
Index of Economic Resources (IER)	557	(1)	557	(1)	887	(4)
Index of Education and Occupation (IEO)	819	(1)	819	(1)	976	(5)

†Based on both the incidence of advantage and disadvantage.
‡Based purely on indicators of disadvantage.
Source: ABS (2023a)

2.3.2 Current industries and land use

Employment

The economic structure of the Victoria catchment differs substantially from that of the NT and Australia as a whole. The proportion of the adult population (aged 15 and older) within the labour force in the catchment is far smaller than in the NT (see participation rates in Table 2-3), indicating that a large proportion of the potential workforce is unable or unwilling to find work. Furthermore, unemployment rates are far higher than the NT and national averages (see unemployment rates in Table 2-3), indicating that a larger proportion of those who are willing and able to seek work have been unable to find work. Trends in the data appear unfavourable, with unemployment rates within the Victoria catchment higher and participation rates lower in the 2016 and 2021 censuses than in earlier periods. In contrast, rates remained broadly steady for the NT and Australia as a whole across the same time frame.

Table 2-3 Key employment data for the Victoria catchment

	UNIT	VICTORIA RIVER SA2 REGION	VICTORIA CATCHMENT†	NORTHERN TERRITORY	AUSTRALIA
Unemployment rate 2021	%	20.85	20.82	5.61	5.09
Unemployment rate 2016	%	17.74	17.83	6.96	6.86
Unemployment rate 2011	%	6.83	6.92	5.28	5.63
Unemployment rate 2006	%	5.09	5.17	4.39	5.24
Participation rate 2021	%	44.99	44.87	61.72	61.08
Participation rate 2016	%	40.80	40.77	61.55	60.26
Participation rate 2011	%	52.97	52.91	63.86	61.38
Participation rate 2006	%	52.29	52.16	62.76	60.36
Major industries of employment – top five industries in Victoria catchment as % of employment 2021					
Agriculture, forestry and fishing	%	29.35	29.17	2.29	2.34
Public administration and safety	%	14.52	14.62	18.16	6.61
Education and training	%	14.52	14.53	9.38	8.81

	UNIT	VICTORIA RIVER SA2 REGION	VICTORIA CATCHMENT†	NORTHERN TERRITORY	AUSTRALIA
Healthcare and social assistance	%	10.59	10.63	14.90	14.54
Construction	%	5.90	5.87	8.03	8.86
Major industries of employment – top five industries in Australia as % of employment 2021 that are not in list above					
Retail trade	%	3.93	3.98	7.23	9.13
Professional, scientific and technical services	%	0.61	0.61	4.85	7.84

†Weighted averages of scores for SA2 regions falling wholly or partially within the catchment boundary.
Source: ABS (2021a), ABS (2016), ABS (2011) and ABS (2006) Census data

There are noticeable differences in the industries providing the most jobs within the catchment (Table 2-3). 'Education and training', 'Healthcare and social assistance' and 'Construction' are important employers in the catchment and nationally; however, 'Retail trade' and 'Professional, scientific and technical services' feature within the top five industries by employment nationally but are far less significant in the Victoria catchment. As is also the case in the NT as a whole, 'Public administration and safety' is relatively more important to the employment prospects of workers in the catchment than the average across the country. Of particular relevance to this Assessment, 'Agriculture, forestry and fishing' is the most significant industry within the Victoria catchment. Furthermore, the sector has been growing relatively more important in the catchment over time. Over the past three censuses (2021, 2016 and 2011), the percentage of employment in the agricultural sector nationally has been reported as 2.5%, 2.5% and 2.3%, respectively, and for the NT, 1.9%, 2.0% and 2.3%, respectively. That is, the proportion of employment in the agricultural industry has been small and fairly steady. In contrast, agricultural employment within the Victoria catchment is large and growing, having provided 26.3% of employment in 2011, 24.0% in 2016 and 29.2% in 2021.

The structural differences between this catchment and elsewhere can have a significant impact on the regional economic benefits that can result from development projects initiated within the catchment compared to development projects that may be initiated elsewhere.

Land use

The Victoria catchment covers an area of about 82,400 km^2, much of which is conservation and natural environments (38%) (Figure 2-11). In the north of these protected lands lies the Bradshaw Field Training Area (7% of the conservation and natural environments), a facility owned by the Australian Government with a southern boundary following the Victoria River and a boundary that also extends outside the Victoria catchment in the north-east. A further 2.05% of the catchment is classified as water and wetlands, most of which is coastal and tidal waters, including reaches in the Angalarri River. Nearly all of the remaining catchment area (62%) is used for grazing natural vegetation. Intensive agriculture and cropping make up a very small portion of the catchment: rainfed and irrigated agriculture and intensive animal production together comprise just 0.02% of the land area. The other intensive localised land uses are transport, communications, services, utilities and urban infrastructure (0.22%).

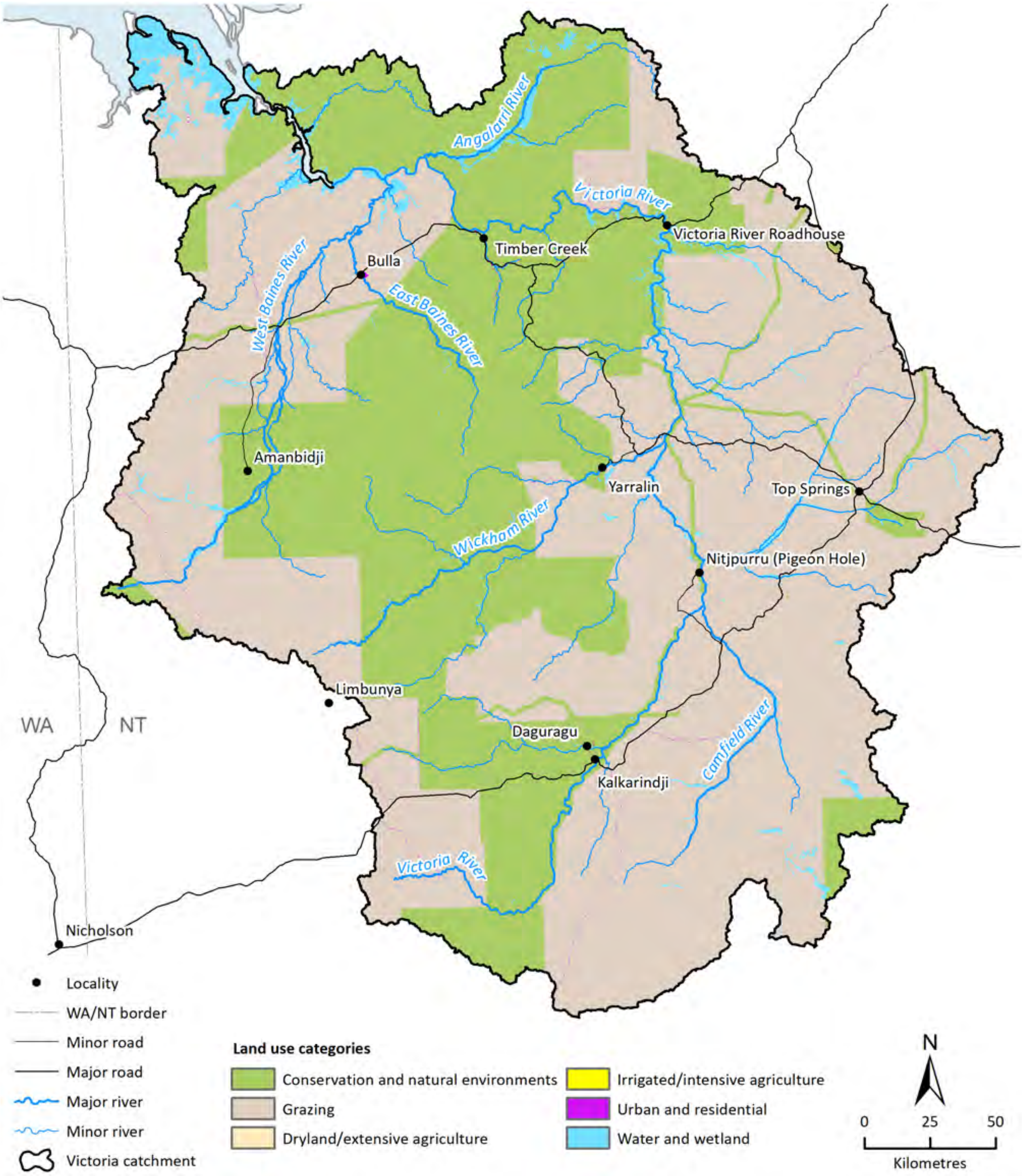


Figure 2-11 Land use classification for the Victoria catchment

Areas of some land uses (e.g. irrigated/intensive agriculture) are too small to be shown on the map.

Source: NT Land Use Mapping Project 2016–2022, Department of Environment, Parks and Water Security, NT Government,https://www.ntlis.nt.gov.au/metadata/export_data?type=html&metadata_id=ECEEDF0AD4826221E0532144CD9BC059

Agriculture and fisheries

The estimated value of agricultural production for the Victoria catchment is given in Table 2-4, together with the value of agricultural production for the NT as a whole. The catchment provides a substantial proportion of the revenue for livestock from the NT but has no cropping.

Table 2-4 Value of agricultural production for the Victoria catchment (estimated) and the Northern Territory for 2020–21

	VICTORIA CATCHMENT† ($ million)	NORTHERN TERRITORY ($ million)
Total value of crops	0	$141.1
Total value of livestock slaughtered and other disposals	$110.2	$605.1
Total agriculture	$110.2	$746.2

†Weighted averages of scores for SA2 regions falling wholly or partially within the catchment boundary.
Source: ABS (2022b) Value of agricultural commodities in 2020−21

The most recent annual survey data from the ABS describing the value of agriculture by different types of industries (2021–22 survey) are only available at a much larger scale than the Victoria catchment (state and territory level), preventing estimation of the value of agriculture products within the catchment. Hence estimates have been presented for the previous year (Table 2-4) for which data were available at finer scale (SA2 level, as used for socio-economic and demographic catchment estimates).

Agriculture is the major source of employment in the Victoria catchment, providing 29% of the work, as shown in Table 2-3. This is much higher than the proportion of employment in agriculture on a national level. Extensive grazing of beef cattle, valued at $110.2 million in 2020–21 (Table 2-4), dominates agricultural production in the Victoria catchment. The first cattle were brought overland to the Victoria River District (VRD) in the 1880s.

Present-day cattle grazing occurs on rainfed native and naturalised pastures where productivity is constrained by the variable climate, and in most areas, low-fertility soils; however, vast tracts of moderately fertile cracking clay soils support economically important grasslands. The constraints of a variable climate and low-fertility soils have shaped the types of beef production systems currently operating in the Victoria catchment, which target live exports to South-East Asia through Darwin Port.

Despite more than a century of trying to establish crop industries in the NT, there is still very little irrigated or rainfed cropping in the Victoria catchment. Agricultural experiments were conducted around the time of the First World War, and the Second World War prompted another wave of interest in facilitating northern agricultural development, which included a set of agricultural experimental stations. In 1942, approval was given to establish army farms at Katherine and Mataranka (east of the Victoria catchment) with the aim of more efficiently supplying the fruit and vegetables needed to maintain the nutrition of troops. The army experimental farm at Katherine was initially established to test what fruit and vegetables were suitable for the area. After the war this became the Katherine Experimental Station, where a wider range of crops were explored (run by the Australian Government until it was handed over to the NT Government in the 1980s). Several crops, such as peanuts in the 1950s, initially proved to be agronomically suitable for the local environment but could not be established as competitive local industries, partly because of difficulties with market access and high transport costs. The Victoria River Research Station, also known as Kidman Springs Research Station, commenced operations in 1960 and is the NT's principal pastoral research station, carrying out research on cattle productivity and sustainability of the pastoral landscape.

There is currently no active aquaculture in the Victoria catchment. An application for prawn aquaculture farming by Project Sea Dragon Pty Ltd was lodged with the NT Government in 2015. Significant milestones were completed in 2020 progressing the approval process, and initial construction contracts awarded. The project is currently awaiting secure funding. A comprehensive situational analysis of the aquaculture industry in northern Australia (Cobcroft et al., 2020) identified key challenges, opportunities and emerging sectors.

Offshore, the Victoria River drains into one of the most valuable fisheries in the country. The Northern Prawn Fishery (NPF) spans the northern Australian coast between Cape Londonderry in WA to Cape York in Queensland (Figure 2-12), with most of the catch being landed at the ports of Darwin, Karumba and Cairns. Over the 10-year period from 2010–11 to 2019–20, the annual value of the catch from the NPF has varied from $65 million to $124 million with a mean of $100 million (Steven et al., 2021). The Victoria catchment flows into the Joseph Bonaparte Gulf NPF region (Figure 2-12), one of the smallest regions by annual prawn catch.

Like many tropical fisheries, the target species exhibit an inshore–offshore larval life cycle and are dependent on inshore habitats, including estuaries, during the postlarval and juvenile phases (Vance et al., 1998). Monsoon-driven freshwater flood flows cue juvenile prawns to emigrate from estuaries to the fishing grounds. Flood magnitude explains 30% to 70% of annual catch variation, depending on the prawn fishery region (Buckworth et al., 2014; Vance et al., 2003). Fishing activity for banana prawns and tiger prawns (*Penaeus* spp.), which combined constitute 80% of the catch, is limited to two seasons: a shorter banana prawn season from April to June and a longer tiger prawn season from August to November. The specific dates of each season are adjusted depending on catch rates. Banana prawns generally form the majority of the annual prawn catch by volume. Key target and by-product species are detailed by Woodhams et al. (2011). The catch is often frozen on-board and sold in domestic and export markets.

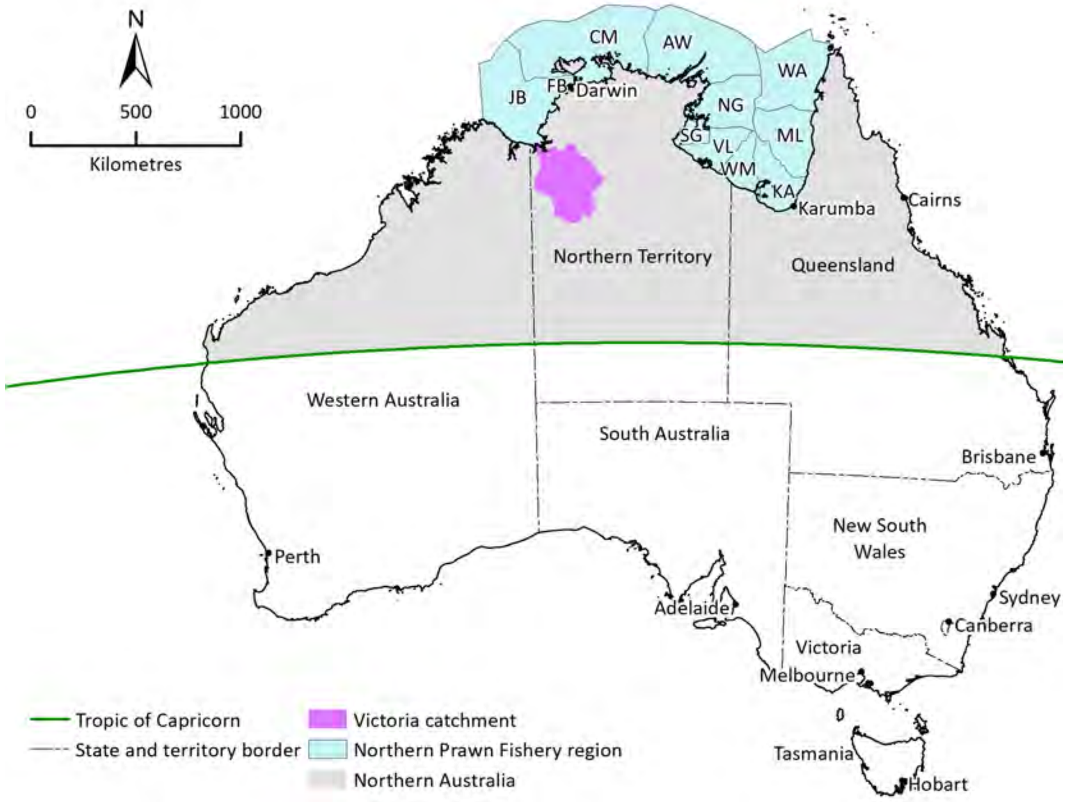


Figure 2-12 Regions in the Northern Prawn Fishery (NPF)

The regions in alphabetical order are Arnhem-Wessels (AW), Coburg-Melville (CM), Fog Bay (FB), Joseph Bonaparte Gulf (JB), Karumba (KA), Mitchell (ML), North Groote (NG), South Groote (SG), Vanderlins (VL), Weipa (WA) and West Mornington (WM).

Source: Dambacher et al. (2015)

The NPF is managed by the Australian Government (via the Australian Fisheries Management Authority) through input controls, such as gear restrictions (number of boats and nets, length of nets) and restricted entry. Initially comprising over 200 vessels in the late 1960s, the number of vessels in the NPF has reduced to 52 trawlers and 19 licensed operators after management initiatives including effort reductions and vessel buy-back programs (Dichmont et al., 2008). Given recent efforts to alleviate fishing pressure in the NPF, there is little opportunity for further expansion of the industry. However, any development of water resources in the Victoria catchment would need to consider the downstream impacts on prawn breeding grounds and the NPF.

There is little available information on the impacts of pesticides and fertilisers on the environment in northern Australia, outside of the catchments flowing into the Great Barrier Reef. The companion technical report on agricultural impacts on water quality (Motson et al., 2024) provides a review of available information for northern Australia.

Tourism

Overview

For a remote and sparsely populated area with little tourism development, the catchment of the Victoria River experiences a relatively high volume of visitation largely represented by self-drive tourists. Most of this visitation is attributable to the Victoria Highway (part of national Highway 1) traversing the region connecting all points east via Katherine to all points west via Kununurra. The Victoria catchment's regional centre is the township of Timber Creek, which has approximately 300 residents (ABS, 2021d). Timber Creek provides an important half-way stopping point for self-drive travellers between Katherine (289 km east) and Kununurra (226 km west). Access to much of the Victoria catchment north and south of the Victoria Highway is via unsealed roads that usually require four-wheel-drive (4WD) vehicle access. As per much of Australia, travellers exploring remote parts of the region are advised to be self-sufficient, experienced and safety conscious (NT Parks and Wildlife Commission, 2024). Seasonality impacts tourism as wet-season rains frequently flood much of the region restricting road access for extended periods. High summer temperatures and humidity directs most tourist visitation therefore occurring in the drier, cooler months between May and October (Tourism NT, 2024a).

Supporting organisations and visitation statistics

The Victoria catchment falls within the Katherine Daly tourism region (Figure 2-10), which extends from the Gulf of Carpentaria to the NT–Western Australian border (TRA, 2023). The Katherine Daly tourism region includes the townships of Katherine, Daly Waters, Borroloola, Mataranka, Pine Creek and Wadeye (all outside the Victoria catchment). Tourism NT (https://www.tourismnt.com.au/), established as a commission by the NT government under the Tourism NT Act 2012, is the primary representative and promotional organisation for tourism across in the NT.

The three-year average (to December 2022) tourist numbers to the Katherine Daly tourism region was approximately 287,000 visitors who stayed for an average of 3.4 nights (Tourism NT, 2023). Only 1% of these visitors were of international origin, while 62% were from within the NT and 37% were from interstate. Of the intra-territory and interstate visitors, 43% and 21%, respectively, were travelling for business. These tourism numbers would have been impacted by Covid during this period. The total visitor expenditure in the Katherine Daly region for the 2022 calendar year was $217 million, of which $213 million is attributed to domestic visitors and visitor expenditure in the Victoria catchment was estimated at no more than $20 million/year. Visitor statistics since June 2007 indicate the highest levels of visitation to Katherine Daly occurred in 2022, suggesting a strong post-Covid recovery of self-drive tourism in the region. Like in much of northern Australia, tourist visitation across the region is highest during the dry season, with peak visitation during the September quarter. Tourist visits across the Katherine Daly region pre-COVID-19 show peak visitation (between 33% and 45% depending on origin – interstate, intrastate or international) during the September quarter (dry season), and least visitation (between 5% and 13% depending on origin) during the March quarter (wet season) (Tourism NT, 2019). However, the lack of all-weather sealed roads in the Victoria River SA2 means tourism in the Victoria catchment is likely to be considerably more seasonal than in the broader region. In the broader region, the data are highly skewed to Katherine, which accounted for approximately half the visitors to the Katherine Daly region pre-COVID-19 (142,000 visitors in the year ending December 2022); however, the Victoria catchment was reported to have received 27,000 visitors in the year ending December 2022 (Tourism NT, 2023).

Predominant visitor market – self-drive tourists

Approximately 34% of overnight visitors to the Katherine Daly tourism region are reported to visit national parks, while 12% participate in fishing, 10% take part in charter boat or river cruise tours, and 9% participate in Indigenous cultural experiences (of these last two activities there are currently no businesses in the Victoria catchment). Cultural tourism experiences include art, craft, and cultural displays, specialised guided tours, and traditional activities and food experiences (Tourism NT, 2023). Fishing is one of the Victoria catchments' biggest drawcards, providing a scenic setting to catch barramundi. Timber Creek is the gateway to Judbarra National Park and Jasper Gorge's sandstone escarpment ranges and ancient boab trees (https://northernterritory.com/katherine-and-surrounds/destinations/timber-creek).

Self-drive tourism is the predominant visitor market in the Katherine Daly tourism region, with 83% of intra-territory travellers and 57% of interstate travellers using a private vehicle or rental car (Tourism NT, 2023). Bus and coach travel represents the next largest proportion of visitors (17% of interstate and 9% of intra-territory visitors), followed by aircraft (15% of interstate and 7% of intra-territory visitors; Tourism NT, 2023). As the Victoria Highway provides the only major, sealed road through the Victoria catchment, a large proportion of visitors who explore more remote parts are likely to be doing so with 4WD vehicles and may be motivated by opportunities for adventure and exploration. Studies of 4WD tourists in Australia have identified a diverse range of motivations and market types, ranging from those who regard 4WD vehicles as a necessary means to reach otherwise inaccessible places to experience solitude or participate in other activities to those who purposely seek out rough terrain for the purpose of an adventure driving experience (Taylor and Prideaux, 2008).

Despite differing motivations of different types of self-drive visitors, an important overarching travel motivation, and the overwhelming perception of remote northern Australia, is the experience of an ancient, unchanging, vast, and 'empty' landscape, with limited human presence and opportunities for exploration, solitude and an authentic connection with the natural environment (Lane & Waitt 2007; Ooi & Laing 2010).

Tourism infrastructure

Domestic airports to access the Victoria catchment are located in Darwin and Katherine in the NT and Kununurra WA. Airstrips exist at Timber Creek, Victoria River Downs station and Kalkarindji for public use and emergency landing by the Royal Flying Doctor Service.

Visitor services and tours operating from the township of Timber Creek include a hotel – caravan park (Timber Creek Travellers Rest), a hotel–restaurant (the Timber Creek Hotel), an Indigenous-owned store and caravan park (Wirib Store & Tourism Park) and a roadhouse. Sightseeing attractions and features include the historical Timber Creek Police Station complex, a walking trail and lookout, and Gregory's Tree – a large and ancient boab of Indigenous cultural significance and historical significance (Tourism NT, 2024b). A short distance (10 km) west of Timber Creek on the Victoria Highway is Big Horse Creek Campground, which features a public boat ramp to the Victoria River and other amenities. East of Timber Creek, where the Victoria Highway crosses the Victoria River, is another roadhouse and caravan park with nearby amenities that include a boat ramp. This region provides an entry point to the eastern section of the Judbarra National Park, within which there are campgrounds, 4WD tracks, walking trails, scenic lookouts and other amenities (NT Parks and Wildlife Commission, 2024). Other tourism-related infrastructure throughout the Victoria catchment includes a caravan park at Kalkarindji located on the Buntine Highway approximately 460 km south-west of Katherine (NT Parks and Wildlife Commission 2024; Tourism NT, 2024b).

A pre-Covid profile for the Victoria Daly Region local government area, which covers the Victoria catchment and extends north-west to encompass Claravale, Daly River and Pine Creek, indicates that 20 tourism businesses were operating in this region at the time of their 2019 survey. Of these 20 businesses, 12 were 'non-employing', four had fewer than five employees and three had more than 20 employees (TRA, 2019).

Regional attractions

Judbarra National Park is one of the major attractions for visitors in the Victoria catchment and is the second-largest park in the NT (Tourism NT, 2024c). The park contains a diversity of landscapes, native vegetation and fauna, and geological features (such as Limestone Gorge). The park offers self-drive tourists a wide range of nature-based activities, camping and a series of 4WD trails. Fishing in the Victoria River and connected waterways is promoted as a popular activity for visitors, and barramundi are promoted as the prized species among a variety of estuary species. Fishing is permitted within the Judbarra National Park, and there are legal size and catch limits and restrictions on types of fishing gear (i.e. no nets, traps or spear guns are allowed). The unsealed Buchanan Highway provides access to the scenic Jasper Gorge and Lupayi Campground.

In the south of the Victoria catchment, Kalkarindji is known for having abundant geodes scattered over the ground that contain crystallised, rare minerals such as prehnite, amethyst, jasper, agate, smoky quartz and calcite (NT Government 2016). Fossicking is promoted as a popular tourist activity in this area but requires written consent from the mineral title owner within a designated mineral lease area (https://fossicking.nt.gov.au/declared-fossicking-areas/wave-hill).

Tourism development opportunities and considerations

The state of northern Australia's tourism economy is closely tied to the state of its ecosystems (Prideaux, 2013). With a large proportion of the Victoria catchment in a relatively 'natural' state, there is potential for growth in nature-based tourism. However, like other remote areas of northern Australia, the region's remoteness and distance from urban centres (Bugno and Polonsky, 2024), lack of supporting infrastructure, limited human capital and financial resources, and low awareness of tourism system characteristics (Summers et al., 2019) considerably constrain its potential. However, opportunities for tourism development in such areas can be realised with sufficient planning and coordination between enterprises and public sector partners, realising Indigenous aspirations and combining an in-depth understanding of the region's characteristics (Schmallegger & Carson 2010). The seasonality of visitation also limits enterprise profitability (Bugno and Polonsky, 2024) and permanent employment opportunities. Also important to consider is that much of the catchment's appeal to self-drive visitors is likely to be the absence of human presence and commercial infrastructure, which present opportunities for exploration and solitude (Lane and Waitt, 2007; Ooi and Laing, 2010). Hence, development that alters the region's current characteristics could be alienating to some current visitor markets.

While water resource development for agriculture has the potential to negatively affect tourism and future opportunities in the Victoria catchment, for example, through declining biodiversity and perceived reduced attractiveness (Pickering and Hill, 2007; Prideaux, 2013), such development may present opportunities to foster tourism growth. For example, Lake Argyle in the East Kimberley region (WA), developed as an irrigation dam to supply the Ord River Irrigation Area, is now advertised as being one of northern WA's major attractions. It offers a wide range of tourism activities and hosts a diversity of wildlife (https://www.australiasnorthwest.com/explore/kimberley/lake-argyle/). While visitors to the Kimberley region reportedly perceived Lake Argyle in the same way they perceived some 'natural' local attractions such as billabongs, irrigated agriculture of the Ord River Irrigation Area is perceived differently, as being 'domesticated' (Waitt et al., 2003).

Elsewhere in northern Australia, water resource infrastructure, including Fogg Dam (NT), Tinaroo Dam (Queensland) and Lake Moondarra (Queensland), has resulted in increased visitation by tourists for the enhanced wildlife or recreation opportunities they provide. However, the ongoing contributions of dam to their local economies vary. For example, the value of recreational fishing varies between dams depending upon whether there are other dams nearby and their proximity to tourism traffic (Rolfe and Prayaga, 2007). The relatively low visitation to the Victoria catchment suggests that the recreational fishing value of a new dam in the Victoria catchment would be limited, particularly in those parts of the Victoria catchment near Lake Argyle.

Agritourism opportunities, for example, through accommodation on pastoral properties and other travel support (fuel), offer an opportunity for revenue diversification, although impediments such as highly variable seasonal demand limit profitability (Bugno and Polonsky, 2024).

Tourism has the potential to enable economic development within Indigenous communities because Indigenous tourism enterprises, usually microbusinesses, often have some competitive advantages (Fuller et al., 2005). Successful tourism developments in regional and very remote areas such as the Victoria catchment are highly likely to depend on establishing private and public sector partnerships, ensuring effective engagement and careful planning with Traditional Owners and regional stakeholders, and building interregional network connectivity and support (Greiner, 2010; Lundberg and Fredman, 2012).

As well as economic and employment opportunities, tourism can cause impacts such as native habitat loss, and foot traffic, bikes or vehicles may cause environmental damage such as erosion and a loss of amenity to local residents (Larson and Herr 2008). Other risks include the spread of weeds and root rot fungus (*Phytopthora cinnamomi*) carried on vehicles and people (Pickering and Hill, 2007).

Given the importance of climate on tourism seasonality, demand and travel patterns in northern Australia (Hadwen et al., 2011; Kulendran and Dwyer, 2010), the increased temperatures and occurrence of extreme weather-related events (e.g. drought, flood, severe fires and cyclones) associated with climate change are likely to be significant threats to the industry in the future. These will likely negatively affect tourist numbers, the length and quality of the tourist season, tourism infrastructure including roads, and the appeal of the landscape and its changing biodiversity (Amelung and Nicholls, 2014; Prideaux, 2013).

Mining and petroleum

Across Australia, mining uses about one-tenth of the water used by irrigated agriculture, and water for mining is assigned a higher reliability than agriculture. The largest contributor to the NT's Gross State Product in 2022–23 (28%) was the mining (minerals) industry, providing $4.4 billion to the NT economic output (Department of Treasury and Finance, 2023). Although there are no active mines in the study area, known mineral occurrences in the Victoria catchment include barite, copper, lead and prehnite. Mining and petroleum exploration licences cover 61% of the

Victoria catchment (Apx Figure B-2) and future demand for minerals is highly speculative as is mining water consumption and use.

Appendix B presents the current mining and petroleum industry setting in the Victoria catchment, commodities' water use, critical minerals and strategic materials occurrences identified in the Victoria catchment, and regulatory frameworks.

2.3.3 Current infrastructure

Transport

The Victoria catchment is serviced by two significant roads: the Victoria and Buntine highways (Figure 2-13). The Victoria Highway is one of many highways that make up Australia's National Highway 1. It runs east–west for a distance of 557 km, linking the Stuart Highway (the major north−south highway through the centre of Australia) at the town of Katherine, to the Great Northern Highway west of Kununurra in WA. Although sealed and well trafficked by both tourist and commercial vehicles (Figure 2-17), few services exist on this route within the catchment. Groceries and fuel can be purchased from smaller stores at locations such as Timber Creek, Kalkarindji and Yarralin. Roadhouses at Victoria River Roadhouse and Top Springs also supply fuel. Flooding causes road closures during the wet season and in some places can be protracted.

The Buntine Highway leaves the Victoria Highway just outside the north-east of the catchment and travels through Top Springs and Kalkarindji (sealed) before crossing into WA (unsealed) where it intersects Duncan Road that continues to Halls Creek. The Buntine Highway carries more commercial traffic than the Victoria Highway (Figure 2-17), largely to service the cattle industry.

The Buchanan Highway is the only other road in the catchment classified to carry Type 2 road trains (Figure 2-14). It provides access to what was once Australia's largest cattle station, Victoria River Downs Station, and other stations in the central and east of the catchment. The Buchanan Highway is also a popular tourist route through the scenic Jasper Gorge. Type 2 road trains are vehicles up to 53 m in length, typically a prime mover pulling three 40-foot (approximately 12 m) trailers (Figure 2-15). Apart from these highways, the Victoria catchment is serviced by a sparse network of mainly unsealed roads, all subject to flooding and wet-season closures. Figure 2-13 shows the network of roads within the Victoria catchment categorised by rank and type of road surface. All road network information in this section is from spatial data layers in the Transport Network Strategic Investment Tool (TraNSIT; Higgins et al., 2015).

Figure 2-14 shows the heavy vehicle access for roads within the Victoria catchment, as determined by the National Heavy Vehicle Regulator. All unclassified non-residential roads in the study area can be accessed by Type 2 road trains. Despite the poorer road conditions of many of the local unsealed roads, large (Type 2) road trains are permitted due to minimal safety issues from low traffic volumes and minimal road infrastructure restrictions (e.g. bridge limits, intersection turning safety). Drivers would regularly use smaller vehicle configurations on the minor roads due to the difficult terrain and single lane access, particularly during wet conditions.

Figure 2-16 shows the mean speed achieved for freight vehicles for the road network. The road speed limits are usually higher than the mean speed achieved for freight vehicles, particularly on unsealed roads. Heavy vehicles using such unsealed roads would usually achieve mean speeds of no more than 60 km/hour, and often as low as 20 km/hour when transporting livestock.

The nearest access to a good-quality standard-gauge rail is outside the catchment at Katherine in the east. This provides freight access to Darwin Port (East Arm Wharf) to the north and to major southern markets via Alice Springs. The rail line is primarily used for bulk commodity transport (mostly minerals) to Darwin Port. There are no branch lines in the Victoria catchment, so goods must be transported to and from loading points by road.

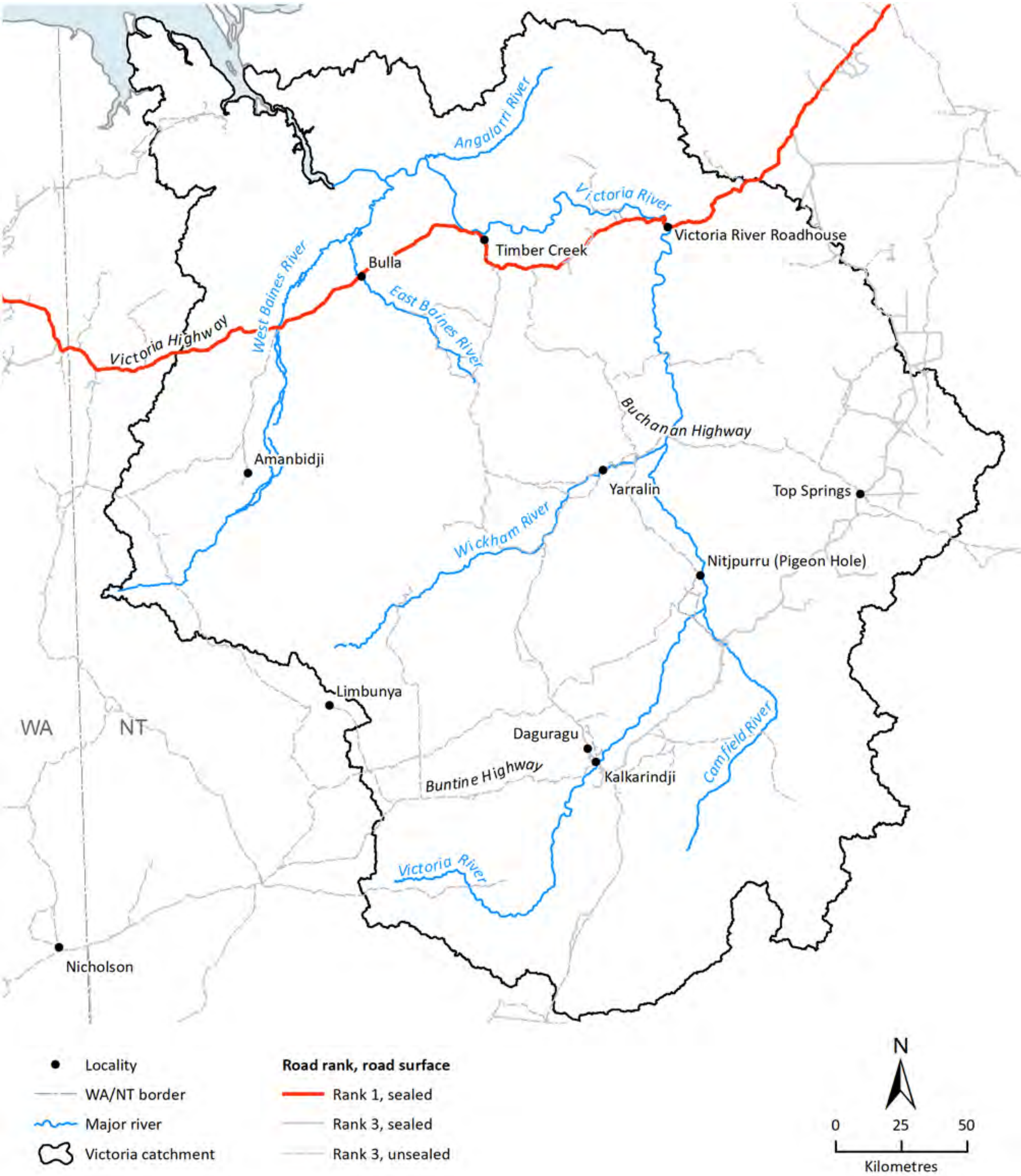


Figure 2-13 Road rankings and conditions for the Victoria catchment

Rank 1 = well-maintained highways or other major roads, usually sealed; Rank 2 = secondary 'state' roads; Rank 3 = minor routes, usually unsealed local roads. The 'Rank 1' road is the Victoria Highway, which runs from Katherine (in the east) to Kununurra (in WA).

Figure 2-14 Roads accessible to Type 2 vehicles across the Victoria catchment: minor roads not classified

Type 2 vehicles are illustrated in Figure 2-15.

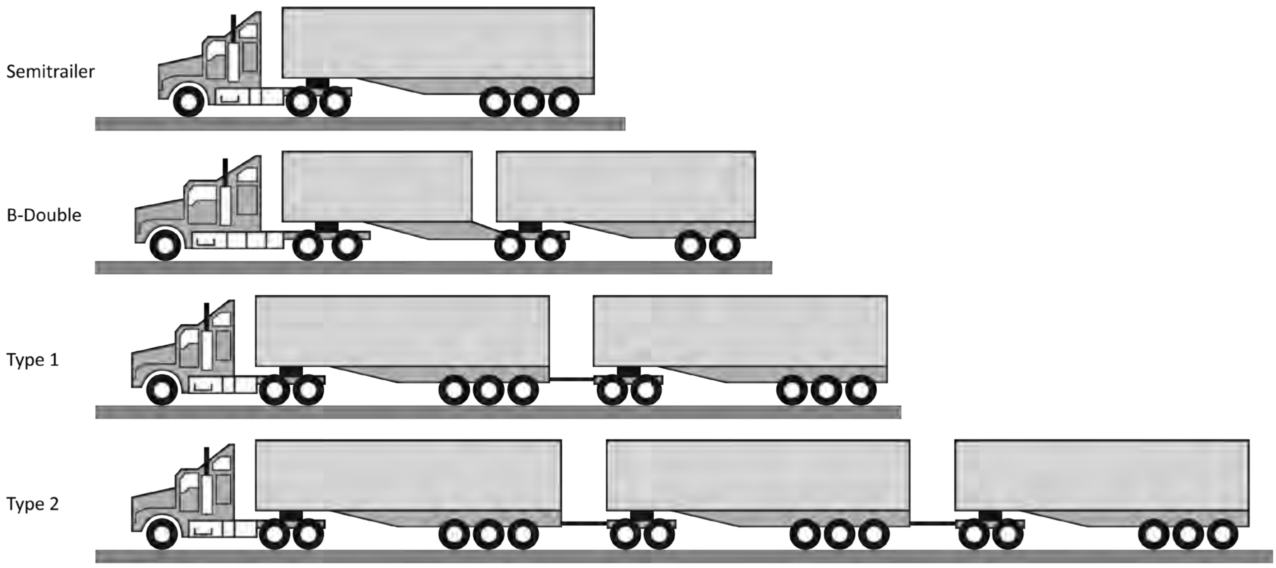


Figure 2-15 Common configurations of heavy freight vehicles used for transporting agricultural goods in Australia

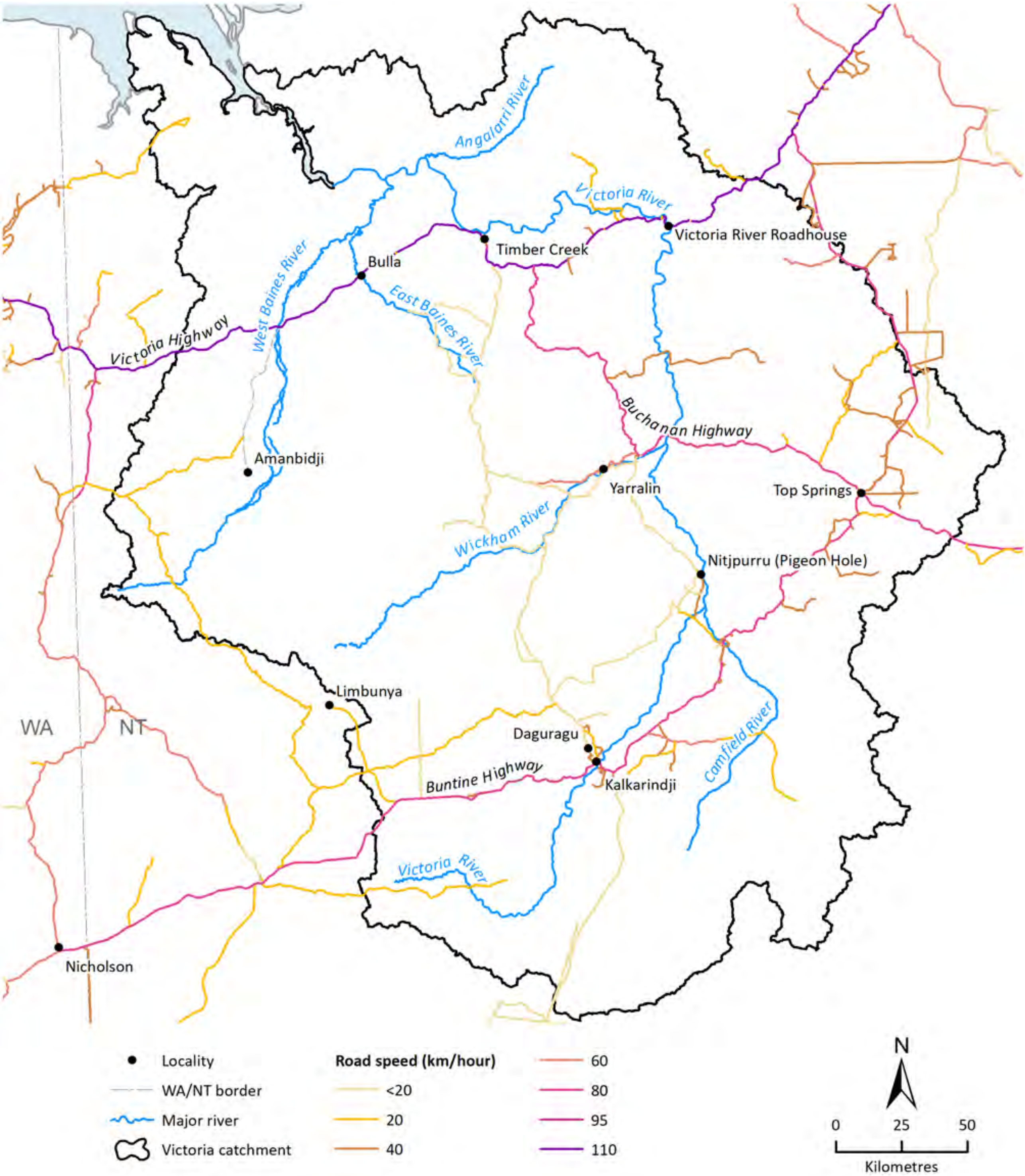


Figure 2-16 Mean speed achieved for freight vehicles on the Victoria catchment roads

Source: Spatial dataset of the location and attributes of roads and ferries sourced from HERE Technologies (2021)

Supply chains and processing

Table 2-5 provides the volumes of commodities (excluding cattle) annually transported into and out of the Victoria catchment, and Figure 2-17 shows the number of trailers and locations of existing pastoral enterprises in the catchment. As previously noted, agricultural production is currently dominated by beef and live cattle export. This is reflected in the annual volumes of commodities transported across the road network with large volumes of freight transporting cattle, mainly via the Buntine Highway. Live export of cattle via Darwin Port accounts for most cattle movements, but there are also substantial transfers of cattle between properties and smaller volumes directed to domestic markets via abattoirs and feedlots.

Table 2-5 Overview of commodities (excluding livestock) annually transported by road into and out of the Victoria catchment

Indicative transport costs are the mean for each commodity and include differences in distances between source and destinations.

COMMODITY	DESTINATION	INBOUND (t)	OUTBOUND (t)	INDICATIVE COST ($/t)
Construction	Construction site	30,081	9000	122.18
Fuel	Fuel station	11,537		85.90
General	Supermarket	852		46.87
Horticulture	Supermarket	687		83.03
Other food	Supermarket	290		68.60
Processed food	Supermarket	1085		75.70

Source: 2021 data from TraNSIT (Higgins et al., 2015)

There are currently no processing facilities for agricultural produce within the Victoria catchment. The Katherine cotton gin officially opened in December 2023, the nearest processing facility, will see its first season of operation in 2024 and could support producers in the catchment. Rainfed and irrigated agriculture (0.02% of the catchment area) is currently for property requirements. The closest large-scale meatworks was run by Australian Agricultural Company at Livingstone, about 40 km south of Darwin, but has not operated since 2018. When operating, the meatworks had all-weather road access by large (Type 2) road trains from the Victoria catchment boundary.

The closest port for bulk export of agricultural produce from the Victoria catchment is in Darwin. Darwin Port, operated by Landbridge Group, handles about 20,000 to 30,000 20-foot equivalent units each year, split roughly evenly between imports and exports. The main exports are dry bulk commodities (mainly manganese) and livestock, but there are also annual exports of about 100 20-foot equivalent units of refrigerated containers. Exports of new bulk agricultural produce would require construction of a new storage facility.

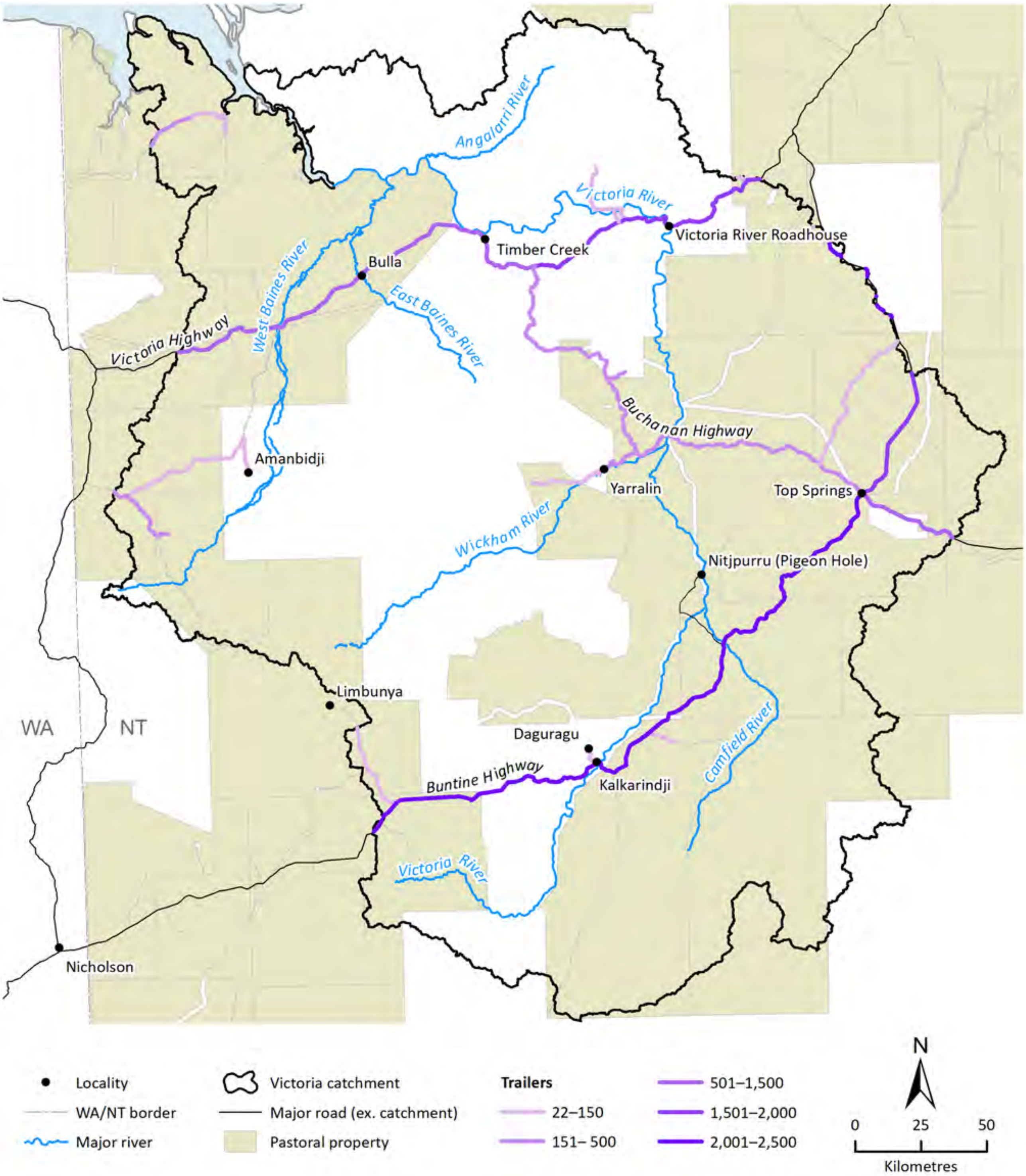


Figure 2-17 All enterprises in the Victoria catchment and amount of annual trucking to and from them

The thickness of purple lines indicates volume of traffic (as number of trailers per year) on regional roads connecting local enterprises.

Energy

The Victoria catchment is in a remote part of the NT that does not have access to major electricity networks and the small communities rely on diesel generators or hybrid diesel – solar systems provided by Power and Water Corporation.

The largest electricity network in the NT is the Darwin–Katherine Interconnected System (DKIS), which connects the capital of Darwin to Katherine further south by a 132-kV transmission line.

(Figure 2-18). The DKIS is electrically isolated from other grids in Australia (but see below for how NT electricity and natural gas transmission systems are interconnected). The DKIS transmission network does not reach the Victoria catchment, passing through Katherine 150 km to the east of the catchment boundary.

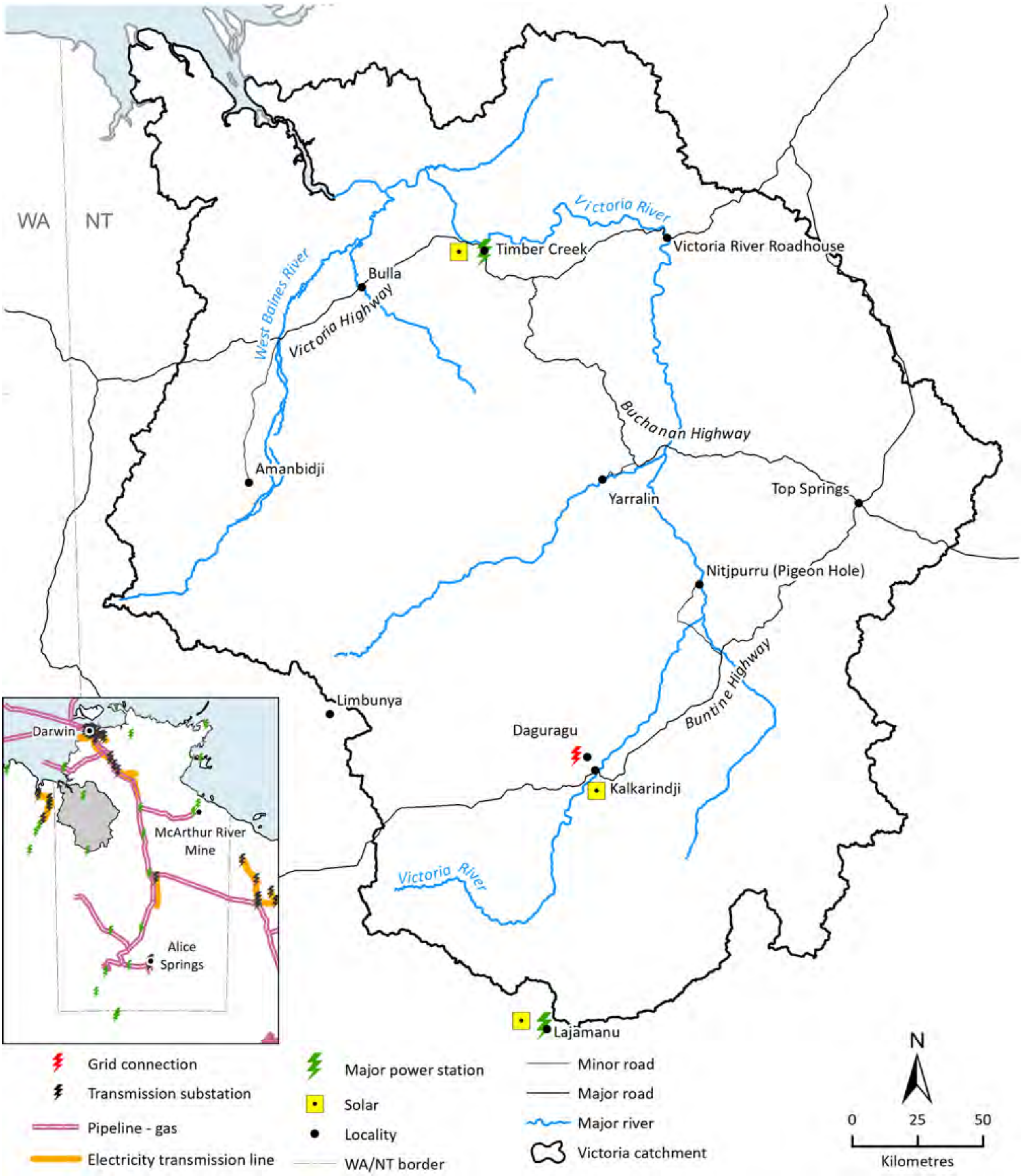


Figure 2-18 Electricity generation and transmission network in the Victoria catchment

Distribution networks are not shown, but communities marked with red lightning symbols are connected to nearby generation or transmission sources of electricity. The inset shows the pipeline and transmission network across the NT with the Amadeus Gas Pipeline running north–south (bi-directional) through Katherine.

The two largest off-grid remote communities in the Victoria catchment rely on hybrid systems powered by diesel generators supplemented with solar: Kalkarindji (408 kW solar system) and Timber Creek. Distribution lines link nearby smaller settlements to these off-grid sources of electricity: Daguragu is connected to Kalkarindji.

Historically, gas pipelines have been a cheaper way of transporting energy than electrical transmission lines (DeSantis et al., 2021; GPA, 2021). So, a network of natural gas pipelines has been a cost-effective way of linking energy supplies across the NT by connecting sources of gas to electricity generators and other demand centres. However, gas power generation is not available in the Victoria catchment. The Amadeus Gas Pipeline is a bi-directional pipeline running from the gas fields of the Amadeus Basin near Alice Springs in the south northwards to Darwin (Figure 2-18). The McArthur River Pipeline connects to the Amadeus Gas Pipeline at Daly Waters and runs east to the generator at the McArthur River Mine (zinc and lead). The Northern Gas Pipeline, which runs 622 km between Tennant Creek in the NT and Mount Isa in Queensland (south of the Victoria catchment), provides a connection between the energy systems of the NT and the eastern states.

Water

Most communities in the Victoria catchment source their water from groundwater for the purposes of stock, domestic and community water supplies. Surface water is also used in some applications: water is pumped from the occasional dam or stream for use by the agricultural and aquacultural industries. There are no major water transmission pipelines in the catchment and only one small dam (Forsyth Creek Dam). Almost all water use in the catchment occurs outside water control districts or water allocation plan areas. The Victoria catchment mostly occurs to the west of the Daly Roper Beetaloo Water Control District, though a small portion of the district occupies the eastern margin of the catchment to the north and south of Top Springs (Figure 2-19). The only water allocation plan currently applicable to the Victoria catchment is the Georgina Wiso Water Allocation Plan, which coincides with a small portion of the eastern margin of the catchment to the west of Top Springs (Figure 2-19).

Surface water entitlements

Licensed surface water entitlements are sparse across the Victoria catchment (Figure 2-19). Four surface water licences have been granted for a combination of use for agriculture and aquaculture, all in the northern parts of the catchment (Figure 2-19). The largest entitlement (of 100 GL/year) is for use in aquaculture with the water sourced from Forsyth Creek near the mouth of the Victoria River (Figure 2-19). The second-largest entitlement is 50 GL/year for use in agriculture with the water sourced from Forsyth Creek Dam in the upper reaches of Forsyth Creek in the northern part of the catchment. Two much smaller surface water entitlements, one sourced from Weaner Dam (1.2 GL/year) and the other from the Victoria River (0.7 GL/year), exist for agricultural use in the north-western Victoria catchment (Figure 2-19).

Groundwater entitlements

There are currently no licensed groundwater entitlements in the Victoria catchment. However, there are three licensed entitlements totalling 7.4 GL/year for use in agriculture to the north-east of the Victoria catchment, occurring in the proposed Flora Tindall Water Allocation Plan area. The groundwater is sourced from the Tindall Limestone Aquifer, which is connected to the limestone aquifer hosted in the Montejinni Limestone along the eastern margin of the Victoria catchment. The Montejinni Limestone hosts the largest and most productive regional-scale groundwater system in the catchment.

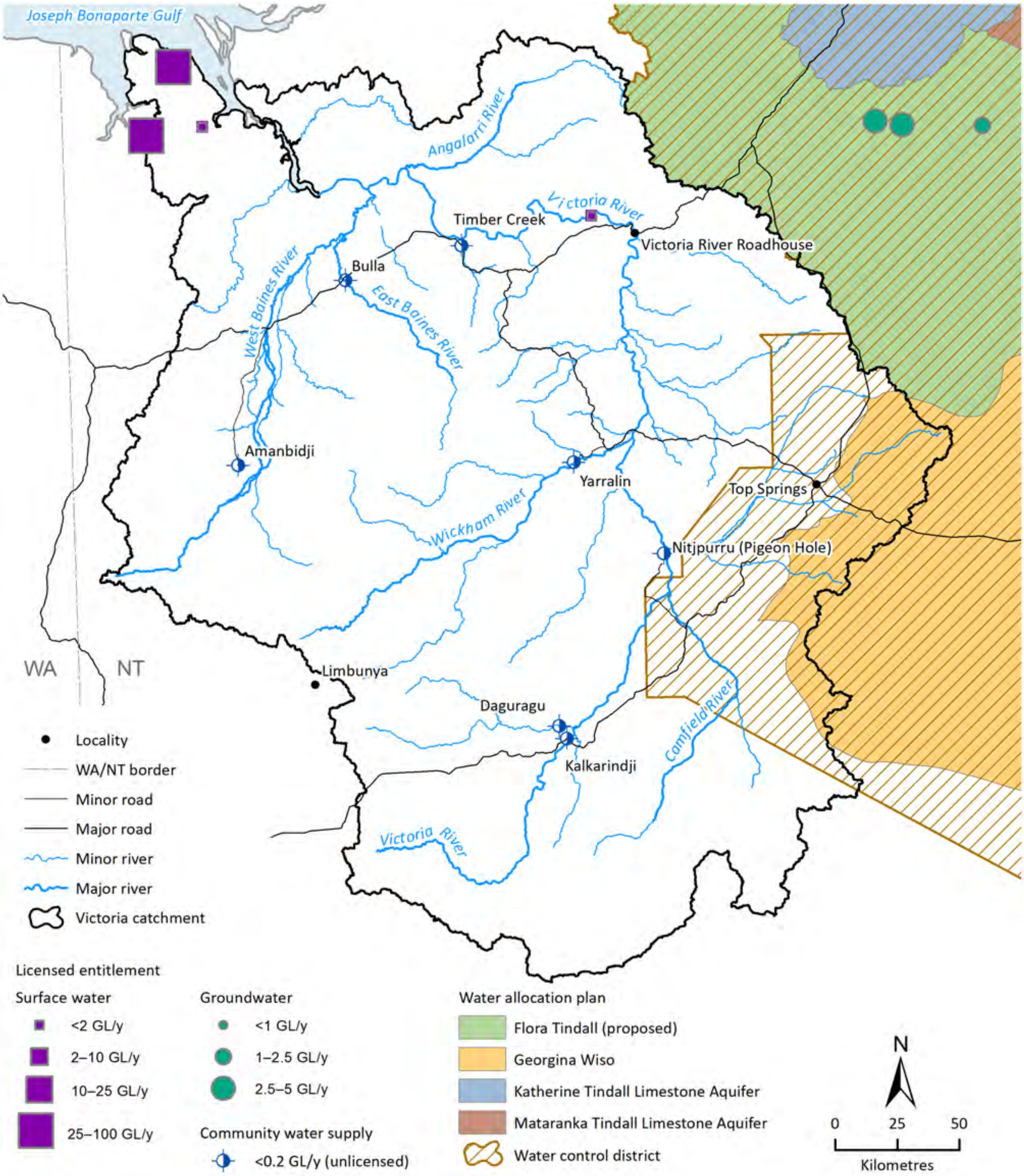


Figure 2-19 Location, type and volume of annual licensed surface water and groundwater entitlements

Data sources: Water allocation plan areas and the Daly Roper Beetaloo Water Control District sourced from NT Department of Environment, Parks and Water Security (2024a, 2024b)

Groundwater resources from a variety of local- to intermediate-scale groundwater systems hosted mostly in fractured and weathered rock aquifers provide important sources of community water supplies. The annual volume of groundwater extracted for community water supplies is only small (i.e. <0.2 GL/year), so a water licence is not required (Figure 2-19). Groundwater is also widely used across the catchment in small quantities for stock and domestic water supplies for which a water licence is also not needed. For more information on groundwater resources of the Victoria catchment, see the companion technical report on hydrogeological assessment by Taylor et al. (2024).

Community infrastructure

The availability of community services and facilities in remote areas can play an important role in attracting or deterring people from living in those areas. Development of remote areas therefore also needs to consider whether housing, education and healthcare are sufficient to support the anticipated growth in population and demand, or to what extent these would need to be expanded.

There are no hospitals in the Victoria catchment, but like most remote parts of Australia, the area is serviced by a primary health network (PHN). Australia is divided into 31 PHNs, and one of these covers the whole of the NT. General practitioners and allied health professionals provide most primary healthcare in Darwin and the regional centres within the NT PHN, while smaller communities are supported by remote health clinics (NT PHN, 2020). The Victoria catchment falls within the Katherine Health Service District (HSD) (also known as the Big Rivers Region) of the NT PHN where the Sunrise Health Service Aboriginal Corporation and Katherine West Health Board (KWHB) provide remote health services. PHNs work closely with local hospital networks, and for the Katherine/Big Rivers Region the associated hospital is Katherine Hospital, which is located approximately 150 km by road outside the eastern border of the Victoria catchment. This hospital has 60 beds and provides emergency services, surgical and medical care, paediatrics and obstetrics (NT PHN, 2020).

There are three health centres (Kalkarindji, Timber Creek and Yarralin) in the Victoria catchment staffed by a health centre coordinator, doctor, remote area nurses and support staff and regularly visited by specialist services and various Katherine West Health Board program staff. Health clinics are found in four communities (Amanbidji, Bulla, Lingara and Nitjpurru (Pigeon Hole)) staffed by visiting doctors, remote area nurses and Aboriginal health workers.

A network of six government schools covers the small communities throughout the Victoria catchment. A total of 321 FTE students are enrolled in these schools with 40.3 teachers (FTE) in 2022 (Table 2-6). The largest school in the catchment is at Kalkarindji. There are a further six schools in Katherine, outside the Victoria catchment and about 290 km north-east of Timber Creek, and there is also a school of the air in Katherine that serves 183.1 students (FTE) across the region.

At the time of the 2021 Census, about 22% of private dwellings were unoccupied, which is higher than the national and NT means, although the absolute number of unoccupied dwellings is small (Table 2-7). This suggests that the current pool of housing may have some capacity to absorb small future increases in population.

Table 2-6 Schools servicing the Victoria catchment

SCHOOL NAME	SCHOOL TYPE	YEAR RANGE	STUDENTS (FTE†)	TEACHERS (FTE)
Schools in the Victoria catchment				
Amanbidji School	Combined	Preschool – Year 9	15	4.2
Bulla Camp School	Combined	Preschool – Year 9	13	1.5
Kalkarindjii School	Combined	Preschool – Year 12	184	18.6
Pigeon Hole School (Nitjpurru)	Primary	Preschool – Year 6	19	4
Timber Creek School	Combined	Preschool – Year 9	37	3
Yarralin School	Combined	Preschool – Year 9	53	9
Schools in Katherine (outside the Victoria catchment)				
Casuarina Street Primary School	Primary	Preschool – Year 6	344.6	25
Clyde Fenton Primary School	Primary	Preschool – Year 6	157	11.2
Katherine High School	Secondary	Year 7 – Year 12	475.6	44.2
Katherine School of the Air	Combined	Preschool – Year 12	183.1	13.3
Katherine South Primary School	Primary	Preschool – Year 6	275	15.6
Kintore Street Special School	Special	Preschool – Year 12	61	11.8
MacFarlane Primary School	Primary	Preschool – Year 6	174.2	12.8

†FTE = full-time equivalent.
Source: ACARA (2022) (data presented with permission)

Table 2-7 Number and percentage of unoccupied dwellings and population for the Victoria catchment

INDICATOR	UNIT	VICTORIA RIVER SA2 REGION	VICTORIA CATCHMENT†	NORTHERN TERRITORY	AUSTRALIA
Total population 2021	People	2609	1600	232,605	25,422,788
Total unoccupied private dwellings 2021	Dwellings	135	83	10,404	1,043,776
% private dwellings that are unoccupied	%	22.20	22.29	12.83	10.12

†Weighted averages of scores for SA2 regions falling wholly or partially within the catchment boundary.
Source: ABS (2021a) Census data

Part II Agricultural development options

Part II analyses the farm-scale performance of potential irrigated agricultural development options and covers the agronomic principles involved in implementing them.

Chapter 3 provides background information on tropical agronomy including the environmental factors affecting crop performance (climate, soils, land suitability, water resources), the range of potential crop options and crop management considerations.

Chapter 4 describes the approach used for crop modelling and other quantitative analyses of a set of 19 possible crop options for the Victoria catchment and the methods used to estimate their potential performance (in terms of yields, water use and farm gross margins).

Chapter 5 presents the results of the farm-scale analyses, uses narrative risk analyses to illustrate opportunities and challenges for establishing viable new enterprises, and interprets the practical implications of the information provided in Part II for the types of cropping systems that could be fine-tuned to Victoria catchment environments.

Part III analyses the scheme-scale viability of irrigated development options and economic considerations beyond the farm gate that would be required for those developments to succeed.

Baling hay in northern Australia

Source: CSIRO – Nathan Dyer

3 Biophysical factors affecting agricultural performance

3.1 Climate

Climate is a key factor in determining the productivity of agricultural and pastoral production systems. While daily temperature, radiation and rainfall influence the rate of crop growth, extreme weather events such as floods, hail, drought or heat waves have additional episodic, and sometimes catastrophic, effects on agricultural production systems. Crop water use is determined by the interaction between atmospheric evaporative demand (controlled by air temperature, vapour pressure deficit (VPD) and windspeed), crop canopy and root system capacity, and the amount of water stored in the soil.

The climate of the catchment of the Victoria River is discussed in detail in the companion technical report on climate (McJannet et al., 2023), and briefly summarised below (Figure 3-1; Figure 3-2). The Victoria catchment has a hot and arid climate that is highly seasonal with an extended dry season between May and October. The Victoria catchment receives, on average, 681 mm of rain per year, 95% of which falls during the summer wet season (1 November to 30 April). Mean daily temperatures and potential evaporation are high relative to other parts of Australia. On average, annual potential evaporation is approximately 1900 mm; however, the annual net evaporative loss (annual evaporation minus rainfall) is a deficit of around 1220 mm.

Overall, the climate of the Victoria catchment generally suits the growing of a wide range of crops, though in most years rainfall would need to be supplemented with irrigation. The variation in rainfall from one year to the next is moderate compared to elsewhere in northern Australia yet is high compared to other parts of the world with similar mean annual rainfall. The length of consecutive dry years is not unusual in the Victoria catchment and the intensity of the dry years is similar to many centres in the Murray–Darling Basin and east coast of Australia. Since 1969–70, 72% of seasons experienced no tropical cyclones, 21% one tropical cyclone, and 6% two tropical cyclones in part of the Victoria catchment.

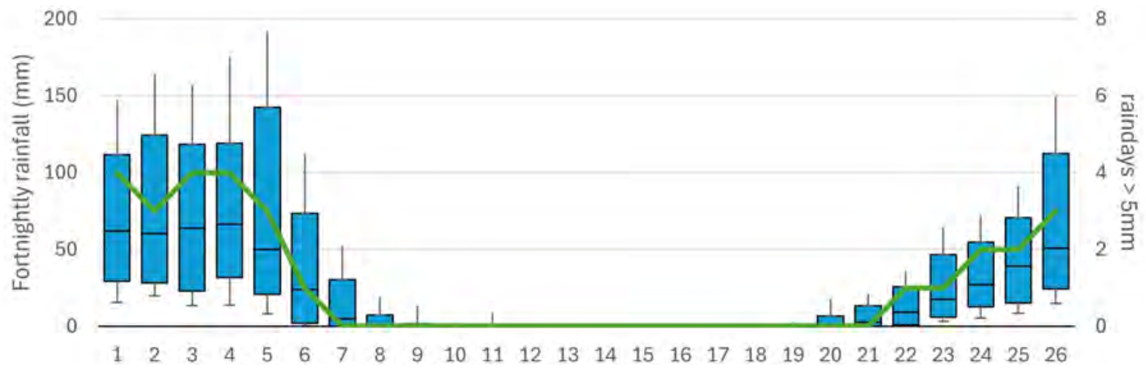
Future climate projections for the Victoria catchment suggest little change in rainfall: approximately 13% of the global climate models (GCM) project an increase in mean annual rainfall by more than 5%, about half project a decrease in mean annual rainfall by more than 5% and about a third indicate ‘little change’.

Each of the key climate parameters that control plant growth and crop productivity are discussed in turn under the subheadings below, although it should be noted that they are interrelated and never act in isolation. Throughout this section, the hot and arid climate of the Victoria catchment is contrasted against that of more temperate southern agricultural areas (using Griffith, NSW, as an example), to highlight how different cropping systems in northern Australia are to those where most of the country’s farming expertise resides.

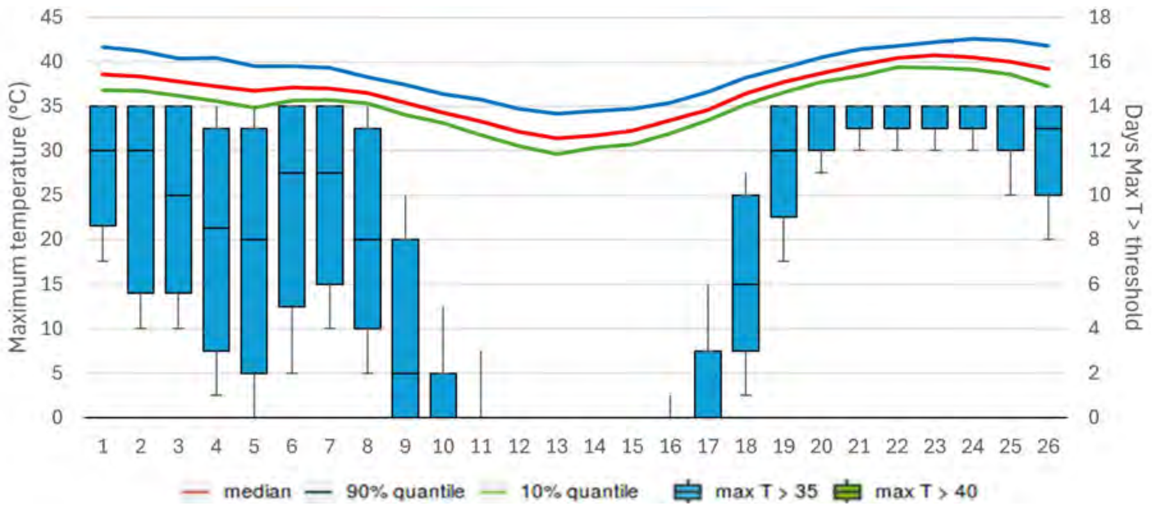
3.1.1 Rainfall

Rainfall in the Victoria catchment largely occurs during the summer wet season. Variability in rainfall is high, with total rainfall over a 14-day period varying by over 150 mm between seasons at Kidman Springs (Figure 3-1). Irrigation can be used to supplement rainfall in the wet season when below average rainfall is experienced, and also facilitate cropping during the dry season (winter months) when sufficient irrigation water is available.

(a) Rainfall, and number of days per fortnight daily rainfall exceeds 5 mm



(b) Maximum temperature, and number of days per fortnight minimum temperatures are above 35 °C and 40 °C thresholds



(c) Minimum temperature, and number of days per fortnight minimum temperatures are below 10 °C and 5 °C thresholds

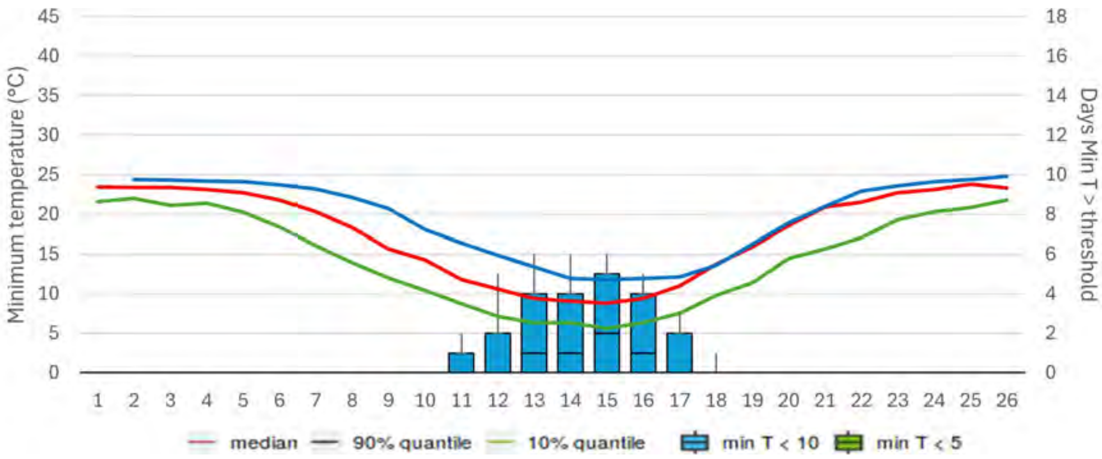
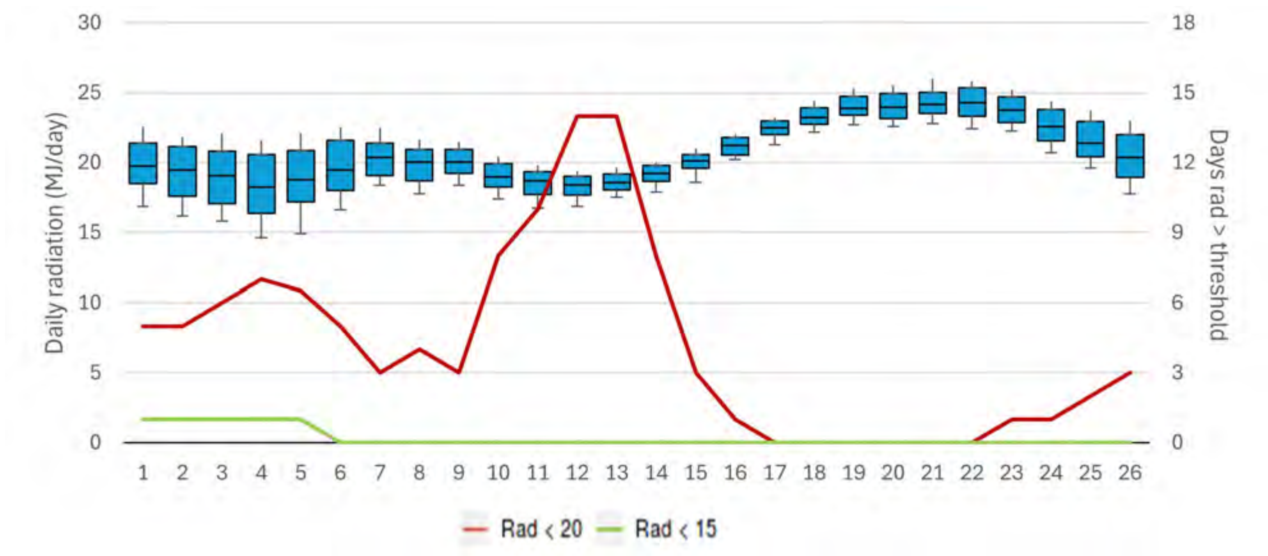


Figure 3-1 Long-term fortnightly climate variation in (a) rainfall, (b) maximum and (c) minimum temperatures for the historical climate (1890 to 2022) at Kidman Springs

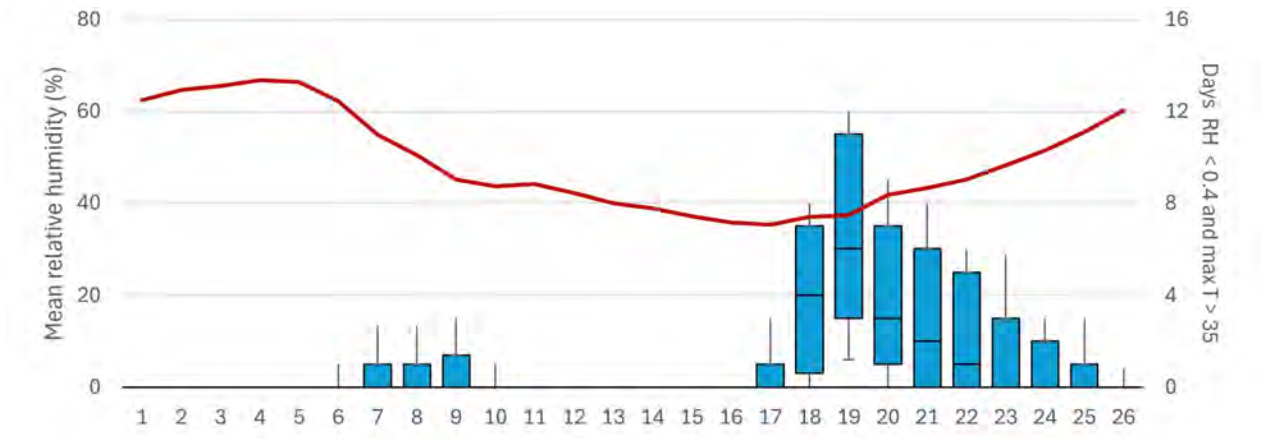
Whiskers on box plots show 10% and 90% exceedance values.

Source: Data sourced from SILO website https://www.longpaddock.qld.gov.au/silo/ (Jeffrey et al., 2001)

a) Solar radiation, and number of days per fortnight radiation is below 20 and 15 MJ per square metre per day thresholds



(b) Relative humidity (RH), and number of days per fortnight RH is below 40% while temperatures exceed 35 °C



(c) Vapour pressure deficit, and number of days per fortnight RH is above 40% while temperatures exceed 35 °C

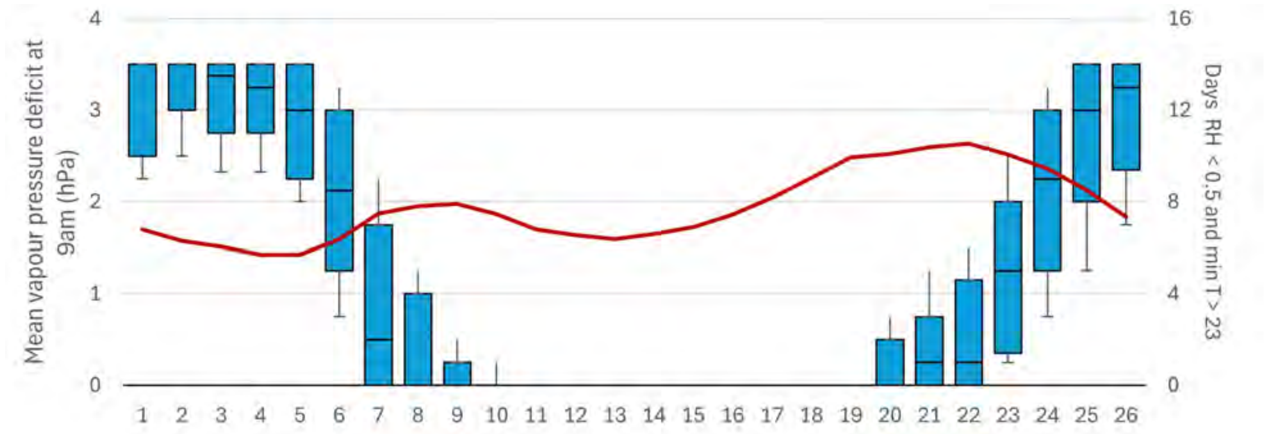


Figure 3-2 Long-term fortnightly climate variation in (a) solar radiation, (b) relative humidity (RH) and (c) vapour pressure deficit (VPD) under the historical climate (1890 to 2022) at Kidman Springs

Whiskers on box plots show 10% and 90% exceedance values.

Source: Data sourced from SILO website https://www.longpaddock.qld.gov.au/silo/ (Jeffrey et al., 2001)

Wet-season rainfall is associated with the monsoon trough, tropical lows or intense storms, which also have implications for crop growth and management. The former can reduce crop yield potential through warm night temperatures and lower solar radiation (due to prolonged cloud cover) as shown for the wet season (December to March) in the Kidman Springs example (Figure 3-2). On the other hand, intense storm events produce strong winds, which have the potential to physically damage crops. Excessive rainfall can also complicate the management of agricultural land, for example in delaying farm operations, or the loss of soil nutrients such as nitrogen through leaching, runoff and denitrification. Waterlogging can also reduce crop growth on clay soils and reduce machine access to fields on heavier soils found in floodplains of the Victoria catchment.

The mean annual rainfall, averaged over the Victoria catchment, is 681 mm (McJannet et al., 2023). Annual rainfall is highest in the northern part of the catchment that receives more active monsoon episodes during the wet season. Rainfall is lowest in the most southerly part the catchment. Mean annual rainfall is about 950 mm at Timber Creek in the north and about 670 mm at Wave Hill in the south. The Victoria catchment is relatively flat, and consequently there is no noticeable topographic influence on climate parameters such as rainfall or temperature. The highest monthly rainfall totals typically occur during January, February and March.

While daily wet-season rainfall is strongly correlated with the Australian Monsoon Index, seasonal rainfall variability experienced in the Victoria catchment is strongly influenced by Indonesian sea surface temperatures and El Niño–Southern Oscillation indices (Rogers and Beringer, 2017). Year-to-year variation in the timing and amount of rainfall affects the amount of water available for irrigation due to fluctuations in stream flows and the consequent opportunities for water harvesting. Irrigated cropping options need to consider the timing and amount of water available.

3.1.2 Evaporation

Evaporation is the ‘drying’ process by which water is lost from open water, plants and soils to the atmosphere. It has become common usage to also refer to this as evapotranspiration. Transpiration is ‘that part of the total evaporation that enters the atmosphere from the soil through the plants’ (Shuttleworth, 1993).

The rate and amount of water evaporated from the soil surface is influenced by surface shading by the crop canopy or surface stubble residues and soil water in the surface soil layers. Crop transpiration is the product of not only solar radiation but also air temperature, air humidity and wind that affect the vapour pressure gradient between plant leaf stomata and the atmosphere (see Section 3.1.5), along with crop factors such as the height and leaf area of the crop, the extent of the root system and the amount of water in the soil.

Evaporation losses from water storages (dams and ringtanks) and delivery systems (diversion streams and channels) need to be considered in determining the overall water availability to meet crop water demand. The mean annual potential evaporation (PE) for the Victoria catchment is 1900 mm (McJannet et al., 2023). Seasonal and inter-annual variation in PE is illustrated for Kidman Springs (Figure 3-3). The mean annual rainfall deficit (mean annual net evaporative water loss from potential open storages) across the Victoria catchment is about 1250 mm (McJannet et al., 2023).

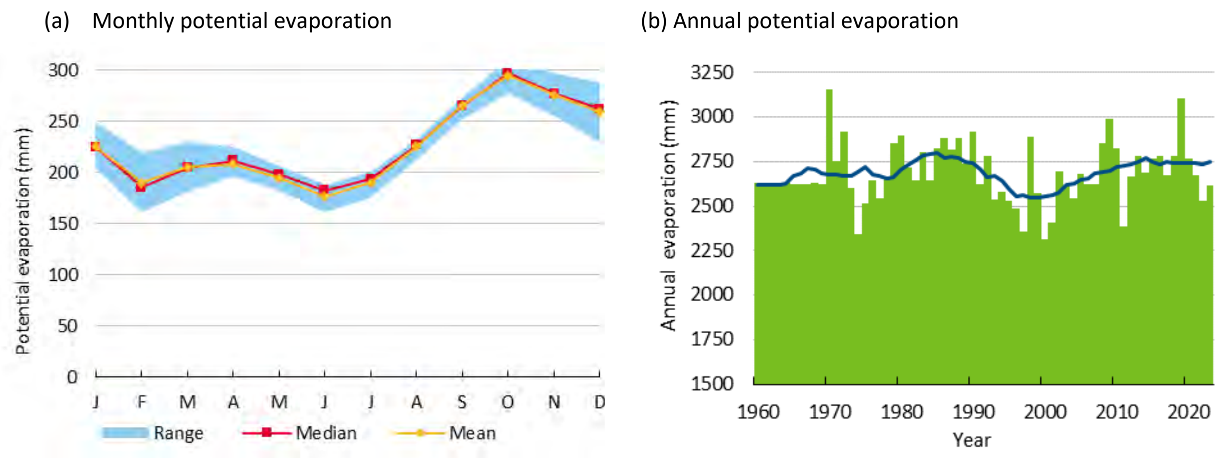


Figure 3-3 Historical potential evaporation (PE) in the Victoria catchment at Kidman Springs for (a) monthly PE (range is the 20th to 80th percentile monthly PE) and (b) time series of annual PE (line is the 10-year running mean)

Source: Data sourced from SILO website https://www.longpaddock.qld.gov.au/silo/ (Jeffrey et al., 2001)

3.1.3 Radiation

Shortwave radiation from sunlight influences plant growth through the process of photosynthesis converting atmospheric carbon dioxide into carbohydrates within the plant. The potential amount of solar radiation intercepted by the crop is determined by latitude (which influences day length), time of year, cloudiness, atmospheric transparency and scattering, and crop canopy characteristics for the growth stage. Solar radiation during the summer months (December to March) is supressed in the Victoria catchment due to increased cloud cover associated with the monsoon trough over northern Australia (Figure 3-4a). While long-term mean radiation during the wet season is reduced to less than 18 MJ per metre square per day from mid-January, radiation levels during the dry season remain high compared to agricultural regions in southern Australia. Figure 3-4a demonstrates how differences in latitude between the Victoria catchment (tropical latitude, about 16°S) and Griffith in southern NSW (subtropical latitude 34.3°S) affect monthly solar radiation. For the Kidman Springs example, solar radiation from April to October remained above 18 MJ per metre square per day, much higher than the radiation experienced during the same period at Griffith (Figure 3-4a), indicative of the subtropical and temperate patterns of radiation in the southern parts of Australia where most crop production occurs. Farmers in the Victoria catchment can maximise crop yields by successfully managing the time of sowing and growing season length to maximise peak radiation intercepted by the crop (March–April and August–September) while avoiding the temperature extremes experienced in October and November.

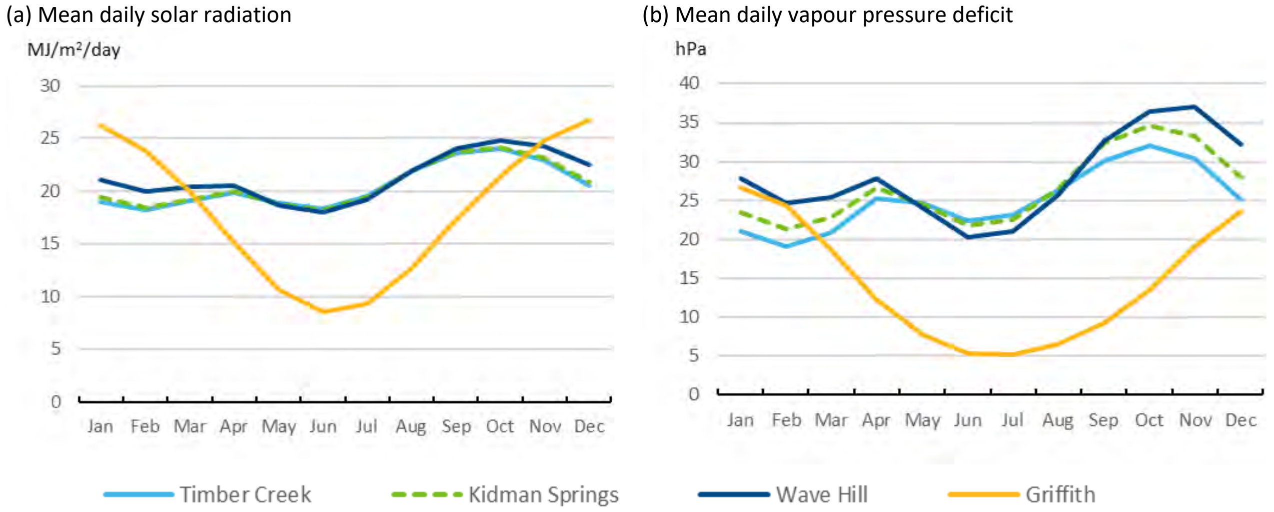


Figure 3-4 Monthly mean daily (a) solar radiation and (b) vapour pressure deficit for three locations in the Victoria catchment (Timber Creek, Kidman Springs, Wave Hill: latitude 15.6–17.4°S) and Griffith (subtropical: latitude 34.3°S)

3.1.4 Temperature

Temperature influences all plant physiological processes and plays a role in determining the length of crop development phases. The optimal temperature for plant growth and therefore maximum individual crop productivity varies between crop species. Temperature extremes at sensitive phenological stages can adversely affect crop productivity. Plant species have differing temperature thresholds for optimum growth and differing responses during periods of extreme high or low temperature. High plant canopy temperatures reduce the efficiency of photosynthesis via increased respiration (particularly at night) and photorespiration, the latter affecting C3 crops (e.g. rice, soybean, mungbean, sesame, cotton, forage legumes). For northern Australia, the highest temperatures generally occur during the months of October to December as shown for the Victoria catchment (Figure 3-5), where the long-term mean daily maximum temperature can exceed 39 °C and night temperature (i.e. minima) exceed 24 °C. High temperature effects (both day and night) on plant photosynthesis are exacerbated by high humidity and low solar radiation.

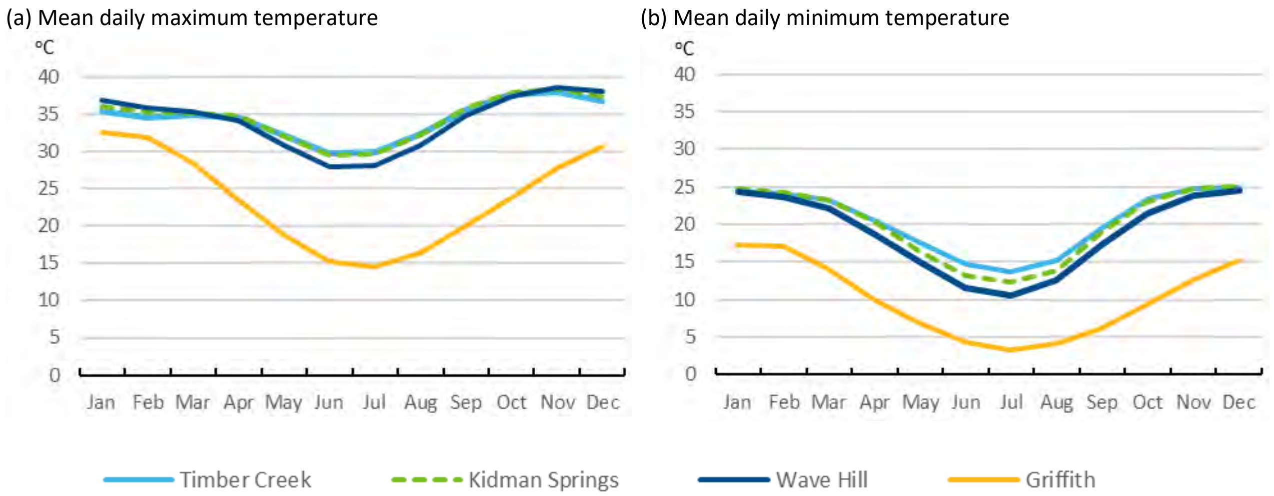


Figure 3-5 Monthly mean daily (a) maximum and (b) minimum daily temperatures for three locations in the Victoria catchment (Timber Creek, Kidman Springs, Wave Hill: latitude 15.6–17.4°S) and Griffith (subtropical: latitude 34.3°S)

Figure 3-5 shows that while the amplitude of annual mean monthly temperatures experienced in the Victoria catchment are smaller than those further south in Griffith, the differences in mean monthly maximum temperatures between the two locations are greatest between August and October. The onset of the wet season (December to March) generally coincides with periods of hot temperatures (slightly cooler than the pre-monsoonal build-up), lower solar radiation and higher humidity/lower VPD (Figure 3-4).

When high temperatures occur at times that crops are growing rapidly and soil water profiles are depleted, the cooling effects of transpiration are diminished and crop canopy temperatures rise. Under such stressed conditions, photosynthesis is reduced and plant tissue damage can occur. Collectively these physiological effects are often referred to as 'water stress'. Prior to the onset of summer rains, low soil water, higher air temperatures and high solar radiation combine to heat soils, particularly those low in vegetative cover. High soil temperatures can reduce seedling emergence and crop establishment. For an irrigated crop, higher temperatures induce higher evaporative demand and increase evapotranspiration, resulting in a higher irrigation requirement to achieve maximum production.

3.1.5 Vapour pressure deficit

Relative humidity (RH), the amount of water vapour in the air as a proportion of the potential amount of water the air can hold for a given air temperature and altitude, is well understood. But VPD is a more accurate measurement of how plants respond to changes in humidity and temperature. VPD is the difference between the current partial pressure of water vapour in the atmosphere and the amount of water vapour that could be held at saturation (at 100% RH at the current temperature). At higher VPDs, the vapour pressure gradient between plants and the atmosphere is stronger, which drives higher rates of transpiration and water use by crops (Rashed, 2016). It is the combination of VPD and high air temperature that reduces the ability of plants to transpire and regulate temperature. High temperatures and low VPD (particularly at night) are as detrimental to canopy temperature regulation as high temperatures and high VPD. During periods of high temperature, supplementary irrigation may assist in reducing plant stress but is of limited value during periods of high VPD. The long-term mean RH for Kidman Springs fluctuates around 40% in the dry season and slightly above 60% in the wet season (Figure 3-2). The occurrence of periods of high humidity also influences the development of many plant diseases. Irrigated crops can be exposed to high levels of humidity that can favour disease infection during the wet season and during cooler nights in the dry season. Lower RH in the spring build-up to the monsoonal season (September to November) correlates with an increase in VPD and higher maximum and minimum temperatures that would require additional irrigation resources to meet higher surface evaporation and transpiration loss (Figure 3-2; Figure 3-4b).

3.1.6 Wind speed

Wind can be both beneficial and harmful to crop productivity. It can aid the process of pollination and is particularly important in the development of fruit and seed from wind-pollinated flowers. However, strong winds can cause excessive water loss through transpiration which can cause crops and trees to wilt, and strong wind can also increase the variability of water distribution on crops under spray irrigation systems. In strong winds, tall crops, particularly crops that are covered with water from rain or spray irrigations, may lodge (fall over), leading to lower photosynthetic potential and making crops more difficult to harvest. Combined with other factors, winds can be particularly harmful; for example, wind-blown sand particles can damage vegetative surfaces. Average monthly wind speed varies in different parts of the Victoria catchment, particularly in the November to March period when average monthly wind speed decreases further away from the coast. By way of example the average monthly wind speed in January is 8 to 10 km/hour on the coast and 2 to 4 km/hour in the southern part of the Victoria catchment (BOM, 2024a). In July the average monthly windspeed is 10 to 15 km/hour across most of the Victoria catchment (BOM, 2024b). Destructive winds and potential flooding associated with tropical cyclones pose a significant threat, particularly to tree crops.

3.1.7 Cyclones

Cyclones are a significant risk to any above-ground infrastructure (sheds, irrigation pivots, etc.) and to tree crops with long life cycles. Tropical cyclones and tropical lows also contribute a considerable proportion of total annual rainfall in the Victoria catchment, but the actual amount is highly variable from one year to the next (see McJannet et al., 2023). There is a reasonably high risk of cyclones in the Victoria catchment from November to April, predominantly in the northern coastal part of the district and particularly in La Niña years (Figure 3-6). For the 53 tropical cyclone seasons from 1969–70 to 2021–22, 72% of seasons experienced no tropical cyclones, 21% one tropical cyclone, and 6% two tropical cyclones in part of the Victoria catchment (McJannet et al., 2023).

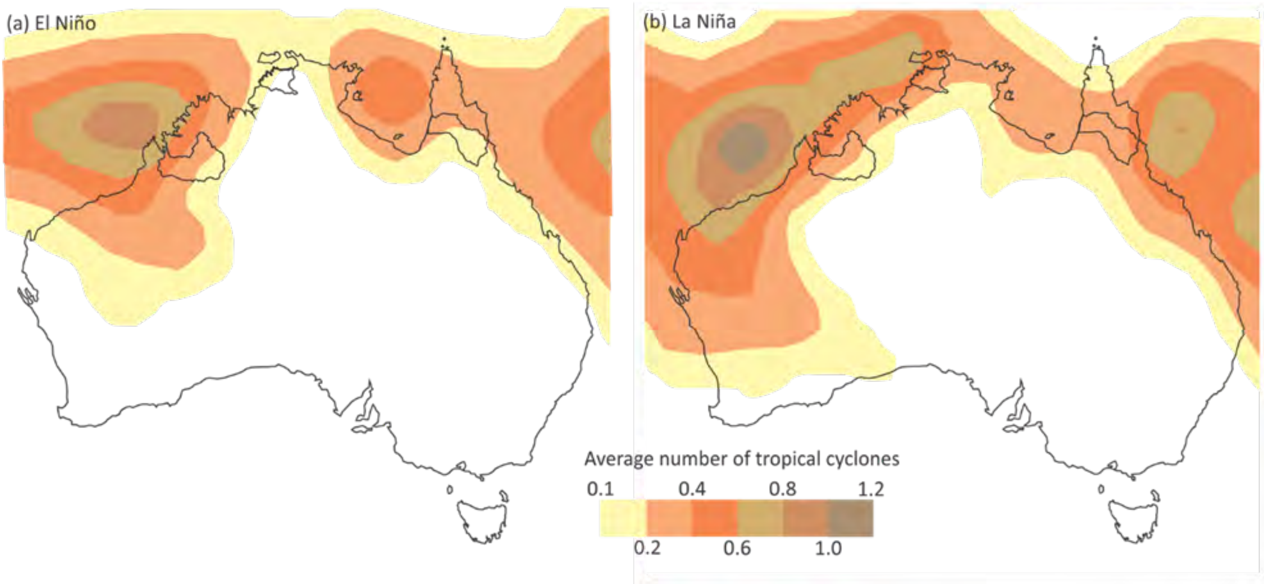


Figure 3-6 Mean annual number of tropical cyclones in Australian for (a) El Niño years and (b) La Niña years

Adapted by Petheram and Bristow (2008) from Bureau of Meteorology cyclone maps http://www.bom.gov.au/climate/maps/averages/tropical-cyclones/.

3.1.8 Future climate

Australia's climate has been progressively warming since the early 1900s (CSIRO and BoM, 2015). Mean overnight minimum temperatures have increased by 1.1 °C and mean daily maximum temperatures by 0.8 °C. Northern Australia, including the Victoria catchment, has experienced a mean temperature increase of between 0.5 and 1.0 °C since 1910. Temperatures are expected to increase in the future, resulting in an increased number of extremely hot days. While winter rainfall has declined by 19% in the south-west of the country, parts of northern Australia have experienced above average increases in rainfall since the 1970s. Future climate projections of rainfall for northern Australia do not show a clear trend, with some models suggesting decreases and others projecting increases in rainfall. An analysis of 32 downscaled global climate model – patterned scaled (GCM-PS) for the Victoria catchment showed that four (or 13%) of the projections for GCM-PSs indicate an increase in mean annual rainfall by more than 5%, two (or 6%) of the projections indicate a decrease in mean annual rainfall by more than 5%, and about 81% of the projections indicate a change in future mean annual rainfall of less than 5% under a 1.6 °C warming scenario. Hence, it can be argued that, based on the selected 32 GCM-PSs, the consensus result is that mean annual rainfall in the Victoria catchment is not likely to change under Scenario C (McJannet et al., 2023). The same analysis projected mean annual change in GCM-PSs PE shows PE increases of about 2% to 10%. However, different methods of calculating PE give different results. Consequently, there is considerable uncertainty as to how PE may change under a warmer climate.

In addition to changes in temperature, evaporation and rainfall as a consequence of increased greenhouse gas emissions, agricultural production will also be affected directly by elevated atmospheric CO_2 concentrations. The direct impacts of elevated atmospheric CO_2 concentrations on crop physiological processes of photosynthesis and leaf stomatal conductance are well-documented from free air CO_2 enrichment experiments (e.g. Hendrey et al., 1993; Tubiello et al., 2007). In the absence of temperature stress, elevated CO_2 improves water use efficiency of crops and grasses by regulating a stomatal closure response in the plant to increase intercellular CO_2 (Parry et al., 2004) and by the passive effects of increasing CO_2 relative to vapour gradients between substomatal spaces and the atmosphere. One anomaly of projected increases in mean temperature associated with elevated greenhouse gases is temperature-induced acceleration of crop development as a result of an increase in the rate of thermal time accumulation. While overall crop yields may decrease in response to increased daily temperature, the rate of decline may be mitigated due to a shortening of the vegetative and grain-filling periods, which may result in phenological development and maturation occurring earlier and possibly within a more favourable climate period, which is crop and temperature dependent (Hatfield et al., 2015). The timing and use of supplementary irrigation will also have a role in reducing the severity of temperature-induced stress in crops.

3.2 Soils and land suitability

3.2.1 Soils

Soils play a vital role in enabling crop production by providing a medium for physical support, nutrient supply and cycling (including associated soil organic matter and soil biota), and water storage and supply. The companion technical report on digital soil mapping and land suitability (Thomas et al., 2024) classified soils of the Victoria catchment into soil generic groups (SGGs) (Figure 3-7; Table 3-1). The ten SGGs provide a means of aggregating soils with broadly similar properties and management considerations.

Each of the SGGs has a different potential for agriculture, some with almost no potential, such as the shallow and/or rocky soils (e.g. SGG 7, Table 3-1) and some with moderate to high potential (e.g. SGG 9, Table 3-1) depending on other factors such as flooding and the amount of salt in the profile.

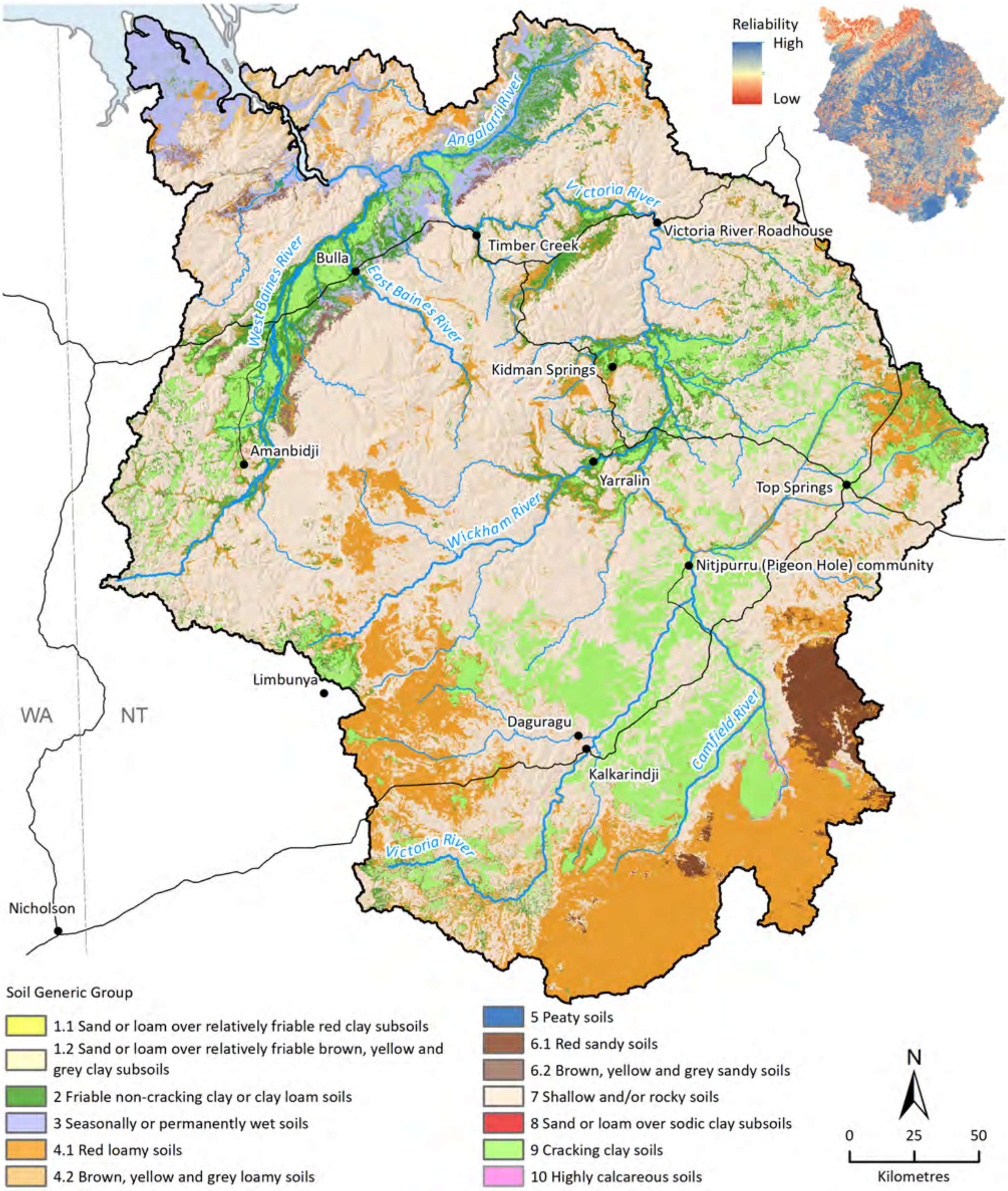


Figure 3-7 The soil generic groups (SGGs) of the Victoria catchment produced by digital soil mapping

The inset map shows the data reliability, which for SGG mapping is based on the confusion index as described in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024).

Table 3-1 Soil generic groups (SGGs), descriptions, management considerations and correlations to Australian Soil Classification (ASC) for the Victoria catchment

Figure 3-7 shows the distribution of the SGGs within the Victoria catchment while Table 3-2 provides the areas, in hectares, within the catchment.

SGG	SGG OVERVIEW	GENERAL DESCRIPTION	LANDFORM	MAJOR MANAGEMENT CONSIDERATIONS	ASC CORRELATION
1.1	Sand or loam over relatively friable red clay subsoils	Strong texture contrast between the A and B horizons, A horizons generally not bleached. B horizon not sodic and may be acid or alkaline. Moderately deep to deep well-drained red soils	Undulating plains to hilly areas on a wide variety of parent materials	The non-acid soils are widely used for agriculture; the strongly acid soils are generally used for native and improved pastures	Red Chromosols and Kurosols except those with strongly bleached A horizons (the AT, AV, AY, AZ, BA or BB subgroups)
1.2	Sand or loam over relatively friable brown, yellow and grey clay subsoils	As above but moderately well-drained to imperfectly drained brown, yellow and grey soils	As above	As above but may be restricted by drainage-related issues	Brown, yellow and grey Chromosols and Kurosols except those with strongly bleached A horizons (the AT, AV, AY, AZ, BA or BB subgroups)
2	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 soils	Plains, plateaux and undulating plains to hilly areas on a wide variety of parent materials	Generally high agricultural potential because of their good structure, their moderate to high chemical fertility and water-holding capacity. Ferrosols on young basalt and other basic landscapes may be shallow and rocky	Ferrosols and Dermosols without sodic B horizons (EO, HA, HC, HO, BA or HB subgroups)
3	Seasonally or permanently wet soils	A wide variety of soils grouped together because of their seasonal or permanent inundation. No discrimination between saline and fresh water	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 and Podosols with long-term saturation
4.1	Red loamy soils	Well-drained, neutral to acid red soils with little or only gradual increase in clay content at depth. Moderately deep to very deep red soils	Level to gently undulating plains and plateaux, and some unconsolidated sediments, usually alluvium	Moderate to high agricultural potential with spray or trickle irrigation due to their good drainage. Low to moderate water-holding capacity, often hardsetting surfaces	Red Kandosols
4.2	Brown, yellow and grey loamy soils	As above but moderately well-drained to imperfectly drained brown, yellow and grey soils	As above	As above but may be restricted by drainage-related issues	Brown, yellow and grey Kandosols
5	Peaty soils (not found in the Victoria catchment)	Soils high in organic matter	Predominantly swamps	Low agricultural potential due to very poor drainage	Organosols

SGG	SGG OVERVIEW	GENERAL DESCRIPTION	LANDFORM	MAJOR MANAGEMENT CONSIDERATIONS	ASC CORRELATION
6.1	Red sandy soils	Moderately deep to very deep red sands. May be gravelly	Sandplains and dunes; aeolian, fluvial and siliceous parent material	Low agricultural potential due to excessive drainage and poor water-holding capacity. Potential for irrigated agriculture	Red Tenosols and Red Rudosols
6.2	Brown, yellow and grey sandy soils	Moderately deep to very deep brown, yellow and grey sands. May be gravelly	As above	Low agricultural potential due to poor water-holding capacity combined with seasonal drainage restrictions. May have potential for irrigated agriculture	Brown, yellow and grey Tenosols. Rudosols and Podosols without long-term saturation
7	Shallow and/or rocky soils	Very shallow to shallow <0.5 m. Usually sandy or loamy but may be clayey. Generally weakly developed soils that may contain gravel	Crests and slopes of hilly and dissected plateaux in a wide variety of landscapes	Negligible agricultural potential due to lack of soil depth, poor water-holding capacity and presence of rock	Most soils <0.5 m, mainly very shallow to shallow Rudosols, Tenosols, Calcarosols and Kandosols
8	Sand or loam over sodic clay subsoils	Strong texture contrast between the A and B horizons; A horizons usually bleached. Usually alkaline but occasionally neutral to acid subsoils. Moderately deep to deep	Lower slopes and plains in a wide variety of landscapes	Generally low to moderate agricultural potential due to restricted drainage, poor root penetration and susceptibility to gully and tunnel erosion. Those with thick to very thick A horizons are favoured	Sodosols; bleached Chromosols and Kurosols (those with AT, AV, AY, AZ, BA or BB subgroups). Dermosols with sodic B horizons (EO, HA, HC, HO, BA or HB subgroups)
9	Cracking clay soils	Clay soils with shrink–swell properties that cause cracking when dry. Usually alkaline and moderately deep to very deep	Floodplains and other alluvial plains. Level to gently undulating plains and rises (formed on labile sedimentary rock). Minor occurrences in basalt landscapes	Generally moderate to high agricultural potential. The flooding limitation will need to be assessed locally. Many soils are high in salt (particularly those associated with the treeless plains). Gilgai and coarse-structured surfaces may occur	Vertosols
10	Highly calcareous soils	Moderately deep to deep soils that are calcareous throughout the profile	Plains to hilly areas	Generally moderate to low agricultural potential depending on soil depth and presence of rock	Calcarosols

Source: Companion technical report on digital soil mapping and land suitability (Thomas et al., 2024)

The Victoria catchment contains soils from nine of the ten SGGs, the exception is peaty soils (SGG 5). Of the nine SGGs found in the catchment, only three occupy more than 10% of the area and together these soils represent 86.6% of the catchment (Table 3-2). The dominant soils of the Victoria catchment are the red loamy soils, principally on the tablelands in the south and south-west (SGG 4.1, making up 17.5%), the shallow and/or rocky soils principally found throughout the central parts of the catchment (SGG 7, 57.4%) and the cracking clay soils typically found along the rivers and broad alluvial plains (SGG 9, 11.7%).

Table 3-2 Area and proportions covered by each soil generic group (SGG) for the Victoria catchment

SGG	DESCRIPTION	AREA (ha)	% OF STUDY AREA
1.1	Sand or loam over relatively friable red clay subsoils	780	0.01
1.2	Sand or loam over relatively friable brown, yellow and grey clay subsoils	2,010	0.02
2	Friable non-cracking clay or clay loam soils	536,580	6.5
3	Seasonally or permanently wet soils	295,660	3.6
4.1	Red loamy soils	1,439,840	17.5
4.2	Brown, yellow and grey loamy soils	80,440	0.9
5	Peaty soils	0	na
6.1	Red sandy soils	127,470	1.6
6.2	Brown, yellow and grey sandy soils	46,060	0.56
7	Shallow and/or rocky soils	4,730,850	57.4
8	Sand or loam over sodic clay subsoils	990	0.01
9	Cracking clay soils	962,440	11.7
10	Highly calcareous soils	16,880	0.2

na = not applicable, not found in the Victoria catchment
Source: Companion technical report on digital soil mapping and land suitability (Thomas et al., 2024)

3.2.2 Land suitability

The overall suitability of a location for a particular land use is determined by a range of attributes. Examples of these attributes include climate at a given location, slope, drainage, permeability, available water capacity (AWC), pH, soil depth, surface condition and texture. From these attributes a set of limitations are derived, which are then considered against each potential land use. Note that the use of the term suitability in the Assessment refers to the potential of the land for a specific land use such as furrow-irrigated cotton.

The Thomas et al. (2024) report provides a complete description of the land suitability assessment framework and the material presented below is summarised from that report. The framework aggregated individual crops into a set of 21 crop groups that have shared land suitability constraints. Land suitability was then determined for 58 land use combinations of crop group × season × irrigation type (including rainfed cropping). Thomas et al. (2024) calculated the overall suitability for a particular land use by considering the set of relevant attributes at each location and determining the most limiting attribute among them. This most limiting attribute then determined the overall land suitability classification on a scale from Class 1 ('suitable with negligible limitations') to Class 5 ('unsuitable with extreme limitations') for that particular combination of crop group × season × irrigation type. Note that this classification explicitly excludes consideration of flooding, risk of secondary salinisation, or availability of water. The intention is that such risks would be considered separately, along with further detailed soil physical, chemical and nutrient analyses before planning any developments at scheme, enterprise or property scale. Caution should therefore be employed when using these data and maps at fine scales.

To provide an aggregated summary of the land suitability products, an index of agricultural versatility was derived for the Victoria catchment (Figure 3-8). Versatile agricultural land was calculated by identifying where the highest number of 14 selected land use options were mapped as being suitable (i.e. suitability classes 1 to 3). Qualitative observations on each of the areas mapped as ‘A’ to ‘E’ in Figure 3-8 are provided in Table 3-3.

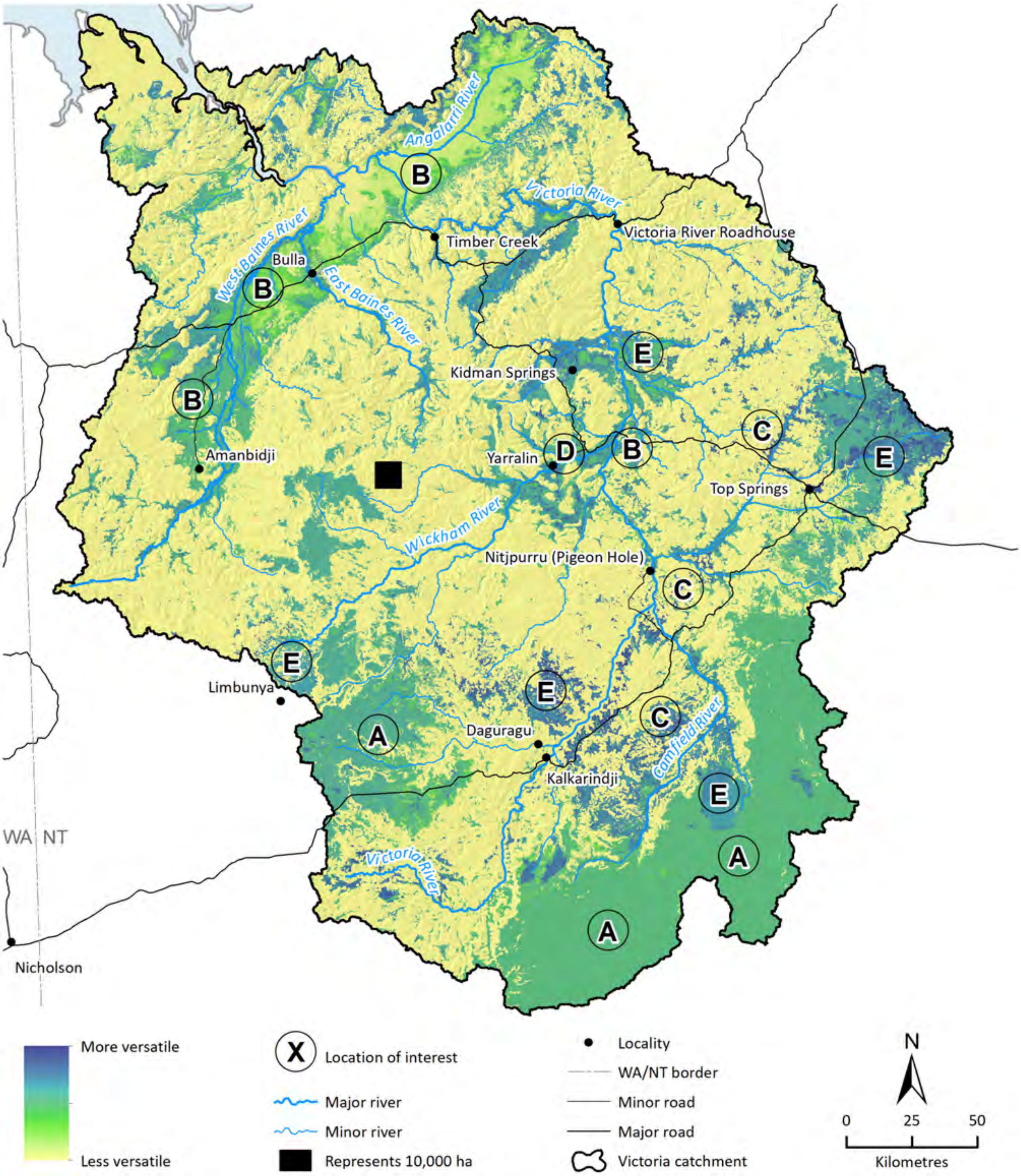


Figure 3-8 Agricultural versatility index map for the Victoria catchment

High index values denote land that is likely to be suitable for more of the 14 selected land use options. The map shows specific areas of interest (A to E) from a land suitability perspective, which are discussed in Table 3-3. Note that the versatility index mapped here does not consider flooding, risk of secondary salinisation or availability of water.

Source: Companion technical report on digital soil mapping and land suitability (Thomas et al., 2024)

Table 3-3 Qualitative land evaluation observations for locations in the Victoria catchment shown in Figure 3-8

Further information on each soil generic group (SGG) and a map showing spatial distribution can be found in Thomas et al. (2024).

AREA	LOCALITY/LOCATION NAME	COMMENT
A	Loamy soils of the western Sturt Plateau, the plateau west of Kalkarindji and the southern part of the catchment	Moderately permeable red loamy soils (SGG 4.1) with varying amounts of iron nodules. Moderately deep to deep loamy soils are suitable for a diverse range of irrigated horticulture and spray-irrigated grain and pulse crops, forage crops, timber crops, sugarcane and cotton. Soils with hard iron nodules may be suitable for small crops, but abundant amounts of nodules will restrict the amount of available soil water for crop growth and cultivation operations. Very shallow soils are generally unsuitable for cropping due to very low available soil water and restricted rooting depth
B	Cracking clays soils on broad alluvial plains of the major rivers, particularly the Victoria, West Baines and mid-Baines rivers	Comprises rarely flooded plains on the Victoria River and West Baines River and regularly flooded plains on the Baines, East Baines and lower West Baines rivers. Soils are mainly moderately well-drained to imperfectly drained brown or grey cracking clay soils (SGG 9) with self-mulching to hardsetting structured surfaces. The imperfectly drained clay soils of the Baines River alluvium grade to poorly drained grey clays (SGG 3) lower in the catchment. The cracking clay soils are suitable for furrow or spray-irrigated sugarcane, dry-season cotton, grain and pulse crops, and forage crops. The main limitations are flooding on the floodplains during the wet season, workability and landscape complexity due to the small and/or narrow areas limiting paddock size and irrigation infrastructure layout due to land dissection. Management of wet-season cropping needs to consider crop tolerance to seasonal wetness and flood duration, depth and frequency
C	Brown, black and red cracking clay soils derived from basalt, mainly in the eastern and southern parts of the catchment	Moderately deep to deep, moderately well-drained to well-drained self-mulching cracking clay soils (SGG 9) on basalt plains, scattered throughout the eastern part of the catchment but mainly in the south. Surface gravels, cobble and stone present. Soils are suitable for a range of spray-irrigated grain and pulse crops, mainly dry-season cropping. Wet-season cropping may be restricted by seasonal wetness and flooding. Extents are generally minor, resulting in small and/or narrow areas limiting paddock size and irrigation infrastructure layout
D	Red friable loamy soils on levees of the Victoria River and Wickham River	Predominantly very deep, well-drained red and brown friable loams (SGG 2) on narrow levees. Soils subject to severe sheet and gully erosion throughout the catchment, and wind erosion in the lower rainfall areas in the south. The narrow levees are suitable for a range of spray-irrigated grain and forage crops and trickle-irrigated horticultural crops, but the generally long thin units of land restrict irrigation layout and machinery use in most areas
E	Grey cracking clay soils of the Cenozoic alluvium scattered through the eastern, southern and western parts of the catchment	Very deep, gilgaied, self-mulching, grey and occasionally grey-brown cracking clay soils (SGG 9) subject to seasonal wetness occur in the lower landscape positions of the deeply weathered plateaux and as level plains overlying a diverse range of other geologies. Suitable for dry-season furrow or spray-irrigated grain and pulse crops, forage crops and cotton. Deep gilgai microrelief may restrict land-levelling operations in some areas

Source: Companion technical report on digital soil mapping and land suitability (Thomas et al., 2024)

3.3 Irrigation systems

3.3.1 Irrigation efficiency and pumping costs

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

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

Once water is delivered to the field, it needs to be applied to the crop using an irrigation system. In-field application efficiency is the percentage of water applied that is available for crop uptake. Efficiency losses occur when applied water evaporates, runs off the field or drains below the root zone. The application efficiency of irrigation systems typically varies between 60% and 90%, with more efficient pressurised systems being more expensive.

There are three types of irrigation systems that can potentially be applied in the Victoria catchment: surface irrigation, spray irrigation and micro irrigation (Table 3-4). Irrigation systems need to be tailored to the soil, climate and crops that may be grown, and matched to the availability and source of water for irrigation. System design also needs to consider investment risk in irrigation systems as well as likely returns, degree of automation, labour availability, and maintenance and operation costs, including pumping costs (Table 3-5). Typically spray and micro irrigation systems are more suitable for permeable or well-drained soils, whereas less expensive surface systems are suitable predominantly on clay soils. Surface irrigation systems have the lowest pumping costs, particularly where they can mainly rely on gravity to distribute water.

Table 3-4 Details of irrigation systems applicable for use in the Victoria catchment

Adapted and updated from Ash et al. (2018), Hoffman et al. (2007), Raine and Bakker (1996) and Wood et al. (2007). Updated to December 2023 dollar values.

IRRIGATION SYSTEM	TYPE	APPLICATION EFFICIENCY (%)	CAPITAL COST ($/ha)	LIMITATIONS
Surface	Basin, border and furrow	60% to 85%	$900 to $4100	For most crops; topography, sandy soils and surface levelling costs may be limiting factors
Spray	Centre pivot	75% to 90%	$3100 to $6800	Not suitable for tree crops; high energy requirements for operation
	Lateral move	75% to 90%	$3100 to $6200	Not suitable for tree crops; high energy requirements for operation
Micro	Drip	80% to 90%	$7300 to $11000	High energy requirement for operation; high level of skills needed for successful operation

Table 3-5 Pumping costs by irrigation operation

Adapted and expanded from Culpitt (2011) with costs calculated from first principles based on assumptions of $2.022/L for diesel ($2.51/L less $0.488/L rebate), $0.30/kWh for electricity, and diesel consumption of 0.25 L/kWh equivalent. Bore pumping is the cost to lift water to the surface per m TDH (total dynamic head) required, where the TDH and maximum flow rate depend on the nature of the aquifer. 1 m TDH = 9.8 kPa.

		SURFACE			SPRAY		MICRO		BORE
ITEM	UNITS	FLOOD HARVESTING	SURFACE IRRIGATION	TAILWATER RETURN	CENTRE PIVOTS	LATERAL MOVES	SUBSURFACE DRIP	LOW PRESSURE DRIPPERS	PER m TDH
Total dynamic head (TDH)	m	7	6	5.5	50	35	50	17	per m
Pumping plant efficiency	%	50%	50%	50%	66%	66%	75%	66%	40%
Energy required	kWh/ML	38.2	32.7	30.0	206.4	144.5	181.7	70.2	6.8
Equivalent diesel requirement	L/ML	9.5	8.2	7.5	51.6	36.1	45.4	17.5	1.7
Pumping cost, electricity	$/ML	$11.40	$9.80	$9.00	$61.90	$43.40	$54.50	$21.10	$2.00
Pumping cost, diesel	$/ML	$19.30	$16.50	$15.20	$104.40	$73.00	$91.80	$35.50	$3.40

3.3.2 Surface irrigation systems

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

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

Surface irrigation can generally be adapted to almost any crop and has a lower capital cost compared with alternative systems (Table 3-4), therefore it is well-suited to broadacre crops that have lower gross margins and larger cropped areas. Surface irrigation systems perform better when soils are of uniform texture because infiltration characteristics of the soil play an important part in the efficiency of these systems. They are not so well-suited to sandy soils due to losses along the furrows. Therefore, surface irrigation systems should be designed into uniform soil management units and layouts (run lengths, basin sizes) tailored to match soil characteristics and water supply volumes. Australian agriculture is increasingly employing water inflow controls to automate surface irrigation systems.

High application efficiencies are possible with surface irrigation systems that are well designed and managed, and sited on appropriate clay soils. On ideal soil types and with systems capable of high flow rates, efficiencies can be as high as 85%. On poorly designed and managed systems on soil types with high variability, efficiencies may be below 60%.

The major cost in setting up a surface irrigation system is generally land grading and levelling, and construction of structures to enable storage, water capture and recycling of runoff water. Costs are directly associated with the volume of soil that must be moved. Typical earthworks volumes are in the order of 800 m^3/ha but can exceed 2500 m^3/ha. Volumes greater than 1500 m^3/ha are generally considered excessive due to costs (Hoffman et al., 2007).

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

3.3.3 Spray irrigation systems

Spray irrigation systems discussed here refer specifically to lateral move and centre pivot irrigation systems. Centre pivot systems consist of multiple sprinklers spaced laterally along a series of irrigation spans, supported by a series of towers. The towers are self-propelled and rotate around a central pivot point, forming an irrigation circle of generally less than 500 m radius with areas less than 80 ha. Output volumes of individual sprinkler heads are set based on proximity to the centre of the circle so that water is applied at a constant rate per hectare across the arc covered by the pivot. The time taken for the pivot to complete a full circle can range from as little as half a day to multiple days depending on crop water demands and application rate of the system. The rotation speed of the centre pivot and flow rate of sprinklers are used determine the irrigation application rate.

Lateral or linear move systems are similar to centre pivot systems in construction but instead of moving in a circle around a central point, an entire row of sprinklers moves laterally down a rectangular-shaped field. Water is supplied by a channel or flexible hose running the length of the field. Lateral system lengths are generally in the range of 800 to 1000 m.

Spray irrigation systems offer the advantage over surface systems that they can be more easily utilised on rolling topography and generally require less land forming. Furthermore, fertiliser can be applied through fertigation where crop nutrients are injected through the irrigation system rather than applied to the field.

Both centre pivot and lateral move irrigation systems have been extensively used for irrigating a range of annual broadacre crops and are capable of irrigating most field crops. They are generally not suitable for tree crops or vine crops. Saline irrigation water applications in arid environments would rapidly rust standard components of the system and can lead to foliage damage (since water is sprayed from above the crop). Centre pivot and lateral move systems usually have higher capital costs but are capable of very high efficiencies of water application. Generally, application efficiencies for these systems range from 75% to 90% (Table 3-4). A key factor for deciding whether spray systems are suitable is sourcing the energy needed to operate these systems, which are usually powered by electricity or diesel depending on costs and infrastructure available. Under high groundwater pressure, centre pivots and lateral moves may be propelled using water pressure (without the need for additional energy from pumping). Wind can have a negative effect on spray irrigation systems, with strong winds increasing the variability of water distribution and very strong winds having the ability to damage centre pivot and lateral move infrastructure.

3.3.4 Micro irrigation systems

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

With pressurised irrigation systems such as micro irrigation, water application can be more easily controlled, and fertigation can be used to precisely apply nutrients during irrigation. For high-value crops, such as horticultural crops, where crop yield and quality parameters dictate profitability, micro irrigation systems should be considered suitable across the range of soil types and climate conditions.

Properly designed and operated micro irrigation systems are capable of very high application efficiencies, with field efficiencies of 80% to 90% (Table 3-4). In some situations, micro irrigation systems also offer labour savings and improved crop quality (i.e. more marketable fruit through better water control and precision application of crop nutrients). Intensive management of micro irrigation systems, however, is critical; to achieve these benefits requires a much greater level of expertise than other traditional systems such as surface irrigation systems. Micro irrigation systems also have high energy requirements, with most systems operating at pressures of about 15 to 500 kPa (about 15 to 50 m TDH) with diesel or electric pumps most often used (Table 3-5).

3.4 Crop types

3.4.1 Broadacre crops

Cereal crops

Cereal production is well-established in Australia. The area of land devoted to producing grass grains (e.g. wheat, barley (*Hordeum vulgare*), rice, grain sorghum, maize, oats (*Avena sativa*) and triticale (× *Triticosecale*)) each year has stayed relatively consistent at about 20 million ha over the decade from 2012–13 to 2021–22, yielding over 55 Mt with a value of $19 billion in 2021–22 (ABARES, 2022). Production of cereals greatly exceeds domestic demand, and the majority (82% by value) was exported in 2021–22 (ABARES, 2022). Significant export markets exist for wheat, rice, barley and grain sorghum, with combined exports valued at $15 billion in 2021–22. There are additional niche export markets for grains such as maize and oats.

Amongst the cereals, summer crops such as grain sorghum and maize have the highest potential in the Victoria catchment. These could be grown opportunistically using rainfed production, utilising stored soil water from the wet season, or in the dry season using irrigation.

To grow cereal crops, farmers would 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.

Pulse crops

Pulse production is well-established in Australia. The area of land devoted to production of pulses (mainly chickpea (*Cicer arietinum*), lupin (*Lupinus* spp.) and field pea (*Pisum sativum*) each year has varied from 1.1 to 2.0 million ha over the decade from 2012–13 to 2021–22, yielding over 3.8 Mt with a value of $2.5 billion in 2021–22 (ABARES, 2022). The vast majority of pulses (93% by value) were exported in 2021–22 (ABARES, 2022). Pulses produced in the Victoria catchment would most likely be exported, although there is presently no cleaning or bulk handling facility.

Many pulse crops have a relatively short growing season, meaning they are well-suited to opportunistic rainfed production, as well as irrigated production either as a single crop or in rotation with cereals or other non-legume crops. In the Victoria catchment, pulse crops would most likely be suited to a production system where harvesting is in the dry season to avoid the negative impacts of rain on seed quality.

Pulses are often advantageous in rotation with other crops because they provide a disease break and, being legumes, are able to fix atmospheric nitrogen into the soil, often providing carry-over nitrogen for subsequent crops. Even where this is not the case, their ability to meet their own nitrogen needs can be beneficial in reducing costs of fertiliser and associated freight. Pulses are a high-value broadacre crop (chickpeas and mungbeans have in recent years achieved prices over

$1000/t) yet produce modest yields (e.g. 1 to 3 t/ha), which means freight costs represent a smaller percentage of the value of the crop compared with higher yielding, lower value cereal crops. This becomes of great importance as the distance from processing facilities and ports increases. To grow pulse crops, farmers would require access to tillage, fertilising, planting, spraying and harvesting equipment. Harvesting is generally a contract operation, and in larger growing regions other activities can also be performed under contract. The equipment required for pulse crops is the same as that required for cereal crops, so farmers intending a pulse and cereal rotation would not need to purchase extra equipment.

Oilseed crops

Soybean, canola (*Brassica napus*), sunflowers (*Helianthus annus*) and sesame are oilseed crops used to produce vegetable oils and biodiesel and as high-protein meals for intensive animal production. Soybean is also used in processed foods such as tofu. It can provide both green manure and soil benefits in crop rotations, with symbiotic nitrogen fixation adding to soil fertility and sustainability in an overall cropping system. Soybean is used commonly as a rotation crop with sugarcane in northern Queensland. Summer oilseed crops such as soybean, sunflower and sesame are more suited to tropical environments than winter-grown oilseed crops such as canola. Cottonseed, a by-product of cotton farming separated from the lint during ginning, is also classified as an oilseed. Cottonseed is used for animal feed and oil extraction.

The area of land in Australia devoted to production of oilseeds (predominantly canola) each year has varied between 2.1 and 3.4 million ha over the decade from 2012–13 to 2021–22, yielding over 8.4 Mt with a value of $6.1 billion in 2021–22 (ABARES, 2022). Most oilseed production (98% by value) was exported in 2021–22 (ABARES, 2022). Canola dominates Australian oilseed production accounting for 98% of the gross value of oilseeds in 2021–22. Soybeans, sunflower and other oilseeds (including peanuts) each accounted for less than 1%.

There is growing interest in soybean production in the NT, particularly from overseas companies looking to export oil to Asia. Soybean is generally grown for grain but is a useful forage crop (cut green or baled) for livestock. Soybean is sensitive to photoperiod (day length) and requires careful consideration in selection of the appropriate variety for a particular sowing window. Newer varieties will need suitability testing in the Victoria catchment to ensure they match the local climate.

Sunflowers are widely grown in central Queensland and in recent years they have been grown in some areas of the Ord Valley. Crop yields are known to decline from southern Australia to northern Australia due to a less suitable climate in the north. There has been little evaluation of sunflowers in the NT.

With no oilseed processing facility in the NT, soybean and sunflowers would need to be transported a significant distance until sufficient scales of production are achieved to justify the investment in processing facilities. Given both their modest yield and price, transport costs are likely to be a major constraint on profitability unless there is a well-developed supply chain into Asia.

Root crops, including peanuts

Root crops including peanuts, sweet potatoes and cassava (*Manihot esculenta*), are potentially well-suited to the lighter soils found across the Victoria catchment. Root crops such as these 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 mechanical pulling. While peanut is technically an oilseed crop, it has been included in the root crop category due to its similar land suitability requirements (i.e. the need for it to be pulled from the ground as part of the harvest operation).

The most widely grown root crop in Australia, peanut, is a legume crop that requires little or no nitrogen fertiliser and is very well-suited to growing in rotation with cereal crops, as it is frequently able to fix atmospheric nitrogen in soil for following crops. The Australian peanut industry currently produces approximately 15,000 to 20,000 t/year from around 11,000 ha, which is too small an industry to be reported separately in Australian Bureau of Agricultural and Resource Economics and Sciences statistics (ABARES, 2022). The Australian peanut industry is concentrated in Queensland. In northern Australia, a production area is present on the Atherton Tablelands, and peanuts could likely be grown in the Victoria catchment. The Peanut Company of Australia established a peanut-growing operation at Katherine in 2007 and examined the potential of both wet- and dry-season peanut crops, mostly in rotation with maize. Due to changing priorities within the company, coupled with some agronomic challenges (Jakku et al., 2016), the company sold its land holdings in Katherine in 2012 (and Bega bought the rest of the company in 2018). For peanuts to be successful, considerable planning would be needed in determining the best season for production and practical options for crop rotations. The nearest peanut-processing facilities to the Victoria catchment are Tolga on the Atherton Tablelands or Kingaroy in southern Queensland.

The stubble remaining after peanut harvest can be used as a high-quality supplementary feed for cattle. Most of the equipment suitable for cereal production (for planting, fertilising, spraying and harvesting) can be used for root crop production; however, specialised equipment is required to remove the roots from the ground prior to harvest. Such harvesting considerations mean that heavy clay soils are not suitable for peanut production. The residue makes good-quality hay that can be sold locally to the cattle industry, if farms have the required hay-making equipment. It is likely that producers who grow peanuts will need to invest in a shelling machine to shell the peanuts prior to transport. While peanuts can be transported with shells, the shells add significant weight and volume to transport, which ultimately reduces profits.

Industrial crops

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

Cotton

Rainfed 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. It varied from 70,000 to 600,000 ha between 2012–13 and 2021–22; a mean of 400,000 ha/year has been grown over the decade (ABARES, 2022). Likewise, the gross value of cotton lint production varied greatly over the past decade, from $0.3 billion in 2019–20 to $5.2 billion in 2021–22. Genetically modified cotton varieties were introduced in 1996 and now account for almost all cotton produced in Australia (over 99%). Australia was the fourth largest exporter of cotton in 2022, behind the United States, India and Brazil. Cottonseed is a by-product of cotton processing and is a valuable cattle feed. Mean lint production in Australia in 2015–16 was 7 bales/ha (ABARES, 2022).

Cotton has a chequered history in northern Australia: the crop has shown vulnerability to insect pests (particularly in the mid-1970s in the Ord River region); moratoria on genetically modified crops by the WA and NT governments prevented commercial investment early this century (Yeates et al., 2013; Yeates, 2001); and production constraints have restricted the scale of production required to encourage investment in local processing facilities. Although many of these issues have been resolved, some negative public perceptions and misconceptions remain. Growers of genetically modified cotton are required to comply with the approved practices for growing those varieties, including preventative resistance management.

Research and commercial test farming have demonstrated that the biophysical challenges are manageable if cotton growing is tailored to the climate and biotic conditions of northern Australia (Moulden et al., 2006; Grundy et al., 2012; Yeates et al., 2013). Specialised harvesting and baling equipment is required for cotton production. In recent years, irrigated cotton crops achieving 10 to 12 bales/ha have been grown successfully in the Ord River Irrigation Area. Cotton trials were also conducted at Katherine in the early 2000s but, due to the length of the wet season, poorly drained soils and the economic area required to support a cotton gin, no cotton industry developed at the time. The need to grow cotton in the dry season to avoid insect pests was historically a limiting factor in regions with a long wet season. More recently however, the lifting of restrictions on genetically modified cotton in 2018 and the development of new varieties have permitted wet-season production. The NT cotton industry is supported by the new cotton gin located outside Katherine, which was officially opened in December 2023. Recent studies suggest that rainfed cotton may be viable in the Katherine-Daly and Tipperary regions (Yeates and Poulton, 2019).

Other industrial crops

Other industrial crops, such as tea (*Camellia sinensis*) and coffee (*Coffea* spp.), are unlikely to yield well in the Victoria catchment due to climate constraints. Sugarcane requires a large area (possibly greater than 25,000 ha) with reliable annual water, as well as a central sugar milling facility. There has been interest in hemp production. Hemp is a photoperiod-sensitive summer annual with a growing season of 70 to 120 days, depending on variety and temperature. Hemp is well-suited to growing in rotation with legumes as hemp can use the nitrogen fixed by the legume crop. Industrial hemp can be harvested for grain with modifications to conventional headers, otherwise all other standard farming machinery for ground preparation, fertilising and spraying can be used. There are legislative restrictions to growing hemp in Australia and northern Australian jurisdictions (the NT, WA and Queensland) have all implemented legislation to license growing of industrial hemp to facilitate development of the industry. To date, recent initial hemp trials in the NT have not been successful from an agronomic or market perspective.

3.4.2 Forage crops

Forage, hay and silage are crops that are grown for consumption by animals. Forage is consumed in the paddock in which it is grown and is often referred to as 'stand and graze'. Hay is cut, dried, baled and stored before being fed to animals, usually in yards for weaning or when animals are being held for sale. Silage production resembles that for hay, but harvested forage is stored wet in wrapped bales or covered ground pits, where anaerobic fermentation occurs to preserve the feed's nutritional value. Silage is often used as a production feed to grow animals to meet the specifications of premium markets.

Rainfed 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, with further room for expansion since fodder costs comprise less than 5% of beef production costs (Gleeson et al., 2012).

The Victoria catchment is suited to rainfed or irrigated production of forage, hay and silage, which could support cattle producers in the surrounding area. Significant amounts of rainfed hay production occur in the Douglas-Daly region, to the north-east of the Victoria catchment. Most of that hay is either used for feeding cattle destined for live export or used as part of a feed pellet used on boats carrying live export cattle.

Forage crops, both annual and perennial, include sorghum, Rhodes grass (*Chloris gayana*), maize and Jarra grass, with specific forage cultivars. If irrigated, these grass forages require considerable amounts of water and nitrogen as they can be high yielding (20 to 40 t dry matter per ha per year). Given their rapid growth, crude protein levels can drop quickly to less than 7%, reducing their value as a feed. To maintain high nutritive value (10% to 15% crude protein), high levels of nitrogen fertiliser must be applied and in the case of hay, the crop needs to be cut every 45 to 60 days.

Forage legumes are desirable because of their high protein content and their ability to fix atmospheric nitrogen in the soil. The nitrogen fixed during a forage legume phase is often in excess of requirements and remains in the soil as additional nitrogen available to subsequent crops. Annual production of legumes tends to be much lower than grasses (10 to 15 t dry matter per ha per year) but their input costs are usually much lower due to reduced nitrogen fertiliser requirements and, because they are shorter cycle crops, their total water use is often lower. Cavalcade and lablab (*Lablab purpureus*) are currently grown in northern Australia. The high crude protein content of forage legumes means that growth rates of cattle can be high.

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. Hay is best stored dry, and silage requires either bunkers or large tarpaulins for covering silage above ground to maintain anaerobic conditions. Grass crops usually make better silage than legume crops because they have higher levels of sugars to aid with fermentation. Forage crops such as maize can be grown until the head just reaches the 'milk stage' to provide high levels of digestible energy while the leaves and stems are still green and high in protein.

3.4.3 Horticultural crops

Intensive horticulture is an important and widespread industry in Australia, occurring in every state, particularly close to capital city markets. Horticultural production varied between 2.9 and 3.3 million t/year between 2012–13 and 2021–22, of which 65% to 70% was vegetables (ABARES, 2022). Unlike broadacre crops, most horticultural production in Australia is consumed domestically. The total gross value of horticultural production was $13.2 billion in 2021–22 (up from $9.3 billion in 2012–13) of which 24% was from exports (ABARES, 2022). Horticulture is also an important source of jobs, employing approximately a third of all people who work in agriculture.

Horticultural production is more intensive than broadacre production and has a higher degree of risk, such as a short season of supply and highly volatile prices as a result of highly inelastic supply and demand. Managing these issues requires a heightened understanding of risks, markets, transport and supply chain issues (including associated interactions with other horticultural production regions).

Production is highly seasonal and can involve multiple crops produced on individual farms to manage labour resources. The importance of freshness in many horticultural products means seasonality of supply is important in the market. Farms in the NT have the advantage of being able to produce out-of-season supplies to southern markets. However, they must also compete with production regions in northern Queensland and northern WA, which are already established production areas with associated infrastructure and are geographically closer to most of the urban centres of southern Australia.

Horticultural row crops

Horticultural row crops are generally short-lived, annual crops grown in the ground such as watermelon and rockmelon. Almost all produce is shipped to major markets (cities) where central markets are located. Row crops such as watermelon and rockmelon use staggered plantings over a season (e.g. every 2 to 3 weeks) to extend the period over which harvested produce is sold. This strategy allows better use of labour and better management for risks of price fluctuations. Often only a short period of time with very high prices is enough to make melon production a profitable enterprise.

Horticultural row crops are well-established throughout the NT. The NT melon industry, consisting of watermelon (seedless), rockmelon and honeydew, produces approximately 25% of Australia's melons. Melon production is well-suited across many parts of the NT and would be well-suited to the Victoria catchment.

Intensive production of vegetables is widely practised close to Darwin, with $61 million in production annually. Asian vegetables consist mainly of okra (*Abelmoschus esculentus*), snake bean (*Vigna unguiculata* ssp. *sesquipedalis*), cucumber (*Cucumis sativus*) and Asian melons. Asian melons (e.g. bitter (*Momordica charantia*), hairy (*Benincasa hispida*), and luffa (*Luffa* ssp.)) are from the cucurbit family and are climbing annual plants. They are consumed as immature fruits either in stir fries, soups or curries. While these crops may also be grown in the Victoria catchment, the high cost of transportation to Darwin would be a disadvantage in comparison to farms already situated in the Darwin area.

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 generally with micro equipment, but overhead spray is also feasible. Leaf fungal diseases need to be carefully managed when using spray irrigation. Micro spray equipment has the advantage of being able to deliver fertiliser along with irrigation.

Horticultural tree crops

Some fruit and tree crops, such as mangoes and citrus, are well-suited to the climate of the Victoria catchment. Other species, such as avocado and lychee (*Litchi chinensis*), are not likely to be as well-adapted to the climate and soils. Tree crops are generally not well-suited to cracking clays, which make up some of the arable soils for irrigated agriculture in the Victoria catchment. Horticultural tree production is more feasible on the lighter, well-drained soils in the south of the Victoria catchment.

A feature of fruit tree production is the time lag between planting and production, meaning decisions to plant need to be made with a long time frame for production and return in mind. Mango production in the NT is buffered somewhat against large-scale competition as its crop matures earlier than the main production areas in Queensland and it can achieve high returns. Mango production in the NT had a gross value of $129 million in 2020, accounting for 38% of the $341 million total value of horticultural production in the NT and half of mangoes produced (by mass) in Australia (Sangha et al., 2022). Other niche tropical fruit trees such as jackfruit (*Artocarpus heterophyllus*), rambutan and dragon fruit (*Selenicereus undatus*) are being commercially grown closer to Darwin. Prices received for niche crops can be very high when demand outstrips production, but the market is very sensitive to oversupply, particularly from cheaper overseas imports.

The perennial nature of tree crops makes a reliable year-round supply of water essential. Some species, such as mango and cashew (*Anacardium occidentale*), can survive well under mild water stress until flowering. It is critical for optimum fruit and nut production that trees are not water stressed from flowering through to harvest, approximately from June to between November and carrying through to February, depending on plant species and variety. Very little rain falls in the Victoria catchment over this period, and farmers would need to have a system in place to access reliable irrigation water during this time. High night-time minimum temperatures can reduce flowering in mangoes, and this has been a problem in orchards in the NT that may be exacerbated in the Victoria catchment areas that experience high minimum temperatures.

Specialised equipment is required for fruit and nut tree production. The requirement for a timely and significant labour force necessitates a system for attracting, managing and retaining sufficient staff. In a remote location the cost of providing accommodation to such staff may be significant. Tree pruning and packing equipment is highly specialised for the fruit industry, as are the micro irrigation systems typically used in horticulture (see Section 3.3.4).

3.4.4 Plantation tree crops

Of the potential plantation tree crops that could be grown in the Victoria catchment, Indian sandalwood and African mahogany are likely to be the most economically feasible. Many other plantation species could be grown but returns are much lower than for sandalwood or African mahogany. African mahogany is well-established in plantations near Katherine and in north Queensland. Indian sandalwood is grown in the Ord River Irrigation Scheme (WA), around Katherine (NT) and in north Queensland. The first commercial crops of Indian sandalwood grown in Australia began being harvested in 2013 in the Ord River Irrigation Scheme and over the 24-year period of their cultivation to date many agronomic challenges have been solved. The economic viability of Indian sandalwood relies heavily on sandalwood oil price, and with the long lead time to production, decisions to plant Indian sandalwood is higher risk compared to many other cropping options. The recent liquidation of Quintis demonstrates the risks with forestry plantations and throws into doubt the viability of current and future Indian sandalwood production in the north.

Although they are fertile, the cracking clay soils found in parts of the Victoria catchment are not well-suited to tree crops due to increased potential for root shearing without very careful and ongoing irrigation management, and their susceptibility to seasonal inundation. Plantation species require greater soil depth than most other crop species so deeper loams and sands can be well-suited where irrigation is available.

Plantation tree crops require over 15 years to mature, but once established they can tolerate prolonged dry periods. Irrigation water is critical in the establishment and in the first 2 years of a plantation for a number of species. In the case of Indian sandalwood (which is a hemi root parasite), the provision of water is not just for the trees themselves but the leguminous host plant. Some plantation tree crops can be grown under entirely rainfed conditions (e.g. African mahogany).

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

3.4.5 Niche crops

Niche crops such as guar (*Cyamopsis tetragonoloba*), chia (*Salvia hispanica*), quinoa (*Chenopodium quinoa*), bush foods, and others may be feasible in the Victoria catchment, but there is limited verified agronomic and market data available for these crops. Niche crops are niche due to the limited demand for their products. As a result, small-scale production can lead to very attractive prices, but only a small increase in productive area can flood the market, leading to greatly reduced prices and making production unsustainable.

There is growing interest in bush products, but insufficient publicly available information for inclusion with the analyses of irrigated crop options in this report. Bush product production systems could take many forms, from culturally appropriate wild harvesting targeting Indigenous cultural and environmental co-benefits to intensive mechanised farming and processing, resembling something like macadamia farming, with multiple possible combinations and variants in between. The choice of production system would have implications for the extent of Indigenous participation in each stage of the supply chain (farming, processing, marketing and/or consumption), the co-benefits that could be achieved, the scale of the markets that could be accessed (in turn affecting the scale of the industry for that bush product), the price premiums that produce may be able to attract, and the viability of those industries. The current publicly available information on bush products is mainly focused on eliciting Indigenous aspirations, biochemical analysis (for safety, nutrition and efficacy of potential health benefits of botanicals), and considerations of safeguarding Indigenous intellectual property (e.g. Woodward et al., 2019). Analysing bush products in a comparable way to other crop options in this report would first require these issues to be resolved, for communities to agree on the preferred type of production systems (and pathways for development), and for agronomic information on yields, production practices and costs to be publicly available.

3.4.6 Aquaculture

Aquaculture opportunities were not evaluated in this Assessment but were covered as part of a previous resource assessment for the Darwin catchments (Irvin et al., 2018). Appendix A draws on that report to summarise: (i) the three most likely candidate species for new aquaculture industries in the Victoria catchment; (ii) an overview of the different types of intensive and extensive production systems that could be employed; and (iii) the financial viability of different options for aquaculture development, presenting an updated financial analysis that follows the same approach used previously in Irvin et al. (2018).

3.5 Crop and forage management

3.5.1 Irrigation

Irrigated agriculture in the Victoria catchment will be limited by the amount of irrigation water that can be reliably supplied. The companion technical reports on river model scenario analysis (Hughes et al., 2024a), surface water storage (Yang et al., 2024) and hydrogeological assessment (Taylor et al., 2024) provide an overview of reliable water yields. Irrigation is required to allow reliable establishment and production of most crops at the time of year they are optimally grown. The Victoria catchment exhibits a strong wet-season/dry-season rainfall pattern (Figure 3-1). Short-duration crops sown during the wet season (November to April) may require little or no supplementary irrigation, while those sown during the drier winter months may require full irrigation during the growing period to meet crop transpiration demand. Perennial crops also require irrigation through the dry season. The primary determinants of the amount of irrigation water required are the time of year the crop is grown, the duration of the growing season, how much water can be stored in the soil (particularly what is available at the time of sowing), the amount of in-crop rainfall received, and PE (especially during periods when the canopy is fully developed). The amount of irrigation required per hectare is also determined by the crop grown and crop management, such as the irrigation system used. Section 3.3 covered the various types of irrigation systems that could be used in the Victoria catchment, together with the implications of each for crop management, including irrigation efficiency and pumping costs.

When irrigation water is limited, farmers need to consider a range of factors to determine the best way to make use of the limited water. Where multiple crops of different value are grown on the farm, the decision would be straightforward to give priority to irrigating a high-value horticultural plantation crop such as mangoes over planting a low-value broadacre crop. In other situations, a decision would need to be made about whether to grow a small area of fully irrigated crop, or a large area of partially irrigated crop. The choice of strategy in this situation can be heavily dependent on the amount of rain likely to fall during the cropping period, the degree to which water stress affects yields and the farmer’s attitude to risk. For example, one study showed that deficit irrigating wheat could be a viable strategy for managing water limitations in subtropical areas of south-eastern Australia (Peake et al., 2016), while yields of crops like cotton can be very sensitive to water deficits. Seasonal variability in water supplies could suggest that different irrigation strategies are better suited to different years/season types (for example full versus partial irrigation; Gaydon et al., 2012). Ultimately this would be an economic decision about trading off the high irrigated water use efficiency that can be achieved with deficit irrigation against the impact on crop yield, harvest quality and revenue.

Opportunities for rainfed cropping in the Victoria catchment may be limited. Rainfed crops, grown without any applied irrigation water, rely on rainfall (either stored in the soil or received during crop growth) for all of their water requirements. The more rainfall that is received, the greater a rainfed crop will typically yield. Rainfed yields are usually lower than irrigated yields, but in years receiving above average rainfall during the growing season rainfed yields may be similar to irrigated yields with careful management. Short-duration crops such as mungbean and sorghum established during the wet season are able to utilise in-crop rainfall during early stages of crop development, and then rely on stored water in the soil to minimise water stress during the later grain-filling period (restricted to areas of soils with high water-holding capacity in the Victoria catchment). Harvesting would occur at the end of the wet season. To achieve increased rainfed yields in seasons with above average in-crop rainfall, additional fertiliser inputs and pest management are also required. The inter-annual variability of rainfall means that continuous year-on-year rainfed cropping is unlikely to be feasible in the Victoria catchment. Opportunistic cropping, pursued when conditions are favourable, particularly in the higher rainfall areas of the catchment in combination with soils that possess high water-holding capacity, is likely to provide the most profitable and sustainable approach to rainfed cropping.

3.5.2 Sowing time and cropping calendar

Time of sowing can have a significant effect on achieving economical crop and forage yields, and on the availability and amount of water for irrigation required to meet crop demand. Cropping calendars identify optimal sowing times and compare the growing seasons of different crops. Optimal sowing times presented here for the Victoria catchment are a compromise between optimising yield and the consideration of soil trafficability for sowing the crop. In practice optimal sowing times would also account for water availability and economic considerations. A cropping calendar is an essential crop management planning tool that is used to schedule farm operations for a given crop, from land preparation and sowing/planting times through the growing season to harvest (Figure 3-9) so that crops can be reliably and profitably grown. The calendar assumes best agronomic management in establishment, weed and insect control, and nutrient and water inputs to minimise stress during crop and grain development.

Sowing windows vary in both timing and length among crops and regions, and consider the likely suitability and constraints of weather conditions (e.g. heat and cold stress, radiation and conditions for flowering, pollination and fruit development) during each subsequent growth stage of the crop. Limited field experience currently exists in the Victoria catchment for most of the crops and forages evaluated. The cropping calendar in Figure 3-9 is therefore based on knowledge of crops derived from past and current agricultural experience in the Ord River Irrigation Area (WA), Katherine and Douglas-Daly (NT) and the Burdekin region (Queensland), combined with an understanding of plant physiology, which enables crop response to differences in local climates to be anticipated. The optimum planting window and growing season for each crop were further refined through local experience and use of the APSIM (Agricultural Production Systems sIMulator) cropping systems model.

Some annual crops have both wet-season and dry-season cropping options. Perennial crops are grown throughout the year, so growing seasons and planting windows are less well defined. Generally, perennial tree crops are transplanted as small plants (not seeds), and in northern Australia this is usually timed towards the beginning of the wet season to take advantage of wet-season rainfall.

Sometimes crops can be successfully sown outside of the identified sowing windows without incurring a substantial yield penalty. In this analysis, sowing dates between September and November have generally been avoided because high evaporative demand and low water availability (see Section 3.1) are not conducive to seedling establishment; however, it is possible to sow at this time for many crops.

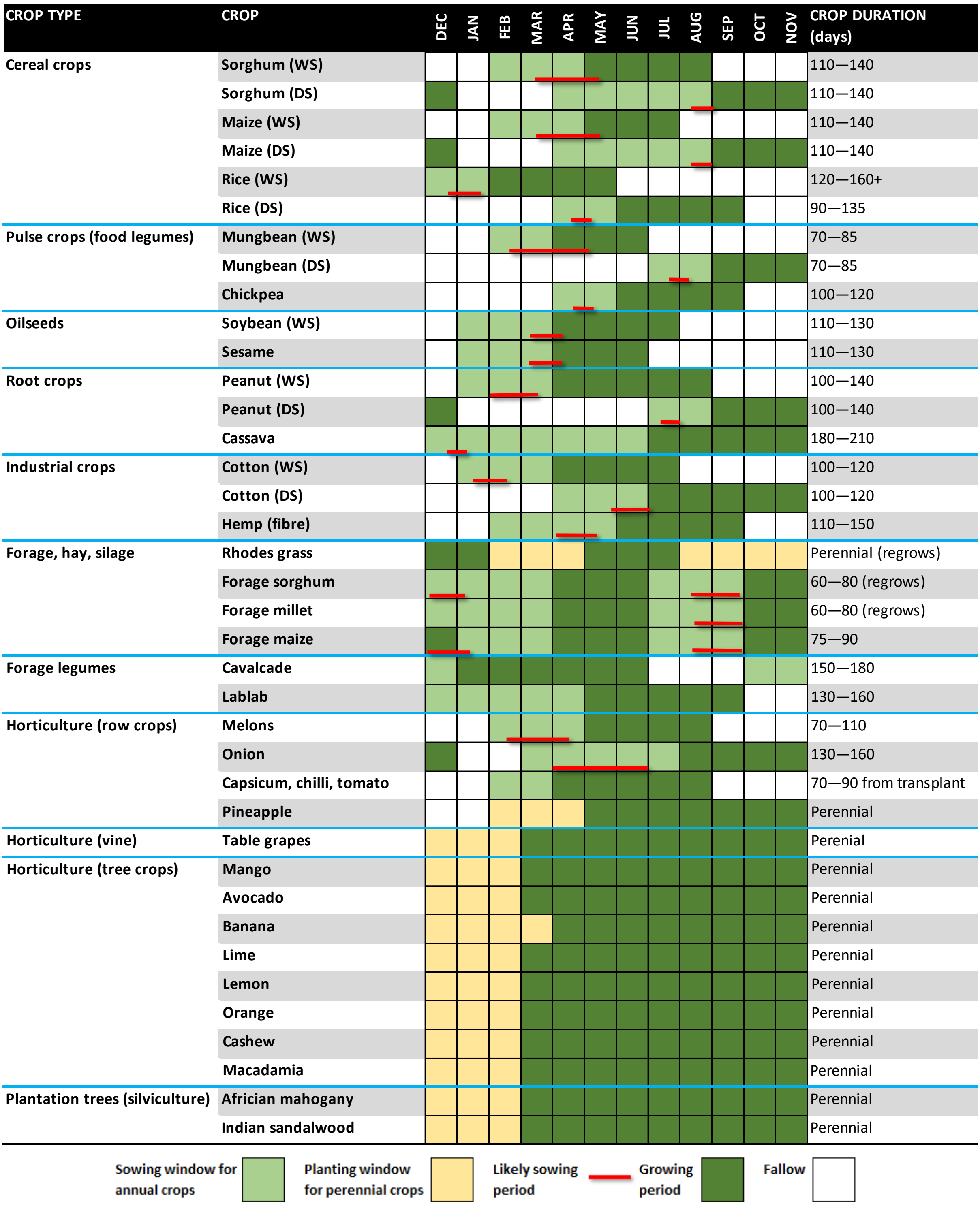


Figure 3-9 Annual cropping calendar for cropping options in the Victoria catchment

WS = wet season; DS = dry season

Figure 3-9 considers only the optimal climatic conditions for crop growth and is intended to be used to with considerations of other operational constraints specific to the local area. Such constraints would include wet-season difficulties in access and trafficability and limitations on the number of hectares per trafficable day that available farm equipment can sow or plant. For example, clay-rich alluvial Vertosols are likely to present severe trafficability constraints throughout much of the wet season in the Victoria catchment, while sandier Kandosols would present far fewer trafficability restrictions in scheduling farming operations (Figure 3-10).

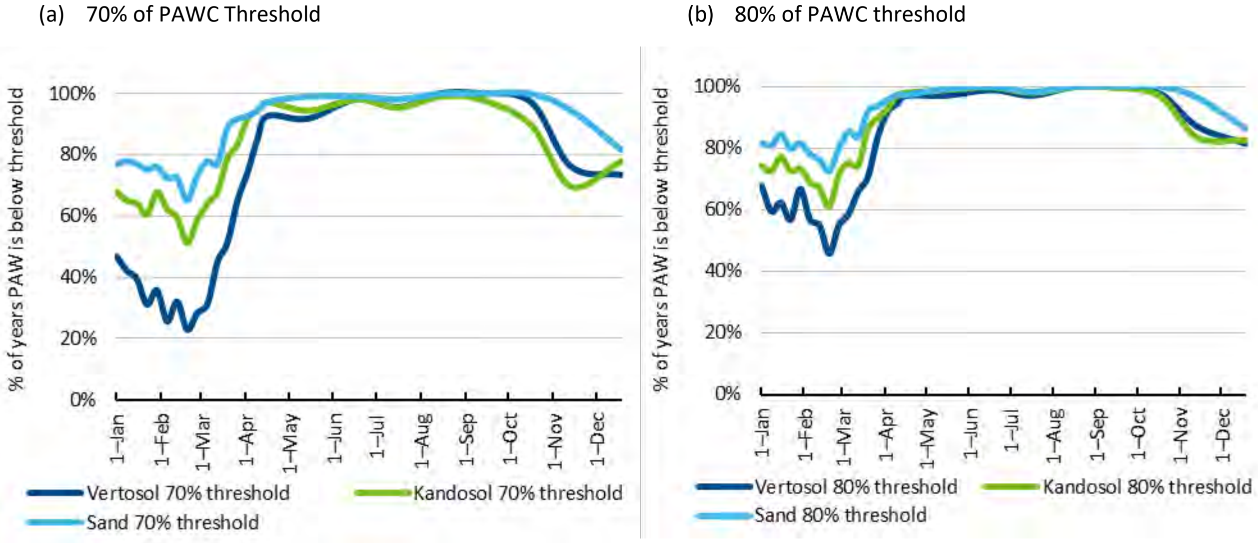


Figure 3-10 Soil wetness indices that indicate when seasonal trafficability constraints are likely to occur on Vertosols (high clay), Kandosols (sandy loam) and sand at Kidman Springs for (a) threshold of 70% of plant available water capacity (PAWC) and (b) 80% of PAWC

The indices show the proportion of years (for dates at weekly intervals) when plant available water (PAW) in the top 30 cm of the soil is below two threshold proportions (70% and 80%) of the maximum PAW value. Lower values indicate there would be fewer days at that time of year when fields would be accessible and trafficable. Estimates are from 100-year APSIM simulations without a crop. In actual farming situations, once a crop canopy is established later in the season, crop water extraction from the soil would assist in alleviating these constraints.

Many suitable annual crops can be grown at any time of the year with irrigation in the Victoria catchment. Optimising crop yield alone is not the only consideration. Ultimately, sowing date selection must balance the need for the best growing environment (optimising solar radiation and temperature) with water availability, pest avoidance, trafficability during the season and at harvest, crop rotation, supply chain requirements, infrastructure development costs, market access considerations, and potential commodity price. For example, for annual horticultural crops growing season selection is based on meeting market windows outside of when southern production areas can supply product, or to coincide with optimal growing conditions for yield and quality; while cotton is most reliable when flowering occurs in the sunny warm months of April–May and picking follows in the dry months of July–August.

Many summer crops from temperate regions are suited to the tropical dry season (winter) because temperatures are closer to their optima and/or there is more consistent solar radiation (e.g. maize, chickpea and rice). For sequential cropping systems (that grow more than a single crop in a year in the same field), growing at least one crop partially outside its optimal growing season can be justified if it increases total farm profit per year and there are no adverse biophysical consequences (e.g. pest build-up).

Growers also manage time of sowing to optimally use stored soil water and in-season rainfall and to avoid rain damage at maturity. Access to irrigation provides flexibility in sowing date and in the choice and timing of crop or forage systems in response to seasonal climate conditions. Depending on the rooting depth of a particular species and the length of growing season, crops established at the end of the wet season may access a full profile of soil water (e.g. 200+ mm plant available water capacity (PAWC) for some Vertosols). While timing of sowing to maximise available water can reduce the overall irrigation requirement, it may expose crops to periods of lower solar radiation and extreme temperatures during plant development and flowering. It may also prevent the implementation of a sequential cropping system.

3.5.3 Nutrition

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

3.5.4 Weed and pest management

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

3.6 Cattle and beef production

3.6.1 Characteristics of the beef production system

About 62% of the Victoria catchment is used for grazing of natural vegetation by beef cattle and this is the dominant land use by area. The typical beef production system is a cow-calf operation with sale animals turned-off at weights to suit the live export market (see below). The industry had an estimated annual gross value of $110 million in 2019–20 (Table 2-4).

The within-year variation produced by the wet–dry climate is the main determinant for cattle production. Native pasture growth is dependent on rainfall, therefore, pasture growth is highest during the December to March period. During the dry season, the total standing biomass and the nutritive value of the vegetation declines. Changes in cattle liveweight closely follow this pattern, with higher growth rates over the wet season than the dry season. In many cases, cattle lose liveweight and body condition throughout the dry season until the next pulse of growth initiated by wet-season rains.

A large area of land is needed to maintain one unit of cattle (typically termed an AE, or adult equivalent). This carrying capacity of land is determined primarily by the soil (and landscape) type, the mean annual rainfall and its seasonality, and the consequent native vegetation type. The NT Government estimates of carrying capacity on the Victoria River District (VRD; the VRD is a NT pastoral district aligned to property boundaries, not identical to but comparable with the Victoria catchment) range from a maximum of 12.5 to 23.0 AE/km^2 (i.e. 8.0 to 4.3 ha/AE) on the basalt-derived cracking clays of the Wavehill land system in 'A' condition (from a four point scale of pasture quality where 'A' is highest and 'D' is lowest) to a low of 0.5 AE/km^2 (i.e. 200 ha/AE) on 'C' condition pastures of land systems within the Spinifex plains land type. Note that 'D' condition lands across the region have a recommended carrying capacity of zero AE/km^2 (Pettit, undated).

A whole-of-industry survey (Cowley, 2014) provides a snapshot of the industry as it was in 2010. While some of the survey results described below have inevitably changed since then, the general enterprise type has not changed significantly in the last decade and the following can be considered still current. Cowley (2014) presents data for the whole of the Katherine region, broken into five districts: Roper, Sturt Plateau, Katherine/Daly, Victoria River and Gulf. The information below comes from the VRD except where noted to be from the Katherine region as a whole (i.e. across all five districts). As noted above, the VRD does not follow Victoria catchment boundaries but can be considered broadly representative of those properties within the catchment.

The VRD is characterised by large property sizes, most of those surveyed being between 2000 and 4000 km^2, with the median paddock size being 120 km^2 (Cowley, 2014).

About 44% of properties in the VRD had attempted the introduction of non-native species to improve the pastures, although the area of seeding was only 4.4% of the property (Cowley, 2014). Typically, this involved low-input operations where seed was broadcast into an uncultivated seedbed and pastures were rainfed only. The improved pastures were predominantly 'grass only' (e.g. buffel grass, *Cenchrus ciliaris*) with a lesser amount being 'legume only' (e.g. *Stylosanthes* spp). Most producers did not fertilise their improved pastures. Rainfed hay was produced on only a few properties.

While prescribed burning is common in the VRD, the proportion of area burnt was lower in those properties surveyed than elsewhere in the broader Katherine district.

Cattle were typically run in paddocks (median of 20 per property) with cattle relying on man-made water points (median of 58 per property) and permanent natural water points (estimated median of 24 per property). Watering point development and paddock subdivision were common in the 2010 survey and have continued since (Cowley, 2014). The most common grazing strategy was a combination of continuous grazing and wet-season spelling. Rotational grazing, or cell grazing, was not typically used. Grazing management strategies were not found to be as important as better utilisation of pastures within whatever grazing management was being applied (Hunt et al., 2013).

The VRD is characterised by its large percentage of properties (56%) that are company owned (Cowley, 2014) as distinct from owner-manager. Often, these company owned, or ‘corporate’, properties are run within a system of other properties, which allow transfer of cattle between properties and sharing of staff and resources (Cowley, 2014). Corporate properties are typically the larger properties in the VRD, containing the most cattle; therefore, the overall proportion of land and production from the corporate properties is larger than 56%. Owner-manager properties were more likely to consist of only one property and be run as a stand-alone enterprise.

It is not uncommon for larger properties, or aggregations of several properties, in the VRD to change hands for tens of millions of dollars, up to a maximum of about $100 million. These properties often form part of much larger diversified agricultural and other interests within the corporate structures that own them. This suggests that at least some property owners in the VRD have access to the capital and management expertise required to develop prospective areas on the properties for intensified agricultural development. Indeed, at least one property in the VRD is part of a vertically integrated supply chain, which includes breeding in the VRD with backgrounding and finishing occurring east of the VRD, close to an all-weather sealed road. This allows the owners to target both live export and domestic markets, an option not available to other producers in the Victoria catchment.

About 78% of all cattle across the Katherine region were Brahman, with about another 17% being Brahman derived. The majority of surveyed properties in the VRD ran between 15,000 and 20,000 head of cattle. Most cattle in the VRD (68%) were bred for live export with 22% bred to be transferred and grown-out elsewhere. Across the broader Katherine region, 83% of cattle turned-off made their way to live export either directly or indirectly through inter-company transfers, or backgrounding or floodplain agistment closer to Darwin. The most common live export destination was South-East Asia.

Across the Katherine region most of the cattle were sold off-property early in the dry season, at the time of the first round of mustering. The most common sales months were May to July, with a secondary peak in September–October. This corresponds to the common practice of two rounds of mustering, with the first early in the dry season and the second late in the dry season.

Liveweight gain data are not available, but the Katherine region survey results reported by Cowley (2014; Table 14) provide the following information. Light steers were turned-off at a mean weight of 243 kg at a mean age of 1 year and a mean weight of 246 kg at a mean age of 1.5 years. Heifers and steers for live export were turned-off at a mean weight of 299 kg and 308 kg respectively, at a mean age of 1.8 years. Heavier steers for live export were turned-off at a mean weight of 405 kg at a mean age of 2.7 years. Estimated mean annual mortality rates across the Katherine region ranged from 3.8% for weaner heifers to 5.5% for old cows. Weaning rates for surveyed properties in the VRD district averaged 62%.

While the cattle typically graze on native pastures, many properties supplementary feed hay to the weaner cohort, partly to train them to be comfortable around humans for management purposes and partly to add to their growth rates during the dry season when the nutritive value and total standing biomass of native pastures is falling. Urea-based supplements and supplements containing phosphorus were fed to a range of age and sex classes of the cattle. The urea-based supplements are to provide a source of nitrogen for cattle grazing dry-season vegetation while the phosphorus supplements, mostly provided over the wet season, are used because phosphorus is deficient in many areas yet it is required for many of the body's functions such as building bones, metabolising food and producing milk (Jackson et al., 2015). Winter (1988), working in the Katherine region, found substantial benefits to phosphorus fertilisation and supplementation, particularly in early and late wet-season periods and when grazing pastures that had been oversown with legumes. Supplements were fed in 89% of the properties surveyed in the VRD. The most common animal health treatment was vaccination against botulism (Cowley, 2014).

4 Approach for evaluating agricultural options

4.1 Multi-scale framework for evaluating agricultural viability

The approach used to analyse the viability of agricultural development options draws on similar past technical assessments of new irrigated farming (Ash et al., 2014, 2018; Petheram et al., 2013a, 2013b; Stokes et al., 2017; Stokes and Jarvis, 2021; Stokes et al., 2023) and a historical analysis of the successes and challenges of agricultural developments across northern Australia (Ash et al., 2014). The Assessment takes a multi-scale approach, from farm to regional scales (Figure 4-1):

- The *farm-scale performance component* is a bottom-up analysis of farm performance, working from the biophysical and management determinants of crop yields and water use to indicative farm gross margins (GMs) that could be achieved for a range of cropping and fodder options (methods covered here in Chapter 4, with results presented in Chapter 5).
- The *scheme-scale viability component* takes a generic top-down approach, working backwards from the costs of developing new enterprises and water resources (Chapter 7) to the water pricing and farm GMs that would have to be sustained in the long term to cover those costs (Chapter 8).
- The *regional-scale component* looks at the knock-on economic effects that could occur if new agricultural areas were developed in the catchment of the Victoria River (Chapter 9), and the market opportunities and constraints for the supply chains required for new farm produce (Section 2.2).

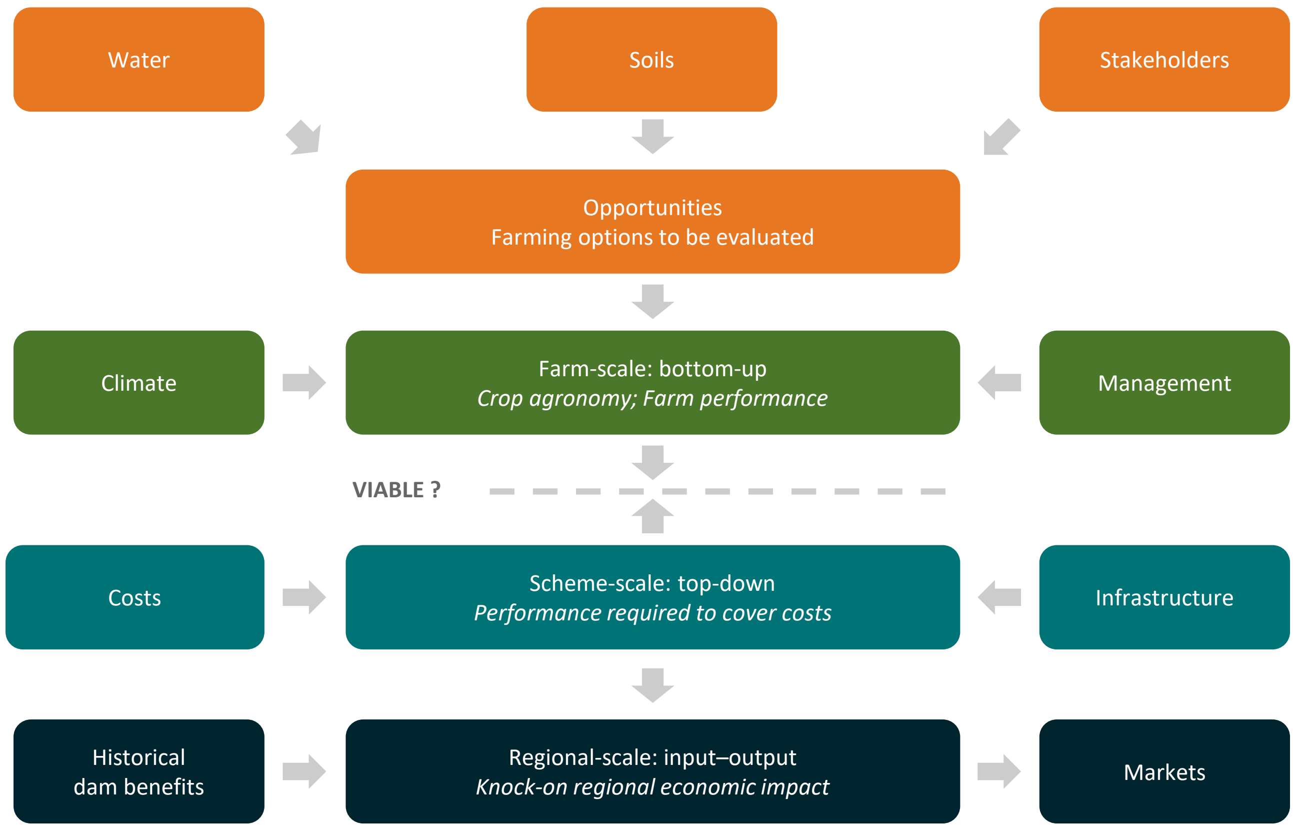


Figure 4-1 Overview of multi-scale approach for evaluating the viability of agricultural development options

The combined analytical framework also allows fully integrated cost–benefit analysis of specific case studies, based on farm-scale analyses and information from assessments of land and water resources and associated water storage options.

The added effort of rigorously adhering to such an integrating framework is more than offset by the advantages it provides: (i) biophysical and financial resources are all accounted for in a consistent and coherent manner; (ii) the design of all analyses remains focused on the ultimate goal of identifying the most suitable development options; and (iii) interpretation of results is focused on maximising the viability of those opportunities in the context of Victoria catchment environments and mitigating the risks and challenges involved. It also avoids becoming distracted by sub-disciplinary 'optimisations' of intermediate metrics, such as maximising crop yields, maximising water use efficiency, or minimising unit costs of water and farm infrastructure, which can lead to suboptimal outcomes for configuring greenfield irrigation developments.

The aim of the farm-scale analyses was to determine: (i) the level of farm 'performance' that can be achieved in the Victoria catchment (specifically quantified here in terms of crop yields and water use (Section 4.2), and GMs (Section 4.3)); (ii) the relative ranking of crop options that show the most potential; (iii) the management practices that can maximise those opportunities, while dealing with local challenges; and (iv) the cropping systems that could combine that understanding into possible working configurations of farming options and crop sequences on profitable commercial farms. Ultimate financial viability would depend on additional capital and overhead costs and associated considerations for developing water resources and establishing new enterprises (which are covered in chapters 6 to 8).

4.2 Crop yields and water use

4.2.1 Analysis approach

Nineteen irrigated crop options were selected to evaluate their potential performance in new irrigated farms in the Victoria catchment (Table 4-1). The crops were selected to ensure that there was at least one option for each of the 13 ‘major crop groupings’ used in the companion technical report on digital soil mapping and land suitability (Thomas et al., 2024), provided that they had the potential to be viable in the Victoria catchment (based on knowledge of how well these crops grow in other parts of Australia), were of commercial interest for possible development in the region, and there was sufficient information on their agronomy and farming costs/prices for quantitative analysis.

Some of the 13 major land suitability crop groupings were subdivided to give a total of 21 ‘crop groups’, based on shared sensitivities to soil constraints (Thomas et al., 2024). Of these 21 ‘crop groups’, the crop types chosen for analysis were considered those most likely to be development ready for the Victoria catchment. There were varying reasons for not choosing crop for analysis, for example: (i) leafy green vegetables were considered unsuited to the often dry and desiccating conditions in the Victoria catchment (land suitability crop group 5); (ii) there was insufficient suitable land and water for rice (crop group 8); (iii) sugarcane (crop group 11), while suited to the Victoria catchment climate, was excluded because there was insufficient scale of contiguous suitable soils to support a local mill (see Section 7.4.4); and (iv) only the most suitable type of forage for hay production was evaluated (perennial grass, in crop group 14, not annual forages (crop group 12) or legume forages (crop group 13)). Note that the typology of crop groupings used in the land suitability assessments (Thomas et al., 2024) was based on crop responses to soil constraints, and does not correspond to the standard agronomic classification of crops according to the types of commodities they produce (as used in Table 4-1 and the rest of this report, following the Australian Bureau of Agricultural and Resource Economics and Science (ABARES) typology). The analyses used a combination of Agricultural Production Systems sIMulator (APSIM) crop modelling and climatically informed extrapolation to estimate potential yield and water use for each of the 19 crop options (Table 4-1).

Table 4-1 Crop options for which performance was evaluated in terms of water use, yields and gross margins

The methods used for estimating crop yield and irrigation water requirements are coded as: A = APSIM; E = climate-informed extrapolation. 'A, E' indicates that A is the primary method and E is used for sensibility testing. Mango (KP) is Kensington Pride, and mango (PVR) is an indicative new high-yielding variety likely to have plant variety rights (e.g. Calypso).

CROP TYPE	CROP	IRRIGATION WATER ESTIMATE METHOD	YIELD ESTIMATE METHOD
Broadacre crops			
Cereal	Sorghum (grain)	A, E	A, E
	Maize	A, E	A, E
Pulse	Mungbean	A, E	A, E
	Chickpea	A, E	A, E
	Soybean	A, E	A, E
Oilseed	Sesame	E	E
	Peanut	A, E	A, E
Industrial	Cotton (dry season)	A, E	A, E
	Cotton (wet season)	A, E	A, E
	Hemp	E	E
Forage	Rhodes grass	A, E	A, E
Horticulture (row)	Rockmelon	E	E
	Watermelon	E	E
	Onion	E	E
	Capsicum	E	E
Horticulture (tree)	Mango (PVR)	E	E
	Mango (KP)	E	E
	Lime	E	E
Plantation tree	African mahogany	E	E
	Sandalwood	E	E

Agronomic climate analogues for the Victoria catchment

The nature of evaluating greenfield farming options in locations like the Victoria catchment, where little irrigated commercial farming currently occurs, is that there is very limited agronomic data available of the type that is required for quantitative analyses. However, there are good analogues for Victoria catchment climate and soils in agronomically similar environments at similar latitudes where irrigated cropping is well-established: the Katherine-Daly Basin (NT) is indicative of irrigated farming systems and potential crops grown on well-drained loamy soils, and the Ord River Irrigation Area (WA) is indicative of furrow irrigation on heavy clay soils. Figure 4-2 shows the close similarities in climate between possible cropping locations in the Victoria catchment and Katherine (NT) and the Ord River (Kununurra, WA):

- The rainfall over the November to March period is highest at Timber Creek, which is similar to the Katherine and Kununurra sites. Kidman Springs and Wave Hill are drier than Timber Creek by 50–100 mm/month rainfall in the November to March period.
- There are very small differences in solar radiation in May to August, but Victoria catchment sites have higher solar radiation than Katherine in the other months.
- The maximum temperature is higher in the December to March months at the Victoria catchment sites than Katherine. During the May to August period, the Victoria catchment sites have similar maximum temperature to each other and the Katherine/Kununurra sites with the exception of Wave Hill being cooler.
- At Wave Hill, the lower minimum temperatures from April to October can extend growing season length. However, lower rainfall prior and after this period permits flexibility in planting date to avoid the lower temperatures if required.
- The climate from October to mid-December at all locations is characterised by extreme high temperatures and high evaporative demand. The hot conditions during this period are not optimal for active growth for the majority of crops and are only suitable for crop maturation and desiccation. Risks of pre-harvest weathering and poor trafficability increases significantly after mid-November.

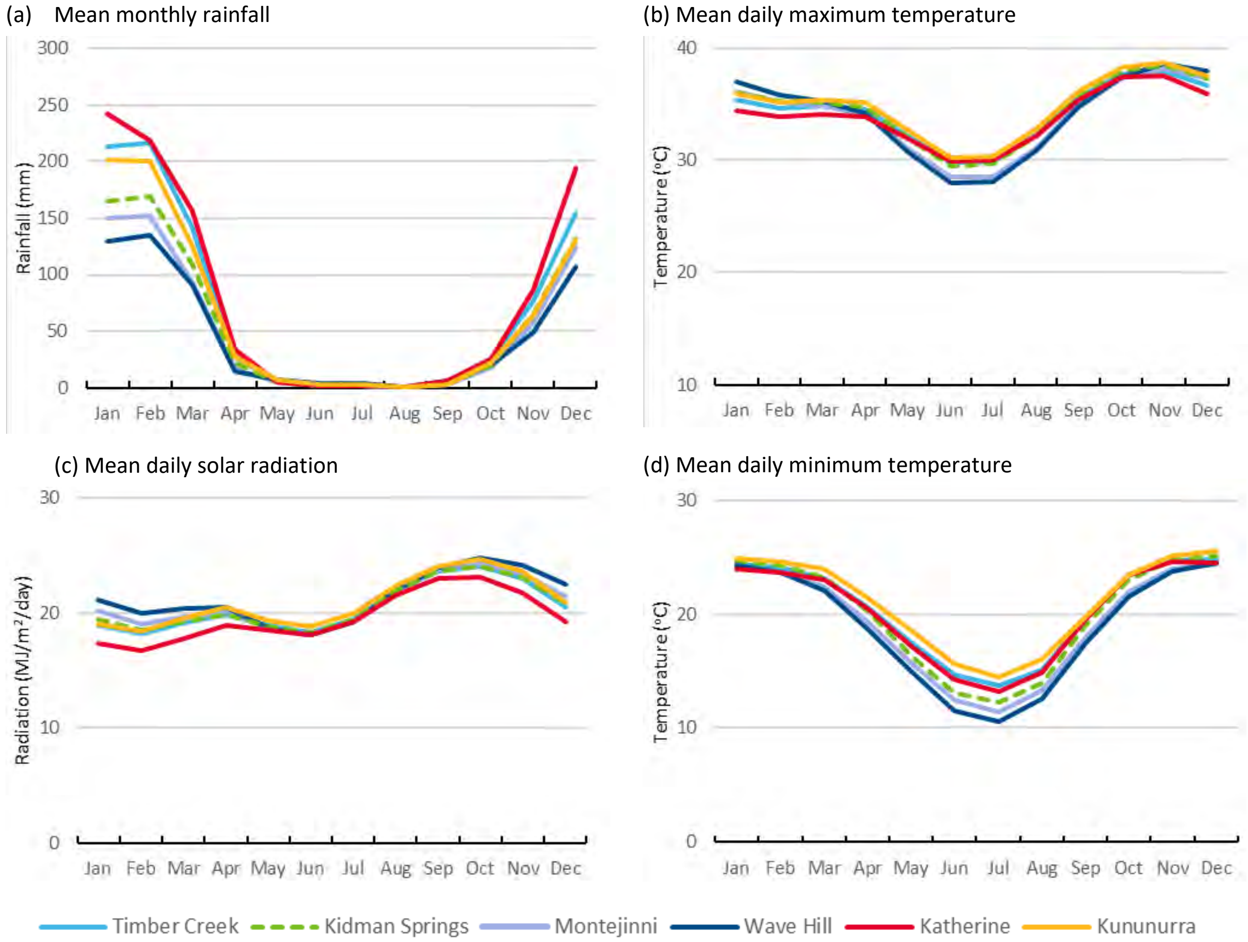


Figure 4-2 Climate comparisons of Victoria catchment sites versus established irrigation areas at Katherine and Ord River (WA)
Victoria catchment locations are Timber Creek, Kidman Springs, Montejinni and Wave Hill.

The approach here was therefore to initially estimate likely ranges of crop yields and water use based on cropping knowledge from these climatically analogous regions, data sourced from past research and farming experience at nearby locations, and consideration of biophysical differences between Victoria catchment environments and those of source data (Figure 4-2). For example, crop yields of 7 to 10 t/ha (sorghum), 2.2 t/ha (mungbean) and 5 t/ha (peanut) have been achieved under irrigation in Queensland (GRDC, 2017; QDAF, 2017), and irrigated broadacre crops such as cotton, mungbean, niche grains, peanuts, sesame and forages have produced excellent yields when grown on these soils in Katherine-Daly and Ord Valley (Beach, 1995; O'Gara, 2010; Yeates and Martin, 2006; Yeates et al., 2022).

Table 4-2 shows the extrapolated estimates made this way for ranges of likely yields, irrigation water requirements, and growing seasons for the broadacre crops that were simulated in APSIM. These estimates were used for sensibility testing and calibration of modelled outputs. For other crops where there was no APSIM model, yield and water use were estimated in a similar manner, using expert experience and climatically informed extrapolation from the most similar analogue locations in northern Australia where commercial production currently occurs (those estimates are provided with the results in Section 5.2). Given the lack of direct cropping data available from within the Victoria catchment, a 20% margin of error should be allowed for all these estimates at the indicative catchment level (with further allowance for variation between farms and fields). Optimum planting windows within the growing season for each species are shown in Figure 3-9 (Section 3.5.2).

Table 4-2 Crop yields and median irrigation water requirement delivered to the field

WS = wet-season planted (December to early March); DS = dry-season planted (late March to August); Y = year (for perennial crop). Overhead spray irrigation usually requires 10% more irrigation water than subsurface tape.

CROP (YIELD UNIT)	IRRIGATION WATER REQUIREMENT (ML/ha)		LIKELY YIELDS (t/ha or bales/ha)
	Subsurface tape	**Furrow (clay)**	
Sorghum (t)	4.2 DS	6.0 DS	7.0–8.0
Mungbean (t)	2.3 WS, 3.0 DS	3.0 WS, 4.3 DS	1.7–2.2
Chickpea (t)	3.4 DS	5.0 DS	2.5–3.0
Soybean (t)	5.4 DS	7.7 DS	3.5–4.0
Peanut (t)	4.0–5.0 WS	Cannot farm on clay	3.5–4.5
Cotton (bales)	4.0 WS, 6.0 DS	6.0 WS, 8.0 DS	10–12 WS, 9–11 DS
Rhodes grass (t)	12–14 Y, 4.2 WS	18 Y, 6.0 WS	35 Y, 9 WS

Sources: Climatically extrapolated from data in Beach (1995), O'Gara (2010), Yeates and Martin (2006) and Yeates et al. (2022)

Agricultural Production Systems sIMulator

APSIM was used to estimate the crop water use and yield for those crops where modules were available (Table 4-1). All crops were sown on 1 May, with the exception of peanut, sown on 15 March, and wet-season cotton, which was sown in early February. Yield estimates from APSIM should be considered the maximum potential under ideal management and growing conditions (e.g. before allowing for pest damage or imperfect management).

Crop water use in APSIM outputs was estimated from fully irrigating the crop assuming 100% efficiency. Irrigation was triggered in simulations whenever PAW (plant available water) for the top 80 cm of the soil profile fell below a crop-specific threshold proportion (65% to 80%) of plant available water capacity (PAWC). Adjustments were then made to this 100%-efficiency estimate of crop water use to estimate the amount of irrigation water that would be applied on-farm (including application losses), based on the type of irrigation system used, as described in Section 3.3.

APSIM is a modelling framework that simulates biophysical processes in farming systems (Holzworth et al., 2014) and has been used for a broad range of applications, including on-farm decision making, seasonal climate forecasting, risk assessment for government policy making and evaluating changes to agronomic practices (Keating et al., 2003; Verburg et al., 2003). It has demonstrated utility in predicting performance of commercial crops, provided that soil properties are well characterised (Carberry et al., 2009). Some crop modules have been validated for environments similar to the Victoria catchment and used in previous assessments of cropping potential (Ash et al., 2014; Carberry et al., 1991; Pearson and Langridge, 2008; Webster et al., 2013; Yeates, 2001).

Many APSIM crop modules use a deterministic modelling approach to simulating crop processes of development, growth and partitioning, and hence require detailed measurements from field observations to parametrise and validate the model for each location. Such field observation data do not exist for the Victoria catchment and were beyond the scope of this Assessment to acquire. In particular, some APSIM crop models under estimate crop water use in inland northern Australian environments (where crop water use is elevated by windy conditions with high vapour pressure deficits (VPDs) that APSIM has not been calibrated to). Detailed cotton trials with accurate measurements of water use, windspeeds and VPDs at Katherine were able to simulate these high levels of water use with a locally calibrated APSIM cotton model (Yeates and Martin, 2006). However, such well-calibrated models are not available for the Victoria catchment, and the meteorological data required are not widely available (even outside the Victoria catchment APSIM is not typically configured and calibrated to use windspeed data). To address this problem, if APSIM estimates of crop water use (after allowing for application losses) were outside the range estimated for sensibility testing by more than 10%, then an adjustment multiplier was applied to bring it into the estimated range (Table 4-2).

Variation in Victoria catchment environments

For the main APSIM simulations of farm performance (crop yield and water use for each crop in Table 4-2), four locations were selected to represent some of the best potential farming conditions across the varied environments available in the Victoria catchment. Each location consisted of a soil type and the climate associated with those areas of soils:

- A Vertosol in the northern region, using Timber Creek (15.66°S, 130.48°E) climate.

This soil represents some of the better farming conditions among the cracking clays on the alluvial plains of the major rivers (SGG 2 and 9, marked ‘B’ in Figure 3-8). The PAWC of this soil for sorghum was 212 mm. Only small, dissected patches of this soil are suitable for cropping because of limitations from floodplain inundation, workability and the complex distribution of flood channels (which both break up patches that would be large enough to crop and cut off wet-season access to some larger pockets of otherwise suitable soil).

- A Dermosol at Yarralin area using the Kidman Springs (16.12°S, 130.96°E) climate.

This soil represents some of the better farming conditions among the brown non-cracking clay soils and the red friable loamy clay soils (SGG 2, marked ‘C’ and ‘D’ in Figure 3-8). The PAWC of this soil for sorghum was 156 mm.

- A Vertosol at Top Springs Area, using Montejinni (16.67°S, 131.76°E) climate.

This soil is the same as the Vertosol above, with a different climate.

- A Kandosol with the Wave Hill (17.39°S and 131.12°E) climate.

This soil represents some of the better farming conditions amongst the loamy soils (SGG 4.1 and 4.2, marked ‘A’ in Figure 3-8). Using grain sorghum as an indicator crop, the PAWC of the modelled soil was 79 mm (noting that PAWC differs between crops with different rooting patterns and physiologies).

Additional APSIM simulations were conducted to demonstrate agronomy principles, such as seasonal patterns of stored PAW and crop responses across a range of different levels of irrigation. To isolate the effects of a single factor at a time in these models (e.g. comparing Kandosol to Vertosol), all other factors were kept the same (e.g. the same climate for two different soils), which could result in additional combinations of soils and climate beyond the three listed above (used in the main simulations of crop performance).

The locations of the four meteorological stations used for the simulations are also shown in Figure 3-8. The availability of meteorological data is very poor for the Victoria catchment in terms of density of weather stations, gaps in historical records and the range of agronomically relevant measurements made (particularly the absence of vapour pressure and windspeed data). This limited the choice of the locations that could be modelled and the accuracy with which crop water demand can be modelled (i.e. before making calibration adjustments of the type used in Table 4-1).

4.2.2 Cropping systems

New agricultural developments that focus on annual field crops may require sequential cropping (more than a single crop in a year) to generate sufficient revenue to cover the substantial costs of developing new enterprises. Annual broadacre crops have been grown sequentially for many decades in tropical Australia (e.g. in the Burdekin and Ord irrigation areas and the Mareeba–Dimbulah Water Supply Scheme). The approach used was to explore what cropping systems could be practically implemented in the Victoria catchment environments, as a way of synthesising and interpreting the results from the other farm-scale analyses. The aim was not to be prescriptive about cropping systems, but rather to provide insights on the issues and opportunities associated with developing integrated cropping systems relative to farming individual crops.

4.2.3 Rainfed cropping

Although the focus of this Assessment was on irrigated crop and forage production, some limited analysis was also undertaken for opportunistic rainfed cropping. The APSIM simulations for the rainfed analyses were used to illustrate general agronomic principles across the contrasting environments in the Victoria catchment (rather than for the full analyses of farm performance done for irrigated cropping options).

4.3 Greenfield crop gross margin tool

The annual farm GM is the difference between the revenue received for harvested produce and the variable costs incurred in growing, harvesting and marketing the crop each year. It is a key, but partial, metric of farm financial performance. GMs here are calculated and expressed per hectare of cropped farmland, without explicitly specifying the total area farmed other than that it would be of sufficient scale to be cost efficient in the Victoria catchment context (notionally about 500 ha for broadacre farms and 200 ha for horticulture). Undertaking a comparative analysis of farm GMs for multiple greenfield development options in a region lacking established commercial farms creates unique challenges that required a bespoke 'greenfield farm GM tool' to be developed (Figure 4-3).

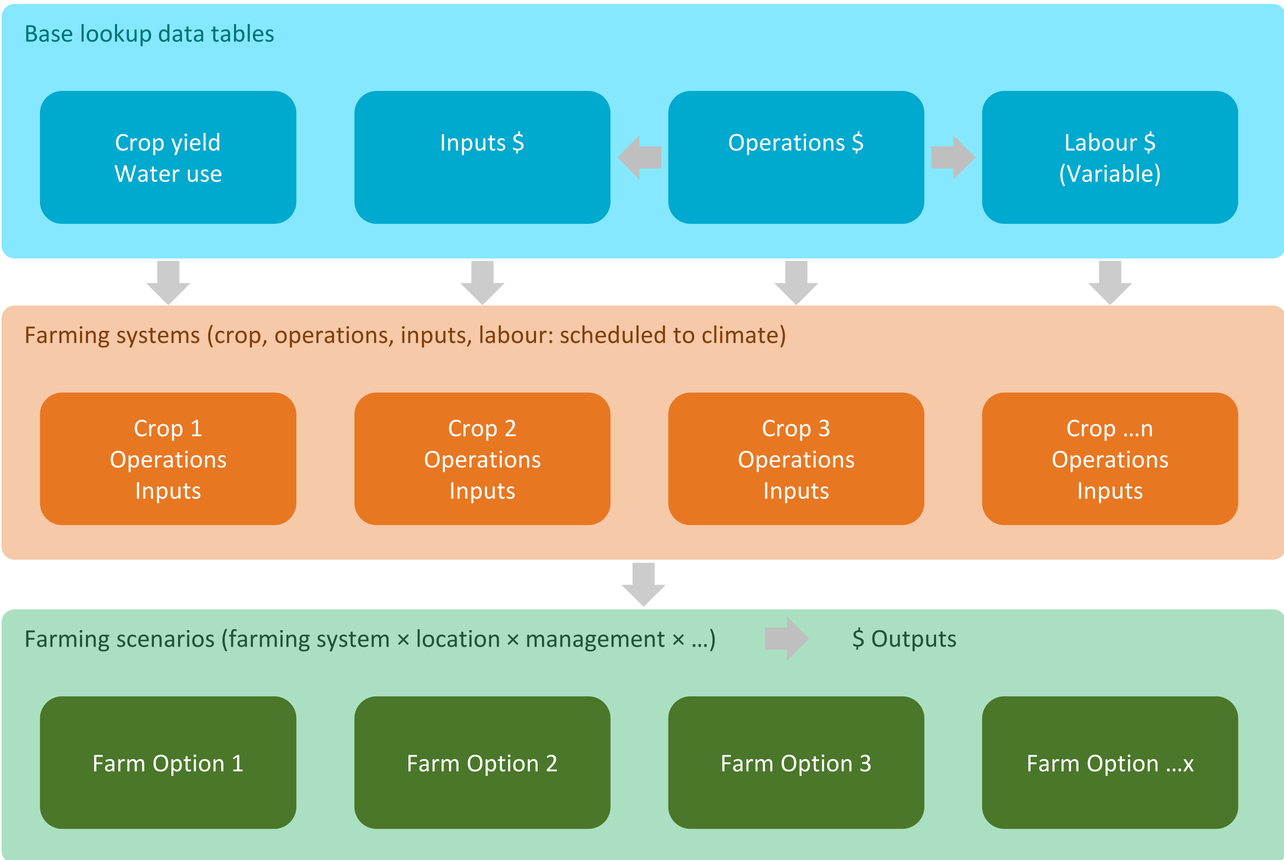


Figure 4-3 Farm gross margin tool used for consistent comparative analysis of different greenfield farming options

The challenges faced, and the approach taken to address them, are summarised below:

- Mix of GM templates of different historical provenance:
  Previous similar assessments have built on-farm GM tools from multiple different sources that used different approaches for farm financial accounting. A consistent accounting approach was required in this Assessment both so that cropping options could be compared on a like-for-like basis, and so that accounting was compatible with how these GMs were combined with capital and overhead costs in subsequent full discounted cashflow (DCF) analyses (Chapter 8). For example, if a particular farming operation is treated and costed as being undertaken by an outsourced contractor, then capital costs of the associated equipment should not be included in subsequent capital costs of farm establishment used in full financial analyses. In addition, a consistent GM analysis framework provides for a smoother and more automated workflow, including the input of required data from the farm agronomy parts of the evaluation, and output of data from the subsequent scheme financial analyses.
- Inappropriate translation from existing to greenfield farming location:
  When using a farm GM template for an established farming region (mainly southern and coastal areas) there are implicit assumptions about what farming operations are conducted and when they are scheduled, based on proven local practices. But when those templates are extrapolated to a new location without proven commercial farming, those implicit assumptions can break down and the GM accounting can become disconnected from the farming practices that would actually be required locally. In greenfield situations there is a need to tightly couple GM accounting with how farm operations would be scheduled and conducted in those locations (e.g. scheduling of farm operations and the equipment required needs to consider seasonal trafficability and other climate constraints, as does the choice of which fertilisers and pest/weed management methods are used and how they are applied). Building GMs 'bottom-up' from an explicit, locally adapted schedule of farm operations ensures this is the case.
- Arbitrary inconsistencies in assumptions:
  When using GM templates from multiple different sources there are inevitably arbitrary differences in assumptions and costings (or, at least, it is laborious to keep these rigorously synchronised across templates). For example, such discrepancies would include the choice of fertilisers, which micronutrients are being applied (on the same soils), and which markets are being used for pricing transport costs of farm inputs and produce (including the point in the supply chain to which goods are delivered, freight is costed and payments to farmers are priced). These issues can be addressed with a standardised set of data tables, and rigorously logging the assumptions and the basis used for estimating each cost. An added advantage of this approach is that once a GM is developed for a farming system in one scenario, it is easier to rigorously adapt it to other applications (because it is obvious precisely how assumptions have changed and the exact cost basis on which new values need to be adjusted).

The farm GM tool consisted of three main types of components, as illustrated in Figure 4-3. The foundation of analyses was a set of data tables with all the farm agronomic performance data generated in Section 4.2 (crop yields and water use) and a standard set of costs for inputs, farm operations and labour requirements to be applied consistently to all farming scenarios. Each farming system to be evaluated then had its own template that drew on the standard data tables.

The farming system templates consisted primarily of a schedule of farm operations that linked to the machinery operating costs in the data tables, together with associated costs of inputs and labour requirements. Each farming operation allowed specifying up to three simultaneous compatible activities, for example, using a 166 kW tractor with airseeder and harrows to (i) plant 13 kg/ha cotton seed, (ii) with a Bollgard fee, and (iii) 100 kg/ha Granulock Z fertiliser, all in a single operation. Each operation also had a date associated with it, used to display a calendar of the farming operations, so that sensibility testing could ensure the farming system being costed was operationally viable and agronomically sound (relative to local climatic and trafficability constraints and optima, as discussed in Section 3.5.2). Farming templates also included other parameters specific to that farming system, such as the prices received for produce (which allowed splitting yield into different products/produce classes and specifying different prices for the same crop grown under different conditions in variant farming systems). The final component of the GM tool consisted of farming scenarios, which are parameter sets for each scenario specifying details of the farming system, crop performance data, and crop management required to calculate the final of set of GMs to be compared. The scenario parameters included specifying the type of irrigation, in order to automatically account for associated irrigation application losses and pumping costs. An adjustment could also be made to the total calculated cost of labour required for all farm operations to account for the portion that would be performed by permanent staff (accounted for separately in the overhead costs: noting labour costs have both variable (mainly seasonal workers) and fixed/overhead (mainly permanent staff) components).

Because this Assessment focuses on the viability of *greenfield* irrigated development (i.e. including a new water source), the cost of water is not included in GMs as a variable cost, but is accounted for the in the capital and operating costs of the new water source. The costs of the water sources are treated on a consistent like-for-like basis, so that alternate water sources can be substituted for each other in any arbitrary pairing with different farming options in the later scheme-level analyses of financial viability (see Chapter 8).

All costs were specified in real constant December 2023 Australian dollars (as is the standard throughout this Assessment, adjusted for inflation from older sources where necessary). Costs of farming inputs were based on prices from suppliers in Darwin, and freight costs assumed that this is where they would be purchased. Since agricultural commodity prices (versus inputs) typically fluctuate more over time, they were notionally set at the average for the past decade (e.g. as documented in ABARES (2022) data series). Commodity prices do not represent a forecast, just a long-term historical precedent (to reduce the effects of temporary spikes and dips in current prices). Investors would need to make their own decisions about long-term future trends in input costs and commodity prices (see also Section 2.2.7 covering recent volatility in farmers' terms of trade).

Farm GMs were calculated, together with breakdown summaries of variable costs and revenue, for each farming option listed in Table 4-1. Given the uncertainties in estimating farm performance in greenfield situations, narrative risk analyses were also undertaken to illustrate how different challenges and opportunities could affect farm GMs.

4.4 Modelling the integration of forage and hay crops within existing beef cattle enterprises

A commonly held view within the northern cattle industry is that the development of water resources would allow graziers to integrate irrigated forages and hay into existing beef cattle enterprises, thereby improving their production and, potentially, their profitability. Currently, cattle graze on native pastures, which rely solely on rainfall and any consequent overland flow. The quality of these pastures is typically low, and it declines throughout the dry season, so that cattle either gain little weight, or even lose weight, during this period.

Theoretically, producing on-farm irrigated forage and hay would give graziers greater options for marketing cattle, such as: (i) meeting market liveweight specifications for cattle at a younger age; (ii) meeting the specifications required for markets not typically targeted by cattle enterprises in the Victoria catchment; and (iii) providing cattle that meet market specification at a different time of the year. Forages and hay may also allow graziers to implement management strategies, such as early weaning or weaner feeding, which should lead to flow-on benefits throughout the herd, including increased reproductive rates. Some of these strategies are already practised within the Victoria catchment but rely on hay or other supplements purchased on the open market. By growing hay on-farm, the scale of these management interventions might be increased, at reduced net cost. Furthermore, the addition of irrigated feeds may also allow graziers to increase the total number of cattle that can be sustainably carried on the property.

Very few graziers use irrigated hay or forage production to feed cattle on-farm in the Victoria catchment. In fact, very few cattle enterprises in northern Australia are set up to integrate on-farm irrigation, notwithstanding the theoretical benefits. Despite the apparent simplicity of the concept, fundamentally altering an existing cattle enterprise in this way brings in considerable complexity, with a range of unknowns about how best to increase productivity and profitability. The most comprehensive guide to what might be possible to achieve by integrating forages into cattle enterprises can be found in Moore et al. (2021), who have used a combination of industry knowledge, new research and modelling to consider the costs, returns and benefits. Because there are so few on-ground examples, modelling has been used in a number of studies to consider the integration of forages and hay into cattle enterprises, summarised in Watson et al. (2021b).

This study in the Victoria catchment used CLEM (Crop Livestock Enterprise Model; Version 2023.11.7349; https://www.apsim.info/clem/Content/Details/About.htm) to model the impact of on-farm irrigated forages and hay for a representative property in the Victoria catchment. CLEM is a whole-of-farm model. Native pasture (modelled with GRASP; Rickert et al., 2000) and several irrigated forage and hay options (modelled with APSIM; Holzworth et al., 2014) were prepared as input into CLEM on a monthly time step. Animal production, herd dynamics, financial parameters (overhead and variable costs and cattle and hay prices) and management actions within CLEM were then parameterised with information from a number of sources (Section 5.4.1). CLEM's output then included information on cattle production and hence herd dynamics as well as financial metrics, which were used to compare across the base-enterprise, forage and hay options.

Central to CLEM is a set of animal production equations that calculate reproductive rates, milk production, liveweight changes, mortality and other key functions. It is a relatively new model that builds on the Northern Australia Beef Systems Analyser (NABSA; Ash et al., 2015) but models the performance of all individual animals within the herd, rather than calculating outputs for each cohort of livestock (typically age and sex class).

5 Performance of agricultural development options

This chapter presents the results and interpretation of the farm-scale analyses detailed in Chapter 4. It begins with a discussion of agronomic principles of rainfed and irrigated cropping in the catchment of the Victoria River (Section 5.1). Those principles provide context for the results of the 19 individual crop options that were analysed in terms of crop yields, the amount of irrigation water used, and gross margins (GMs) (the three metrics referred to collectively as farm 'performance' in this and the following chapters) (Section 5.2). The irrigated crop options are grouped into broadacre, horticulture and plantation tree crops. The viability of these options is then discussed in a section on cropping systems, which considers the mix of farming practices that could most profitably be integrated within local Victoria catchment environments, using both single and sequential cropping systems (Section 5.3). The final section evaluates the viability of integrating irrigated forages into existing beef production systems (Section 5.4).

This chapter aims to determine: (i) the level of farm performance that can be achieved in the Victoria catchment; (ii) the relative ranking of crop options that show the most potential; (iii) the management practices that can maximise those opportunities, while dealing with the local constraints; and (iv) the cropping system configurations that might conceivably use that understanding to implement mixes of these crop options on profitable commercial farms. Ultimate financial viability would depend on additional capital and overhead costs and associated considerations for developing water resources and establishing new enterprises (covered in chapters 6 to 8 that follow).

5.1 Principles of rainfed and irrigated cropping

5.1.1 Rainfed broadacre cropping

Rainfed cropping (crops grown without irrigation, relying only on rain) has been practised by farmers in the NT for almost 100 years, yet only small areas of rainfed crop production currently occur each year. This indicates that despite the theoretical possibility that rainfed crops could be produced using the significant rainfall that occurs during the wet season in the Victoria catchment, in practice there are major agronomic and market-related challenges to rainfed crop production that have prevented its expansion to date.

As rainfed farming depends on stored soil water and in-crop rainfall, the timing of crop establishment to maximise both production and economic yield is critical. Without the certainty provided by irrigation, rainfed cropping is opportunistic in nature, relying on favourable conditions in which to establish, grow and harvest a crop. The annual cropping calendar in Figure 3-9 shows that, for many crops, the sowing window includes the month of February. For relatively short-season crops such as forage sorghum and mungbean, this coincides with both the sowing time that provides close-to-maximum crop yield and the time at which the season's water supply can be most reliably assessed with a high degree of confidence. Table 5-1 shows how plant available soil water content at sowing and subsequent rainfall in the 90 days after each sowing date varies over three different sowing dates for a Vertosol in the Victoria catchment at Kidman Springs. As sowing is delayed from February to April, the amount of stored soil water increases. However, there is a significant decrease in rainfall in the subsequent 3 months after sowing. Combining the median plant available water (PAW) in the soil profile at sowing, and the median rainfall received in the 90 days following sowing, provides totals of 460, 262 and 166 mm for the February, March and April sowing dates, respectively.

For 'drier than average years' (80% probability of exceedance), the soil water stored at sowing and the expected rainfall in the ensuing 90 days (<330 mm) would result in water stress and comparatively reduced crop yields. In 'wetter than average years' (20% probability of exceedance), the amount of soil water at the end of February combined with the rainfall in the following 90 days (606 mm) is sufficient to grow a good short-season crop (noting that the timing of rainfall is also important since some rain is 'lost' to runoff, evaporation and deep drainage between rainfall events). Opportunistic rainfed cropping would target those wetter years where PAW at the time of sowing indicated a higher chance of harvesting a profitable crop.

Table 5-1 Soil water content at sowing and rainfall for the 90-day period following sowing for three sowing dates, based on a Kidman Springs climate on a Vertosol

PAW = plant available water stored in soil profile. The 80%, 50% (median) and 20% probability of exceedance values are reported, for the 100 years between 1920 and 2020. The lower-bound values (80% exceedance) occur in most years, while the upper bound values only occur in the most exceptional upper 20% of years.

SOWING DATE	PAW AT SOWING DATE (mm)			RAINFALL IN 90 DAYS FOLLOWING SOWING DATE (mm)			TOTAL STORED SOIL WATER + RAINFALL IN SUBSEQUENT 90 DAYS (mm)		
	80%	**50%**	**20%**	**80%**	**50%**	**20%**	**80%**	**50%**	**20%**
1 February	129	149	194	175	310	425	330	460	606
1 March	134	154	189	50	104	231	200	262	393
1 April	128	142	185	1	13	50	138	166	213

The success of rainfed cropping is clearly dependent on wet-season rainfall, but also the ability of the soil to store water for the crop to use as it finishes growing into the dry season. Figure 5-1 highlights the effects of diminishing water availability and increasing evapotranspiration likely to be encountered when sowing a rainfed crop at the start of April or later. This constraint is much more severe for sandier soils that have less capacity to store PAW (like Kandosols in the Victoria catchment, Figure 5-1a), compared to finer-textured soils (like the alluvial Vertosols in the Victoria catchment, Figure 5-1b).

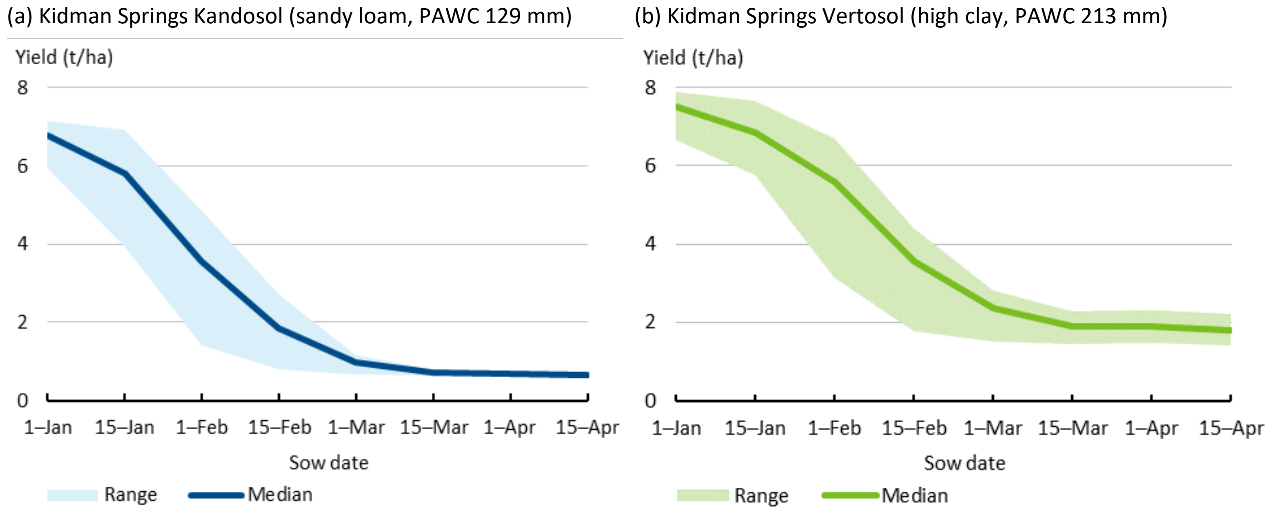


Figure 5-1 Influence of planting date on rainfed grain sorghum yield at Kidman Springs for (a) Kandosol and (b) Vertosol

Estimates are from APSIM simulations with planting dates on the 1st and 15th of each month. PAWC values give the plant available water capacity that each soil profile can store. The shaded band around the median line indicates the 80% to 20% exceedance probability range in year-to-year variation.

Well-drained, but infertile, Kandosols predominate in the south of the Victoria catchment and across northern Australia generally (Williams et al., 1985). Such soils also tend to be susceptible to erosion and hardsetting, which can decrease the infiltration of intense monsoon rainfall into the soil for storage and increase the difficulty of establishing crops. The low water-holding capacity of sandy Kandosols, in combination with the extreme heat that often occurs in the Victoria catchment between rain events, can quickly induce water stress at any stage during the crop life cycle. This contrasts with cropping systems in southern Australia where crops on similar soils are grown during winter when temperatures are cooler and rainfall is more regular and less intense, so crops experience less water stress.

Heavier clay soils, such as Vertosols in alluvial areas of the Victoria catchment, hold more PAW, so rainfed crops grown on these soils would likely experience less water stress (Figure 5-1). However, alluvial soils are subject to frequent inundation and waterlogging during the wet season due to their location in the landscape and particularly poor drainage in some Victoria catchment Vertosols (Figure 3-10). This means that crops cannot always be sown at optimum times; fertiliser can be lost to runoff, drainage and denitrification; and in-crop management (e.g. for weed, disease and insect control) cannot be undertaken cost-effectively with ground-based equipment in a timely manner, a critical requirement for rainfed crop production to succeed (Robertson et al., 2016).

Soil is rarely uniform within a single paddock, let alone across entire districts. Without the homogenising input of irrigation to alleviate water limitations (and associated high inputs of fertilisers to alleviate nutrient limitations), yields from low-input rainfed cropping are typically much more variable (both across years and locations) than yields for irrigated agriculture. Furthermore, the capacity of the soil to supply stored water varies with soil type but it also depends on crop type and variety because each crop's root system has a different ability to access water, particularly deep in the profile. This makes it harder to make generalisations about the viability of rainfed cropping in the Victoria catchment as farm performance (e.g. yield and GM) is much more sensitive to slight variations in local conditions. Rigorous estimates of rainfed crop performance on which investment decisions could be confidently made would require detailed localised soil mapping and crop trials.

Socio-economic factors have also been identified as limitations to the development of rainfed farming in the NT (Chapman et al., 1996). Lack of significant local markets for broadacre commodities mean that transport costs to markets are much higher than costs incurred by alternative production regions across southern Australia, and that GMs for low-value, small-grained commodity crops (such as sorghum and maize) are too low to justify significant expansion of rainfed cropping for these crops. Producers also experience difficulties in attracting and retaining a trained labour force to hot, remote locations. These challenges have combined to prevent expansion of rainfed cropping in the NT. These socio-economic constraints affect irrigated agriculture too, in an interrelated way, since the two types of farming typically complement each other in achieving sufficient combined economies of scale to overcome many of these constraints. A core of irrigated farming often provides the impetus to attract an expansion of rainfed farming around it (and, conversely, the limited scale of irrigated broadacre farming in the NT has impeded development of rainfed cropping).

Despite the challenges described above, recent efforts in the NT have identified potential opportunities for rainfed farming using higher value crops, such as pulses or cotton. A preliminary Agricultural Production Systems sIMulator (APSIM) assessment of the potential for rainfed cotton in the region suggested that mean lint yields of 2.5 to 3.5 bales/ha may be possible at a range of locations in the vicinity of the Victoria catchment (Yeates and Poulton, 2019). However, there was very high variability in median yields between farms (1–5 bales/ha), depending on management and soil type.

5.1.2 Irrigated cropping responses and options

Crops that are fully irrigated can yield substantially more than rainfed crops. Figure 5-2 shows how yields for sorghum grown on Kandosols in the Victoria catchment increase as more water becomes available to alleviate water limitations and meet increasing proportions of crop demand. With sufficient irrigation, yields are highest for (wet-season sown) crops grown over the dry season when radiation tends to be less limiting (plateau of Figure 5-2a versus Figure 5-2b). For wet-season sowing, unirrigated yields can approach fully irrigated yields in good years (yields exceeded in the top 20% of years, marked by the upper shaded range in Figure 5-2a). However, irrigation allows greater flexibility in sowing dates, allows sowing in the dry season too (for crops that would then grow through the wet season), and generates more reliable (and higher median) yields.

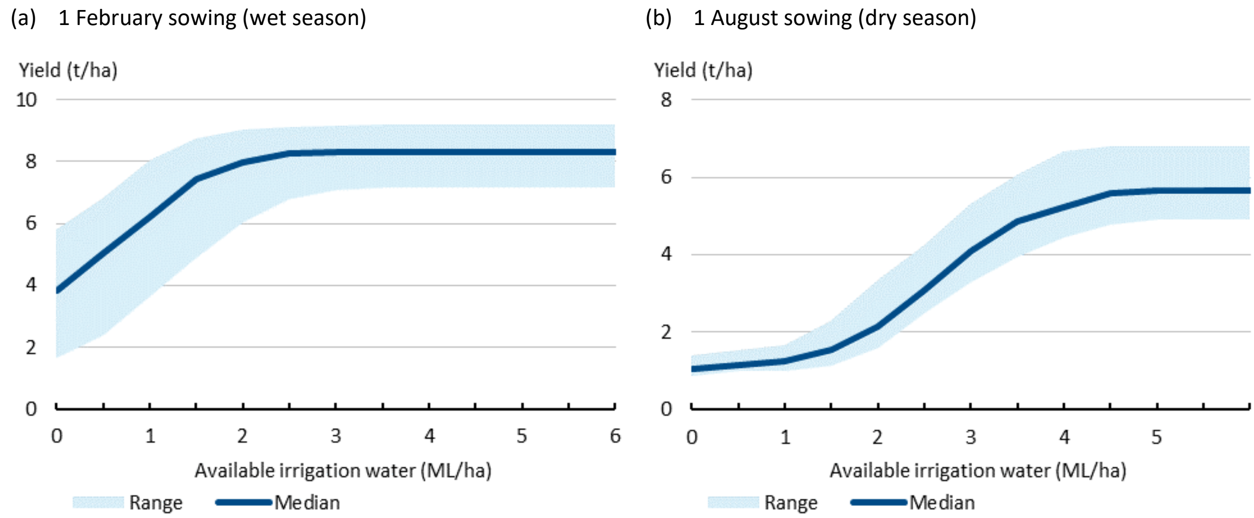


Figure 5-2 Influence of available irrigation water on grain sorghum yields for planting dates (a) 1 February and (b) 1 August, for Kandosols with a Kidman Springs climate

Estimates are from 100-year APSIM simulations. The shaded band around the median line indicates the 80% to 20% exceedance probability range in year-to-year variation. Rainfed production is indicated by the zero point where no allocation is available for irrigating.

The different amounts of irrigation water available (Figure 5-2) also indicate the range of options for growing crops from rainfed (zero ML/ha available irrigation water), to supplemental irrigation (where less water is available than required to maximise yield, but sufficient to achieve higher and more reliable yields than from purely rainfed cropping), to full irrigation (where there is sufficient water to achieve close to the maximum yield). Increasing amounts of 'available' water do not mean that those volumes were applied in Figure 5-2, only that it was available to apply to crops when needed; so, the yield curves plateau once crop demand is fully met. The simulations did not seek to 'optimise' supplemental irrigation strategies in years where available water was insufficient to attain maximum crop yields; irrigators would need to make those decisions in years where available water was lower than total crop demand. A key advantage of irrigated dry-season cropping in northern Australia is that the availability of water in the soil profile and surface water storages is largely known at the time of planting (in the early wet season; Table 5-1). This means irrigators have good advance knowledge for planning how much area to plant, which crops to grow, and what irrigation strategies to use, particularly in years where they have insufficient water to fully irrigate all fields. A mix of irrigation approaches could be used, such as expanding the scale of a core irrigated cropping area with other less intensively farmed areas, opportunistic rainfed cropping, opportunistic supplemental irrigation, opportunistic sequential cropping and/or adjusting the area of fully irrigated crops grown to match available water supplies that year.

5.2 Performance of irrigated crop options

Measures of farm performance (in terms of yields, water use and GMs) are presented for the 19 cropping options that were evaluated (Table 4-1). As noted in Chapter 4, given the limited commercial irrigated farming currently occurring in the Victoria catchment that can provide real-world data, estimates of crop water use and yields should be considered as indicative, and to have a possible 20% margin of error at the catchment scale (with further variation expected between farms and fields).

GMs are a key partial metric of farm performance but should not be treated as fixed constants determined by the cropping system alone. They are a product of the farming and business management decisions made by individual farmers, input prices, commodity prices and market opportunities. As such, the GMs presented below should be treated as indicative of what might be attained for each cropping option once its sustainable agronomic potential has been achieved. Any divergence from assumptions about yields and costs would flow through to GM values, as would the consequences of any underperformance or overperformance in farm management. It is unrealistic to assume that the levels of performance in the results below would be achieved in the early years of newly established farms, and allowance should be made for an initial period of learning when yields and GMs are below their potential (see Chapter 8). Collectively however, the GMs and other performance metrics presented here provide an objective and consistent comparison across a suite of likely cropping options for the Victoria catchment and an indicative maximum performance that could be achievable for greenfield irrigated development for each of the groupings of crops below.

5.2.1 Irrigated broadacre crops

Table 5-2 shows the farm performance (yields, water use and GMs) for the ten broadacre cropping options that were evaluated. For crops that were simulated with APSIM, estimates are provided for four climate locations in the Victoria catchment with the dominant soil at each location used in the modelling (Vertosol at Timber Creek, Red Dermosol at Kidman Springs, Vertosol at Montejinni and Red Kandosol at Wavehill) and include measures of variability (expressed in terms of years with yield exceedance probabilities of 80%, 50% (median) and 20%). For other crops, yield and water use estimates (and resulting GMs) were estimated based on expert experience and climate-informed extrapolation from the most similar analogue locations in northern Australia where commercial production currently occurs.

The broadacre cropping options with the best GMs (>$2000/ha) were cotton (both wet-season and dry-season cropping), forages (Rhodes grass) and peanuts. These suggest GMs of $4000 to $5000 might be achievable for broadacre cropping in the Victoria catchment, although not necessarily at scale. Sorghum, mungbean, soybean and maize had intermediate GMs (about $1500/ha).

Simulated yields (and consequent GMs) were generally lowest on the Kandosol and highest on the Vertosol because of the increased buffering capacity that a high PAWC clay soil provides against hot weather that triggers water stress even in irrigated crops. The Dermosol yields and GMs were slightly lower than the Vertosol due to its lower plant available water capacity (PAWC).

Table 5-2 Performance metrics for broadacre cropping options in the Victoria catchment: applied irrigation water, crop yield and gross margin (GM) for three environments

Performance metrics are an indication of the upper bound that could be achieved after best-management practices for Victoria catchment environments had been identified and implemented. All options are for dry-season (DS) irrigated crops sown between mid-March and the end of April (end of the wet season), except for the wet-season (WS) cotton, sown in early February. Variance in yield estimates from APSIM simulations is indicated by providing 80%, 50% (median) and 20% probability of exceedance values (Y80%, Y50% and Y20%, respectively), together with associated applied irrigation water (including on-farm losses) and gross margins (GMs) in those years. Peanut is omitted for the Vertosol location because of the practical constraints of harvesting root crops on clay soils. No crop model was available for sesame or hemp, so indicative estimates for the catchment were used. Cotton yields and prices are for lint bales (227 kg after ginning), not tonnes (t). PAWC = plant available water capacity.

CROP	APPLIED IRRIGATION WATER (ML/ha/y)			CROP YIELD (Yield units)			YIELD UNIT	PRICE ($/unit)	VARIABLE COSTS ($/ha/y)	TOTAL REVENUE ($/ha/y)	GROSS MARGIN ($/ha/y)		
	Y80%	Y50%	Y20%	Y80%	Y50%	Y20%					Y80%	Y50%	Y20%
Vertosol (212 mm PAWC), Timber Creek climate (~1000 mm annual rainfall)													
Cotton WS	4.6	4.9	4.8	10.7	11.4	12	bales/ha	700	4017	8998	4820	5292	5557
Cotton DS	5.5	6.0	5.7	7.9	8.9	10	bales/ha	700	3610	7007	2776	3397	4003
Sorghum (grain)	5.8	6.5	6.9	9.7	10.2	11	t/ha	350	2037	3568	1431	1532	1662
Mungbean	2.5	3.5	4.1	0.9	1.6	2	t/ha	1200	1003	1713	126	710	1115
Chickpea	3.1	3.5	3.7	1.6	1.9	2	t/ha	750	1110	1389	131	279	490
Soybean	7.8	8.4	9.2	4.7	5.0	5	t/ha	650	1624	3277	1471	1653	1748
Rhodes grass (hay)	19.7	20.6	21.7	43.1	44.3	45	t/ha	220	5046	9748	4549	4702	4817
Maize	7.0	7.4	7.8	9.9	10.3	11	t/ha	380	2106	3910	1702	1804	1903
Red Dermosol (156 mm PAWC), Kidman Springs climate (~950 mm annual rainfall)													
Cotton WS	4.6	4.8	4.9	10.3	11.3	12	bales/ha	700	4003	8877	4277	4875	5219
Cotton DS	5.7	5.5	5.2	5.2	6.5	7	bales/ha	700	3215	5138	1093	1923	2521
Sorghum (grain)	6.7	7.2	7.7	10.4	11.2	12	t/ha	350	2152	3914	1563	1762	1907
Mungbean	3.3	3.9	4.7	1.0	1.5	2	t/ha	1200	1038	1664	142	626	1089
Chickpea	2.8	3.1	3.4	1.0	1.2	1	t/ha	750	1039	896	–268	–143	19
Soybean	8.1	8.8	9.3	4.5	4.8	5	t/ha	650	1668	3147	1331	1479	1607

CROP	APPLIED IRRIGATION WATER (ML/ha/y)			CROP YIELD (Yield units)			YIELD UNIT	PRICE ($/unit)	VARIABLE COSTS ($/ha/y)	TOTAL REVENUE ($/ha/y)	GROSS MARGIN ($/ha/y)		
	Y80%	Y50%	Y20%	Y80%	Y50%	Y20%					Y80%	Y50%	Y20%
Peanut	7.4	8.0	8.2	6.8	7.2	8	t/ha	1000	3991	7237	2924	3246	3528
Rhodes grass (hay)	22.2	24.8	24.1	43.4	44.7	46	t/ha	220	5246	9827	4453	4582	4730
Maize	7.1	7.3	7.7	9.9	10.4	11	t/ha	380	2126	3943	1696	1817	1869
Vertosol (212 mm PAWC), Montejinni climate (~850 mm)													
Cotton WS	4.7	4.6	4.9	9.7	10.7	11	bales/ha	700	3895	8444	3920	4549	5006
Cotton DS	5.9	5.7	5.8	4.6	6.5	8	bales/ha	700	3198	5109	744	1910	2986
Sorghum (grain)	6.5	7.2	7.7	10.5	11.2	12	t/ha	350	2139	3907	1599	1768	1856
Mungbean	3.4	4.2	4.7	1.5	2.0	2	t/ha	1200	1072	2234	680	1163	1527
Chickpea	3.7	4.1	4.4	2.1	2.4	3	t/ha	750	1179	1765	409	586	820
Soybean	8.6	9.3	9.8	5.0	5.3	6	t/ha	650	1682	3434	1623	1752	1870
Rhodes grass (hay)	22.1	24.0	24.5	43.7	45.0	46	t/ha	220	5166	9899	4588	4733	4836
Maize	7.7	8.2	8.4	10.0	10.4	11	t/ha	380	2138	3957	1716	1819	1876
Red Kandosol (79 mm PAWC), Wavehill climate (~850 mm)													
Cotton WS	3.7	3.6	3.7	7.4	9.2	10	bales/ha	700	3798	7247	2308	3449	4100
Cotton DS	3.0	4.4	4.1	2.1	3.7	5	bales/ha	700	2916	2883	–886	–32	1076
Sorghum (grain)	5.4	5.8	5.6	10.4	10.7	11	t/ha	350	2401	3760	1293	1359	1525
Mungbean	2.6	3.2	3.6	1.3	1.6	2	t/ha	1200	1165	1790	302	625	1144
Chickpea	1.6	1.9	2.3	0.8	1.0	1	t/ha	750	1077	735	–438	–341	–199
Soybean	6.6	7.0	7.3	4.3	4.5	5	t/ha	650	1888	2956	980	1068	1172
Peanut	4.8	5.1	5.3	5.0	5.6	6	t/ha	1000	3695	5573	1489	1878	2198
Rhodes grass (hay)	20.3	20.9	20.1	41.7	42.8	44	t/ha	220	5945	9426	3324	3481	3620
Maize	5.5	5.8	5.9	10.0	10.2	11	t/ha	380	2289	3895	1471	1606	1645

CROP	APPLIED IRRIGATION WATER (ML/ha/y)			CROP YIELD (Yield units)			YIELD UNIT	PRICE ($/unit)	VARIABLE COSTS ($/ha/y)	TOTAL REVENUE ($/ha/y)	GROSS MARGIN ($/ha/y)		
	Y80%	**Y50%**	**Y20%**	**Y80%**	**Y50%**	**Y20%**					**Y80%**	**Y50%**	**Y20%**
General estimate for Victoria catchment (not soil specific)													
Sesame	na	6.2	na	na	0.9	na	t/ha	1300	2135	1170	na	–965	na
Hemp (grain seed)	na	5.9	na	na	1.1	na	t/ha	3150	2671	3465	na	794	na

A breakdown of the variable costs for growing broadacre crops shows that the largest two costs are the costs of inputs (31%) and farm operations (32%) (Table 5-3). Both of these cost categories would have similar dollar values when growing the same crop in southern parts of Australia, but the cost category that puts northern growers at a disadvantage is the higher market costs (26%, for freight and other costs involved in selling the crop – also see Section 2.2.4). Total variable costs consume 77% of the gross revenue generated, which leaves sufficient margin for profitable farms to be able to temporarily absorb small declines in commodity prices or yields without creating severe cashflow problems.

Table 5-3 Breakdown of variable costs relative to revenue for broadacre crop options

The first nine crops (Cotton WS to Rhodes grass) are for the Dermosol (intermediate performance), and the last two crops are for general catchment estimates. 'Input' costs are mainly for fertilisers, herbicides and pesticides; the cost of farm 'operations' includes harvesting; 'labour' costs are the variable component (mainly seasonal workers) not covered in fixed costs (mainly permanent staff); 'market' costs include levies, commission and transport to the point of sale. WS = wet season; DS = dry season

CROP	TOTAL REVENUE	TOTAL VARIABLE COSTS	PERCENTAGE BREAKDOWN OF VARIABLE COSTS				VARIABLE COSTS VS REVENUE
	($/ha/y)	($/ha/y)	INPUTS (%)	OPERATIONS (%)	LABOUR (%)	MARKET (%)	(%)
Cotton WS	8877	4003	35%	35%	5%	25%	45%
Cotton DS	5138	3215	43%	32%	6%	18%	63%
Sorghum (grain)	3914	2152	23%	18%	9%	51%	55%
Mungbean	1664	1038	38%	28%	19%	15%	62%
Chickpea	896	1039	42%	31%	16%	12%	116%
Soybean	3147	1668	32%	22%	17%	29%	53%
Peanut	7237	3991	31%	41%	9%	19%	55%
Rhodes grass (hay)	9827	5246	16%	56%	11%	17%	53%
Maize	3943	2126	23%	18%	11%	48%	54%
Sesame	1170	2135	29%	38%	9%	24%	182%
Hemp (grain seed)	3465	2671	36%	32%	10%	23%	77%
Mean	**4040**	**2528**	**31%**	**32%**	**12%**	**26%**	**77%**

Risk analyses were conducted for the two broadacre crops with the highest GMs: cotton and forages. The risk analysis used a narrative approach, where variable values with the potential to be different from those used in in the GMs were varied and new GMs calculated. The narrative approach allows the impact of those variables to be determined. The cotton analysis explored the sensitivity of GMs to opportunities and challenges created by changes in cotton lint prices, crop yields and distance to the nearest gin (Table 5-4). Results show that high recent cotton prices (about $800/bale through 2022) have created a unique opportunity for those looking to establish new cotton farms in NT locations like the Victoria catchment, since growers could transport cotton to distant gins or produce suboptimal yields and still generate GMs above $4,500/ha. At lower cotton lint prices, a local gin becomes more important for farms to remain viable. High cotton prices and the opening of a cotton gin 30 km north of Katherine in December 2023 have reduced some of the risk involved in learning to grow cotton as GMs increase from both these developments. At high yields and prices, sequentially cropping cotton seems an attractive option, however the specific licence permits that limit cotton planting windows for Bollgard cotton will need to be adhered to and may limit the ability for sequential cotton cropping.

Table 5-4 Sensitivity of cotton crop gross margins ($/ha) to variation in yield, lint prices and distance to gin

The base case is the Timber Creek Vertosol (Table 5-2) and is highlighted for comparison. The gin locations considered are a local gin near a new cotton farming region in the Victoria catchment, the new gin in Katherine, and two other potential gins in the NT (Adelaide River) and north-west Queensland (Richmond). Cotton lint prices are for the average over 2020-2024 ($700/bale), high prices from that period ($800/bale), and lower prices from 2015-2020 ($500/bale). Effects of a lower yield are also tested (the 6.5 bales/ha estimated as the dry-season yield for this location versus the base case of 11.4 bales/ha for wet-season cropping).

FREIGHT COST/TONNE (DISTANCE TO GIN)	COTTON CROP GROSS MARGIN ($/ha)					
	LINT PRICE = $500/bale		**LINT PRICE = $700/bale**		**LINT PRICE = $800/bale**	
	YIELD		YIELD		YIELD	
	6.5 bales/ha	11.4 bales/ha	6.5 bales/ha	11.4 bales/ha	6.5 bales/ha	11.4 bales/ha
$8 (50 km to local gin)	920	3204	2220	5484	2870	6624
$46 (300 km to Katherine gin)	779	2959	2079	5292	2729	6379
$94 (500 km to Adelaide River gin)	665	2758	1965	5038	2615	6178
$308 (2000 km to Richmond gin)	–187	1264	1113	3544	1763	4684

The narrative risk analysis for irrigated forages also looked at the sensitivity of farm GMs to variations in hay price and distance to markets, but here focuses on the issues of local supply and demand (Table 5-5). Forages, such as Rhodes grass, are a forgiving first crop to grow on greenfield farms as new farmers gain experience of local cropping conditions and ameliorate virgin soils while producing a crop with a ready local market in cattle. While there are limited supplies of hay in the region, growers may be able to sell hay at a reasonable price, given the large amount of beef production in the Victoria catchment and challenges of maintaining livestock condition through the dry season when the quality of native pastures is low. This would particularly be the case in dry years, when the quantity and quality of native pasture is low and demand for livestock dietary supplements increases. The scale of unmet local demand for hay limits opportunities for expansion of hay production without depressing local prices and/or having to sell hay further away, both of which lead to rapid declines in GMs (to below zero in many cases, Table 5-5). Another opportunity for hay is for feeding to cattle during live export, which could be integrated into an existing beef enterprise to supply their own live export livestock; this would require the hay to be pelleted. Section 5.4 considers how forages could be integrated into local beef production systems for direct consumption by livestock within the same enterprise. Hay and fodder crops will play an important role for a potential feedlot industry developing in the NT.

Table 5-5 Sensitivity of forage (Rhodes grass) crop gross margins (GMs) to variation in yield and hay price

The base case is the Timber Creek Vertosol (Table 5-2) and is highlighted for comparison. Transporting the hay further distances would increase opportunities for finding counter-seasonal markets paying higher prices, but this would be rapidly offset by higher freight costs.

FREIGHT COST/TONNE (DISTANCE TO DELIVER)	FORAGE CROP GROSS MARGIN ($/ha)		
	HAY PRICE/TONNE		
	$150	$220	$300
$20 (local)	1,600	4,702	8,247
$46 (300 km to Katherine)	448	3,550	7,095
$308 (2000 km to Richmond)	–11,160	–8,059	4,514

5.2.2 Horticultural crops

Table 5-6 shows estimates of potential performance for a range of horticultural crop options in the Victoria catchment. Upper potential GMs for annual horticulture (about $4000 per hectare per year) were less than upper potential GMs for farming perennial fruit trees (about $6000 per hectare per year). Capital costs of farm establishment and operating costs increase as the intensity of farming increases, so ultimate farm financial viability is not necessarily better for horticulture compared to broadacre crops with lower GMs (see Chapter 8). Note also that perennial horticultural crops typically require more water than annual crops because irrigation occurs for a longer period each year (mean of 9.0 versus 4.8 ML per hectare per year, respectively, in Table 5-6); this also, indirectly, affects capital costs of development since perennial crops require a larger investment in water infrastructure compared to annual crops to support the same cropped area.

Table 5-6 Performance metrics for horticultural options in the Victoria catchment: annual applied irrigation water, crop yield and gross margin (GM)

Applied irrigation water includes losses of water during application. Horticulture is most likely to occur on well-drained Kandosols. KP = Kensington Pride mangoes; PVR = new high-yielding mango varieties with plant variety rights (e.g. Calypso). Product unit prices listed are for the dominant top grade of produce, but total yield was apportioned among lower graded/priced categories of produce as well in calculating total revenue. Transport costs assume sales of total produce are a split among southern capital markets in proportion to their size. Applied irrigation water accounts for application losses assuming efficient pressurised micro irrigation systems.

CROP	APPLIED IRRIGATION WATER (ML/ha/y)	CROP YIELD (t/ha/y)	PRICE ($/unit)	PRICING UNIT (unit)	VARIABLE COSTS ($/ha/y)	TOTAL REVENUE ($/ha/y)	GROSS MARGIN ($/ha/y)
Row crop fruit and vegetables, annual horticulture (less capital intensive)							
Rockmelon	5.3	25.0	28	15 kg tray	43,699	44,000	301
Watermelon	6.0	47.0	450	500 kg box	53,449	42,300	–11,149
Capsicum	3.2	32.0	19	8 kg carton	71,959	76,000	4,041
Onion	4.7	30.0	15	10 kg bag	37,607	41,850	4,243
Fruit trees, perennial horticulture (more capital intensive)							
Mango (KP)	7.8	9.3	24	7 kg tray	22,242	28,398	6,156
Mango (PVR)	7.8	17.5	21	7 kg tray	43,257	47,250	3,993
Lime	11.4	28.5	18	5 kg carton	95,666	100,890	5,224

Crop yields and GMs can vary substantially among varieties, as is demonstrated here for mangoes. Mango production is well-established in multiple regions of northern Australia, including in the Darwin, Douglas-Daly and Katherine regions of the NT, with a smaller area of orchards at Mataranka in the Roper catchment. For example, the well-established Kensington Pride (KP) mangoes typically produce 5 to 10 t/ha while newer varieties can produce 15 to 20 t/ha. These new varieties (such as Calypso) are likely to be released with plant variety rights (PVR) accreditation. Selection of varieties also needs to consider consumer preferences and timing of harvest relative to seasonal gaps in market supply that can offer premium prices.

Prices paid for fresh fruit and vegetables can be extremely volatile (Figure 5-3) because produce is perishable and expensive to store, and because regional weather patterns can disrupt target timing of supply, causing unintended overlaps or gaps in combined supply between regions. This creates regular fluctuations between oversupply and undersupply, against inelastic consumer demand, to the extent that prices can fall so low at times that it would cost more to pick, pack and transport produce than farms receive in payment. Among this volatility are some counter-seasonal windows in southern markets (where prices are typically higher) that northern Australian growers can target.

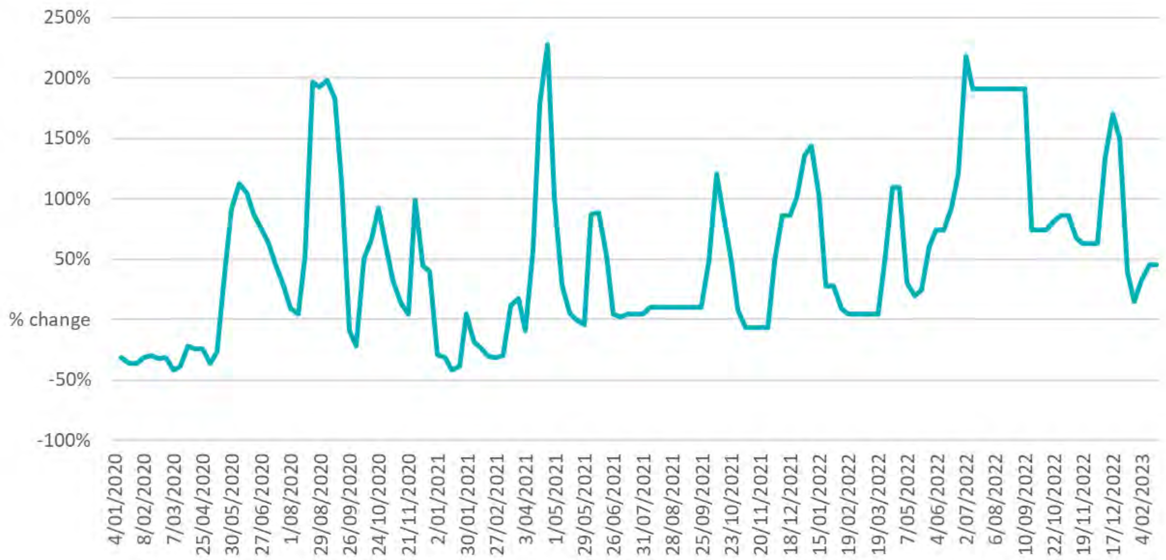


Figure 5-3 Fluctuations in seedless watermelon prices at Melbourne wholesale markets from April 2020 to February 2023

Percent change information available however prices are commercially sensitive and not available

Source: ABARES (2023)

Horticultural enterprises typically run on very narrow margins, where about 90% of gross revenue would be required just to cover variable costs of growing and marketing a crop grown in the Victoria catchment (Table 5-7). This makes crop GMs extremely sensitive to fluctuations in variable costs, crop yield and produce prices, amplifying the effect of already volatile prices for fresh fruit and vegetables. Most of the variable costs of horticultural production occur from harvest onwards, mainly in freight. This affords the opportunity to mitigate losses if market conditions are unfavourable at the time of harvest, since most costs can be avoided (at the expense of forgone revenue) by not picking the crop.

The narrative risk analysis for horticulture used the crop with the lowest GM (watermelons: Table 5-7) to illustrate how opportunities for reducing freight costs and targeting periods of higher produce prices could improve GMs to find niches for profitable farms (

Table 5-8). Reducing freight costs by finding backloading opportunities or concentrating on just the smaller closest southern capital city market of Adelaide would substantially improve GMs. The base case already assumed that growers in the Victoria catchment would target the predictable seasonal component of watermelon price fluctuations (Figure 5-3), but any further opportunity to attain premiums in pricing could help convert an unprofitable baseline case into a profitable one. This example also highlights the issue that while there may be niche opportunities that allow an otherwise unprofitable enterprise to be viable, the scale of those niche opportunities also then limits the scale to which the industry in that location could expand, for example: (i) there is a limit to the volume of backloading capacity at cheaper rates; (ii) only supplying produce to the closest market excludes the largest markets (e.g. accessing the larger Sydney and Melbourne markets remains non-viable except when prices are high, Table 5-8); and (iii) chasing price premiums restricts the seasonal windows into which produce is sold or restricts markets to smaller niches that target specialised product specifications. Niche opportunities are seldom scalable, particularly in horticulture, which is a contributing factor to why horticulture in any region usually involves a range of different crops (often on the same farm).

Table 5-7 Breakdown of variable costs relative to revenue for horticultural crop options

'Input' costs are mainly for fertilisers, herbicides and pesticides; the cost of farm 'operations' includes harvesting; 'labour' costs are the variable component (mainly seasonal workers) not covered in fixed costs (mainly permanent staff); 'market' costs include levies, commission and transport to the point of sale. WS = wet season; DS = dry season

CROP	TOTAL REVENUE	TOTAL VARIABLE COSTS	PERCENTAGE BREAKDOWN OF VARIABLE COSTS				VARIABLE COSTS VS REVENUE
	($/ha/y)	($/ha/y)	INPUTS (%)	OPERATIONS (%)	LABOUR (%)	MARKET (%)	(%)
Row crop fruit and vegetables, annual horticulture (less capital intensive)							
Rockmelon	44,000	43,699	27%	16%	11%	46%	99%
Watermelon	42,300	53,449	12%	15%	16%	60%	126%
Capsicum	76,000	71,959	45%	14%	11%	40%	95%
Onion	44,000	37,607	12%	18%	11%	60%	90%
Fruit trees, perennial horticulture (more capital intensive)							
Mango (KP)	28,398	22,242	22%	22%	14%	42%	78%
Mango (PVR)	47,250	43,257	20%	24%	17%	38%	92%
Lime	100,890	95,666	23%	22%	19%	36%	95%
Mean	**54,691**	**54,030**	**22%**	**19%**	**15%**	**46%**	**96%**

Table 5-8 Sensitivity of watermelon crop gross margins ($/ha) to variation in melon prices and freight costs

The base case (Table 5-2) is highlighted for comparison.

FREIGHT COST (MARKET LOCATION)	WATERMELON GM (PERCENTAGE DIFFERENCE FROM BASE PRICE)				
	$225 (–50%)	$337 (–25%)	$450 (BASE PRICE)	$675 (+50%)	$900 (+100%)
$350/t (backloading to Adelaide)	–20,150	–11,096	–1,961	16,228	34,417
$440/t (close market: Adelaide)	–24,380	–15,326	–6,191	11,998	30,187
$550/t (all capital cities)	–29,550	–20,496	–11,361	6,828	25,017
$616/t (Sydney)	–32,652	–23,598	–14,463	3,726	21,915
$584/t (Melbourne)	–31,308	–22,254	–13,119	5,070	23,259

The risk analysis also illustrates just how much farm financial metrics like GMs amplify fluctuations to input costs and commodity prices to which they are exposed. For horticulture, far more than broadacre agriculture, it is very misleading to look just at a single ‘median’ GM for the crop, because that is a poor reflection of what is going on within an enterprise. For example, a –50% to +100% variation in watermelon prices would result in theoretical annual GMs fluctuating between –$20,496/ha and $25,017/ha (Table 5-8). While, in practice, potentially negative GMs could be greatly mitigated (by not harvesting the crop), this still creates cashflow challenges in managing years of negative returns between years of windfall profits. This amplified volatility is another contributor to horticultural farms often growing a mix of produce (as a means of spreading risk). For row crop production, another common way of mitigating risk is using staggered planting through the season, so that subsequent harvesting and marketing are spread out over a longer target window to smooth out some of the price volatility.

5.2.3 Plantation tree crops (silviculture)

Estimates of annual performance for African mahogany and sandalwood are provided in Table 5-9. The best available estimates were used in the analyses, but information on plantation tree production in northern Australia is often commercially sensitive and/or not independently verified. The measures of performance presented, therefore, have a low degree of confidence and should be treated as broadly indicative noting that actual commercial performance could be either lower or higher. Plantation forestry has long life cycles with low-intensity management during most of the growth cycle, so variable costs typically consume less of the gross revenue (27%) than for broadacre or horticultural farming (Table 5-10). However, long-life-cycle production systems have additional risks over annual cropping. There is a much longer period between planting and harvest for adverse events to affect the yield quantity and/or quality, and prices of inputs and harvested products could change substantially over that period. Market access and arrangements with buyers could also change. The long lags from planting to harvest also mean that potential investors need to consider other similar competing pipeline developments (that may not be obvious because they are not yet selling product) and long-term future projections of supply and demand (for when their own plantation will start to be harvested and enter supply chains). The cashflow challenges are also significant given the long-term outlay of capital and operating costs before any revenue is generated. Carbon credits might be able to assist with some early cashflow (if the 'average' state of the plantation, from planting to harvest, stores more carbon than the vegetation it replaced and the regulatory environment facilitates the generation of carbon credit units in the region).

Investments into forestry plantations must be seriously evaluated. Quintis, one of the NT's largest forestry businesses, entered into receivership in April 2024. Forestry enterprises must accurately predict commodity prices well into the future and commit to long-term spending to maintain forestry assets. Compounding these issues, forestry operations have limited ability to diversify their income or change crop as market demand changes.

Table 5-9 Performance metrics for plantation tree crop options in the Victoria catchment: annual applied irrigation water, crop yield and gross margin (GM)

Yields are values at final harvest and for sandalwood are just for the heartwood component. African mahogany pricing unit is for a 800 kg cube, and 10% of the African mahogany yield is marketable cubes. Other values are annual averages assuming a 20-year life cycle of the crop (representing the idealised ultimate steady state of an operating farm that was set up with staggered plantings for a steady stream of harvests). No discounting is applied to account for the substantial timing offset between when costs are incurred and revenue is received: any investment decision would need to take that into account. African mahogany performance is for unirrigated production.

CROP	CROP LIFE CYCLE (y)	APPLIED IRRIGATION WATER (ML/ha/y)	CROP YIELD AT HARVEST (t/ha)	PRICE ($/unit)	PRICING UNIT	VARIABLE COSTS ($/ha/y)	TOTAL REVENUE ($/ha/y)	GROSS MARGIN ($/ha/y)
African mahogany	20	unirrigated	160	4,000	cube	980	4,000	3,020
Sandalwood	20	4.7	4	8,800	t heartwood	1,100	1,760	660

Table 5-10 Breakdown of variable costs relative to revenue for plantation tree crop options

'Input' costs are mainly for fertilisers, herbicides and pesticides; the cost of farm 'operations' includes harvesting and labour; 'market' costs include levies, commission and transport to the point of sale.

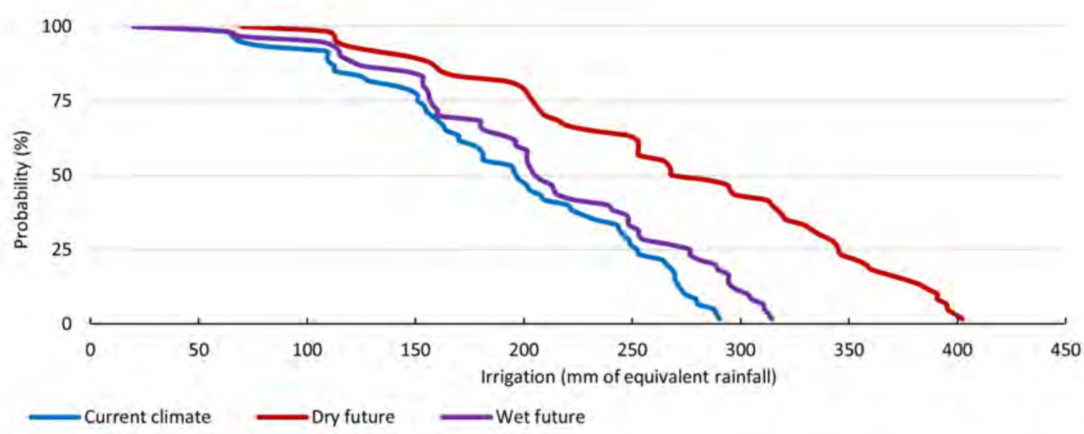
CROP	TOTAL REVENUE	TOTAL VARIABLE COSTS	PERCENTAGE BREAKDOWN OF VARIABLE COSTS			VARIABLE COSTS VS REVENUE
	($/ha/y)	($/ha/y)	INPUTS (%)	OPERATIONS (%)	MARKET (%)	(%)
African mahogany	4,000	980	18%	38%	45%	24%
Sandalwood	1,760	1,100	4%	83%	10%	62%
Mean	**2,880**	**1,040**	**11%**	**61%**	**28%**	**43%**

5.2.4 Climate change and crop production

As noted previously (Section 3.1.8), mean annual rainfall in the Victoria catchment is projected by most global climate model – patterned scaled (GCM-PS) to change by less than 5%, more models project >5% wetting (13%) than >5% drying (6%). As an illustrative example of the possible impacts of climate change on future cropping in the Victoria catchment, APSIM was used to simulate grain sorghum yield and water use for Kidman Springs under current (historical) climate and two contrasting 2070 scenarios from GCM-PS projections: a hotter drier future (based on GFDL-CM3, 3.4 °C warmer and 52 mm/year drier than current), and a hotter wetter future (based on CCSM4, 2.7 °C warmer and 81 mm/year wetter than current). Simulations of both climate change scenarios used CO_2 levels of 725 ppm, as projected for a future climate under RCP 8.5 (Riahi et al., 2011).

APSIM simulation results for irrigated sorghum, sown in mid-January, indicated that the irrigation requirement was higher under the drier future climate scenario (Figure 5-4a), representing a median increase in annual demand for irrigation water of 70 mm (0.7 ML/ha) above the baseline scenario in a median year. Little change occurred between the irrigation requirement for the baseline and wetter future climate scenarios. Median sorghum grain yields of both wet and dry warming scenarios were lower than baseline yields, due to the detrimental effect of extreme temperatures on crop growth and development, which are worse in the drier climate scenario (about 0.6 t/ha lower) than the wetter scenario (about 0.1 t/ha lower) (Figure 5-4b).

(a) Irrigation water requirement



(b) Yield with irrigation

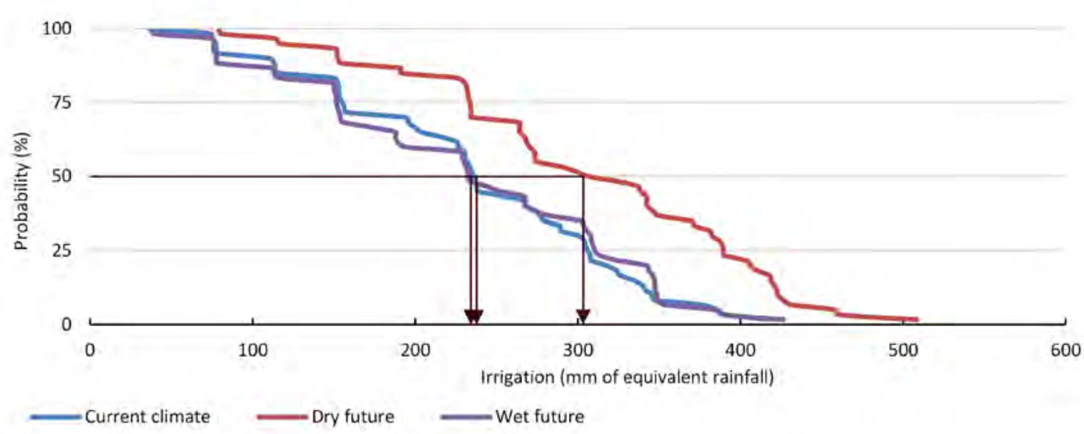


Figure 5-4 Probability of exceedance graphs for (a) simulated irrigation requirement (mm) and (b) grain yield (t/ha), for a grain sorghum crop grown under current climate conditions and for both a drier and wetter future climate scenario at Kidman Springs in the Victoria catchment

Note that the APSIM model results provide an estimate of crop responses to alternative climate change scenarios while holding farming practices constant. Projections of real-world impacts are constrained by incomplete knowledge of crop and farming system response to alternative environmental conditions. The effect of extreme temperatures on sensitive crop growth processes (particularly flowering) in northern Australia is not well understood, and crop responses in reality may differ from those presented here. Additionally, adaptive management changes are available to farmers that may mitigate the negative effect of climate change on crop growth (e.g. using alternative sowing times to avoid heat stress during critical growth periods, and sowing longer duration varieties (including new climate-adapted varieties that may be developed) to counteract the reduced growth periods caused by higher temperatures). Nonetheless, it is prudent for any potential developer to consider the risks that future lower yields and higher water use could have on new farm developments, and the implications of this for recovering the costs of investments.

For some crops, climate change impacts could involve more than just incremental changes in yields. This is particularly the case for crops that are already at the edge of their distributional ranges for phenological triggers (such as cold triggers for flower initiation in mangoes, e.g. NESP Earth Systems and Climate Change Hub (2019)). At the lower end of impacts, phenological changes may primarily change just the timing of harvest. Depending on how the new seasonal supply coincides with altered phenology and production windows from other regions, price premiums for out-of-season production could be affected. In worse cases, flowering, pollination and/or fruit set (or other phenological progression) may be curtailed in an increasing number of years, until crop production may no longer be viable without new climate-adapted varieties.

5.3 Cropping systems

This section evaluates the types of cropping systems (crop species × growing season × resource availability × management options) that are most likely to be profitable in the Victoria catchment based on the above analyses of GMs (Section 5.2), information from companion technical reports in this Assessment, and cropping knowledge from climate-analogous regions (relative to local biophysical conditions). Cropping system choices could include growing a single crop during a 12-month period, or growing greater than one, commonly referred to as sequential, double, or rotational cropping. This section covers the principles for implementing both types of cropping systems (beyond the issues for individual crops already dealt with in sections 3.4 and 5.2), with an emphasis on sequential cropping systems and the mix of cropping options that might be grown in sequence on a unit of land in the Victoria catchment.

5.3.1 Cropping system considerations

Selecting two or more crops to grow in sequence increases the complexity, beyond the issues already discussed, in finding and adapting individual cropping options for the Victoria catchment. The rewards from successfully growing crops in sequence (versus single cropping) can be substantial if additional net annual revenue can be generated from the same initial capital investment (to establish the farm). To find viable mixes of cropping options for the Victoria catchment, developers will need to consider each of the four key factors below.

Markets

Whether growing a single crop or sequential cropping, the choice of crop(s) to grow is driven by the markets and supply chains that can provide a sufficient price and reliability of demand, while being able to supply those markets at sufficient scale and affordable cost. As the price received (and scale of markets) for different crops fluctuates, so too will the crops grown. In the Victoria catchment, freight costs, determined by the distance to selected markets and processing facilities, must also be considered. A critical scale of production may be needed for a new market opportunity or supply chain to be viable (e.g. exporting grains from Darwin would require sufficient economies of scale for the required supporting port infrastructure and shipping routes to be viable). Crops such as cotton, peanut and sugarcane require a nearby processing facility. A consistent and critical scale of production is required for processing facilities to be viable (see Section 7.4). From 2024, cotton will have the advantage of local processing with an operational gin 30 km north of Katherine. Transporting raw cotton from the Victoria catchment to this gin would go a long way to improving the viability of cotton production (Table 5-4), where it would be possible from parts of the Victoria catchment to get to the gin and back in a day, without the added expense of an overnight stop.

Most horticultural production from the Victoria catchment would be sent to capital city markets, often using refrigerated transport. Victoria catchment horticultural production would have to accept a high freight cost compared to the costs faced by producers in southern parts of Australia. The competitive advantage of horticultural production in the Victoria catchment is that higher market prices can be achieved from 'out-of-season' production compared to large horticultural production areas in southern Australia. Annual horticultural row crops such as melons would use staggered plantings, for example, planting at fortnightly intervals over a 3 to 4-month period, to reduce risk of exposure to low market prices and to make it more likely that very high market prices would be achieved for at least some of the produce. Market considerations are covered in more detail in Section 2.2.

Operations

Farmers need to be skilled at managing the operational complexity of adapting crop mixes and production systems to Victoria catchment environments (including soils, water resources and climates), particularly in 'learning' through the challenging establishment years.

Sequential cropping can require a trade-off against sowing at optimal times to allow crops to be grown within a back-to-back schedule. This trade-off could lead to slightly lower yields from planting at suboptimal times. For annual horticultural crops there would be additional trade-offs in the seasonal window over which produce can be sent to market (affecting opportunities to target seasonal peaks in prices and to use staggered planting dates to mitigate risks from price fluctuations).

Growing crops sequentially depends on timely transitions between the crops and selecting crops that are agronomically and operationally compatible with each other, including growing seasons that reliably fit together in the available cropping windows. In the Victoria catchment's variable and often intense wet season, rainfall increases operational risk via reduced trafficability and the subsequent limited ability to conduct timely operations. A large investment in machinery (either multiple or larger machines) could increase the area that could be planted per day when fields are trafficable within a planting window. With sequential cropping, additional farm machinery and equipment may be required where there are crop-specific machinery requirements, or to help complete operations on time when there is tight scheduling between crops. Any additional capital expenditure on farm equipment would need to be balanced against the extra net farm revenue generated.

Sequential cropping can also lead to a range of cumulative issues that need careful management, for example: (i) build-up of pests, diseases and weeds; (ii) pesticide resistance, which is often exacerbated by sequential cropping; (iii) increased watertable depth; and (iv) soil chemical and structural decline (e.g. Piaui, 2010; Chauhan et al., 2012; Lopes et al., 2012; Lopes and Guilherme, 2016). Many of these challenges can be anticipated before beginning sequential cropping. Integrated pest, weed and disease management would be essential when multiple crop species are grown in close proximity (adjacent fields or farms). Many of these pests and controls are common to several crop species where pests (e.g. aphids) move between fields. Such situations are exacerbated when the growing seasons of nearby crops partially overlap or when sequential crops are grown, because both scenarios create 'green bridges', that facilitate the continuation of pest life cycles. When herbicides are required, it is critical to avoid products that could damage a susceptible crop the following season or sequentially.

Water

Cropping systems are strongly influenced by the nature of water resources in terms of their costs to develop, the volume and reliability of supply, and the timing of when water is available relative to optimal planting windows (see companion technical reports on river modelling calibration (Hughes et al., 2024b), surface water storage (Yang et al., 2024) and hydrogeological assessment (Taylor et al., 2024).

Sequential cropping leads to a higher annual crop water demand (versus single cropping) because: (i) the combined period of cropping is longer; (ii) it includes growing during the Victoria catchment's dry season; and (iii) PAW at planting will have been depleted by the previous crop. Typically, an additional 1.5 ML/ha on well-drained soils, and 1 ML/ha on clays, is required for sequential cropping relative to the combined water requirements of growing each of those crops individually (with the same sowing times). This additional water demand needs to be accounted for in initial farm planning, particularly where on-farm water storage or dry-season water extraction is required.

Irrigating using surface water in the Victoria catchment would face issues with the reliability and the timing of water supplies. Monitored river flows need to be sufficient to allow pumping into on-farm storages for irrigation (i.e. to meet environmental flow and river height requirements). The timing of water availability is analysed in the companion technical report on river model scenario analysis (Hughes et al., 2024a). The availability of water for extraction each wet season affects the options for sequencing a second crop.

The cost of developing water sources (or the price at which water is supplied to irrigators) is also critical in determining what crops are grown, because only high-value cropping options will be able to afford to pay for more expensive water (see Chapter 8). For example, in other parts of Australia that use ‘deep’ bore water (>50 m total dynamic head (TDH)) for irrigation, farming is restricted to high-value horticulture because of the high capital and pumping costs involved in accessing and distributing that water.

Soils

Farming systems are governed by the nature of the soil resources in terms of their scale and distribution, their proximity to water sources and supply chains, their farming constraints, the crops they can support with viable yields, and their costs to develop (see companion technical reports on digital soils mapping and land suitability (Thomas et al., 2024), flood modelling (Karim et al., 2024) and Part III of this report). Large arable areas of cracking clay soils are found on alluvial plains scattered through the Victoria catchment and particularly in significant areas of the West Baines River and the Barkly Tableland (SGG 9, marked B, C and E in Figure 3-3). Extensive areas of loamy soils occur in the southern part of the catchment and the plateau west of Kalkarindji (SGG 4.1, marked A in Figure 3-3). There are good analogues of these Victoria catchment environments in successful irrigated farming areas in other parts of northern Australia. Katherine is indicative of farming systems and potential crops grown on well-drained loamy soils irrigated by pressurised systems and the Ord River Irrigation Area is indicative of furrow irrigation on heavy clay soils.

The good wet-season trafficability of the well-drained loamy Kandosols permits timely cropping operations and would enhance the implementation of sequential cropping systems. However, Kandosols also present some constraints for farming. Kandosols are inherently low in organic carbon, nitrogen, potassium, phosphorus, sulfur and zinc with other micronutrients often requiring supplementation (boron, copper and molybdenum). Very high fertiliser inputs are therefore required when first cultivated. Due to the high risk of leaching of soluble nutrients (e.g. nitrogen and sulfur) during the wet season, in-crop application (multiple times) of the majority of crop requirement for these nutrients is necessary (Yeates, 2001). In addition, high soil surface temperatures and surface crusting combined with rapid drying of the soil at seed depth reduce crop establishment and seedling vigour for many broadacre species sown during the wet season and early dry season, for example, maize, soybean and cotton (Abrecht and Bristow, 1996; Arndt et al., 1963).

In contrast, the cracking clay Vertosols have poor trafficability following rainfall (Figure 3-10), inundation or irrigation, disrupting cropping operations. These constraints are compounded by poor wet-season drainage restricting crop choice to waterlogging tolerant species and means that crops cannot always be sown at optimum times. Farm design is a major factor on cracking clay soils and needs to minimise flooding of fields from nearby waterways, ensure prompt runoff from fields after irrigation or rain events, and ensure that farm roads maintain access to fields. Timely in-field bed preparation can reduce delays in planting. Clay soils also have some advantages, particularly in costs of farm development, by allowing lower-cost surface irrigation (versus pressurised systems) and on-farm storages (where expensive dam lining can be avoided if soils contain sufficient clay) (see Yang et al., 2024). Clay soils also typically have greater inherent fertility than Kandosols (but initial sorption by clay means that phosphorus requirements can be high for virgin soils in the first 2 years of farming).

5.3.2 Potentially suitable cropping systems

Crop species that could potentially be grown as a single crop per year were identified and rated for the Victoria catchment (Table 5-11) based on indicators of farm performance presented above (yields, water use and GMs: Section 5.2), and considerations of growing season, experiences at climate-analogous locations, past research, and known market and resource limitations and opportunities. Many of these crops currently have small to medium-sized high-value markets, hence they are sensitive to Australian and international supply. Annual horticulture, cotton, peanut and forages are the most likely to generate returns that could exceed farm development and growing costs (Table 5-11).

Table 5-11 Likely annual irrigated crop planting windows, suitability and viability in the Victoria catchment

Crops are rated as to how likely they are to be financially viable: *** = likely at low-enough development costs; ** = less likely for single cropping (at current produce prices); *^{S} = marginal but possible in a sequential cropping system. Rating qualifiers are codes as ^{L} development limitation, ^{M} market constraint, ^{P} depends on sufficient scale and distance to local processor, and ^{B} depends on distance to and type of beef (livestock production) activity it is supporting. Farm viability is dependent on the cost at which land and water can be developed and supplied (Chapter 8). na = not applicable.

CROP	RATING	CROP	RATING
Wet season (planted December to early March)		**Dry season (planted late March to August)**	
Cotton	***^{P}	**Annual horticulture**	***^{M}
Forages	***^{B}	**Cotton**	***^{P}
Sugarcane	***^{LP}	**Niche grains (e.g. chia, quinoa)**	***^{SM}
Peanut (not on clay)	***^{LMP}	na	na
Mungbean	**	**Mungbean**	**
Maize	**	na	na
Chickpea	**	na	na
Rice	**^{L}	na	na
Sorghum (grain)	*^{S}	**Sorghum (grain)**	*^{S}
Soybean	*^{S}	**Soybean**	*^{S}
Sesame	*^{S}	**Sesame**	*^{S}

Due to good wet-season trafficability on loamy soils, there are many possible sequential cropping options for the Victoria catchment Kandosols (Table 5-12). Given the predominance of broadleaf and legume species in many of the sequences (Table 5-12), a grass species is desirable as an early wet-season cover crop. Although annual horticulture and cotton could individually be profitable (Table 5-11), an annual sequence of the two would be very tight operationally. Cotton would be best grown from late January with the need to pick the crop by early August, then destroy cotton stubble, prepare land and remove volunteer cotton seedlings. That scheduling would make it challenging to fit in a late-season melon crop that would need to be sown by late August to early September. Similar challenges would occur with cotton followed by mungbean or grain sorghum.

Fully irrigated sequential cropping on the Victoria catchment Vertosols would likely be opportunistic and favour combinations of short-duration crops that can be grown when irrigation water reliability is greatest (March to October), for example, annual horticulture (melons), mungbean, chickpea and grass forages (2 to 4 months growing season length). Following an unirrigated (rainfed) wet-season grain crop with an irrigated dry-season crop could also be possible. However, seasonally dependent soil wetting and drying would limit timely planting and the area planted, which means that farm yields between years would be very variable. Sorghum, mungbean and sesame are the species most adapted to rainfed cropping due to favourable growing season length and their tolerance to water stress and higher soil and air temperatures. The scattered distribution of suitable pockets of clay soils would limit the scale of farming at any location within the Victoria catchment (which would restrict opportunities for establishing local processors).

Table 5-12 Sequential cropping options for Kandosols

E = early in month; L = late in month; M = middle of month

SPECIES	GROWING SEASON	SPECIES	GROWING SEASON
Wet season (planted December to early March)		**Dry season (planted late March to August)**	
Mungbean **Sorghum (grain)** **Peanut (not on clay)**	E-February to L-April January to April January to April or February to May	**Annual horticulture**	M-May to L-October
Cotton	L-January to E-August	**Mungbean** **Sorghum (grain)** **Forage/silage**	M-August to L-October M-August to M-November M-August to E-November; cut then retained as wet-season cover crop
Mungbean	E-February to L-April	**Cotton**	E-May to E-November
Mungbean **Peanut** **Sesame** **Soybean**	E-February to L-April E-January to L-April E-January to L-April E-January to L-April	**Maize**	May to October
Sesame or Sorghum (grain)	January to L-April	**Chickpea**	May to August
Mungbean **Sesame** **Soybean**	E-February to L-April January to L-April January to L-April	**Grass forage/silage**	May to E-November; cut then retained as wet-season cover crop

5.4 Integrating forages into livestock systems

5.4.1 Base-enterprise

A base-case beef cattle enterprise was developed for the Victoria catchment. The nominal soil type was a cracking clay (black soil) such as found on the Ivanhoe land system (Pettit, undated) in B condition. The rainfall location used was Kidman Springs, because of the length and quality of record. Output from the model was used for the period 1963–64 to 2021–22. The parameter estimates used to set up the model were derived from a number of published sources (Ash et al., 2018; Chudleigh et al., 2019; Cowley, 2014; Jackson et al., 2015; McLean and Holmes, 2015; Meat and Livestock Australia, 2006; Moore et al., 2021; Pettit, undated; Tyler et al., 2012) as well as local knowledge and online sources (e.g. https://afia.org.au/; https://www.feedcentral.com.au/; https://feedtest.com.au/index.php/about/feedtest-information; https://www.nutrienagsolutions.com.au/livestock/live-export; https://www.mla.com.au/prices-markets/statistics/nlrs-indicators/).

The base-enterprise was set up in the Crop Livestock Enterprise Model (CLEM) as a self-replacing cow-calf operation, focused on selling into the live export market, with castrate males sold at a minimum 280 kg liveweight (but noting that actual sale weights of individuals were typically in excess of this because there were only two sale dates per year). Any remaining castrate males were sold at the first selling month after the animals reached 25 months age. The base-enterprise was set up with two rounds of mustering. The main selling month (muster) was May with the second muster and consequent sales in September. The mating system was 'controlled' (i.e. bulls were introduced to the cows in January and removed at the end of May).

Young females, aged between 16 and 20 months, were sold in May. The selling criterium was set as the bottom 30% by weight (as a proportion of normalised weight). The model then dynamically balanced breeder numbers by selling excess breeders at the first or second muster, while keeping the maximum number of breeders at or below a set amount, depending on feed availability. For the base-enterprise, maximum breeder numbers were set at 2050. The maximum breeder numbers were set in order to maintain an annual utilisation rate of 20% (cattle offtake of native pasture equal to 20% of native pasture growth, averaged across years), as recommended by Walsh and Cowley (2014) and in the Land Condition Guide of Pettit (undated) for clay soils.

The utilisation rate was set at 20% for all six management options (including irrigated forages) detailed below. In order to achieve a 20% utilisation rate the maximum number of breeders was altered for each management option. In the base-enterprise, calves were weaned at 170 kg liveweight minimum or 7 months old in May and a second weaning in September at 100 kg minimum or 5 months old. Calves were naturally weaned once they had reached an age of 8 months. Animals marked for sale were sold in May and September, or October (depending on the management option). Remaining breeders were sold when they reached a maximum age of 120 months. All animals were fed a supplement containing nitrogen and phosphorus between May and November and a phosphorus supplement between December and April. In its current configuration, CLEM assumes that phosphorus is not limiting so that the addition of a phosphorus supplement in the model is for the purposes of accurate costing rather than altering production outputs.

Broadly speaking, these enterprise characteristics can be thought of as a small cattle enterprise within the Victoria catchment run by an owner-manager. The exception to this is the use of controlled breeding. While not unknown in the Victoria catchment, it is not commonly practised for the whole herd, although Cowley (2014) reports that 33% of producers in the Victoria River District (VRD) carried out some form of controlled mating and 44% of maiden heifers in the VRD were control mated. However, the concentration of calving in the CLEM model due to the controlled mating made it much easier to track cohorts of animals for comparisons across the forage and hay options.

The VRD is characterised by a high proportion of corporately owned cattle enterprises (56%) as distinct from privately owned, with 67% of properties in the range between 2000 and 4000 km^2, with a maximum of 13,500 km^2 (Cowley, 2014). Of the surveyed properties, the most common herd size in the VRD was in the range of 15,000 to 20,000 head. The results from this CLEM analysis can be scaled to these much larger numbers by multiplying by a factor (say 5–7) so that for example, a 2800 adult equivalent (AE) herd multiplied by a factor of 6 represents a 16,800 AE herd, although of course economies of scale will reduce some of the costs in the larger enterprises.

Variable and overhead costs were drawn from a number of sources (see above) and then indexed from either the date of publication, or the period of collection, through to December 2023, recognising that there has been high volatility, and general increases in costs, since that time.

Similarly, livestock prices in recent years have been highly volatile with Meat and Livestock Australia's National Feeder Steer Indicator for 'Qld Yearling Steer 280 to 330 kg liveweight' reaching a maximum in January 2022 of 661 cents/kg, but with a mean over the 10-year period between February 2014 and February 2024 of 349 cents/kg. It was 361 cents/kg in February 2024. (https://www.mla.com.au/prices-markets/statistics/nlrs-indicators/). Clearly, such volatile livestock prices will have a big impact on enterprise profitability, with or without irrigated forages. In CLEM, liveweight prices can be set for different age and sex classes. The VRD base-enterprise model was set up to test the sensitivity of beef prices based on the following:

- LOW beef price. Beef prices were set to 275 cents/kg for males between 12 months and 24 months old, declining across age and sex classes to 134 cents/kg for cows older than 108 months. For the modelled base-enterprise option, this gave a price of 230 cents/kg averaged across the herd and across years.
- MED beef price. Beef prices were set to 350 cents/kg for males between 12 months and 24 months old, declining across age and sex classes to 170 cents/kg for cows older than 108 months. For the modelled base-enterprise option, this gave a price of 293 cents/kg averaged across the herd and across years.
- HIGH beef price. Beef prices were set to 425 cents/kg for males between 12 months and 24 months old, declining across age and sex classes to 206 cents/kg for cows older than 108 months. For the modelled base-enterprise option, this gave a price of 356 cents/kg averaged across the herd and across years.

A GM per AE was calculated as the total revenue from cattle sales minus total variable costs (Table 5-13). A profit metric, earnings before interest, taxes, depreciation and amortisation (EBITDA) was also calculated as total revenue minus variable and overhead costs, which allows performance to be compared independently of financing and ownership structure (McLean and Holmes, 2015) and is used in the analysis of net present value (NPV).

5.4.2 Irrigated forage and hay options

As outlined in Section 4.4, the use of forages and hay grown on-farm to supplement cattle is uncommon in northern Australia. Across the entire Katherine region (which includes the VRD catchment) Cowley (2014) reports two of the surveyed properties with areas of irrigated pastures. Ten producers reported making hay, principally for their own use. The amount grown was relatively low, being a median of 270 t/property, which at 27 t/ha (for example) this would require only 10 ha of production. There is still much to be learned about the most appropriate forage and hay species to grow, how best to manage the forages and hay to ensure high-quality feed, which cohort(s) of cattle to feed, how the feeding should be managed and which market specifications should be targeted to obtain maximum return.

The number of possible combinations of options is large, making it difficult to compare options. The modelling outlined in this section took a conservative approach, using three species of forage and hay crops, feeding young cattle only and keeping a constant market specification based on a minimum sale weight of 280 kg, noting that the mean sale weight was greater than this because sales occurred only twice per year, in May and September (for the two base-enterprise and the lablab stand and graze options, see below) or May and October (for the forage sorghum stand and graze option and the two hay options). The primary market was considered to be live export, either directly or through sales to backgrounders or agistment, closer to Darwin. In the VRD 68% of cattle were bred for live export, with a further 22% bred and transferred for growing elsewhere (Cowley, 2014), with most of these also going to live export.

Ideally, production would increase by allowing male animals to reach minimum selling weight at a younger age and allowing for greater weight gain during the dry season when animals on native pasture alone either lose weight, or gain very little weight. There are also potential benefits to the reproductive capacity of the herd by providing better nutrition to young females. Finally, the addition of forages and hay allows more cattle to be carried, while still maintaining a utilisation rate of native pastures at around 20%.

The approach considered three different forage and/or crop options, which were modelled in APSIM and used as an input to the CLEM modelling:

- Rhodes grass, which is a perennial grass, capable of high biomass values but requiring careful management to optimise biomass and nutritive content. At high biomass levels, the nitrogen content is diluted. It also requires frequent cutting in order to maintain sufficiently high dry matter digestibility. Rhodes grass is probably the most common crop grown on irrigation on cattle enterprises in northern Australia, and while there are some data available regarding its management and production in an environment broadly comparable with the Victoria catchment (e.g. Giovi Agriculture, 2018), readily published data for comparison are scarce.

- Forage sorghum, an annual grass crop, grown over a period of 7 months. Careful management of forage sorghum is required if cattle are put on to the crop to graze it directly (i.e. stand and graze) due to the risk of prussic acid poisoning (O'Gara, 2010).
- Lablab, an annual legume crop which typically provides a higher quality of feed compared to the two grasses but over a shorter period, and at lower biomass yields.

These options were compared against a base-enterprise and a base-enterprise plus hay that included buying hay for feeding to weaners for the 2 months following weaning, which is a common practice in the northern grazing industry, including in the Victoria catchment (Cowley, 2014; Tyler et al., 2012).

The costs for producing the irrigated forages and hay were based on those that sat behind the Northern Australia Beef Systems Analyser (NABSA) modelling found in Ash et al. (2018) and indexed to consumer price index (CPI). These costs were treated as variable costs and were on a per hectare basis.

The area of forages and hay grown was determined by matching the monthly availability from the irrigated forages and hay with the nutritional demands of the cattle being fed, accepting small shortfalls rarely. Such an approach over estimates the amount of land required for irrigation because in practice a manager can move livestock from the irrigated area to native pasture within time steps of a day and can be more flexible in approach than the model allows.

A total of six options were tested (all included nitrogen and phosphorus supplementation) with summarised results shown in Table 5-13:

1. Base-enterprise. No supplementary hay or forage feeding. The weaning criteria in May was 7 months old or 170 kg and that in September was 5 months old or 100 kg. Natural weaning occurred at 8 months old.

2. Base-enterprise plus hay. That is, base-enterprise but with the addition of reasonable quality hay bought off-farm to supplement the weaners in the first 2 months after weaning. Weaning weight was reduced to a minimum of 140 kg or 5 months old at the May weaning and 100 kg or 5 months old at the September weaning. Natural weaning occurred at 8 months old. The same weaning criteria were applied to the four irrigated options below.

3. Irrigated forage sorghum fed as stand and graze from June to October for all animals that were weaned and less than 24 months. In the model, the animals did not have access to native pasture (although in practice the animals would be moved between the irrigated forage sorghum and native pasture as required). In the model, the aim was to reduce irrigated forage shortfalls in any month to a minimum and balance that with the number of hectares irrigated, noting that any additional hectares incurred a cost. The irrigated area was set to 220 ha.

4. Irrigated forage sorghum grown for hay, which was fed from June to October for all animals that were weaned and less than 24 months old at the time of access to the irrigated forage or hay. The animals remained in a paddock with access to native pasture and the amount of hay provided was set to 80% of their potential intake. About 20% of the hay was considered to be wasted by trampling, etc. Excess hay was sold into the market. The irrigated area was set to 210 ha.

5. Irrigated lablab fed as stand and graze from June to September for all animals that were weaned and less than 24 months old at the time of access to the irrigated forage or hay. In the model, the animals did not have access to native pasture (although in practice the animals would be moved between the irrigated lablab and native pasture as required). In the model, the aim was to reduce irrigated forage shortfalls in any month to a minimum and balance that with the number of hectares irrigated, noting that any additional hectares incurred a cost. The irrigated area was set to 320 ha.
6. Irrigated Rhodes grass grown for hay, which was fed from June to October for all animals that were weaned and less than 24 months old at the time of access to the irrigated forage or hay. The animals remained in a paddock with access to native pasture and the amount of hay provided was set to 80% of their potential intake. About 20% of the hay was considered to be wasted by trampling, etc. Excess hay was sold into the market. The irrigated area was set to 90 ha.

5.4.3 Herd and financial impacts

GMs at MED beef prices for the base-enterprise and feeding options ranged between \$79/AE and \$219/AE (Table 5-13), with GMs for the two base-enterprises being \$219 and \$206 respectively. This is broadly consistent with GMs found in similar studies (Ash and Watson, 2018; Ash et al., 2018; Moore et al., 2021) given the beef prices used here and noting the wide range of assumptions used across these studies. McLean et al. (2023) provide GMs for a range of breakdowns that are also broadly consistent with the base-enterprises reported here, noting that the specific period of analysis has a heavy influence on the GM, due to the volatility of beef prices, with the inclusion of 2020–21 and 2021–22 providing particularly high GMs. For the 12-year average of the period 2010–11 to 2021–22 McLean et al. (2023) provide the following GMs: (i) whole industry average for the northern industry, \$199.79, and top 25%, \$225.13; (ii) northern industry herds of 1600 to 5400 head, whole industry, \$211.25 and top 25%, \$249.22; and finally (iii) the VRD and Katherine region average performance, \$173.83 and top 25%, \$175.02.

Considering GMs only, the decision to irrigate becomes less attractive at LOW beef prices and more attractive at HIGH beef prices. The main aim in the model was to keep forage or hay shortfalls to a minimum while trying to minimise the area of irrigation needed. At all three beef prices, total revenue was highest for the four irrigated forage or hay options compared to the two base-enterprise options but the higher costs for the irrigated options led to lower GMs.

At MED beef prices, EBITDA was highest for the Rhodes grass hay option at \$303,166, while it and the forage sorghum hay produced the highest liveweight sold per year. Forage sorghum stand and graze provided the lowest EBITDA. While production (measured as total liveweight sold per financial year) is clearly boosted by the introduction of irrigated forages or hay, the profitability as measured by EBITDA is highly sensitive to the cost of the irrigated options and the area of irrigation required.

An NPV analysis allows consideration of the capital costs involved in development, which is not captured in the gross margin or EBITDA. The analysis used two costings (\$15,000 and \$25,000/ha) for the capital costs of development used in the NPV analysis (Table 5-14).

Table 5-13 Production and financial outcomes from the different irrigated forage and beef production options for a representative property in the Victoria catchment

Details for LOW, MED and HIGH beef prices are found in the text in Section 5.4.1. Descriptions of the six management options are found in Section 5.4.2. AE = adult equivalent; EBITDA = earnings before interest, taxes, depreciation and amortisation. Cattle are sold twice per year in all options. Cattle are sold in May for all options. Cattle are sold in September for the two base-enterprises and for lablab stand and graze. Cattle are sold in October for forage sorghum stand and graze and the two hay options.

	BASE-ENTERPRISE	BASE-ENTERPRISE PLUS HAY	FORAGE SORGHUM – STAND AND GRAZE	FORAGE SORGHUM – HAY	LABLAB – STAND AND GRAZE	RHODES GRASS – HAY
Forage/hay	None	Bought hay	Forage sorghum	Forage sorghum	Lablab	Rhodes grass
Maximum number of breeders	2,050	2,100	2,230	2,380	2,290	2,788
Mean of herd size (AE) across calendar year	2,525	2,553	2,943	3,084	2,999	3,094
Pasture utilisation (%)	20.1	20.1	20.1	20.1	20.0	20.1
Weaning rate (%)	59.2	60.4	62.6	64.6	63.8	64.6
Mortality rate (%)	6.8	6.8	6.6	6.3	6.2	6.2
Percentage of 'one year old castrate males' (i.e. 8 to 11 months or 8 to 12 months old) sold in September or October	0.0	0.0	8.8	78.4	62.8	78.9
Percentage of 'one and a half year old castrate males' (i.e. 15 to 19 months old) sold in May	77.5	86.8	79.4	20.3	27.6	19.9
Percentage of 'two year old castrate males' (i.e. 20 to 23 months or 20 to 24 months old) sold in September or October	9.1	6.7	11.8	1.3	9.7	1.2
Percentage of 'two and a half year old castrate males' (i.e. 27 to 31 months old) sold in May	13.4	6.6	0.0	0.0	0.0	0.0
Liveweight sold per year (kg)	343,106	351,446	415,624	468,346	443,607	471,258
Gross margin ($/AE) (LOW beef price)	133	120	–6	103	30	115
Profit (EBITDA) ($) (LOW beef price)	72,596	40,766	–282,084	52,172	–173,157	91,099
Gross margin ($/AE) (MED beef price)	219	206	79	171	119	183
Profit (EBITDA) ($) (MED beef price)	288,753	262,178	–32,710	262,928	93,007	303,166
Gross margin ($/AE) (HIGH beef price)	305	294	164	239	208	252
Profit (EBITDA) ($) (HIGH beef price)	504,910	487,103	216,664	473,683	359,172	515,232

Table 5-14 Net present values for forage development options

Details for LOW, MED and HIGH beef prices are found in Section 5.4.1.

OPTION	CAPITAL COSTS	BEEF PRICE	NET PRESENT VALUE
Forage sorghum – stand and graze	$15,000	LOW	–7,251,262
		MED	–7,237,698
		HIGH	–6,912,867
	$25,000	LOW	–9,980,658
		MED	–9,967,095
		HIGH	–9,642,264
Forage sorghum – hay	$15,000	LOW	–3,796,460
		MED	–4,160,544
		HIGH	–4,213,370
	$25,000	LOW	–6,401,793
		MED	–6,765,877
		HIGH	–6,818,704
Lablab – stand and graze	$15,000	LOW	–8,047,011
		MED	–7,869,257
		HIGH	–7,380,227
	$25,000	LOW	–12,017,043
		MED	–11,839,289
		HIGH	–11,350,258
Rhodes grass – hay	$15,000	LOW	–1,182,648
		MED	–1,533,912
		HIGH	1,573,918
	$25,000	LOW	–2,299,220
		MED	–2,650,483
		HIGH	–2,690,489

NPVs were calculated using the same assumptions as elsewhere in this Assessment (i.e. over a 40-year evaluation period at a 10% discount rate and assumed a 50:50 breakdown of assets with a 40-year life span and a 15-year life span). Given the numerous uncertainties involved in estimating the NPV, the analysis was kept deliberately simple. Specifically, EBITDA was used to proxy free cashflows with no adjustments made for working capital and other items that are typically employed to estimate expected free cashflows. In addition, terminal value is assumed to be negligible. The NPV analyses showed that none of the options had a positive NPV. Note that cost of capital theory is complex and investors need to understand their weighted average cost of capital (WACC) and the relative risk of the project compared to the enterprise's existing project portfolio (Section 8.2.1).

A significant proportion of the animal production increases due to the irrigated forage options came from the increased number of breeders that could be carried, while still keeping the utilisation rate of native pastures at about 20%. Rhodes grass hay allowed the highest number of breeders to be carried (2788) compared with 2050 for the base-enterprise. This flowed through to the total number of AE carried. The AE for Rhodes grass hay was 22% higher than that of the base-enterprise and the total liveweight sold was on average 37% higher. The irrigated options also increased the herd's weaning rate by 3.4% to 5.4% compared to the base-enterprise without weaner feeding. Even an increase of several percent is known to have lifetime benefits throughout the herd.

For the two base-enterprises and the two stand and graze options, 100% of the income was from sales of cattle (noting all livestock were sold on a per kilogram basis, including 'cast for age' herd bulls). For the two irrigated hay options, excess hay was sold into the market. This contributed to about 31% (Rhodes grass hay) or 36% (forage sorghum hay) of total income. While the options were not set up for hay sales to be a significant part of the enterprise structure, the irrigated areas required to ensure there were no hay shortfalls meant that excess hay was produced in most years.

The most obvious biophysical impact of the various feeding strategies was the increase in liveweight, compared to the base-enterprise (Figure 5-5). This allowed a greater proportion of the animals to be sold earlier. For example, for the two hay options, more than 78% of the 'one year old castrate males' (i.e. 8 to 12 months old) were sold in October at a minimum weight of 280 kg, while no animals from the same cohort under the two base-enterprise options met the minimum weight at that time (Table 5-13). Over 77% of these animals were retained for an additional wet season, being sold in the following May as 'one and a half year olds' (i.e. 15 to 19 months old). Keeping the utilisation rate at 20.0% meant that carrying these animals for the extra period lowered the number of breeders that could be carried and the overall stocking rate (i.e. AE).

In summary, three patterns of growth to reach sale weight (280 kg) occurred.

For the two base-enterprises, no animals reached sale weight in September as 'one year olds'. By the following May 77.5% (base-enterprise) or 86.8% (base-enterprise plus hay) had reached sale weight. The following September 9.1% (base-enterprise) or 6.7% (base-enterprise plus hay) were sold as 'two year olds'. The remaining 13.4% (base-enterprise) or 6.6% (base-enterprise plus hay) were then sold in the following May as 'two and a half year olds'.

By contrast, the majority of animals in the forage sorghum hay, lablab stand and graze, and Rhodes grass hay options were sold as 'one year olds' in October. The majority of the rest (20.3%, 27.6% and 19.9% respectively) were sold in the following May. The remainder were sold in the next October. None of this cohort remained for sale in the following May as 'two and a half year olds'.

The forage sorghum graze option sat between these two extremes. Very few were sold as 'one year olds' in October, most were sold as 'one and a half year olds' in the following May (79.4%) with all of the remainder sold in the following September.

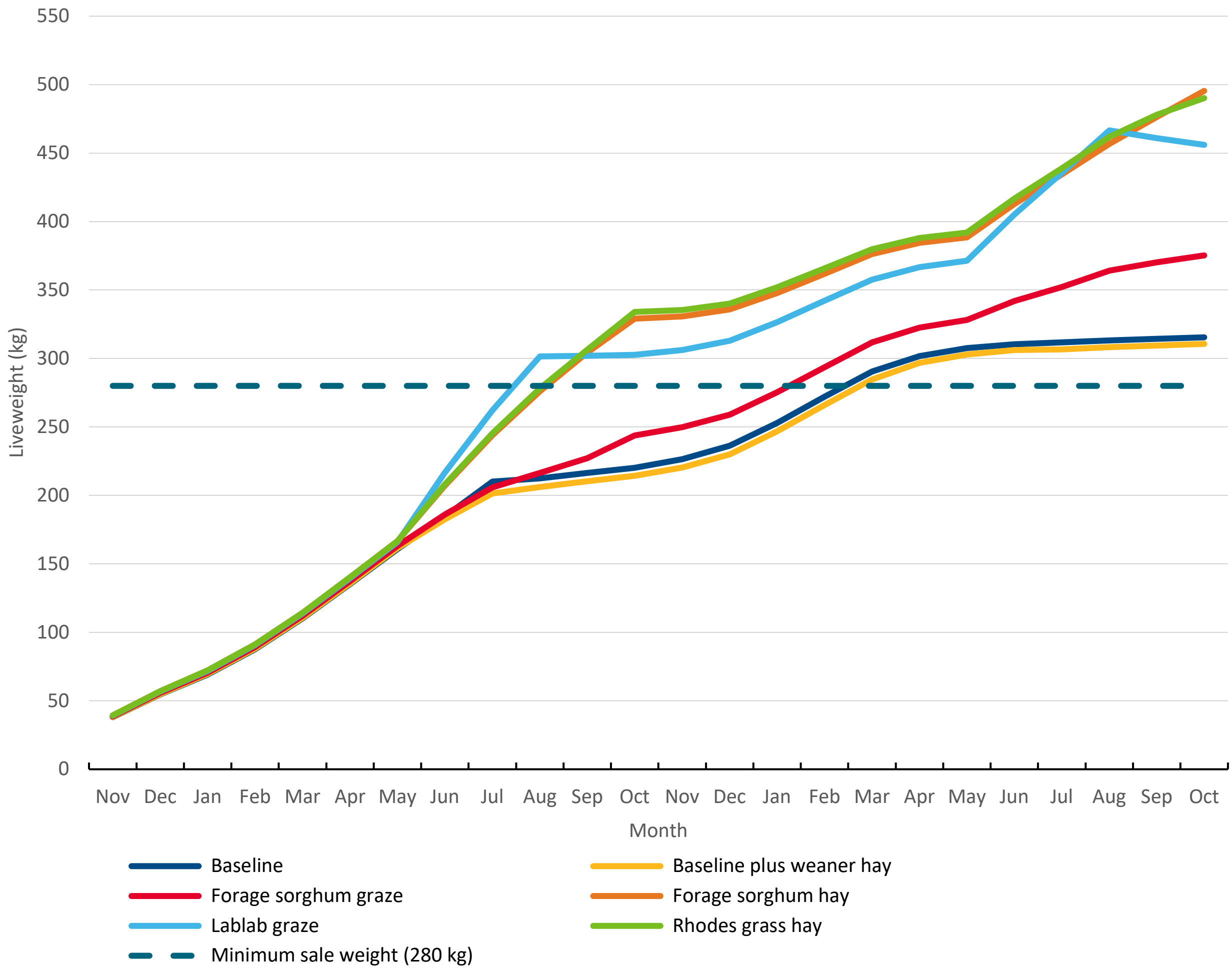


Figure 5-5 Mean liveweights for each option for male animals born at the end of November

For the purposes of this graph, all sales were switched off, in order to show growth rates over the full period of feeding, without the removal of sale animals having an impact on the mean weights of the remainder of the cohort.

Counter-intuitively, the average weight of the castrate males born at the end of November (November-born) was slightly higher for the base-enterprise compared to the base-enterprise plus hay option (Figure 5-5). This due to the different weaning criteria applied. For the base-enterprise the criteria used for the May weaning was 7 months old or 170 kg, compared to the criteria of 5 months old or 140 kg in the base-enterprise plus hay. Therefore, a large majority (90.4%) of the base-enterprise cohort was not weaned in May and remained in the paddock with their mothers. While this allowed them to maintain growth rates slightly better than those weaned at lighter weights and supplemented with hay, by remaining with their mothers they can lower the reproductive rate of the herd. This did not show in the model, possibly because the utilisation rate used was conservative, therefore the cows were able to maintain liveweights conducive to conception and successfully carrying through a pregnancy. By contrast nearly all (99.1%) of the base-enterprise plus hay cohort were weaned in May, at lighter weights, and were supplemented with hay. Note that feeding hay to weaners has other management benefits beyond weight gain.

The forage sorghum stand and graze option provided a 30 kg benefit compared to the base-enterprise plus hay (24 kg benefit against the base-enterprise) by the end of the first year feeding period (June to October) but this was lower than the benefit in the lablab stand and graze option, due to the lower protein content in the full sorghum sward. The lablab option provided the highest growth rates over the feeding period, but the extra month of feeding allowed the two hay options to provide the highest liveweights going into, and through, the wet season. The monthly growth rates are at the upper end of the scale under these conditions but reflect optimum conditions in the model.

While there are advantages to some form of irrigated forage or hay production, the introduction of irrigation to an existing cattle enterprise is not for the faint-hearted. The options here range from an area that would require 2.25 pivots of 40 ha each to an area that would require eight 40-ha pivots. A water allocation of about 1.5 to 2.2 GL would be required to provide sufficient irrigation water. The capital cost of development would range between $1,350,000 for 90 ha of Rhodes grass hay at a development cost of $15,000/ha to $8,000,000 for 320 ha of lablab at a development cost of $25,000/ha. In addition, the grazing enterprise would need to develop the expertise and knowledge required to run a successful irrigation enterprise of that scale, which is quite a different enterprise to one of grazing only. This is a constraint recognised by graziers elsewhere in northern Australia (McKellar et al., 2015) and almost certainly contributes to the lack of uptake of irrigation in the Victoria catchment.

Part III Economics

Part III analyses the scheme-scale viability of irrigated development options and economic considerations beyond the farm gate required to succeed.

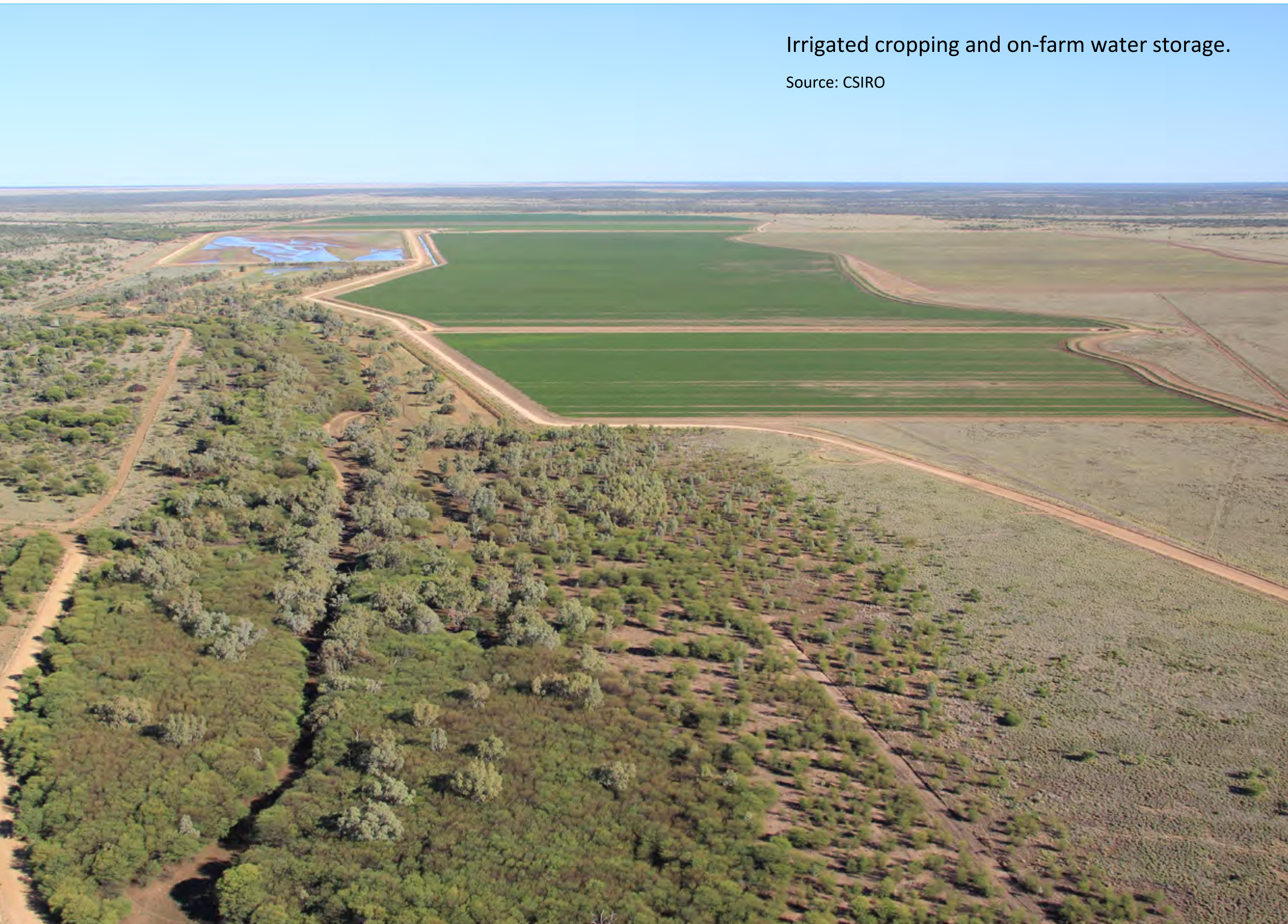
Chapter 6 reviews recent large dam projects in Australia for how well proposed benefits were realised in practice to elicit lessons for future developments and to provide context for the subsequent economic analysis chapters that follow.

Chapter 7 provides indicators of the agricultural demand trajectories for new water in the NT and describes the types and costs of the enabling infrastructure required to support large-scale irrigated development.

Chapter 8 uses a generic financial analysis approach to demonstrate the key determinants of irrigation scheme viability that investors need to balance and provides tools that allow users to estimate the viability of different development configurations.

Chapter 9 quantifies the regional benefits of irrigated development using regional input–output analysis and presents an environmental input–output (I–O) analysis showing how increased agricultural water use would stimulate additional demand from other water users.

Part IV concludes by summarising key principles for identifying agricultural investment opportunities in the Victoria catchment.



Irrigated cropping and on-farm water storage.

Source: CSIRO

6 Lessons learned from recent Australian dam-building experiences

6.1 Introduction

Large public infrastructure projects are complex investments, where it is difficult to decide in advance whether sufficient benefits will be derived to justify the costs involved. This is exacerbated by the fact that many costs are not readily apparent until after construction has begun, and it can take many years after construction is complete before it becomes clear whether the planned growth trajectory and ultimate scale of benefits is achieved. Cost–benefit analysis (CBA) has been widely used to assist decision makers in evaluating the likely net benefits from proposed projects and prioritising investments, including for transport developments (roads, railways, bridges, etc.) and water resource developments (including dams, pipelines, etc.). The economics part of this Assessment, therefore, begins by looking at the lessons that can be learned from past use of CBAs in large infrastructure projects. Lessons from these experiences provide context for the indicative infrastructure costs (Chapter 7), scheme financial analyses (Chapter 8) and regional benefits (Chapter 9) in the following chapters, and an opportunity to better plan and evaluate future water infrastructure projects.

Despite CBA having been very widely used for a long period of time, there are far fewer examples where the estimated costs and benefits (used to justify the project) have been revisited at a later date, after the development has been constructed and in operation for a number of years. Ex-post evaluation of CBAs is important to highlight: (i) whether estimates for both the scale and timing of flows of costs and benefits are achieved in practice, and (ii) opportunities for learning to improve evaluations of future projects. Such insights could improve forecasting and decision making in the future. In a review of Australian dam CBA costings estimates, Petheram and McMahon (2019) observed a strong likelihood of cost overruns compared to CBA estimates. Such biases have implications for the quality of decisions for prioritising investments in projects.

The benefits of ex-post evaluation are increasingly being recognised in Australia. For example, ex-post evaluations have been completed on a sample of national road investment projects since 2005, with findings and lessons learned published to inform future ex-ante and ex-post project evaluations (BITRE, 2018). Infrastructure Australia[1] has provided guidance on developing and appraising high-quality infrastructure project proposals and have encouraged wider application of post-completion reviews, that is, using ex-post comparisons between actual outcomes and the forecasts identified within the business case.[2] This guidance emphasised that the … *overarching*

[1] Infrastructure Australia is an independent statutory body established to advise governments, industry and the community on the investments, processes and reforms required to deliver better infrastructure for all Australians (for more information see https://www.infrastructureaustralia.gov.au/).

[2] The most recently updated guidance, published 2021, includes information on defining problems and opportunities, identifying and analysing options, developing the business case, and preparing an economic appraisal including a CBA (for more information see https://www.infrastructureaustralia.gov.au/publications/assessment-framework).

objective … 'is not to find fault in the implementation of the project, but to capture lessons that can improve future planning, delivery and risk mitigation'… (Infrastructure Australia, 2021a, p. 8).

While there are some examples of ex-post evaluations of the *costing* data from public infrastructure CBAs, such cases are much more common for road and transport related developments than for water infrastructure CBAs. Of the limited examples where water resource development CBAs have been evaluated, the focus has been on exploring the accuracy of the forecast capital costs (rather than on the benefits/demand component of the CBA). Such research has shown a history of cost overruns in dam construction projects, in Australia and internationally, where a capital cost overrun is defined as the percentage difference between the actual cost of constructing the dam and the publicly stated or contracted cost immediately prior to construction. Examples include an international study that found mean cost overruns of 96% for mega-dam construction projects (Ansar et al., 2014), and an Australian-focused study that found mean cost overruns of 120% (Petheram and McMahon, 2019). Systematic biases in costings of large infrastructure projects occur both from under estimating unit costs of individual components and by omitting essential enabling infrastructure components altogether (Ansar et al., 2014; Auditor General Western Australia, 2016; Flyvbjerg et al., 2002; Odeck and Skjeseth, 1995; Wachs, 1990). For example, a review of the Ord-East Kimberley Development Plan (for expansion of the Ord irrigation system by about 15,000 ha) found that there were additional costs of $114 million to the Western Australian Government, beyond the planned $220 million state investment in infrastructure to directly support the expansion (Auditor General Western Australia, 2016).

Literature on ex-post evaluations of the forecast *benefits* from public infrastructure developments is scarce, particularly for water infrastructure. Only one such study was available, an international evaluation that found a sample of large dams from 52 different countries had underperformed with regards to the anticipated benefits and service delivery (World Commission on Dams, 2000a). This study noted that 'Large dams designed to deliver irrigation services have typically fallen short of physical targets, did not recover their costs and have been less profitable in economic terms than expected' (World Commission on Dams, 2000b, p. xxxi). This study's findings included that the forecasting of future demand for water from dam developments around the world was frequently inaccurate, and, with regards to irrigation dams in particular, that the estimates of demand tended to be overstated.

Given that (i) there is limited research exploring the accuracy of benefits/demand forecasting for CBA compared to evaluations of the costing component, and (ii) there are indications that demand forecasts are often poorly related to real water needs, this report focuses on the less researched element of CBAs: the demand for increased water supplies and their associated benefits.

Within Australia, ex-post evaluations of the accuracy of water demand and benefit forecasting in CBA supporting water resource developments have not historically been prepared. However, the importance of such evaluations is increasingly being recognised. For example, the 2021 update to the Infrastructure Australia Assessment Framework recommends post-completion reviews (PCRs) for all major infrastructure projects and requires PCRs for all projects where Infrastructure Australia assessed the original business case (Infrastructure Australia, 2021a, p. 8). Further, the recently published National Water Grid Investment Framework (DCCEEW, 2022) specifies that agreement to conduct a post-completion project evaluation, in consultation with the National

Water Grid, will be an Australian Government condition for investment in future water infrastructure projects.

The review in this chapter used a sample of large and recently constructed Australian dams based on publicly available information and reports. This review provides baseline information regarding the ex-ante and ex-post information available for recent water resource developments, and highlights lessons for possible ways of improving future water infrastructure planning and assessments. The review also provides context for interpreting CBAs from independent analyses (such as those presented in Chapter 8 and those that adhere to the Infrastructure Australia technical guidelines for economic appraisal (Infrastructure Australia, 2021b)) relative to those from project proponents (where there may be selection biases and incentives to present scenarios where benefits exceed costs). Methods for this review are set out in Section 6.2, the summary of the case studies is described in Section 6.3, and key findings are set out in Section 6.4.

6.2 Methods and case study selection

The Australian National Committee on Large Dams (ANCOLD) website[3] lists 570 dams, ranging in capacity from 11 ML to 12,400 GL and constructed between 1857 and 2012 to provide water for domestic, industrial and agricultural use, in addition to hydro-electricity generation and flood mitigation. Based on criteria of having completed construction in 2000 or later, and having a capacity in excess of 40 GL, five developments were selected for review. The geographic locations of the five dams are show in Figure 6-1, and summary information on each dam is provided in Table 6-1.

[3] https://www.ancold.org.au/

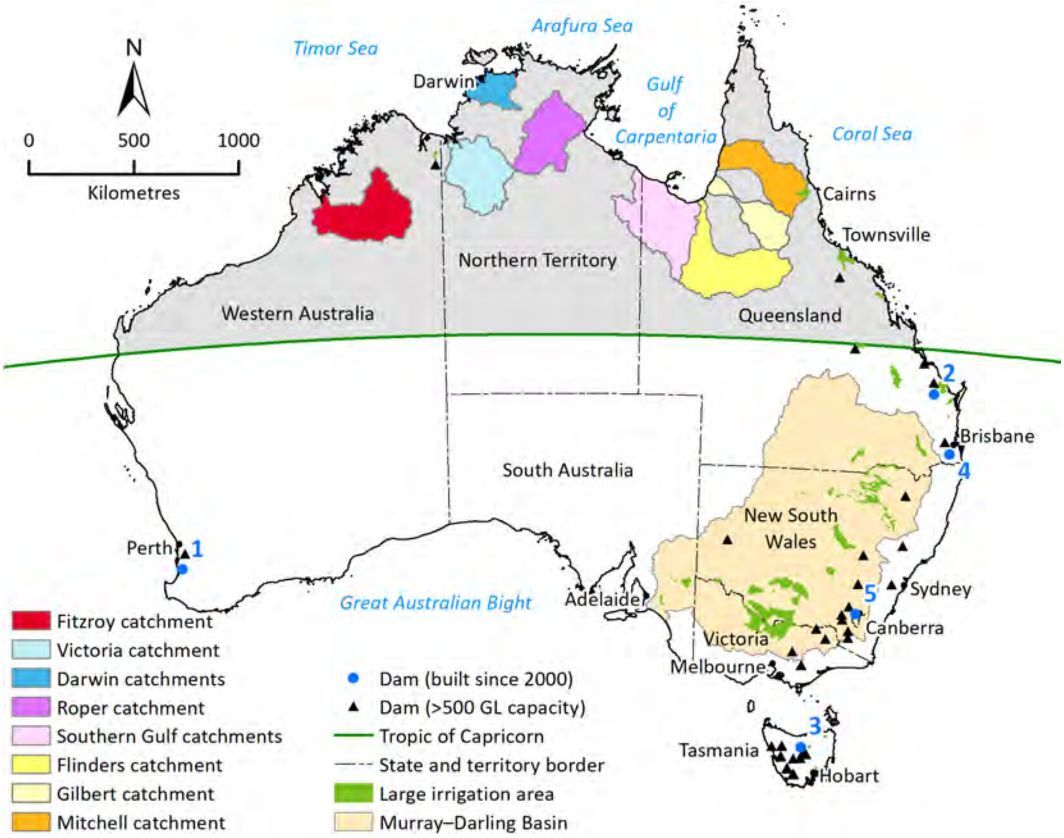


Figure 6-1 Locations of the five dams used in this review

The dams are numbered in blue as 1: New Harvey Dam, 2: Paradise Dam, 3: Meander Dam, 4: Wyaralong Dam and 5: Enlarged Cotter Dam.

Table 6-1 Summary characteristics of the five dams used in this review

Dam completion date and capacity sourced from the Australian National Committee on Large Dams (ANCOLD) website (https://www.ancold.org.au/). Documents reviewed for each dam are listed in Table 6-2.

	NEW HARVEY DAM†	PARADISE DAM	MEANDER DAM	WYARALONG DAM	ENLARGED COTTER DAM
State/territory	WA	Qld	Tas	Qld	ACT
Date completed	2002	2005	2008	2011	2012
Capacity (GL)	59	300	43‡	103	78
New dam or redevelopment of existing dam	Replaces Harvey weir (built 1916, extended 1931), capacity of ~10 GL	New	New	New	Replaces original Cotter Dam (built 1915, extended 1951), capacity of ~4 GL
Primary use(s) proposed for water from dam	Irrigated agriculture	Irrigated agriculture, water supply	Irrigated agriculture, environmental flows, hydro-electric power	Water supply to South East Queensland	Water supply for Canberra
Type of key project documents used for this review	Proposed water allocation plans (no cost–benefit analysis (CBA) available)	CBA and economic impact assessment	CBA	Environmental impact statement (EIS) (no CBA available)	EIS (which included CBA information but actual CBA report unavailable)

†Constructed as part of wider Stirling-Harvey redevelopment scheme, the New Harvey Dam was to supply water to irrigated agriculture to free up water from the Stirling Dam to increase urban water supply.
‡This dam is listed on ANCOLD as having capacity of 24 GL. The dam was constructed with a capacity of 43 GL but designed to make 24 GL of water available for irrigation.

For each case study, publicly available documentation was obtained from government and other sources relating to: (i) initial plans and approval processes for the dams including environmental impact statements (EISs), economic justifications (including CBAs), sustainable water strategies, etc.; and (ii) post-construction publications containing relevant information regarding the use of, and benefit flow from, the dams. Based on the information sourced, the forecast water demand in the project proposal was compared to the actual demand that emerged post construction, providing an ex-post evaluation of the accuracy of demand and benefit forecasts. Overall, the limited availability of data in the public domain (regarding specific quantity, timing and purpose) prevented a precise quantitative analysis of demand forecast (in)accuracies; instead, the information was qualitatively assessed to determine the likelihood of demand having been under or over estimated in the original dam proposals. This review does not seek to provide a systematic review of all relevant literature but focuses on those recent dams for which the best information is publicly available and most relevant to current water infrastructure planning in Australia. While the small sample size is a limitation, it is sufficient to highlight some of the most important CBA principles learned from recent past experience.

A further key limitation relates to the limited availability of detailed reporting on dam developments, both ex-ante and ex-post, in the public domain. This is partially due to the commercialisation of the water authorities in Australia, and consequentially, the commercial-in-confidence nature of much of the data, which is compounded by difficulties in sourcing historical documents that may have been issued in limited hard copy rather than made widely available. This Assessment has focused purely on existing public documents and has not sought to collect independent primary data on actual water usage and benefits over time.

6.3 Proposed and realised outcomes for each case study development

The context and summary of outcomes for each of the five dams selected are set out below. Further details on the expectations and outcomes arising from each development are presented in Table 6-2.

Table 6-2 Summary of the expectations and reported outcomes for each dam reviewed

DAM DEVELOPMENT	PRIMARY OBJECTIVE	FORECAST WATER DEMAND AND BENEFITS FROM DEVELOPMENT	ACTUAL WATER DEMAND AND BENEFITS FROM DEVELOPMENT TO DATE
New Harvey Dam as major component of the wider Stirling-Harvey redevelopment scheme (2002)	To improve water security for the region while enabling continuation of irrigated agriculture in region	Providing additional 34 GL of potable water to supply needs of estimated 350,000 people[1] Supplying 68 GL of existing irrigation licence allocations, to continue to provide irrigation water for dairy and beef pasture and fodder, and some horticulture, whose use in preceding years was around 60 GL per annum[2]	Urban water demand within the region has grown, and has been supported by this development, alongside increasing reliance on the use of two seawater desalination plants (which started production in 2006 and 2011) and now produce 30% of Perth's water supply[11] Analysis comparing pre- and post-dam agriculture in region found small switch towards horticulture, and away from pasture-based agriculture, and that water usage by irrigators has not declined[12] Water continues to be supplied to irrigators, and this water is now traded via an active online trading market[13]
Paradise Dam (2005)	To stimulate regional economic growth and job creation via stimulating irrigated agriculture, plus provide additional water supply	Provide 20 GL/y high-priority water for urban and industrial use[3] Provide 124.2 GL/y medium-priority water for medium-priority use, being mainly agricultural irrigation, expected to be fully taken up by year 19 following commencement of construction of the dam (i.e. 2020)[3] Forecast take up of additional irrigation water: (i) in the short term by existing sugarcane farmers, alongside existing livestock industries, and (ii) in the longer term used to satisfy demand from growth of higher margin intensive horticultural crops (vegetables, citrus, other fruit and nuts), plus chicory, anticipated as a new crop for the region[3] Anticipated substantial agricultural production increases, of 25% for sugarcane, and 5- to 6-fold increase for horticulture[4] Flow-on benefits of construction and operation of a chicory plant, and a new sugarcane and bagasse pulp processing plant, anticipated as a consequence of development but not included in CBA[3]	Around 2.9 GL of high-priority water rights has been reported as being taken up by 2019[14] Around 15 GL of medium-priority water reported as taken up by 2014[15], and 24 GL taken up by 2019[14]. 24 GL represents ~19% of total anticipated yield of 124 GL anticipated by 2020[3] As of 2014 it was reported that the development and diversification of cropping had not matched expectations[15] Rather than new sugar mill being opened as anticipated, an existing mill closed in 2005[16], and a further mill closure was announced in 2020[17] Predicted development of chicory plant in the region does not appear to have materialised Recent reports have argued that the anticipated increases in water demand for irrigated agriculture will materialise, but over a longer time frame than that anticipated in the original CBA[18]
Meander Dam (2008)	To support environmental flows, enable expansion of irrigated agriculture, and produce hydro-electric power	Support increased environmental flows improving ecological health of river[5] Recover agricultural water allocations that would be lost to improved environmental flows, and provide additional water allocations to irrigated agriculture, to be utilised by grazing (dairy), and cropping (poppies, potatoes, peas, beans, broccoli, carrots, onions and other crops), totalling around 24 GL/y by year 18 of project in most likely scenario[5] Enable electricity generation from mini-hydro development of 10,000 MW hours per year[5]	Water supply for irrigation commenced during 2007–08 season, and increased substantially by 2008–09[19] Almost immediately following construction was completed, further construction of an extension including four pipelines commenced, further increasing the water available from 24 GL to 28.8 GL[19] The system operator now reports that 240 irrigators hold licences to access this water, and that 100% of licences have been sold[20]. While this supports the proposition that demand did exist to support the original scheme it is impossible to test if the demand would have arisen without the additional pipeline developments

DAM DEVELOPMENT	PRIMARY OBJECTIVE	FORECAST WATER DEMAND AND BENEFITS FROM DEVELOPMENT	ACTUAL WATER DEMAND AND BENEFITS FROM DEVELOPMENT TO DATE
		Other benefits including flood mitigation, improved water quality/reduced turbidity, increased recreation opportunities[5]	Mini-hydro scheme began generating and exporting electricity in 2008 in line with plan[19]
Wyaralong Dam (2011)	To address water security concerns	Water demand within South East Queensland was predicted to rise by almost 50% by 2026, continuing to grow, with the expectation that demand for water would have more than doubled by 2051[6] Dam expected to provide 18 GL/y, and to provide 8% of anticipated yield from all supply initiatives by 2015[6] When operating in conjunction with Cedar Grove weir and Bromelton Offstream Storage, development expected to provide up to 26 GL/y of additional water, an amount sufficient to meet the needs of more than 300,000 people[7]	Having been approved during drought, which subsequently broke, and coupled with reduced per capita water demand that has endured post-drought, the dam's water has not yet been required Currently is being used as a recreation facility 2016–2046 Water Security Plan identified need for further infrastructure including water treatment plant, pipelines and pumpstations, before dam could provide water to the local community or to the grid[21] Construction of the required water treatment plan is in the early planning stage[22]
Enlarged Cotter Dam (2012)	To address water security concerns	Dam enlargement to increase capacity by 72 GL, and increase water storage capacity in the ACT by 35%[8] Plan would address water needs of anticipated population rises to 405,000 by 2017 and 500,000 by 2032[9] Plan would reduce the times when severe water restrictions would need to be applied, estimated range from $7 million/y at stage 1 to $324.1 million/y at stage 4 restrictions[9] Further benefits anticipated during construction from employment opportunities, and from operation phase through improved workforce skills, enhanced infrastructure and amenities[10]	Population levels appear to be growing as anticipated[23] Water consumption per head has reduced further than anticipated, moderated by voluntary and permanent water conservation measures[24] (similar to stage 1 restrictions elsewhere)[25] No temporary restrictions have been required since completion of this dam, and the 2013 Murrumbidgee to Googong pipeline The developments, alongside efforts to manage consumption, are considered sufficient to supply 'unrestricted demand for the ACT and Queanbeyan 95% of the time until at least 2030'[26]

CBA = cost–benefit analysis; SEQ = South East Queensland

Sources for information:
1 Water and Rivers Commission (2000)
2 Water and Rivers Commission (1998)
3 NECG (2001)
4 National Competition Council (2003)
5 MJA (2003)
6 QWI (2007)
7 Queensland Government (2009)
8 https://www.iconwater.com.au/water-education/our-projects/water-security-projects/enlarged-cotter-dam.aspx
9 ACTEW (2009b)
10 ACTEW (2009a)
11 https://www.watercorporation.com.au/Our-water/Desalination
12 Resource Economics Unit (2007)
13 https://www.harveywater.com.au/
14 Sunwater (2019)
15 Mainstream Economics and Policy (2014)
16 https://www.abc.net.au/news/2005-02-04/fairymead-sugar-mill-to-shut-doors/630858

17 https://www.abc.net.au/news/rural/2020-10-23/bingera-sugar-mill-closure-bundaberg-sugar-cane/12808948
18 Adept Economics (2020)
19 Davey and Maynard (2010)
20 https://www.tasmanianirrigation.com.au/schemes/greater-meander, information on irrigators and entitlements sold based on accessing webpage 12 July 2022
21 SEQWater (2017)
22 https://www.seqwater.com.au/news/wyaralong-water-treatment-plant
23 Based on population level at 2020 https://dbr.abs.gov.au/region.html?lyr=gccsa&rgn=8ACTE, and predictions for 2032 https://www.abs.gov.au/statistics/people/population/population-projections-australia/latest-release - australian-capital-territory
24 Icon Water (2018)
25 https://www.iconwater.com.au/my-home/saving-water/when-can-i-water/permanent-water-conservation-measures.aspx
26 ACT Government (2014, p. 20)

New Harvey Dam

The construction of the New Harvey Dam formed part of the wider Stirling-Harvey redevelopment scheme. It was designed to enable irrigated agriculture within the region to continue with business as usual while supplying significant additional water to the integrated water supply scheme for Perth and other towns in the region, and to meet the anticipated demand for high-priority water resulting from expected population growth in Perth and surrounding regions. Since completion of the development, the objectives appear to have been broadly met, with water use for irrigated agriculture being maintained while priority water uses have been met from a number of sources including the New Harvey Dam and from the construction of two desalination plants in the region. Overall, agricultural demand for irrigation water does appear to have met target.

Paradise Dam

This water infrastructure development was designed to facilitate regional development and to encourage wealth and job creation within the Burnett region, one of the least affluent and least developed locations across Queensland. The project comprised constructing Paradise Dam while also constructing some new weirs in the region and augmenting others. The development was predicted to stimulate substantial increases in agricultural production, to meet anticipated demand generated from both population growth across South East Queensland and export markets, and to contribute some high-priority water to the region. However, the development experienced difficulties following major flood events in 2011 and 2013 when structural problems with the construction of the dam wall emerged, requiring capacity to be restricted. Significant rectification works have been approved with early works expected to commence in 2023.[4] Demand for water has emerged more slowly than anticipated in the CBA, revealing considerable shortfalls between actual and predicted water demand; further, anticipated knock-on developments (such as the construction of a chicory processing plant and a new cane and pulp mill) have also failed to materialise. A recent analysis (Adept Economics, 2020) has critiqued the assumptions in the original CBA as being overoptimistic regarding the trajectory of water demand, and to have failed to take account of possible climate variability. Overall, demand for water does not appear to have met target.

Meander Dam

The proposal to dam the Meander River, prompted by a need to support environmental flows, described benefits including providing additional water for expansion of irrigated agriculture, to enable electricity generation from a mini-hydro development and other benefits including flood mitigation, savings from improved water quality/reduced turbidity, and improved recreation opportunities. Reviewing the actual experience, it appears these benefits have arisen, however, additional pipeline construction works (unforeseen in the original CBA) were required to enable farmers across the region to access the additional water. As of 2022, 100% of the irrigation licences available for the increased irrigation water have been sold.[5] Thus, the predicted water

[4] https://www.sunwater.com.au/projects/paradise-dam-improvement-project/

[5] https://www.tasmanianirrigation.com.au/schemes/greater-meander, information on irrigators and entitlements sold based on accessing webpage 12 July 2022

demand in the CBA appears to have been reasonable but did require additional capital investment to enable the predictions to become reality. Overall, demand for water does appear to have met target, but additional enabling infrastructure spend was required to facilitate this.

Wyaralong Dam

The Wyaralong Dam was proposed as a means to improve the water security for the people of South East Queensland, stimulated by the millennium drought and the growing population in the region. A multi-faceted strategy was developed to address the predicted demand growth to provide water security for South East Queensland for the forecast period up to 2026. Key components of this strategy included traditional water infrastructure developments (dams and pipelines) and the development of climate-resilient water sources (desalination and recycled water projects). While a number of other components of the plan now contribute to the water supply of the region, the Wyaralong Dam has to date supplied no water and is currently used as a recreation facility. While the lack of demand for water from the dam can be partly attributed to the end of the severe drought and moderated by reductions in water consumption per head, post construction the dam was found to be unable to supply water of sufficient quality to the local community and to the grid without the construction of a water treatment plant, pipelines and pump stations. This capital investment was not within the initial project plans or CBA. Construction of the Wyaralong water treatment plant is reported to be in the early planning stages.[6] It would appear that while the demand for water in the South East Queensland region has grown, and continues to grow, growth has been slower than expected and to date has been met from sources other than the Wyaralong Dam. While the dam may be used in the future as a water source for the region, this cannot occur without construction of additional infrastructure beyond that included in the original CBA. Overall, demand for water from this dam does not appear to have met target, and additional enabling infrastructure spend is required before this can occur.

Enlarged Cotter Dam

Against a background of population growth within Canberra and the ACT more widely, and increasing climate uncertainty, the ACT Government considered a range of initiatives to help secure Canberra and the region's water supply into the future and unlock the potential to provide water through extended drought periods. The water security plan describes how water supply needed to be increased to meet the assumed population increase, and to reduce the times where severe water restrictions were required, estimating the economic cost of time spent on water restrictions to be $7 million per year for stage 1 temporary restrictions, rising to $324.1 million per year for stage 4 water restrictions (ACTEW, 2009b). Beyond this dam, the region has taken other significant steps to secure water, including constructing the Murrumbidgee to Googong pipeline (completed in 2013), taking steps towards water trading with other parts of the Murray–Darling Basin, and seeking to reduce consumption per capita (ACT Government, 2014).

While the region has experienced population growth broadly in line with that forecast, the impact of this on the total demand for water has been moderated by reductions in water consumption per head (both voluntary and driven by permanent water conservation measures) over and above

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[6] https://www.seqwater.com.au/news/wyaralong-water-treatment-plant

the reductions forecast. Since late 2010 the use of temporary water restrictions of differing levels has been replaced by permanent, year-round measures, similar to stage 1 temporary restrictions in other regions of Australia.[7] No further restrictions, over and above these permanent measures have yet been required. The net impact of these factors suggest that the predicted increased demand for water has not been realised to the extent anticipated, due to the success of steps taken to moderate consumption. However, the dam has clearly made a contribution towards the objective of reducing the risk of having to implement severe water restriction measures, and thus has delivered this expected benefit. Overall, while demand for water has increased, the increase is less than anticipated due to the greater than anticipated success of encouraging voluntary water conservation measures.

6.4 Key lessons

Dams provide a complex mix of market and non-market benefits

The contexts for proposing new dam developments vary significantly. The five case studies were not just geographically different but were also underpinned by different motivations and priorities. Some focused primarily on irrigated agriculture and regional economic development (including job creation), others focused primarily on providing water security, while others offered a mix of objectives. The dam developments were not always justified by purely financial (and hence easy to monetise) benefits. Non-market, non-financial and social objectives (including water security, food security, etc.) were frequently cited, but are harder to monetise and evaluate directly in CBAs. The prevailing circumstances at the time of the proposal also influenced the way that benefits were framed. For example, urban water security was prioritised more at times of drought. The term 'monetise' is defined here to mean assigning a dollar value to a (dis)benefit for purposes of quantitative analysis (without implying that it would necessarily be tradable in a financial transaction).

The five case studies in this review were justified by a complex mix of market and non-market benefits. Some adverse impacts were also noted, hence named 'disbenefits', relating to reduced recreation opportunities necessary to protect water quality in the dam. While it is never simple to estimate future net benefit flows, quantifying market benefits for inclusion in proposal documents (which included CBAs in some but not all of the case studies selected) is less complex than quantifying non-market benefits. The market and non-market disbenefits and the approaches taken towards evaluating these are summarised in Table 6-3.

Market benefits considered in the proposals included supporting and/or expanding irrigated agriculture (Stirling-Harvey redevelopment, Paradise, Meander) and for hydro-electric power (Meander). The monetary value of such expected benefits can be estimated (by predicting volume of demand that could be met from the dam development each year and the likely market prices) and included in the proposal and/or CBA.

[7] https://www.iconwater.com.au/my-home/saving-water/when-can-i-water/permanent-water-conservation-measures.aspx

Table 6-3 Benefits (and disbenefits) included in proposals justifying the five dams reviewed

BENEFITS (AND DISBENEFITS) INCLUDED IN PROPOSALS TO JUSTIFY DAM	MARKET OR NON-MARKET	CASE STUDY THAT INCLUDED THIS (DIS)BENEFIT	(DIS)BENEFIT INCLUDED IN NARRATIVE	(DIS)BENEFIT QUANTIFIED
Benefits				
Provide irrigation water for agriculture	Market	Stirling-Harvey[1]	Yes	No[2]
		Paradise	Yes	Yes[4]
		Meander	Yes	Yes[4]
Generate hydro-electric power	Market	Meander	Yes	Yes[4]
Stimulate regional economic growth/job creation by encouraging new/existing industries to develop beyond direct impact on current farming activity	Market	Paradise	Yes[5]	Yes[6]
		Wyaralong	Yes	No[12]
		Enlarged Cotter	Yes[10]	No
Provide additional urban water supply	Market/ non-market	Stirling-Harvey	Yes	No
		Paradise	Yes	Yes[4]
		Wyaralong	Yes	No
		Enlarged Cotter	Yes	Yes[11]
Increase water security/improve reliability of water supply for the future	Non-market	Stirling-Harvey	Yes	No
		Paradise	Yes[7]	No
		Meander	Yes[13]	No
		Wyaralong	Yes	No
		Enlarged Cotter	Yes	Yes[11]
Support environmental flows, improving ecological health of the river	Non-market	Meander	Yes	Yes[8]
Mitigate floods	Non-market	Paradise	Yes	No
Reduce salinity	Non-market	Paradise	Yes	No
Mitigate floods and related reduced water treatment costs	Non-market	Meander	Yes	Yes[9]
Increase recreation opportunities	Market and non-market	Stirling-Harvey	Yes	No
		Paradise	Yes	No
		Meander	Yes	No
		Wyaralong	Yes	No
Disbenefits				
Reduce recreation opportunities to protect drinking water quality	Market and non-market	Stirling-Harvey	Yes[3]	No
		Enlarged Cotter	Yes[14]	No

[1] As part of wider Stirling-Harvey redevelopment scheme, the New Harvey Dam was to supply water to irrigated agriculture to free up water from the Stirling Dam to increase urban water supply. As the two dams form an integrated scheme, the combined benefits are reflected in this table rather than a simple focus on either dam individually.
[2] Project sought to maintain current water supply available for irrigated agriculture by replacing one source for another, rather than increasing quantity/value of agriculture in region.
[3] Recreation disbenefits include applying additional restrictions to, or preventing, leisure activities both on water (marroning, fishing, swimming) and on land within the catchment (horse riding, motor rally, trail bikes, off-road driving, hunting).
[4] Discounted cashflow estimated, based on quantified net benefit flow, and presented in cost–benefit analysis (CBA).
[5] Includes anticipated new cane/bagasse pulp mill and new chicory processing plant.
[6] Benefit quantified using input–output (I–O) analysis but not included in CBA calculation of net present value (NPV).
[7] Water security is not a key focus of this proposal, but discussion does note that demand for water will increase as the towns and communities in

the region expand.

[8] Proposal acknowledges that should the dam not be built, current temporary irrigated agriculture water licences would need to be revoked to protect the environmental health of the river. The value of this water to agriculture is incorporated in the CBA, recognising that as the development satisfies the environmental need without sacrificing this flow, then this value is a proxy for this benefit.

[9] Estimated value of avoided damages due to reduced flooding, and reduced water treatment costs due to less need for treating turbidity and bacteriological problems.

[10] Includes economic growth from improved workforce skills, improved capacity and capability of local firms, enhanced infrastructure and amenities.

[11] Based on estimating the economic cost of imposing different levels of temporary water restrictions (from stage 1 to stage 4) and the expected reduction in time when such restrictions were expected to be required.

[12] Environmental impact statement (EIS) quantified expected loss in regional gross domestic product (GDP) and jobs if water supply were to fail due to failure to invest in water security project.

[13] Increased water security and reliability of supply is described as an important benefit but framed via the lens of supporting agricultural and industrial uses rather than relating to urban drinking water.

[14] Potential recreation disbenefits described but mitigation opportunities were considered such that only minor disbenefits were considered likely.

Non-market benefits are more complex to quantify in biophysical and/or monetary terms, and could include motivations such as national security, water security, food security, (re)generation of a socio-economically disadvantaged/declining region, increased resilience, etc. The particular non-market benefits anticipated in the five case studies varied significantly with regards to both the particular benefits considered and the estimation methods used. In some examples, attempts were made to quantify such benefits, while other examples discussed the anticipated benefit in the narrative text without attempting to estimate a monetary value for the benefit flow. Benefits that are particularly difficult to reflect in a CBA are those such as offering improved water security against changes in future rainfall patterns or periods of extreme drought. In these instances, the development is in effect like buying insurance – the benefits are intermittent and only apparent in times when a large adverse impact is avoided/mitigated. Estimating the timing and impact of events such as drought using stochastic analyses are particularly prone to error, and so too is estimating the ‘insurance’ benefit (in both ex-post and post-ante analyses) of having additional dam water for such periods. Decision support tools such as net present value (NPV) and CBA are poorly suited to capturing the nuances of such vital, but intermittent, benefits.

The case studies, all set in very different contexts, illustrate the challenges in quantifying different benefits (especially the intangible and non-market benefits where the dam acts as a form of insurance). Each dam proposal is trying to forecast the future, where the forecasts are hard to quantify, and harder for some objectives and contexts than others. This is particularly the case for projects where the primary development motivations are hard-to-value objectives (such as improved water security). It is likely that the values included in the analysis will in effect be a more easily monetised benefit that will serve as a proxy for the true underlying benefit. For example, it is easier to estimate the monetary impact of imposing specific water restrictions on businesses operating in a region than to estimate the monetary value of a lack of drinking water in a community at some unknown future date.

These issues mean that a single financial metric from CBA is unlikely to be adequate for comparisons across projects in different contexts where different subsets of the full range of benefits may be captured in quantitative analyses. Additional information on the context and non-monetised costs and benefits would ideally be required.

Systematic bias in overstating the anticipated net benefits

The five cases studies used in this review all revealed varying degrees of discrepancies between forecast and realised future demand for water. This is not surprising; forecasting the future is difficult for the simplest of events, and more so for complex projects with a long useful life.

Evaluations of water infrastructure projects need to consider the biophysical (e.g. rainfall, evaporation, river flow, extreme weather events including drought and floods), and socio-economic (e.g. population growth, changes to the mix of industries and agricultural products, economic growth and inflation) outcomes over many years. Furthermore, forecasts are complicated by needing to estimate both the timing and scale of benefits, including how quickly actual demand grows towards its potential.

If the complexity of the task were the primary cause of forecasting errors, then an equal mix of under and overoptimistic estimates would be expected. However, the forecasts in the case studies tended to be consistently optimistic, favouring higher benefit–cost ratios (BCRs). This reflected optimism in both the forecast scale of demand once the developments reached their full potential and the rate at which that potential was achieved. Both biases contribute to over estimating the NPV of a project.

International literature for ex-post evaluation of investments in public infrastructure provides several possible explanations for errors and biases in CBAs (for projects such as railways, bridges, tunnels and roads, in addition to dams) which are likely to be relevant here (Flyvbjerg et al., 2002, 2005; Nicolaisen and Driscoll, 2014; van Wee, 2007; World Commission on Dams, 2000b). First, there is a risk with all reviews such as this that success bias could influence findings. By definition, ex-post evaluation can only be done on project proposals that have been successful in attracting investment and where the developments actually go ahead. A project where net benefits in the CBA are overstated is far more likely to have been selected than a project that understated net benefits. Thus, a review of 'successful' projects is more likely to find over- rather than understated benefits.

Secondly, systematic bias can be introduced by the views of and pressures on those preparing the CBA. For example, when an advocate/proponent of the project controls a CBA process, estimates of benefits/demand and of costs may be influenced (deliberately or subconsciously) by a motivation to achieve a desired outcome. That is, the estimated NPV can be influenced by the decisions made regarding which costs and benefits to include in the analysis, and the scale and timing of those costs/benefits, resulting in inflated benefits and/or understated costs (where the desire is to facilitate the project, or the reverse bias if the desire is to obstruct a project). CBAs prepared by independent analysts (agnostic about whether the project proceeds) may appear pessimistic in comparison to those that are prepared by proponents to meet project selection criteria. When reading and comparing CBAs it is therefore important to consider the context within which they were prepared as this can have a substantial influence on their results.

Summary of key issues

This review highlighted a number of issues with historical use of CBAs for recently built dams in Australia together with ways they could be more rigorously addressed (Table 6-4). These issues arise because of the complexity of the forecasts and estimates required to plan large infrastructure projects and because of pressures on proponents that can introduce systematic biases. However, this report acknowledges that flaws with the use of CBAs in large public infrastructure investment decisions are not unique to regional Australia or to water infrastructure – they are systemic and occur in many different types of infrastructure globally. Under such circumstances it would be inequitable to apply more rigor to CBAs only for some select investments, geographic regions and infrastructure classes, before the same standards are routinely applied in all cases. And there is no incentive for individual proponents to apply more rigor to CBAs if those proposals would suffer from unfavourable comparisons to alternative or competing investments with exaggerated CBRs. In the short term the main value of the information provided here is to assist in more critically interpreting and evaluating CBAs, realistically framed, so that more-informed decisions can be made about the likely viability (and relative ranking) of projects in practice. In particular, it highlights several aspects of CBAs where the claims of proponents warrant critical scrutiny. In the longer term, this analysis supports many of the similar issues raised in past review cycles of Infrastructure Australia's CBA best-practice guidelines and the recommendations that are being progressively added to those guidelines to improve how large public investments are evaluated (Infrastructure Australia, 2021a, 2021b).

Table 6-4 Summary of key issues and potential improvements arising from a review of recent dam developments

	KEY ISSUE	POTENTIAL IMPROVEMENTS
1	**Lack of clear documentary evidence regarding the actual outcome of dam developments compared to assumptions** made in ex-ante proposals, environmental impact statements (EISs) and cost–benefit analyses (CBAs). Ex-post evaluations or post-completion reviews have either not been prepared or not made publicly available	Conducting **ex-post evaluations** of developments and making these publicly available (as recommended by 2021 guidance from Infrastructure Australia and in the 2022 National Water Grid Investment Framework) would enable lessons learned to be shared and to benefit future developments
2	**Predicted increases in water demand** from specific developments generally **do not appear to arise at the scale and/or within the time frame forecast**. While the reasons for this are varied and context-dependent, there does appear to be a systematic bias towards over estimating the magnitude and rate at which new benefits would flow	**Recognising the tendency towards a systematic bias** of over stating benefits and under stating costs, CBAs in project proposals could be improved by: (i) further efforts to present unbiased financial analysis (e.g. **independent review**) and ensuring appropriate sensitivity analysis is included in all proposals, (ii) developing **broadly applicable realistically achievable benchmarks** for evaluating proponents' assumptions and financial performance claims, (iii) using past experiences and **lessons learned** from previous projects with similar context to inform the analysis presented in the proposals (building on Issue 1 above), and (iv) presenting a like-for-like comparison of cost–benefit ratios (**CBRs) for the proposed case vs standard alternatives** (such as water buybacks or a smaller dam, possibly better matched to realistic future demand)
3	The **systematic bias towards optimism** in proposals is **exacerbated by mismatches of forecast demand and the full supporting infrastructure required** to enable this demand to be realised, resulting in additional capital investment (pipelines, treatment plants etc.) being required that was not costed in the original proposal	The same improvements as for Issue 2 in recognising and **addressing inherent bias** apply here
4	Developments are justified based on a complex mix of multiple market and **non-market benefits**, many of which are **hard to monetise** and capture in a single net present value (NPV) figure	CBAs could be improved by presenting clear information on the full portfolio of benefits (and costs and disbenefits) anticipated to arise from a project. While the quantitative part of the CBA would analyse the easily monetised costs and benefits (with metrics such as CBR and NPV), **benefits that are hard to monetise could be formally presented alongside**. This information would be presented in whatever form is most appropriate to the magnitude and nature of that particular benefit. This presentation would enable the relative importance of each element of the mix to be weighed and given appropriate consideration, rather than attention being focused on a single NPV figure, which may have omitted key elements of the project

	KEY ISSUE	POTENTIAL IMPROVEMENTS
5	Improved **water security and reliability** of supply is often the most important benefit offered by dam developments, while also being the hardest to monetise. Dams provide a form of insurance against the risk that water may not be available when needed in future. **Assessing the value of this insurance** requires consideration of the cost of lack of water supply when needed and the likelihood that this could occur	CBAs could be improved by **providing clear information on exactly how the development will serve to improve water security**, the likelihood that such insurance will be required (i.e. an estimate of the risk), and the estimated social and economic impacts if the insurance was not there when required. Such information could be presented alongside, and given equal prominence with, other information regarding the proposal, including the estimated NPV. This is preferable to attempting to 'force' the benefit into an NPV calculation that is ill equipped to deal with such a benefit

7 New infrastructure demand and costs

7.1 Introduction

This chapter is intended simply to serve as a reference of infrastructure costs for the range of components that would be required for new agricultural development in the catchment of the Victoria River, both for the component assets required for on-farm development and those for the supporting off-farm infrastructure. It serves three main purposes: (i) to provide a realistic benchmark of the rate of expansion of agriculture for forecasting demand for additional water (and other enabling infrastructure) in the NT, (ii) to provide benchmark indicators of the realistic costs of infrastructure for those wanting to independently assess the likely viability of development options, and (iii) to collate indicative costs for these different types of infrastructure as a reference for their use in financial analyses in other parts of this Assessment (including chapters 8 and 9).

The information presented is particularly necessary given the systematic tendency of proponents of large infrastructure projects (including for new water supplies) to substantially under estimate development costs and overestimate trajectories of demand (see Chapter 6). This chapter also highlights the wide range of infrastructure assets (and associated private and public investors) that would be affected by new agricultural development. For a new scheme to function efficiently, the needs and responsibilities of investors in all keystone infrastructure assets would need to be considered, including the knock-on effects in creating demand for other types of enabling infrastructure.

Large infrastructure projects, by their nature, are relatively rare and each has unique characteristics and challenges, making it difficult to extrapolate from one project to another. Even when case-specific details are taken into account, there are some challenges that cannot be known in advance and only become apparent once construction has begun. The costs provided here should therefore be taken as broadly indicative only. Actual costs incurred in any specific development project could differ substantially from those provided. A contingency would need to be factored in on top of the base costs presented to make allowance for these uncertainties.

This chapter begins with an overview of growth trajectories in agricultural production and demand for irrigation water in the NT (Section 7.2) as context for why new infrastructure is required, and the rate at which it may need to be built. The chapter then presents costs for five types of new infrastructure that would be required to support an irrigation development and supply chains for new produce:

- development costs of the water and land resources that investors in an irrigation scheme would have to cover (considering both large instream dams and on-farm sources of water) (Section 7.3)
- costs of local processing facilities that may be required by new agricultural industries (built by private investors, who could be part of a vertically integrated project or separate investors) (Section 7.4)

- costs of transport infrastructure (most likely publicly funded with a contribution from developers), and transport costs (Section 7.5)
- costs of electricity transmission and distribution infrastructure (built by energy providers with developers paying the full or partial cost) (Section 7.6)
- costs of community infrastructure such as schools and hospitals (both publicly and privately funded) (Section 7.7).

7.2 Agricultural growth and water demand trajectories

To sustain the growth of irrigated agriculture, particularly high-value and water-intensive horticulture, in the Victoria catchment and the rest of the NT, additional water resources are necessary. Accurate forecasting of the anticipated demand growth is crucial for both the planning of new water infrastructure and the evaluation of individual proposals for such infrastructure. This ensures that projected water demand trajectories and the associated discounted present value generated from new high-value horticulture justify the costs of the infrastructure investments.

To establish realistic growth trajectories for horticulture in the NT, historical agricultural production and water use data from the Australian Bureau of Statistics (ABS) were analysed. It should be noted that the gross value of agricultural production (GVAP) encompasses both irrigated and unirrigated agriculture, while the gross value of irrigated agricultural production (GVIAP) focuses solely on irrigated agriculture. Given that horticulture is predominantly irrigated, the longer GVIAP data series is utilised to estimate water demand trajectories. Figure 7-1 illustrates the growth trends in various agricultural subsectors across Australia and the NT. Notably, the growth trends for broadacre and horticultural crops in the NT have outpaced the national average, while cattle production growth in the NT has been comparatively lower.

The gross value of horticulture in the NT has experienced significant growth, more than tripling between 1991 to 2000 (+233%) and 2001 to 2010 (+210%), and went up by 35% in 2011 to 2021. Current growth trajectories for GVAP in Australia (with NT values in parentheses) indicate a per-decade increase of $2.7 billion ($22 million) for horticulture, $8.9 billion ($37 million) for broadacre crops, and $6.8 billion ($288 million) for livestock industries (as shown by step changes in GVAP from 2001–10 to 2011–21 in Figure 7-1). Horticultural produce is primarily sold domestically for immediate consumption, necessitating growth in local consumer demand to drive industry expansion. Therefore, the growth of horticultural industries is constrained by the growth in demand from local consumers. Any new irrigated developments would compete for a portion of the aforementioned growth values, providing a benchmark for estimating the potential scale of new horticulture within a new irrigation scheme. It also helps determine the trajectory for the rate at which high-value horticulture and the associated water demand for high-value, high-priority water could grow following the completion of a new irrigation scheme.

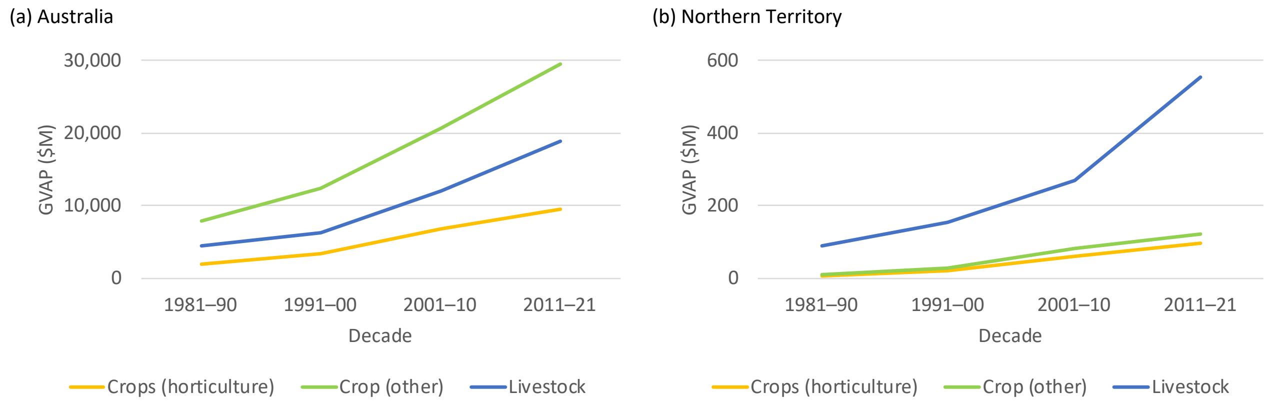

Figure 7-1 Trends in gross value of agricultural production (GVAP) in (a) Australia and (b) the Northern Territory over 40 years (1981–2021)

Data points are decade averages of annual values. The 'Crop (other)' category is predominantly broadacre farming.

Source: ABS (2022a)

The expansion of new horticultural farms is constrained by the seasonal gaps in supply for each crop. As a result, horticulture in a particular location typically involves a combination of products that cater to the specific niche market gaps that can be filled by that location, rather than focusing solely on the cultivation of the most valuable crop. This aspect has significant implications for determining the value of new agricultural production that can financially support and justify the costs associated with publicly funded irrigation schemes. Figure 7-2 illustrates the trends in the GVIAP in response to increasing supplies of irrigation water in Australia. The slopes of the trendlines reflect the increase in gross agricultural production per gigalitre of new water utilised by various categories of Australian agriculture. Each additional gigalitre of water usage can result in either of the following increases in gross value:

- between $2.1 and 3.7 million for the fruit industries
- between $5.6 and 10.3 million for the vegetable industries
- between $2.5 and 5.0 million for mixed horticulture (combining fruits and vegetables data)
- between $0.8 and 1.7 million for a typical mix of agriculture overall.

The horticultural segment of proposed irrigation schemes requires careful examination as the financial viability of these schemes is particularly sensitive to assumptions regarding the scale and rate of expansion of this more valuable form of agricultural production. Moreover, horticulture often necessitates higher security water compared to broadacre cropping. Currently, approximately 30% of the total irrigation water utilised in irrigated farming in Australia is allocated to horticultural production (ABS, 2021b). These values serve as indicative benchmarks for estimating the potential gross values that combinations of new agricultural activities could generate when planning new water supplies.

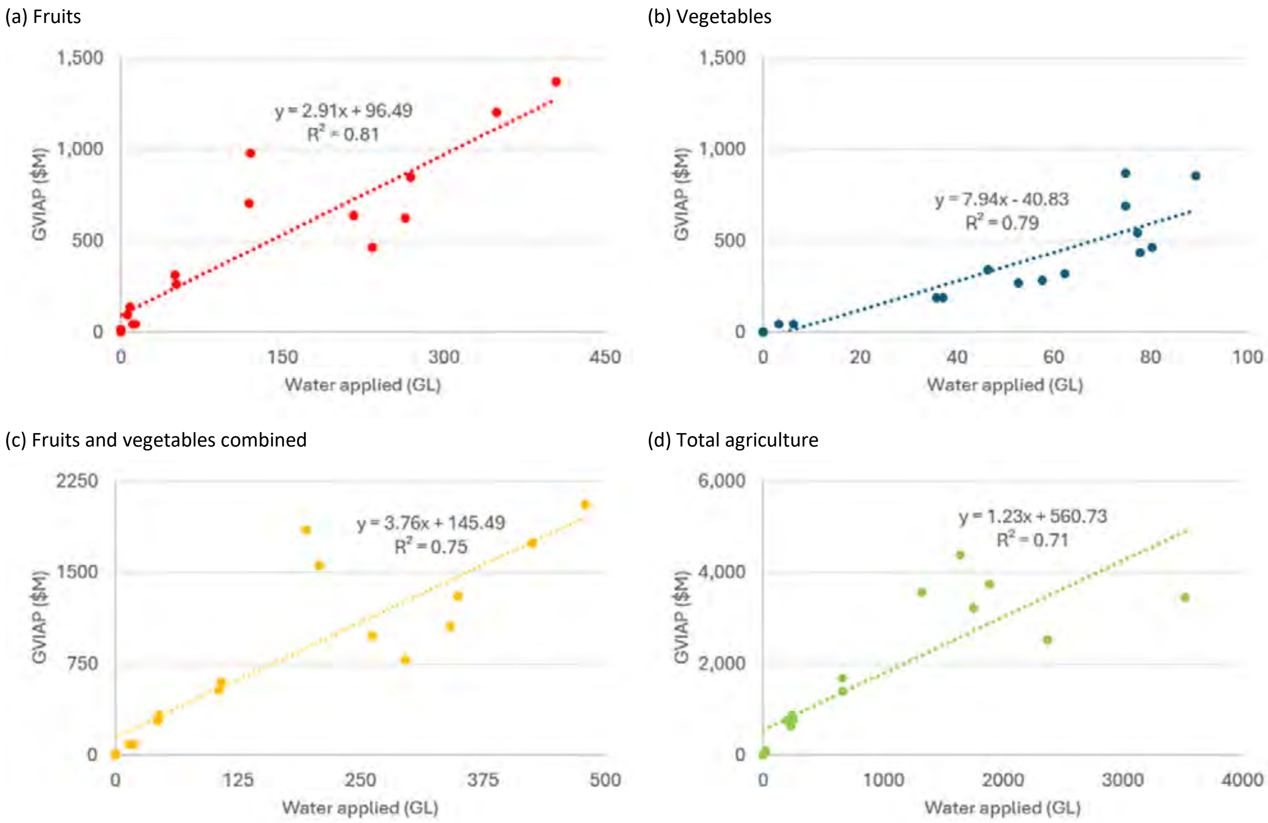

Figure 7-2 National trends for increasing gross value of irrigated agricultural production (GVIAP) as available water supplies have increased for (a) fruits, (b) vegetables, (c) fruits and vegetables combined, and (d) total agriculture

Source: ABS (2022a)

Approximately 25% of the GVAP in Australia is attributed to irrigated agriculture (ABS, 2021b). In the year 2018–19, agriculture consumed a total of 7965 GL of water, accounting for 59% of all water extractions. The majority of this water was utilised for crop irrigation (70%) and pasture irrigation (30%). Among the nearly 8000 GL of water used in 2018–19, 28.6% was sourced from groundwater (2280 GL), 1.5% from recycled water (115 GL), and the remainder from other sources such as rivers, creeks and lakes (ABS, 2021b).

Figure 7-3 illustrates the specific irrigation water requirements for different types of horticultural farms, based on current national water usage records. In the NT, the horticultural farm categories with the highest annual demand for irrigation are ‘nurseries, cut flowers, and cultivated turf’ with an intensity of 10.9 ML/ha and ‘grapevines’ with an intensity of 9.8 ML/ha (ABS, 2021b).

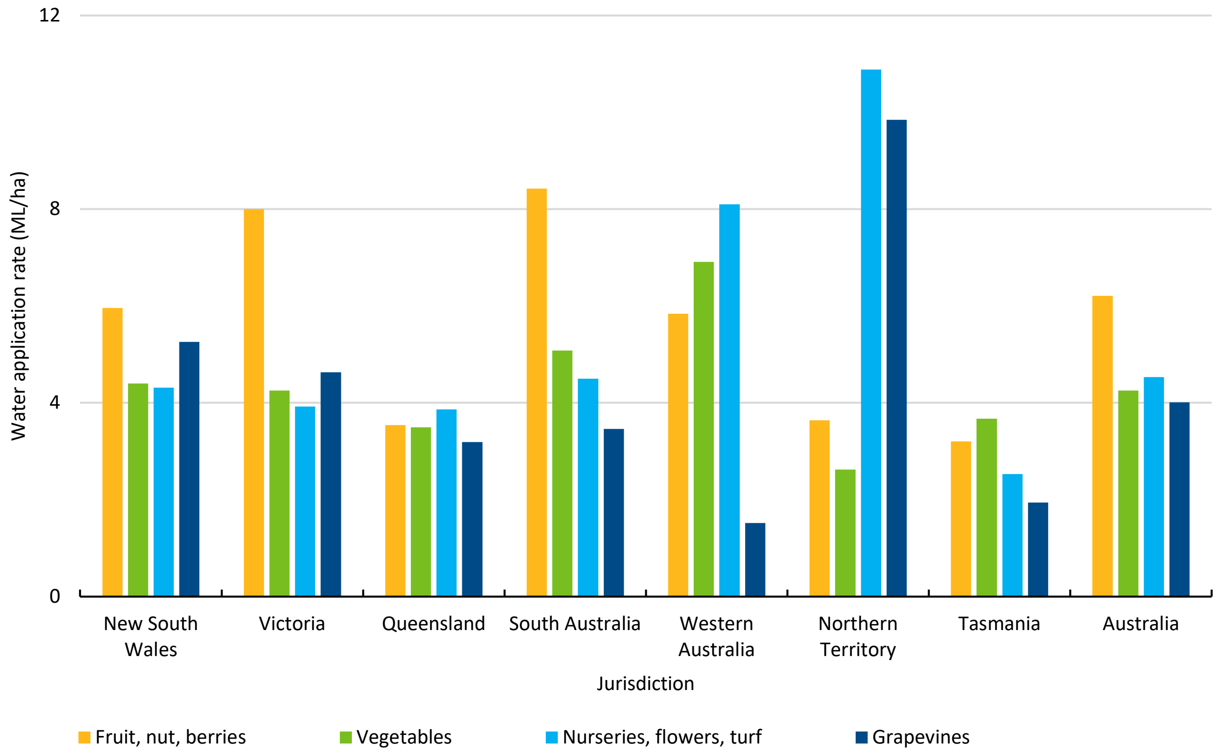

Figure 7-3 Mean annual water application rate by horticultural type across Australian states and territories and Australia as a whole

Source: ABS (2021b)

7.3 Development costs for land and water resources

Establishing new irrigated agriculture would involve the initial costs of developing water and land resources, and additional farm set-up costs for equipment and facilities on each new farm. There are many different options for where and how land and water resources are developed, each of which has implications for cost efficiencies and viability of a greenfield irrigation scheme. The analyses of scheme viability (Chapter 8) are not intended to prescribe particular scheme configurations or development pathways. Instead, the overall evaluation framework was designed to allow flexible comparisons across a wide range of different configurations (Figure 4-1), which required easy substitution of alternative land and water developments used in evaluations. To allow such arbitrary pairings of any land development option with any water development option, the individual options for developing each of these two agricultural resources had to be treated on a like-for-like basis. All water sources are therefore treated on a consistent basis where all capital and operating costs associated with delivering water to the farm at the farmland surface are treated as the costs of that water supply. This means that pumping costs for getting water from a weir to a farm, or pumping costs to lift groundwater to the farmland surface, are treated as costs of the water source (whereas pumping costs to then distribute and apply water on-farm are treated as part of the costs of growing the crop, and were included in the costings of crop GMs in Chapter 5).

This section covers the costs of developing new irrigated farms and the on- and off-farm water sources to supply them (following the distinction above in how they are costed). There may be additional costs, beyond those summarised below, to gain rights to land and water, particularly if an Indigenous land use agreement (ILUA) is required. For example, in WA the Ord Final ILUA involved a compensation package worth $57 million to resolve several native title and heritage issues with the Miriuwung Gajerrong Peoples over 1450 km^2 of land in the Kimberley (Department of Regional Development and Lands, 2009).

7.3.1 Farm establishment costs

The costs of developing new enterprises include capital expenditure on establishment and buildings (including approvals), farmland preparation (including clearing), irrigation systems (excluding the water source), and farm machinery and equipment. Capital costs of development are affected by the type of farm being developed, the siting of the farm (particularly soils and topography), the degree to which infrastructure is engineered, and choices about what activities are outsourced (particularly affecting the requirement for expensive packing and storage facilities on horticultural farms, and the requirement for owning specialised farm machinery).

Indicative costs are provided for a range of farm development scenarios in Table 7-1. The base cases for broadacre farming are a typical furrow-irrigated farm (on clay soils, including water distribution and tailwater recycling) ($9,800/ha capital cost) and a farm on well-draining soils that would require a more expensive pressurised spray irrigation system (all other costs staying the same) ($13,300/ha). To bracket the range of establishment costs for broadacre crops, two other scenarios were used: a 5000-ha furrow-irrigated farm (capturing economies of scale in being able to use assets more efficiently) ($6,400/ha) and a higher cost spray irrigation development engineered to a higher standard and with complex approvals ($18,100/ha). There are opportunities for very large (5000 ha) farms in the Victoria catchment and the ‘Broadacre scale’ scenario indicates the potential efficiencies that scale can provide. These capital costs are also converted to an annualised equivalent (Table 7-1).

Two scenarios are provided as indicators of the range of development costs for horticultural farms, both using high-pressure tape irrigation systems. The lower capital cost scenario (total capital costs $29,200/ha, Table 7-1) is based on direct packing of produce to bins in the field (e.g. for a row crop like melons) and assuming that nearby suitable off-farm accommodation is available for seasonal workers. If farm produce subsequently required grading, packing and cold storage by an off-farm service provider, the savings in upfront capital costs would be offset by additional ongoing costs of production from the outsourced service (that would reduce the farm’s GM). The higher capital cost scenario (total capital costs $81,300/ha, Table 7-1) includes the costs of modern packing and cold storage facilities, and on-site accommodation for seasonal workers (e.g. a remote fruit tree farm).

Table 7-1 Indicative development costs for different types of irrigated farms

All costs are standardised on a per hectare basis. Broadacre farms were based on a farm size of 500 ha, except for the 'large scale' scenario that was 5000 ha. Horticultural farms were based on farm size of 200 ha. The fixed component of maintenance costs was assumed to be 1% of the asset's initial capital cost per year (and an additional variable cost of maintaining farm machinery and equipment was accounted for in crop gross margins in Chapter 5). A contingency would need to be factored in on top of these costs (e.g. an additional 10%). Equivalent annualised costs are based on a 10% discount rate. Costs of the irrigation water source are considered separately.

ITEM	UNITS	BROADACRE LARGE SCALE	BROADACRE FURROW	BROADACRE PIVOTS	BROADACRE HIGH STANDARD	HORTICULTURE LOWER CAPITAL	HORTICULTURE HIGHER CAPITAL
Farm establishment and buildings	$/ha	1,700	4,700	4,700	7,700	11,900	56,600
Farmland preparation	$/ha	2,100	2,300	800	2,500	1,900	7,600
Irrigation system	$/ha	900	1,100	6,100	6,100	5,100	7,600
Farm machinery and equipment	$/ha	1,700	1,700	1,700	1,800	10,300	9,500
Total capital costs	$/ha	6,400	9,800	13,300	18,100	29,200	81,300
Equivalent annualised cost	$/ha/y	800	1,100	1,600	2,200	3,700	9,300
Maintenance costs	$/ha/y	100	100	100	200	300	800
Total annualised costs	$/ha/y	900	1,200	1,700	2,400	4,000	10,100

Source: Based on unit costs of component assets in remote northern Australia from Ash et al. (2018) and Stokes and Jarvis (2021), updated to December 2023 dollar values

7.3.2 Costs for on-farm water sources

Indicative costs for a range of scenarios for developing on-farm water sources are presented in Table 7-2. Costings were based on unit costs of component assets from Ash et al. (2018), including the delivery infrastructure to get water from the water source to the irrigation system (but not the costs of the irrigation system itself, which is already accounted for in the farm development costs above). The costs of developing on-farm water sources are highly dependent on characteristics of the location such as topography, soil texture and the success rate of bores. Each water source therefore included a more expensive and a less expensive scenario to illustrate some of this site-to-site variability.

When compared on an equivalent basis (per unit area) indicative costs for developing on-farm water sources ranged from $4,300/ha to $16,200/ha (Table 7-2). Note that while the capital costs of developing bores is relatively low, pumping costs are typically high (depending on the total dynamic head (TDH) required to lift water to the soil surface). Likewise, high pumping costs would typically preclude water storages that are sited at a much lower elevation than the fields they are irrigating (noting, from the like-for-like approach described before, that pumping costs to the farm surface are treated here as part of the *costs of the water source*).

The companion technical report on surface water storage (Yang et al., 2024) has much more detail on cost, siting and construction considerations for on-farm water storages, including maps of the locations in the Victoria catchment most suited (topography and seepage) to building them.

Table 7-2 Indicative capital costs for developing on-farm water sources (including distribution from source to cropped fields)

Adapted from unit costings of farm development scenarios in Ash et al. (2018) and adjusted to December 2023 dollar values. Pumping costs for bores, or water storages that are below the height of the field they are irrigating, should allow about $2 per megalitre per m TDH.

WATER SOURCE	FARM AREA (ha)	CAPITAL COST ($/farm)	COST PER HECTARE ($/ha)
Gully dam, 6000 ML, well sited	500	2,170,000	4,300
Gully dam, 6000 ML, average siting	500	5,830,000	11,700
Stream diversion, gravity fed	5000	31,460,000	6,300
Stream diversion, requires pumping	5000	81,220,000	16,200
Flood flow pumping in floodplain, 6000 ML	500	7,380,000	14,800
Bores, good success and flow rate	500	2,170,000	4,300
Bores, moderate depth and success rate	500	4,400,000	8,800

7.3.3 Cost for large off-farm water infrastructure developments

Yang et al. (2024) evaluated some of the more cost-effective dam site locations in close proximity to soils suitable for irrigated agriculture in the Victoria catchment, and the costs for building those dams and associated weir and reticulation infrastructure required to deliver that water to farms. Using information from Yang et al. (2024) and Devlin (2024), indicative costings are presented a hypothetical irrigation schemes based on one of these representative dam site locations (Table 7-3). This suggests that dams, together with supporting off-farm infrastructure, could supply water to new enterprises at a capital cost of about $127,500/ha of new irrigated farmland.

Table 7-3 Indicative capital costs for developing a representative irrigation scheme in the Victoria catchment

The dam costings already allow for a road; an indicative allowance has been added for a bitumen road to the irrigation area from the Victoria Highway, and a transmission line from Kununurra, and electricity distribution lines to which farms can connect.

ITEM	LEICHHARDT CREEK COST ($)
Capital costs	
Dam	396,000,000
Weir	2,000,000
Reticulation	10,500,000
Roads and electricity	100,000,000
Total	~510,000,000
Summary metrics	
Irrigated area (ha)	4,000
Cost per hectare (~$/ha)	127,500

Source: Dam and weir costings are based on data from Yang et al. (2024), and reticulation costings based on a per hectare rate from Devlin (2024) and include contingencies; see that report for full details of cost breakdowns and assumptions

The development of new agriculture would have flow-on consequences for local supply chains and demand for supporting infrastructure. These are considered in the following sections.

7.4 Processing costs

7.4.1 Dependence on new local processing facilities

Due to the low value of some unprocessed farm commodities, particularly industrial crops like cotton and sugarcane, local processing is required for the total supply chain costs to be viable. This was demonstrated in the narrative risk analysis presented before that illustrated the influence of distance to gin on cotton GMs (Section 5.2.1). Sugarcane is even more reliant on local processing, because the unprocessed sugarcane weighs about seven times as much as the processed sugar. For example, transporting sugarcane 100 km would cost about $32/t (see Table 7-6), more than half the gross sugarcane revenue (currently about $50/t). Investors in new local processing facilities would require economies of scale and security of supply (e.g. that farmers would not switch to other crops below the scale threshold) in order for their investments to be viable, and these would be essential considerations in the overall planning of a new irrigation scheme for these types of commodities.

7.4.2 Meatworks

Meat processing capacity is concentrated in south-east Queensland and on the eastern coast. Many cattle properties across northern Australia do not have access to local meatworks and have to transport cattle long distances (>1000 km) for processing (if they are not sold for live export). There have been several feasibility studies for the construction of abattoirs in western Queensland (e.g. Cloncurry, Hughenden, Roma) and other parts of northern Australia (e.g. Broome). A study by Meateng (2011) estimated the cost of constructing an abattoir at Broome would be around $33 million with an operational capacity of 100,000 head/year. Another study (Meateng, 2018) estimated the cost of constructing a 100,000 head/year abattoir in north-western Queensland to be about $100 million (not including the provision of land, power, water and road access) with operating costs of about $330/head. However, there has been a long history of meatworks being established in the NT but then struggling to remain viable. For example, Australian Agricultural Company's Livingstone Beef processing facility (situated about 50 km south of Darwin) has not been active since 2018. If the beef industry in the Victoria catchment were to develop a boxed-meat market of sufficient scale, reviving a mothballed meatworks would probably be a more likely scenario than building a new one.

7.4.3 Cotton gin

Indicative costs are provided for a cotton gin with maximum capacity of about 1500 bales/day (Table 7-4). Unprocessed seed cotton contains about 40% cotton lint, meaning that processed cotton bales are much lighter and cheaper to transport. Cotton seed is a by-product that can be used as a livestock feed supplement, with a ready market in the local Victoria catchment cattle industry: trucks taking unprocessed cotton modules to the gin could return with cotton seed. The value of the cotton seed is generally about equal to the costs of processing charged to the grower. Harvested cotton can be stored, but susceptibility to spoilage in wet weather limits the length of the ginning season. An important consideration in remote locations would be how to power a new gin. A minimum area of about 15,000 ha irrigated cotton would be required to reach the scale of production necessary for a new gin to be viable. Higher cotton prices increase the distance that farms can profitably transport modules to the gin (Section 5.2.1), which increases the catchment area of a gin to attain threshold levels of supply, thereby increasing the chance of a cotton gin (and associated new cotton industry) navigating the challenging early years to become sustainable and profitable. A new gin, about 30 km north of Katherine, became operational in 2024, providing opportunities for cotton to be grown in the Victoria catchment.

Table 7-4 Indicative capital and operating (fixed and variable) costs for a cotton gin from two sources

ITEM	SOURCE 1	SOURCE 2	COMMENTS
Gin capacity	≈80,000 bales/y	≈95,000 bales/y	Includes warehousing for 50,000 bales
Capital cost	$36,600,000	$34,300,000	Relocating an underutilised mill, if available, could be much cheaper
Fixed costs	$1,260,000/y	$1,410,000/y	Includes six full-time staff
Variable costs	$27 to $37 per bale	$40 per bale	Depends on scale and the source and cost of energy (on- or off-grid)

Source 1: Rick Jones, Queensland Cotton (August 2017, pers. comm.); Stokes et al. (2017), adjusted to December 2023 dollar values
Source 2: PwC (2019) (with input assumptions also from Queensland Cotton), adjusted to December 2023 dollar values

7.4.4 Sugar mill

The amount of sugar that can be recovered by mills from harvested irrigated sugarcane is typically only about 15% by mass, a ratio known as the CCS (commercial cane sugar). Sugar mills are costly processing facilities that, depending on how they are configured, can produce different mixes of a range of products: sugar, molasses, renewable fuels (e.g. ethanol, biogas/methane or hydrogen), and/or baseload renewable power (from bagasse, the remaining fibre after crushing) (Jackson, 2013). Cane has to be crushed as it is harvested, so crushing operations are constrained by farming practices and trafficability of harvested fields (typically a 6-month crushing season between about mid-June and mid-December for irrigated cane).

The standard practice in current sugarcane growing regions of Australia is for mills to pay for cane at the farm gate using a pricing formula that takes into account the quality (CCS) of the cane and the current sugar price (prices in $/t): cane price = raw sugar price × (CCS – 4) × 0.9 (i.e. millers get the first 4% of sugar extracted and 10% of the rest; growers get paid the value of 90% of sugar extracted above the first 4%). Processing of cane adds about 50% value in the sugar produced alone, and the bagasse (about 15% fibre) would be able to generate about 0.08 MWh of exported power per tonne of cane (about another 15% to 30% value added to the value of the unprocessed cane). With appropriate management, including for pre-harvest water stress, irrigated cane reaches its peak quality around mid-November, and drops off rapidly either side of that date (with lower CCS and higher water content).

Indicative costs are provided below for a basic sugar mill capable of processing about 1000 t of cane per hour, or about 4 million t cane per year (for a 6-month crushing season and 90% mill reliability) (Table 7-5). Cane is first milled through crushers to separate the juice from the moist fibre (bagasse). Bagasse combustion produces steam to power the mill (and excess energy can be used for electricity generation). Juice is clarified to remove impurities before evaporating off water by boiling under partial vacuum. Crystallisation of sucrose occurs by further boiling, crystal seeding and centrifuging. Sugar and fibre can be further processed to produce ethanol. Throughput rates at different stages of processing depend on the quality of the cane, and hence affect the optimal configuration of mill components.

Sugar mills are very large capital investments (about $470 million capital cost) and require a larger scale of farming than cotton to provide sufficient supply to justify such an investment. A minimum area of about 25,000 ha under irrigated sugarcane would be required to reach the scale of production necessary for a new mill to be viable. The information on costs of sugar mills and the scale of production required to support them is provided despite there being insufficient suitable land at scale within close enough proximity to support a sugar mill (why sugarcane was therefore excluded from the set of crop options that were analysed in Part II of this report). The nearest mill, the Ord Sugar Mill near Kununurra (WA) closed in 2007 and cited low world sugar prices, shrinking production and uncertainty about expansion of the Ord irrigation area as the main reasons for the mill closure.

Table 7-5 Indicative capital and operating costs for a basic sugar mill capable of processing 1000 t cane per hour

Costs for cogeneration of electricity or ethanol production would be additional. Costs of each mill component depend on the quality of cane being processed (assumed 15% commercial cane sugar (CCS), 15% fibre and 70% water content). See Jackson (2013) for a more detailed account of sugarcane processing.

ITEM	VALUE ($ million)
Capital costs	
Crushers (extract and purify juice, separate fibre)	117
Evaporation (remove water from purified juice)	109
Pans and centrifugals (crystallise sucrose)	66
Utilities and balance of plant	177
Total capital costs	469
Operating costs (annual, recurrent)	39

Source: Stokes et al. (2017), adjusted for inflation to December 2023 dollar values

7.5 Transport costs

Indicative freight costs were estimated using the Transport Network Strategic Investment Tool (TraNSIT). TraNSIT (Higgins et al., 2015) is a modularised tool that uses detailed spatial information on the road (and rail) network in Australia (Figure 7-4) together with supply chain data on the movement of goods along this network for each agricultural industry. Freight estimates are based on detailed bottom-up modelling of the costs incurred by trains and trucks of different size classes moving different types of products along the transport network. It should be noted that in practice, however, the actual prices charged to customers may not be split evenly in covering the trucking/rail costs of a round trip. Costs can be higher for the leg of the journey for which there is most demand and lower on the return leg (particularly if 'backloading' rates are charged on routes where some trucks would otherwise return empty or with loads below capacity). Costs for long-distance trips (>1 day permitted driving time) do not scale completely linearly, as there are step changes each time the route crosses a threshold that requires drivers to take an overnight break.

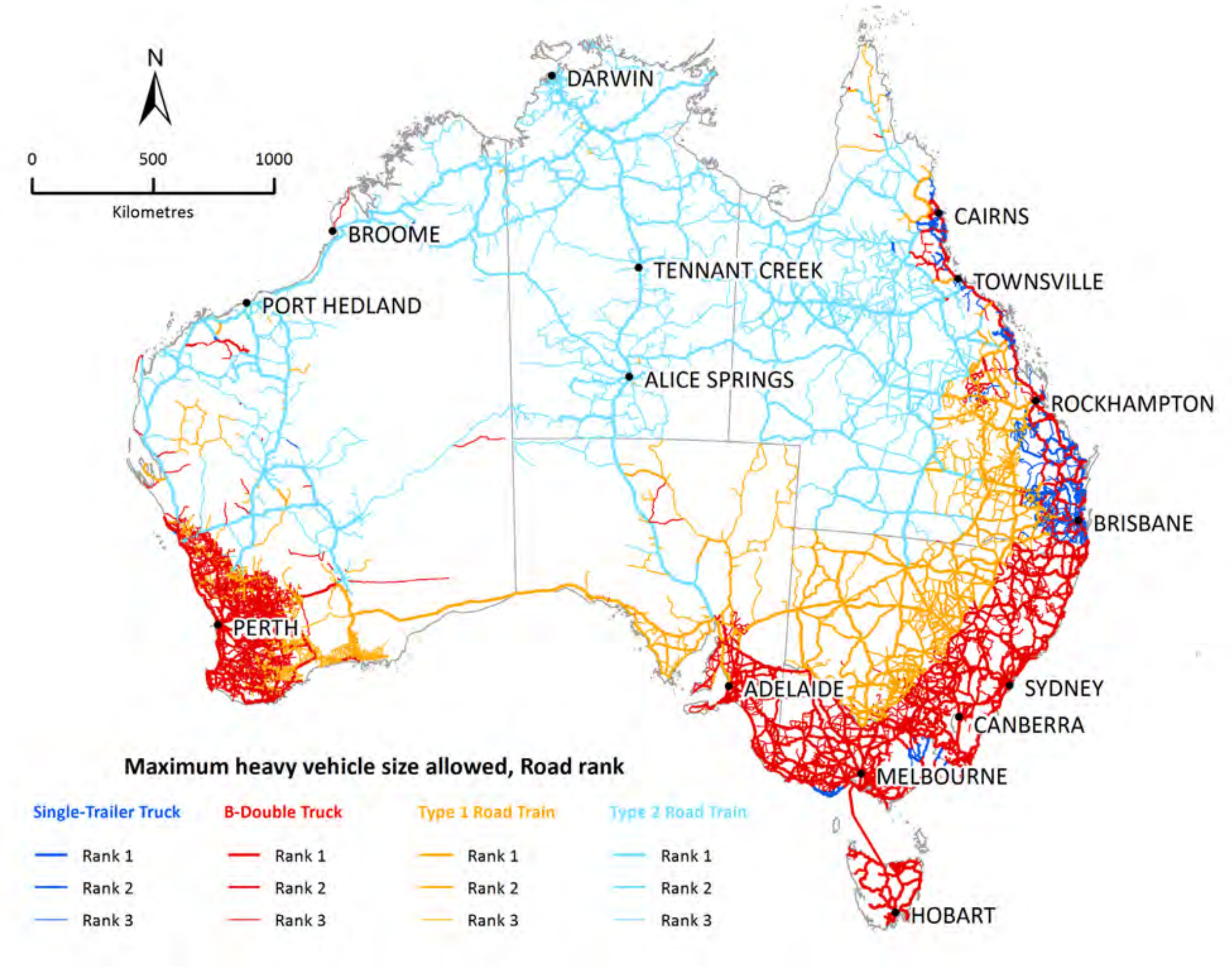

Figure 7-4 Road layer used in TraNSIT, showing road rank and heavy vehicle restrictions
Truck classes listed from shortest to longest in legend (left to right).

Transport costs between Victoria River Roadhouse and key markets and ports are shown in Table 7-6 (with routes show in Figure 7-5). Transporting cattle from Victoria River Roadhouse to Darwin would cost about $71/t and a further $0.29 per tonne per kilometre for the portion of the trip on the unsealed roads from within the Victoria catchment to the Victoria River Roadhouse. Estimated refrigerated freight costs to southern capital city markets (e.g. for most horticultural produce) range from $516/t (Adelaide) to $692/t (Sydney). There would be little opportunities for reduced backloading rates from Victoria River Roadhouse southwards for underutilised trucks on the return leg from supplying retail distribution centres. Cost estimates do not include the disruptions from road closures that can cut off routes or require detours. The road network (predominantly unsealed) within the Victoria catchment is susceptible to wet-season flooding.

Table 7-6 Indicative road transport costs between the Victoria catchment and key markets and ports

The top section of the table gives trip costs from the Victoria River Roadhouse to key destinations. The bottom section gives distance-based costs of getting goods from within the catchment to Victoria River Roadhouse (on unsealed roads) and approximate distance-based costs of getting goods from the Victoria River Roadhouse on sealed roads to other destinations (not specifically listed).

DESTINATION	TRANSPORT COST		
	Unrefrigerated	Refrigerated	Cattle
	Transport costs from Victoria River Roadhouse ($/t)		
Adelaide	440	515	396
Brisbane	515	604	463
Cairns	393	487	354
Darwin	78	92	70
Fremantle	536	639	482
Karumba	306	368	275
Melbourne	584	654	526
Port Hedland	285	344	257
Sydney	616	692	555
Townsville	354	426	319
Wyndham	65	77	59
	Transport costs by distance ($/t/km)		
Properties to Victoria River Roadhouse†	0.32	0.38	0.29
Victoria River Roadhouse to key markets/ports	0.15	0.18	0.14

†For the cost to centres – current movements to centres where distance was <200 km.
Source: 2021 data from TraNSIT (Higgins et al., 2015)

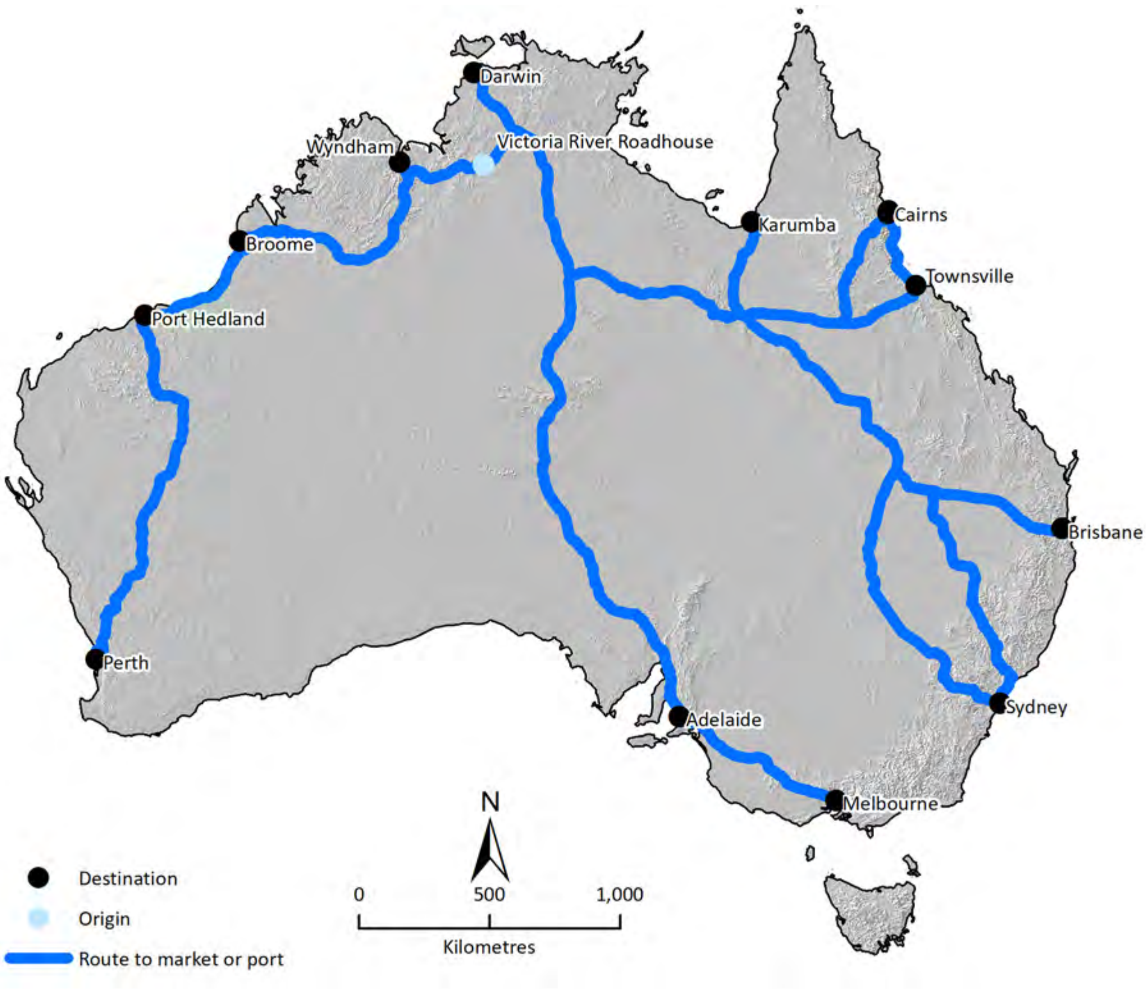

Figure 7-5 Freight paths from the Victoria River Roadhouse to key ports and southern markets
The freight path depends on the vehicle selection and heavy vehicle access (see Figure 7-4).

Upgrading road networks can be an important enabler of regional development, improving the cost efficiencies and reliability of trucking routes. The cost of such upgrades, however, is substantial and highly variable depending on the route-specific works and bridges required. The Northern Australia Beef Roads Programme provided indicative costs of road upgrades across a range of scenarios (CSIRO, 2016; all prices quoted in this paragraph are adjusted to December 2023 dollar values). For example, widening (9 m width) and sealing an existing unsealed road to state road standards was estimated to cost about $1.25 million per km (excluding bridges) in north-west Queensland. Construction costs of road upgrades could exceed $2.4 million per km in some cases, particularly when widening of floodways was required. Estimates of construction costs were as low as $310,000 per km for roads with lower volumes of traffic. In the NT, the cost of construction was about $980,000 per km for upgrading narrow sealed beef roads to two-lane sealed roads with flood immunity (e.g. Tableland Highway). Similar upgrades for beef roads in WA (e.g. Wyndham Spur) involving widening to 11 m, re-alignments and lengthening of culverts were estimated to cost about $1.8 million per km. The most expensive proposed upgrades were bridges and floodways, with a total cost of about $137 million for five bridges along the Great Northern Highway. Upgraded roads improve travel times (e.g. 80 to 100 km/hour), improve safety, reduce vehicle maintenance costs and reduce frequency of road closures.

7.6 Energy infrastructure costs

Obtaining cost estimates for transmission infrastructure connections can be challenging, as costs are often borne by private companies and cost information is not shared publicly. Reliable cost data are also highly dependent on the location and requirements of the facility or load to be connected. A collaborative study by the CO2CRC (a Cooperative Research Centre (CRC) investigating carbon capture and storage technologies) and authored by the Electric Power Research Institute (EPRI, 2015) compiled energy infrastructure costs from a wide range of industry, government and research sources to develop estimates for its levelised cost of energy (LCOE) methodology. This study provides credible technology cost and performance data and projections for Australian electricity over the period 2015 to 2030. It contains data 'building blocks' to use for policy and investment decisions and for further modelling of Australian electricity generation options. For a wide range of technologies, the study includes current and projected capital costs, operation and maintenance costs, and detailed performance data (EPRI, 2015). This reference has been heavily relied upon in the summary of electricity infrastructure costs below (with prices adjusted to December 2023 dollar values).

Transmission and distribution lines

The delivery of electricity typically starts at a power generator from where a step-up transformer converts the electricity to higher voltages for more efficient long-distance transmission. Transmission lines provide for the bulk flow of electrical energy from generation sources to substations closer to end users, where step-down transformers convert the electricity to lower voltages for distribution. Distribution lines deliver electricity to consumers at voltages ready for use. The complex interconnected network of transmission lines, substations, distributions lines and control and conversion systems is often referred to collectively as a grid (such as the Darwin–Katherine Interconnected System (DKIS) in the NT that does not extend west from Katherine, so does not reach the Victoria catchment).

High voltage (HV) transmission lines (132 to 330 kV lines with 50 to 3500 kVA power transfer capability) generally provide the backbone of Australian electricity transmission systems and deliver bulk energy directly from regional generation centres to load centres (EPRI, 2015). Lower voltage transmission lines (110 to 132 kV) are typically used to service mixed loads of residential, commercial and industrial demands and connect to the backbone 220 to 330 kV lines at bulk supply points that interface with the distribution network.

For HV transmission lines, there is also a wide range of nominal voltage levels and thermal capabilities between transmission lines from 132 to 330 kV, which can further vary final costs. For example, 132 to 330 kV transmission line costs can be $0.34 to $1.57 million per km depending on the voltage level and number of circuits, and the substation and switchgear can range from $3 million to $12.2 million depending on the arrangement of the substation (EPRI, 2015).

An important consideration for the capital costs of network connection for both new generators and new loads is the influence of peak loads on capital costs. For generators, siting new power stations close to the existing grid can lower connection costs, but may constrain the technology options (EPRI, 2015). EPRI (2015) states that, 'To use the full output of low-utilisation generators (such as intermittent renewables or peaking gas plants), network connections must be built to the peak capacity even though they might be used for only 20% to 40% of the time on average.

Because connection costs have to be paid by the developer, this precludes all but short lines connecting to the existing grid without increasing an installed project's LCOE. Traditional baseload generators may justify longer connections to the grid.'

This is true also for new load customers; their distribution lines must be sized to peak loads, even though there may be large portions of the day when the line is not delivering to capacity. Use of on-site storage may go some way to mitigate this, but the costs of on-site storage would need to be balanced with the avoided cost of capital for the larger distribution network capacity.

Table 7-7 below provides some indicative transmission and distribution line costs from the EPRI study (EPRI, 2015). The 11 to 66 kV lines are most likely large enough and therefore most relevant for the kinds of developments likely to progress in the Victoria catchment. Others have been included for the cases where projects may be economic for including larger cogeneration or renewables developments.

Table 7-7 Indicative costs of transmission and distribution lines, for sizes relevant to this Assessment

Acquisition of land and easement for the lines would be an additional cost. Costs are a rough guide only since they vary considerably depending on details of individual cases.

ASSET DESCRIPTION	TECHNICAL TRANSFER CAPABILITIES (MVA†)	COST ($ million/km)
Transmission line costs		
220, 275, 330 kV single circuit	800 to 1300	0.86
132 kV double circuit	200 to 500	0.79 to 1.57
132 kV single circuit	45 to 234	0.34 to 0.87
Distribution line costs		
11–33 kV single circuit	1 to 20	0.22 to 0.27
66 kV single circuit	10 to 100	0.24 to 0.49

†megavolt ampere (MVA) = 1 megawatt (MW)
Source: EPRI (2015), adjusted for inflation to December 2023 dollar values

Transformers

Substations connect two transmission or distribution lines of different voltage levels. Substations consist of transformers and associated switchgear and are a substantial part of the costs of connecting to the transmission system for a new-entrant generator (Table 7-8).

Table 7-8 Indicative costs of transformer, for sizes likely to be relevant to developments in the Assessment area

Transformers are categorised by the voltage pairs that they convert between. Excludes switchgear costs. na = not applicable.

TRANSFORMER	TECHNICAL TRANSFER CAPABILITIES (MVA†)	COST ($ million)
275/132 kV	200	9.0 to 12.2
220/110 kV	150	6.2
132/22 kV	na	8.0 to 8.7
110/33 kV	50 to 100	3.0 to 4.5
33/11 kV	5 to 20	1.3 to 2.4

†megavolt ampere (MVA) = 1 megawatt (MW)
Source: EPRI (2015), adjusted for inflation to December 2023 dollar values

7.7 Community infrastructure costs

The availability of community services and facilities in remote areas would play an important role in attracting or deterring people from living in those areas. If local populations increase as a result of new irrigated developments, then demand for public services would increase in the region, and provision of those services would need to be anticipated and planned. Indicative costs for constructing a range of different facilities that may be required to support this growth are listed below (Table 7-9). Healthcare services in remote locations generally focus on primary and some secondary care. The broadest range of tertiary services are concentrated in 'principal referral hospitals' that are mainly located in large cities but serve large surrounding areas by referral (AIHW, 2015). Each 1000 people in Australia require 2.3 (in 'Major cities') to 4.0 (in 'Remote and Very remote areas') hospital beds served by 16 full-time equivalent hospital staff and $3.5 million/year funding to maintain current mean national levels of hospital service (AIHW, 2023).

Table 7-9 Indicative construction costs for different types of community facilities in Darwin

Costs in remote areas, including the Victoria catchment, are estimated to be approximately 30% to 60% higher than those quoted for Darwin. Cost ranges in columns two and three are per square metre; costs in the last two columns are per hospital bed, house or apartment. na = not applicable

BUILDING TYPE	GFA† COST RANGE ($/m²)		TOTAL COST RANGE ($)	
	(low	high)	(low	high)
Private low-rise hospital, 45 to 60 m²/bed	4,500	5,300	257,000	400,000
Private low-rise hospital, 55 to 80 m²/bed + major operating theatre	5,400	6,500	400,000	572,000
House, single- or double-storey, 325 m²	2,100	3,200	669,000	972,000
Residential unit (townhouse), 90 to 120 m²	2,300	2,700	263,000	452,000
Offices, non-CBD, 1 to 3 stories	2,700	3,900	na	na

†GFA = gross floor area, the sum of covered and uncovered floor areas
CBD = central business district
Source: RLB (2021), adjusted for inflation to December 2023 dollar values

Based on a small sample size, the indicative cost for building a new school is $11.3 million per school or about $31,000 per student (Table 7-10). For a larger sample size, the 2017 Queensland infrastructure plan (DILGP, 2017) (adjusted to December 2023 dollar values) valued total public education assets for the state at $21.7 billion for 1239 state schools catering for 581,000 students. It is not clear on what basis the assets were valued, but these values equate to $17.5 million per school or $37,000 per student (which are slightly higher than the costs for the small sample of new schools).

Demand for community services is growing both from population increases in Australia and rising community expectations (DILGP, 2017). New infrastructure would be built to service that demand irrespective of what development occurs in particular parts of the country. However, if new irrigation projects encourage some people to live in more remote parts of Australia, then this could shift the locations of where some services are delivered and associated infrastructure is built. The costs of delivering services and building infrastructure is generally higher in more remote locations. So, the net cost of any new infrastructure that is built to support regional developments is the difference in cost of shifting some infrastructure to more remote locations (not the full cost of facilities that would otherwise have been built elsewhere).

Table 7-10 Indicative construction costs for new schools

NAME	STATE	SUBURB	ESTABLISHED	COST ($ million)	STUDENTS	TYPE	SECTOR	LOCATION
Kingston Primary School	WA	Kingston	2009	14.5	768	Primary school	Government	Provincial
South Halls Head Primary School	WA	Halls Head	2008	14.4	606	Primary school	Government	Inner regional
Geographe Primary School	WA	Geographe	2002	13.7	542	Primary school	Government	Provincial
Mackillop Catholic College	Qld	Mount Peter	2016	6.9	96	Combined	Non-government	Outer regional
St Joseph's Parish School	Qld	Weipa	2016	7.7	85	Primary school	Non-government	Very remote
Holy Spirit College Cooktown	Qld	Cooktown	2015	10.5	89	Special	Non-government	Remote
Mean (≈31,000 $/student)				11.3	364			

Source: Stokes et al. (2017) based on all schools built between 2002 and 2017 in WA, NT and Queensland (Qld) for which construction costs could be found; adjusted for inflation to December 2023 dollar values

Given the size of the Victoria catchment it would be likely that any additional workforce required for agricultural development would be housed locally on-farm, as is the case with cattle properties and cropping developments in other remote areas of northern Australia. Accommodation costs would be absorbed by the developer.

8 Financial viability of new irrigated development

8.1 Introduction

There is a growing emphasis in Australia on greater accountability and transparency for large new infrastructure projects. This includes planning and building of new water infrastructure, and the way water resources are managed and priced (e.g. Infrastructure Australia, 2021a, 2021b; NWG, 2022, 2023). Part of this shift has involved greater scrutiny of the costs and benefits of potential large new public dams. Large infrastructure projects, such as new irrigation developments in the catchment of the Victoria River, would be complex and costly investments. The difficulty in accurately estimating costs and the chance of incurring unanticipated expenses during construction, or not achieving projected water demand and revenue trajectories when completed, means that there are risks to the viability of developments if they are not thoroughly planned and assessed (as discussed in Chapter 6). This chapter therefore provides financial tools to assist in planning and evaluating irrigated development options (and easily comparing alternative configurations).

New irrigation schemes in the Victoria catchment would be costly to develop, such that even when technically feasible options are found, many of these are unlikely to be profitable at the returns and over the time periods expected by many investors. The amount of area in the Victoria catchment that it would be technically feasible to farm (in terms of the scale of suitable land and water resources) is vastly greater than the area where it would be commercially sensible to do so. For example, the current area of irrigated agriculture in tropical Australia west of the Great Dividing Range uses less land area than mining (both <0.1%) (Watson et al., 2021a). Ultimately, financial factors will determine the types and scale of development. This chapter continues the overarching multi-scale agricultural viability framework introduced in Figure 4-1. Part II provided a bottom-up evaluation of farm performance for different crop options and this chapter provides a top-down analysis to determine the farm performance that would be required to pay for different ways of developing farms and water resources.

The costs of developing water and land resources can vary widely, depending on a range of case-specific factors that are dealt with in other parts of this Assessment. These factors include the nature of the water source, the type of water storage, geology, topography, soil characteristics, the water distribution system, the type of irrigation system, the type of crop to be grown, local climate, land preparation requirements and the level to which infrastructure is engineered. The scale and pathways of development are therefore uncertain, so the analyses in this chapter were designed to be flexible and able to accommodate very different scales and configurations of development options. Rather than analysing the cost–benefit of specific irrigation scheme proposals, this chapter presents generic tables for evaluating multiple alternative development configurations, providing threshold farm gross margins and water costs/pricing that would be required to cover infrastructure costs. These provide a powerful (if slightly abstract) set of tools that allows users to answer their own questions about whether various aspects of agricultural land and water developments could be financially viable in the Victoria catchment. Some examples of the questions that can be asked, and which tools to use to answer them, are summarised below (Table 8-1).

Table 8-1 Types of questions that users can answer using the tools in this chapter

For each question the relevant table number is given together with an example answer for a specific development scenario. More questions can be answered with each tool by swapping around the factors that are known and the factor being estimated. (All initial estimates assume farm performance is 100% in all years (i.e. before accounting for risks). See Table 8-2 for supporting generalised assumptions.)

QUESTION (WITH EXAMPLE ANSWER)	RELEVANT TABLE
1) How much can different types of farms afford to pay per megalitre of water they use?	Table 8-3
A broadacre farm with a gross margin (GM) of $4000/ha and water consumption of 8 ML/ha could afford to pay $135/ML while achieving a 10% internal rate of return (IRR).	
2) How much would the operator of a large off-farm dam have to charge for water?	Table 8-5
If off-farm water infrastructure had a capital cost of $5000 for each ML/y supply capacity (yield) at the dam wall, the (public) water supplier would have to charge $537 for each ML to cover its costs (at a 7% target IRR).	
3) For an on-farm dam with known development cost, what is the equivalent $/ML price of water?	Table 8-7
A farm dam that had a capital cost of $1500 for each ML/y supply capacity (yield) to develop would be equivalent to purchasing water at cost of $190 for each ML (at a 10% target IRR).	
4) What farm gross margin (GM) would be required to fully cover the costs of an off-farm dam? **What proportion of the costs of off-farm water infrastructure could farms cover?**	Table 8-4
If off-farm infrastructure had a capital cost of $50,000/ha to build, broadacre farms would need to generate a GM of $5701/ha in order to fully cover the water supplier costs (while meeting a target 7% IRR for the water supplier (public investor) and a 10% IRR for the irrigator (private investor)). A broadacre farm with a GM of $4000/ha could contribute the equivalent of $20,000 to $30,000/ha towards the capital costs of building the same $50,000/ha dam (about 50% of the full costs of building and operating that infrastructure).	
5) What GM would be required to cover the costs of developing a new farm, including a dam or bores?	Table 8-6
A horticultural farm with low overheads ($1500/ha) that cost $40,000/ha to develop (e.g. $30,000/ha to establish the farm and $10,000/ha to build the on-farm water supply to irrigate it) would require a GM of $6702/ha to attain a 10% IRR.	
6) How would risks associated with water reliability affect the farm GMs above?	Table 8-8
If an on-farm dam could fully irrigate the farm in 70% of years and could irrigate 50% of the farm in the remaining years, all farm GMs in the answers above would need to be multiplied by 1.18 (18% higher), and the price irrigators could afford to pay for water would need to be divided by 1.18. For example, in Q4, the GM required to cover the costs of the farm development would increase from $5701/ha to $6727/ha after accounting for risks of water reliability.	
7) How would risks associated with ‘learning’ (initial farm underperformance) affect estimates?	Table 8-10
If a farm with a 10% target IRR achieved a GM that was 50% of its full potential in the first year, and gradually improved to achieve its full potential over 10 years, then GMs above would need to be higher by a factor of 1.26 (26% higher). For example, in Q6, the required farm GM would increase to $8476/ha after accounting for risks of both water reliability and learning (a combined 49% higher than the value before accounting for risks).	

The next section describes the discounted cashflow (DCF) analysis approach used in financial analyses (Section 8.2). As set out in the rationale above, rather than using the DCF for a traditional cost–benefit analysis (CBA) of specific development proposals/scenarios (as in Chapter 6) the analyses are used in a less prescriptive way to provide flexible tools that allow users to evaluate their own development scenarios. The analyses are first used to calculate the water price that irrigators can afford, as a useful common point of reference in subsequent analyses for identifying water sources that farms could pay for (Section 8.3). Analyses then consider the case of irrigation schemes built around a large dam and associated supporting off-farm infrastructure (Section 0). Then the case of self-contained, modular farm developments, with their own on-farm source of water, is considered (Section 8.5). The next section considers how different types of risks would affect the viability of irrigation schemes and provides adjustment factors that can be applied to previous analyses to account for the effects of these risks (Section 8.6). The chapter concludes by summarising the opportunities and principles for achieving sustainable and viable new irrigation developments in the Victoria catchment (Section 8.7).

8.2 Balancing scheme-scale costs and benefits

Designing a new irrigation development in the Victoria catchment would require balancing three key determinants of irrigation scheme financial performance to find combinations that might collectively constitute a viable investment. The determinants are:

- farm financial performance (relative to development costs and water use) (Chapter 5)
- capital cost of development, for both water resources and farms (Chapter 7)
- risks (and associated required level of investment return) (Section 8.6).

Other factors were limited as much as possible and restricted to those with greater certainty and/or lower sensitivity, so that the results can be applied to a wide range of potential development scenarios.

8.2.1 Terminology

Scheme financial evaluations use a DCF approach to evaluate the commercial viability of irrigation developments. The approach, following that of Stokes and Jarvis (2021), is intended to provide a purely financial evaluation of the conditions required to produce an acceptable return from an investor’s perspective. It is not a full economic evaluation of the costs and benefits to other industries, nor does it consider ‘unpriced’ impacts that are not the subject of normal market transactions, or the equity of how costs and benefits are distributed. (Non-market impacts are covered in the companion technical report on ecological assets (Stratford et al. 2024b) and ecological modelling (Stratford et al. 2024c). For the discussion that follows, an irrigation scheme was taken to be all the costs and benefits from the development of the land and water resources to the point of sale for farm produce. The DCF was applied in a non-standard generic manner to back-calculate threshold criteria for different development configurations to break even (rather than the traditional CBA approach of estimating financial performance of a few specific, detailed options). The section below explains the terminology and standard assumptions used.

A 'discounted cashflow analysis' (DCF) considers the lifetime of costs and benefits following capital investment in a new project. Costs and benefits that occur at different times are expressed in constant real dollars (December 2023 dollars), with a discount rate applied to streams of costs and benefits.

The 'discount rate' is the percentage by which future costs and benefits are discounted each year (compounded) to convert them to their equivalent present value.

For an entire project, the 'net present value' (NPV) can be calculated by subtracting the present value of the stream of all costs from the present value of the stream of all benefits. The 'benefit–cost ratio' (BCR) of a project is the present value of all the benefits of a project divided by the present value of all the costs involved in achieving those benefits. To be commercially viable (at the nominated discount rate), a project would require an NPV that is greater than zero (in which case the BCR would be greater than one).

The 'internal rate of return' (IRR) is the discount rate at which the NPV is zero (and the BCR is one). For a project to be considered commercially viable it needs to meet its target IRR, where the NPV is greater than zero at a discount rate appropriate to the risk profile of the development and alternative investment opportunities available to investors. A target IRR of 7% is typically used when evaluating large public investments (with sensitivity analysis at 3% and 10%) (Infrastructure Australia, 2021b). Private agricultural developers usually target an IRR of 10% or more (to compensate for the investment risks involved). A back-calculation approach is used in the tables below to present threshold GMs and water prices that are required for investors to achieve specified target IRRs (therefore, equivalently, NPV is zero at these discount rates).

For the private investor, determining the target IRR appropriate for a specific firm undertaking a specific project requires the investor to understand their weighted average cost of capital (WACC), and the relative risk of the project compared to the firm's existing project portfolio. Cost of capital theory is complex, and forms an important underpinning of corporate finance, investment and capital budgeting theory and practice, and is supported by a significant body of academic literature. Simplistically, the WACC reflects the risk adjusted cost to the firm of sourcing the funds that are used to acquire assets or fund projects, where the funds can be sourced from a variety of sources, ranging from pure equity to pure debt (Modigliani & Miller, 1958). The cost of equity (typically estimated using the capital asset pricing model) estimates the return that shareholders require in return for investing in the firm and incorporates the expected return on the shares and the risk premium required by investors for holding the firm's shares rather than holding risk-free investments, while the cost of debt reflects the return lenders require for the provision of debt funding. Thus, the WACC will vary as perceived levels of risk vary, across investments undertaken by the same firm, and across different investing firms. The implication of this for firms considering investment in water resource development projects is that their target IRR may vary from project to project as the relative risks of different projects vary. Accordingly, project proponents should estimate their WACC on a case-by-case basis, to determine their target IRR, with their target IRR being at least equal to their risk adjusted WACC for the project. This report presents tables based on an indicative target IRR of 10%; recognising that the appropriate target for project proponents in different scenarios may be in excess of this indicative level.

'Project evaluation periods' used in this chapter matched the 'life spans' of the main infrastructure assets: 100 years for large off-farm dams and 40 years for on-farm developments. To simplify the tracking of asset replacements, four categories of life spans were used: 15 and 40 years for farms, and 25 and 100 years for off-farm infrastructure. It was assumed the shorter life span assets would be replaced at the end of their life, and costs were accounted for in full in the actual year of their replacement. At the end of the evaluation period, a 'residual value' was calculated to account for any shorter life span assets that had not reached the end of their working life. Residual values were calculated as the proportional asset life remaining multiplied by the original asset price. Discounted residual values were trivially small (because the evaluation period matched the life spans of the principal, dominant, longer life span assets) and hence analyses were not sensitive to the choice of method for how they were calculated.

'Capital costs' of infrastructure were assumed to be the costs at completion (accounted for in full in the year of delivery), such that the assets commenced operations the following year. In some cases, the costs of developing the farmland and setting up the buildings and equipment were considered separately from the costs of the water source, so that different water sources could be compared on a like-for-like basis. Where an off-farm water source was used, this was treated as a separate investor receiving payments for water at a price that the irrigator could afford to pay.

The main 'costs for operating' a large dam and associated water distribution infrastructure are fixed costs for administering and maintaining the infrastructure, expressed here as percentage of the original capital cost, and variable costs associated with pumping water into distribution channels.

At the farm scale, fixed overhead costs are incurred each year whether or not a crop is planted in a particular field that year. 'Fixed costs' are dominated by the fixed component of labour costs but also include maintenance, insurance, professional services and registrations. An additional allowance is made for annual operation and maintenance (O&M) budgeted at 1% of the original capital value of all assets (with an additional variable component to maintenance costs when machinery was used for cropping operations).

A 'farm annual gross margin' (GM) is the difference between the total revenue from crop sales and variable costs of growing a crop each year. 'Net farm revenue' is calculated by subtracting fixed overhead costs from the GM. 'Variable costs' vary in proportion to the area of land planted, the amount of crop harvested and/or the amount of water and other inputs applied. Farm GMs can vary substantially within and between locations, and as socio-economic conditions change over time, as described in Chapter 5. GMs presented here are the values obtained before subtracting the variable costs of supplying water to farms; these water supply costs are instead accounted for in the capital costs of developing water resources. Equivalent unit costs of supplying each megalitre of water are presented separately below.

8.2.2 Threshold gross margins and water pricing to achieve target IRRs

Financial analyses in this chapter used a generic approach to explore the consequences for development costs of this variation and other key factors that determine whether or not an irrigation scheme would be viable (e.g. farm performance and the level of returns sought by investors). The analyses used the DCF framework described above to back-calculate and fit the water prices and farm GMs that would be required for respective public (off-farm) and private (irrigators) investors to achieve their target IRRs. The results are summarised in tables showing the thresholds that must be met for a particular combination of water development and farm development options to meet investors' target returns. The tables allow viable pairings to be identified based on either threshold costs of water or required farm GMs. Financial viability for these threshold values was defined and calculated as investors achieving their target IRR (or, equivalently, that the investment would have an NPV of zero and a BCR of one at the specified discount rate).

8.2.3 Accounting structure

Analyses first considered the case of irrigation schemes built around public investment in a large *off-farm* dam in the Victoria catchment. They then considered the case of developments using *on-farm* dams and bores.

Cost and benefit streams across the scheme were tracked for the separate components described in Figure 8-1. For farms, the streams were the: (i) capital costs of land development, farm buildings and equipment (including replacement and maintenance costs, and residual values); (ii) fixed overhead costs, applied to the full area of developed farmland; and (iii) total farm GM (across all farms in the scheme), applied to the mean proportion of land in production each year (Figure 8-1). If a development scenario used an 'on-farm water source', then the costs of building and operating that water source were added to the overall farm costs (in the three categories above). Farm developers were treated as private investors who would seek a commercial return.

When an 'off-farm water source' (large dam >25 GL/year) was evaluated, it was treated as a separate public investor paid by farmers for water supplied (which served as an additional stream of costs for farmers and a stream of benefits for the water supplier at their respective target IRRs). For the public off-farm developer, the streams of costs were: (i) the capital costs of developing the water and associated enabling infrastructure (including replacement and O&M costs and residual values), and (ii) the costs of maintaining and operating those assets (Figure 8-1).

Accounting within a water infrastructure CBA needs to rigorously associate each benefit with all the costs and land and water resources used to attain it, and conversely, ensure that each cost and use of resources flows through to the benefit that is generated. To assist with such accounting, it is useful to have a framework that clearly defines the bounds of the overall irrigation development and of the component investments with it (Figure 8-1). For the purposes of this analysis, the irrigation scheme is defined as all the costs, benefits, use of land and transfers of water from when water is extracted by the scheme until agricultural produce is transported to, and revenue received at, the point of sale. The water source could either be part of a single on-farm investment (the green highlighted section of Figure 8-1, where water would be supplied from *on-farm* dams or bores), or there could be additional separate investors in the *off-farm* water infrastructure development (mainly in the blue highlighted section of Figure 8-1, where water would be supplied from a large off-farm dam and farms would pay the operator of the dam and water reticulation infrastructure).

SCHEME	ALL INFRASTRUCTURE AND COSTS FOR CAPTURING AND DIVERTING WATER, ESTABLISHING A NEW IRRIGATION AREA, AND GROWING PRODUCE … TO FARMERS RECEIVING PAYMENT FOR PRODUCE
Scheme accounting (quantities accounted for in each structural component below):	
Costs:	Initial capital costs of developed assets
	Renewal/replacement costs of assets (based on life spans)
	O&M costs of assets (recurrent – annual)
	Other recurrent costs for each asset (pumping to farm gate/surface for water source)
	Annual production costs (for each source of revenue)
Revenue (benefits):	Gross revenue paid to farmers for all agricultural produce
Resource use:	Water use (and transfers, with losses, between components) each year
	Area of farmland in production (using water and generating revenue) each year
Scheme structure / Investment components:	
Off-farm (public)	Everything for water storage and reticulation down to point of discharge
Dams	Dams and associated infrastructure (other than diversion and reticulation)
Diversion	Channels etc. used to divert water to irrigation area
Irrigation area	Roads, transmission lines, water reticulation to connect with farms in irrigation area
Unaccounted	Additional enabling infrastructure excluded from initial project, but required afterwards
Revenue	Payments received for water
Farms (private, three types)	Water costs, all other farming cost … to sale of produce
Water source	Costs of on-farm water source (or water payments for off-farm water source)
Farm development (excluding water source)	Capital costs of greenfield farm establishment (land development, irrigation system, buildings and structures, farm machinery and equipment)
Crop production	Crop growing and marketing costs (other than costs of water supply) to point of sale
Revenue	Sale of farm produce

Figure 8-1 Financial structure of irrigation scheme used in accounting for costs, revenue and use of land and water resources

Standardised accounting rules allow analyses to interchangeably pair any on-farm or off-farm water source with any farm development option. For on-farm water sources, no off-farm water infrastructure would be required, only supporting infrastructure such as roads and electricity supplies (blue highlighted section). O&M = operation and maintenance.

8.2.4 Assumptions

To keep the results as relevant as possible to a wide range of different development options and configurations, the analyses here do not assume what scale a water development would be. Instead, all costs are expressed (i) per hectare of irrigated farmland, and (ii) per megalitre per year of water supply capacity, facilitating comparisons between scenarios (that can differ substantially in size). Section 7.3 provided illustrations of how this approach was used for indicative costing of a range of farmland development options, on-farm water sources, and for the off-farm infrastructure costs for developments configured around the most cost-effective dam sites in the Victoria catchment. Those capital costs of development are referred to extensively in the analyses below.

To further assist in making like-for-like comparisons across different development scenarios, a set of standard assumptions are made about the breakdown of development costs (by life span) and associated ongoing operating costs (Table 8-2). Three indicative types of farming enterprise are used to represent different levels of capital investment associated with the intensity of production and the extent to which farming operations are performed on-farm or outsourced (Table 8-2). Capital costs and fixed costs are higher for horticulture than broadacre farming, but the more expensive irrigation systems used (such as drippers) apply water more precisely and efficiently to crops. The indicative 'Broadacre' farm could, for example, represent hay or cotton farming using furrow irrigation on heavier clay soils. The indicative capital-intensive 'Horticulture-H' farm could, for example, represent high-value fruit tree orchards with a high standard of on-farm packing and cold room facilities, and include accommodation for seasonal workers travelling to remote Victoria catchment farms. The indicative less capital-intensive 'Horticulture-L' farm option could, for example, represent a row crop like melons, with packing directly to bins and using off-farm accommodation for seasonal workers (which reduces the upfront capital cost of establishing the farm, but increases ongoing costs for outsourced services that reduces farm GMs).

For consistency, all costs required to deliver water to the farm at the level of the soil surface are treated as the costs of the *water source* (so different water sources can be substituted for each other on a like-for-like basis: see Section 7.3). Subsequent farm pumping costs to distribute and apply the supplied water to crops are treated as part of the variable costs of growing crops and are already accounted for in the *crop gross margins* presented in Section 5.2. Pumping costs for the *water source* are highly situation-specific for different water sources. In particular, these pumping costs are affected by the elevation of the water source relative to the point of distributing to the farm, for example, the height water needs to be pumped from a weir to a distribution channel, from a farm dam to a field, or the dynamic head required to lift bore water to the field surface. For this reason, *water source* pumping costs are not included in summary tables of water pricing but should be added separately as required at a cost of about $2 per megalitre per metre dynamic head. This is mainly a consideration for groundwater bores but also applies where water needs to be lifted from rivers or irrigation channels. For more information on water infrastructure costs see Chapter 6 (and companion technical reports referenced there) and for crop GMs see Chapter 5.

Table 8-2 Assumed indicative capital and operating costs for new off- and on-farm irrigation infrastructure

Three types of farming enterprise represented a range of increasing intensity, value and cost of production. Indicative base capital costs for establishing new enterprises (excluding water costs) allow on- and off-farm water sources to be added and compared on an equal basis. Annual operation and maintenance (O&M) costs are expressed as a percentage of the capital costs of assets. The Horticulture-H, farm with higher development costs includes on-farm packing facilities, cold storage and accommodation for seasonal workers. The Horticulture-L farm with lower development costs does not include these assets and would have to outsource these services if required (reducing the farm gross margin). IRR = internal rate of return.

SCHEME COMPONENT	ITEM	VALUE			UNIT	O&M COST (% capital cost/y)
Off-farm infrastructure development capital and operating costs (large dam and enabling infrastructure)						
Capital costs	Total capital costs (split by life span below)	Indicative >50,000 (analysed range: 20,000 to 150,000)			$/ha	
	Longer life span infrastructure (100 year)	85			%	0.4
	Shorter life span infrastructure (40 year)	15			%	1.6
Operating costs	O&M (by life span categories)	% capital cost			$/ha/y	
	Off-farm water source pumping costs	~2 (additional)			$/ML/m	
Target IRR	Base (with sensitivity range)	7			%	
Farm development capital and operating costs		**Broadacre**	**Horticulture-L (low capital)**	**Horticulture-H (high capital)**		
Capital costs	Base (excluding water source)	9,000	25,000	70,000	$/ha	
	Water source (on- or off-farm)	Indicative >4000 (analysed range: 3000 to 15,000)			$/ha	
	Longer life span infrastructure (40 year)	50	50	50	%	1.0
	Shorter life span infrastructure (15 year)	50	50	50	%	1.0
Operating costs	O&M (by life span categories)	% capital cost			$/ha/y	
	Farm water source pumping costs	~2 (additional)			$/ML/m	
	Fixed costs	600	1,500	6,500	$/ha/y	
Water use	Crop water use (before losses)	6	6	6	ML/ha/y	
	On-farm water use efficiency	70	90	90	%	
Gross margin	Indicative gross margin	4,000	7,000	11,000	$/ha/y	
Target IRR	Base (with sensitivity range)	10	10	10	%	

Analyses presented below first consider the case of irrigation schemes built around a large dam and associated supporting off-farm infrastructure (Section 0). Then the case of self-contained, modular farm developments with their own on-farm source of water is considered (Section 8.5). For both cases, the water price that irrigators can afford provides a useful common point of reference for identifying suitable water sources that different farm developments could pay for (Section 8.3). Initial analyses assumed all farmland was in full production and performed at 100% of its potential (including 100% reliable water supplies) from the start of the development. Section 8.6 then provides a set of adjustment factors that quantify risks of several sources of anticipatable underperformance.

8.3 Price irrigators can afford to pay for a new water source

Table 8-3 shows the price that the three different types of farms could afford to pay for water, while meeting a target 10% IRR, for different levels of farm water use and productivity. For prices to be sustained at this level throughout the life of the water source, the associated farm GM (in the first column of Table 8-3) would also need to be maintained over this period. The table is therefore most useful when assessing the long-term price that can be sustained to pay off long-lived water infrastructure (rather than temporary spikes in farm GMs during runs of favourable years).

The lowest GM in the first column of Table 8-3 for each farm is the value below which the farm would not be viable even if water was free. This does not necessarily mean that such GMs could readily be achieved in practice: for the capital-intensive Horticulture-H farm in particular, it would be challenging in the Victoria catchment to reach the $17,000 per hectare per year GM to cover the farm's other costs, even before considering the costs of water.

These water prices are likely most useful for public investors in large dams because the sequencing of development creates asymmetric risks between the water supplier and irrigators. Irrespective of the planned water pricing for a dam project, once the dam is built irrigators have the choice whether to develop new enterprises or not, and are unlikely to act to their own detriment in making that investment if they cannot do so at a water price that will allow them to attain a commercial rate of return. These water prices, together with estimates of likely attainable farm GMs in other parts of the Assessment, provide a useful benchmark for checking assumptions about any potential public dam developments in the Victoria catchment.

For on-farm water sources, these water prices can assist in planning water development options that cropping operations could reasonably be expected to afford. Tables in the next sections allow these comparisons by converting capital costs of developing on- and off-farm water sources to volumetric costs (dollar per megalitre supplied). All water prices are based on volumes supplied to the farm gate or surface (after losses getting to that point) per metered megalitre supplied.

Table 8-3 Price irrigators can afford to pay for water based on the type of farm, the farm water use and the farm annual gross margin (GM),while meeting a target 100% internal rate of return (IRR)

Analyses assume water volumes are measured on delivery to the farm gate or surface: pumping costs involved in getting water to the farmland surface would be an additional cost of supplying the water (indicatively $2 per megalitre per metre dynamic head), while pumping costs in distributing and applying the water to the crop are considered part of the variable costs included in the GM. Indicative GMs that the three types of farms could attain in the Victoria catchment are $4,000 and $7,000 per ha per year for Broadacre and Horticulture-L farms, respectively (blue-shaded rows), and $11,000 per ha per year for Horticulture-H. Note that the Horticulture-H farm cannot pay anything for water until it achieves a GM above $17,000 per ha per year.

GROSS MARGIN ($/ha/y)	PRICE IRRIGATORS CAN AFFORD TO PAY ($/ML at farm gate/surface)							
	Farm water use (ML/ha including on-farm distribution and application losses)							
	4	**5**	**6**	**7**	**8**	**9**	**10**	**12**
	Broadacre ($9,000/ha development costs, $600/ha/y fixed costs, 70% on-farm efficiency)							
2,000	25	20	17	14	12	11	10	8
2,500	86	69	57	49	43	38	34	29
3,000	147	118	98	84	74	65	59	49
3,500	209	167	139	119	104	93	83	70
4,000	270	216	180	154	135	120	108	90
5,000	392	314	262	224	196	174	157	131
	Horticulture-L ($25,000/ha development costs, $1,500/ha/y fixed costs, 90% on-farm efficiency)							
5,000	39	31	26	22	19	17	16	13
6,000	241	193	161	138	121	107	97	80
7,000	444	355	296	254	222	197	178	148
8,000	646	517	431	369	323	287	259	215
10,000	1051	841	701	601	526	467	421	350
12,000	1456	1165	971	832	728	647	583	485
	Horticulture-H ($70,000/ha development costs, $6,500/ha/y fixed costs, 90% on-farm efficiency)							
Below 16,000	Farms cannot afford to pay for water (or their other costs) at GMs lower than this							
17,000	203	162	135	116	101	90	81	68
20,000	810	648	540	463	405	360	324	270
25,000	1823	1458	1215	1042	911	810	729	608
30,000	2835	2268	1890	1620	1418	1260	1134	945
40,000	4860	3888	3240	2777	2430	2160	1944	1620
50,000	6885	5508	4590	3934	3443	3060	2754	2295

8.4 Financial targets required to cover costs of large, off-farm dams

The first generic assessment considered the case of public investment in a large dam in the Victoria catchment and whether the costs of that development could be covered by water payments from irrigators (priced at their capacity to pay). The public costs of development include the cost of the dam and water distribution, and any other supporting infrastructure required. Costs are standardised per unit of farmland developed, noting that a smaller area could be developed for a crop with a higher water use (so the water development costs per hectare would be higher).

8.4.1 Farm gross margins to cover full costs of off-farm public water infrastructure

Table 8-4 shows what farm annual GM would be required for different costs of water infrastructure development at the public investors' target IRR. As expected, higher farm GMs are required to cover higher capital costs and attain a higher target IRR. These tables can be used to assess whether water development opportunities and farming opportunities in the Victoria catchment are likely to combine in financially viable ways. Indicative farm GMs that could be achieved in the Victoria catchment are about \$4,000, \$7,000 and \$11,000 per hectare per year for Broadacre, less capital-intensive Horticulture-L (including penalty to GM for outsourcing) and capital-intensive Horticulture-H, respectively (see Section 5.2). In the representative example given in Table 7-3 a dam and supporting backbone infrastructure in the Victoria catchment would likely require in the order of \$125,000/ha of capital investment (see). None of the three farming types is likely to be viable at these farm GMs and water development costs (at a 3% target IRR for the public investor). Alternatively, Broadacre and lower-cost Horticulture-L could both achieve a target 10% IRR for the farm investments while contributing \$100,000/ha (~80%) towards the cost of a dam (including enabling infrastructure and ongoing O&M costs) that costs \$1250,000/ha to build. That is considerably higher than the costs irrigators have historically contributed towards irrigation schemes in some other parts of Australia (about a quarter of capital costs (Vanderbyl, 2021)) but would be a decision for the Australian and NT governments based on their expectations, priorities and investment criteria.

Table 8-4 Farm gross margins (GMs) required in order to cover the costs of off-farm water infrastructure (at the supplier's target internal rate of return (IRR))

Assumes 100% farm performance on all farmland in all years once construction is complete. Costs of supplying water to farms are consistently treated as costs of water source development (and not part of the farm GM calculation). Risk adjustment multipliers are provided in Section 8.6. Blue-shaded cells indicate the capital costs that could be afforded by farms with GMs of $4,000 (Broadacre), $7,000 (Horticulture-L) and $11,000 (Horticulture-H) per ha per year, respectively, for the farm types in the three sections of the table below. Blue-shaded column headers indicate a representative dam development options in the Victoria catchment (Table 7-3).

TARGET IRR (%)	FARM GROSS MARGIN REQUIRED TO PAY FOR OFF-FARM WATER INFRASTRUCTURE ($/ha/y)							
	Total capital costs of off-farm water infrastructure ($/ha)							
	20,000	**30,000**	**40,000**	**50,000**	**70,000**	**100,000**	**125,000**	**150,000**
	Broadacre ($9,000/ha development costs, $600/ha/y fixed costs, 70% on-farm efficiency)							
3	2,604	3,016	3,428	3,840	4,664	5,900	6,930	7,960
5	2,977	3,569	4,160	4,751	5,933	7,707	9,185	10,663
7	3,359	4,139	4,920	5,701	7,263	9,605	11,558	13,510
10	3,941	5,013	6,085	7,157	9,301	12,516	15,196	17,876
12	4,333	5,601	6,869	8,137	10,673	14,478	17,648	20,818
	Horticulture-L ($25,000/ha development costs, $1,500/ha/y fixed costs, 90% on-farm efficiency)							
3	5,584	5,996	6,408	6,820	7,645	8,881	9,911	10,941
5	5,985	6,576	7,167	7,759	8,941	10,715	12,193	13,671
7	6,370	7,150	7,931	8,712	10,274	12,616	14,569	16,521
10	6,952	8,024	9,096	10,168	12,312	15,528	18,208	20,887
12	7,345	8,613	9,881	11,149	13,685	17,489	20,659	23,829
	Horticulture-H ($70,000/ha development costs, $6,500/ha/y fixed costs, 90% on-farm efficiency)							
3	16,618	17,068	17,518	17,967	18,867	20,217	21,342	22,467
5	17,164	17,789	18,413	19,038	20,288	22,162	23,724	25,286
7	17,610	18,416	19,222	20,027	21,638	24,055	26,070	28,084
10	18,215	19,301	20,387	21,472	23,644	26,901	29,615	32,330
12	18,607	19,884	21,161	22,438	24,992	28,823	32,015	35,207

8.4.2 Target water pricing for off-farm public water infrastructure

Table 8-5 shows the price that a public investor in off-farm water infrastructure would have to charge to fully cover the costs of development of off-farm water infrastructure, expressed per unit of supply capacity at the dam wall. Pricing assumes that the full supply of water (i.e. reservoir yield) would be used and paid for every year over the entire lifetime of the dam, after accounting for water losses between the dam and the farm. It can be challenging for farms to sustain the high levels of revenue over such long periods (100 years) to justify the costs of building expensive dams. For these base analyses, the water supply is assumed to be 100% reliable; risk adjustment multipliers to account for reliability of supply are provided in Section 8.6.

Table 8-5 Water pricing required in order to cover costs of off-farm irrigation scheme development (dam, water distribution and supporting infrastructure) at the investors' target internal rate of return (IRR)

Assumes the conveyance efficiency from dam to farm is 70% and that supply is 100% reliable. Risk adjustment multipliers for water supply reliability are provided in Section 8.6. Pumping costs between the dam and the farm would need to be added (e.g. ~$30/ML extra to lift water ~15 m from weir pool to distribution channels). '$ CapEx per ML/y at dam' is the capital expenditure on developing the dam and supporting off-farm infrastructure expressed per ML per year of the dam's supply capacity measured at the dam wall. Blue-shaded cells indicate $/ML cost of water. Blue-shaded column header are indicative of the most cost-effective large dam options available in the Victoria catchment (Table 7-3).

TARGET IRR (%)	WATER PRICE THAT WOULD NEED TO BE CHARGED IN ORDER TO COVER OFF-FARM INFRASTRUCTURE COSTS ($/ML charged at farm gate)								
	Capital costs of off-farm infrastructure ($ CapEx per ML/y at dam)								
	3,000	**4,000**	**5,000**	**6,000**	**8,000**	**10,000**	**12,000**	**14,000**	**16,000**
3	162	215	269	323	431	538	646	754	861
5	239	319	399	479	638	798	958	1117	1277
7	322	429	537	644	859	1073	1288	1502	1717
10	448	598	747	897	1196	1495	1794	2093	2392

For example, in the Victoria catchment one of the more cost-effective dam opportunities in close proximity to large contiguous areas of suitable soils and existing infrastructure would cost about $8,500 per megalitre per year of supply capacity at the dam wall after including the required supporting off-farm water infrastructure (see Table 7-3). This would require farms to pay $913 for each megalitre extracted to fully cover the costs of the public investment at the base 7% target IRR for public investments (read from value between 8,000 and 10,000 in Table 8-2). Comparisons against what irrigators can afford to pay (Table 8-3) show that it is unlikely any farming options could cover the costs of a dam in the Victoria catchment at the GMs farms are likely to be able to achieve (see Section 5.2). When a scheme is not viable (BCR <1), the water cost and pricing tables can be used as a quick way of estimating the BCR and the likely proportion of public development costs that farms would be able to cover. For example, a Broadacre farm that uses 8 ML/ha (measured at delivery to the farm) with a GM of $4000 per hectare per year could afford to pay $135/ML extracted (Table 8-3), which would cover 15% ($135/$913) of the $913/ML price (Table 8-5) required to cover the full costs of the public development. The BCR would therefore be 0.15 (the ratio of the full costs of the scheme to the proportion the net farm benefits can cover). As for the example discussed for Table 8-4, it would be a decision for the public investor as to what proportion of the capital costs of infrastructure projects they would realistically expect to recover from users.

8.5 Financial targets required to cover costs of on-farm dams and bores

The second generic assessments considered the case of on-farm sources of water. Indicative costs for on-farm water sources, including supporting on-farm distribution infrastructure, vary between $4,000 and $15,000/ha of farmland. Costs depend on the type of water source, how favourable the local conditions are for its development, and the irrigation requirement of the farming system.

Since the farm and water source would be developed by a single investor, the first analyses considered the combined cost of all farm development together (without separating out the water component).

8.5.1 Gross margins to cover full costs of farm development with water source

Table 8-6 shows the farm GMs that would be required to cover different costs of farm development at the investors' target IRR. Note that private on-farm water sources are typically engineered to a lower standard than public water infrastructure and have lower upfront capital costs, higher recurrent costs (higher O&M and asset replacement rates) and lower reliability. Based on the indicative farm GMs provided earlier (Table 8-2) and 10% target IRR, a Broadacre farm with $4000 per hectare per year GM could cover total on-farm development capital costs of about $20,000/ha. A lower capital cost Horticulture-L farm with GM of $7000 per hectare per year could afford about $40,000/ha of initial capital costs, and a capital-intensive Horticulture-H farm with GM of $11,000 per hectare per year could pay about $30,000/ha for farm development (Table 8-6). This indicates that on-farm water sources may have more prospects of being viable than large public dams in the Victoria catchment, particularly for broadacre farms and horticulture with lower development costs, if good sites can be identified for developing sufficient on-farm water resources at low-enough cost.

Table 8-6 Farm gross margins (GMs) required in order to achieve target internal rates of return (IRR) given various capital costs of farm development (including an on-farm water source)

Assumes 100% farm performance on all farmland in all years, once construction is complete. Risk adjustment multipliers are provided in Section 8.6. Blue-shaded cells indicate the capital costs that could be afforded by farms with GMs of $4,000 (Broadacre), $7,000 (Horticulture-L) and $11,000 (Horticulture-H) per ha per year.

TARGET IRR (%)	FARM GROSS MARGIN REQUIRED IN ORDER TO ACHIEVE FARMER'S TARGET IRR ($/ha/y)							
	Total capital costs of farm development, including water source ($ CapEx/ha)							
	10,000	**15,000**	**20,000**	**30,000**	**40,000**	**50,000**	**70,000**	**100,000**
	Broadacre ($600/ha/y fixed costs, 70% on-farm efficiency)							
5	1,516	1,957	2,398	3,279	4,160	5,042	6,804	9,449
7	1,669	2,181	2,694	3,718	4,742	5,767	7,815	10,888
10	1,923	2,554	3,185	4,447	5,709	6,972	9,496	13,282
12	2,105	2,821	3,537	4,968	6,400	7,832	10,696	14,991
15	2,389	3,238	4,087	5,785	7,483	9,181	12,578	17,672
20	2,882	3,963	5,044	7,206	9,368	11,530	15,854	22,340
	Horticulture-L ($1,500/ha/y fixed costs, 90% on-farm efficiency)							
5	2,469	2,909	3,350	4,231	5,113	5,994	7,757	10,401
7	2,637	3,149	3,661	4,685	5,710	6,734	8,783	11,856
10	2,915	3,546	4,177	5,439	6,702	7,964	10,488	14,274
12	3,114	3,830	4,546	5,978	7,409	8,841	11,705	16,001
15	3,424	4,273	5,122	6,820	8,519	10,217	13,613	18,708

TARGET IRR (%)	FARM GROSS MARGIN REQUIRED IN ORDER TO ACHIEVE FARMER'S TARGET IRR ($/ha/y)							
	Total capital costs of farm development, including water source ($ CapEx/ha)							
	10,000	**15,000**	**20,000**	**30,000**	**40,000**	**50,000**	**70,000**	**100,000**
20	3,962	5,043	6,124	8,286	10,448	12,610	16,934	23,420
	Horticulture-H ($6,500/ha/y fixed costs, 90% on-farm efficiency)							
5	7,760	8,201	8,642	9,523	10,404	11,286	13,048	15,692
7	8,012	8,524	9,036	10,060	11,085	12,109	14,158	17,231
10	8,427	9,058	9,689	10,951	12,213	13,475	15,999	19,785
12	8,720	9,436	10,152	11,584	13,016	14,448	17,312	21,607
15	9,177	10,026	10,875	12,573	14,271	15,970	19,366	24,461
20	9,963	11,044	12,125	14,287	16,449	18,611	22,935	29,421

8.5.2 Volumetric water cost equivalent for on-farm water source

Table 8-7 converts the capital cost of developing an on-farm water source (per megalitre of annual supply capacity) into an equivalent cost for each individual megalitre of water supplied by the water source. The table can be used to estimate how much a farm could spend on developing required water resources by comparing the costs per megalitre against what farms can afford to pay for water (Table 8-3). For example, a Broadacre farm with a GM of $4000 per hectare per year and annual farm water use of 8 ML/ha and a target 10% IRR could afford to pay $135/ML for its water supply (Table 8-3), which would allow capital costs of $700 to $1000 for each ML/year supply capacity for developing an on-farm supply (Table 8-7). Indicative costs for developing on-farm water sources range from about $500/ML to $2000/ML (based on the range of per hectare costs above) which confirms, by this alternative approach, that there are likely to be viable farming opportunities using on-farm water development in the Victoria catchment.

Table 8-7 Equivalent costs of water per ML for on-farm water sources with various capital costs of development, at the internal rate of return (IRR) targeted by the investor

Assumes the water supply is 100% reliable. Risk adjustment multipliers for water supply reliability are provided in Section 8.6. Pumping costs to the field surface would be extra (e.g. ~$2 per megalitre per metre dynamic head for bore pumping). Blue-shaded cells indicate $/ML cost of water.

TARGET IRR (%)	WATER VOLUMETRIC COST EQUIVALENTUNIT FOR VARIOUS CAPITAL COSTS OF WATER SOURCE ($/ML)								
	Capital costs for on-farm water infrastructure ($ CapEx per ML per y at farmland surface)								
	300	**400**	**500**	**700**	**1000**	**1250**	**1500**	**1750**	**2000**
3	22	29	37	51	74	92	110	129	147
5	26	35	44	61	87	109	131	153	175
7	31	41	51	72	102	128	154	179	205
10	38	51	63	89	127	159	190	222	254
12	43	58	72	101	144	180	216	252	288
15	51	68	85	120	171	213	256	299	342
20	65	87	109	152	217	271	326	380	434

8.6 Risks associated with variability in farm performance

This section assessed the impacts of two types of risks on scheme financial performance: those that reduce farm performance through the early establishment and learning years, and those occurring periodically throughout the life of the development. The effect of these negative risks is to reduce the expected revenue and expected GM.

Setbacks that occur soon after a scheme is established were found to have the largest effect on scheme viability, particularly at higher target IRRs. There is a strong incentive to start any new irrigation development with well-established crops and technologies, and to be thoroughly prepared for the anticipatable agronomic risks of establishing new farmland. Analyses showed that delaying full development for longer periods than the learning time had only a slight negative effect on IRRs, whereas proceeding to full development before learning was complete had a much larger impact. This implies that it is prudent to err on the side of delaying full development (particularly given that, in practice, it is only possible to know when full performance was achieved in retrospect). An added benefit of staging is limiting losses in the cases where small-scale testing proves initial assumptions of benefits to be overoptimistic and that full-scale development could never be profitable, even after trying to overcome unanticipated challenges.

For an investment to be viable, farm GMs must be sustained at high levels over long periods. Thus, variability in farm performance poses risks that must be considered and managed. GMs can vary between years because of either short-term initial underperformance or periodic shocks. Initial underperformance is likely to be associated with learning as farming practices are adapted to local conditions, overcoming initial challenges to reach their long-term potential. Further unavoidable periodic risks are associated with water reliability, climate variability, flooding, outbreaks of pests and diseases, periodic technical or equipment failures, and fluctuations in commodity prices and market access. Unreliability of water supply is less easy to avoid than other periodic risks.

Results for analyses of both periodic and learning risks are shown below. We acknowledge that right to farm and other sovereignty risks, especially with regard to access to water, may become key factors in future years, based on experience from elsewhere. These however are not the subject of the risk discussion here.

Throughout this section, farm performance in a given year is quantified as the proportion of the long-term mean GM a farm attains, where 100% performance is when this level is reached and zero % equates to a performance where revenues only balance variable costs (GM = zero).

8.6.1 Risks from periodic underperformance

Analyses considered periodic risks generically without assuming any of the particular causes listed above. To quantify their effects on scheme financial performance, periodic risks were characterised by three components:

1. Reliability – the proportion of ‘good’ years where the ‘full’ 100% farm performance was achieved, with the remainder of years being ‘failures’ where some negative impact was experienced
2. Severity – the farm performance in a ‘failed’ year where some type of setback occurred

3. Timing – for ‘early’ timing a 10-year cycle was used (e.g. 80% reliability meant that failures would occur in the first 2 years of the scheme and the first 2 years of each 10 years in a cycle after that). For ‘late’ timing, the ‘failures’ came at the end of each 10-year cycle. Where ‘random’ timing was used, each year was represented as having the long-term mean farm performance of ‘good’ and ‘failed’ years (frequency weighted).

Table 8-8 summarises the effects of a range of different reliabilities and severities for periodic risks on scheme viability. Periodic risks had a consistent proportional effect on target GMs, irrespective of development options or costs, so results were simplified as a set of risk adjustment multipliers. The multipliers can therefore be applied to the target farm GMs in the previous section (required to cover capital costs of development at investors’ target IRRs at 100% farm performance) to account for the effects of various risks. These same adjustment factors can be applied to the water prices that irrigators can afford to pay (Table 8-3) but would be used as divisors to reduce the price that irrigators could pay for water.

Table 8-8 Risk adjustment factors for target farm gross margins (GMs) accounting for the effects of the reliability and severity (level of farm performance in ‘failed’ years) of the periodic risk of water reliability

Results are not affected by discount rates. ‘Good’ years = 100% farm performance; ‘failed’ years = <100% performance. ‘Failed year performance’ is the mean farm GM in years in which some type of setback is experienced relative to the mean GM when the farm is running at ‘full’ performance.

FAILED YEAR PERFORMANCE (%)	RISK ADJUSTMENT MULTIPLIER FOR TARGET FARM GROSS MARGINS (VS BASE 100% RELIABILITY TABLES) (unitless ratio)								
	Reliability (proportion of ‘good’ years)								
	1.00	**0.90**	**0.85**	**0.80**	**0.70**	**0.60**	**0.50**	**0.40**	**0.30**	**0.20**
85	1.00	1.02	1.02	1.03	1.05	1.06	1.08	1.10	1.12	1.14
75	1.00	1.03	1.04	1.05	1.08	1.11	1.14	1.18	1.21	1.25
50	1.00	1.05	1.08	1.11	1.18	1.25	1.33	1.43	1.54	1.67
25	1.00	1.08	1.13	1.18	1.29	1.43	1.60	1.82	2.11	2.50
0	1.00	1.11	1.18	1.25	1.43	1.67	2.00	2.50	3.33	5.00

As expected, the greater the frequency and severity of ‘failed’ years, the greater the impact on scheme viability and the greater the increase in farm GMs required to offset these impacts. As an example, the reliability of water supply is one of the more important sources of unavoidable variability in productivity of irrigated farms. Water reliability (proportion of ‘good’ years, where the full supply of water is available) is shown as ‘reliability’ in Table 8-8, and the mean percentage of water available in a ‘failed’ year (where less than the full supply is available) is shown as the ‘failed year performance’ in Table 8-8 (assuming the area of farmland planted is reduced in proportion to the amount of water available). For example, if a water supply was 85% reliable and provided on average 75% of its full supply in ‘failed’ years, a risk adjustment factor of 1.04 (Table 8-8) would have to be applied to baseline target GMs (Table 8-4 and Table 8-6) and the prices irrigators can afford to pay for water (Table 8-3). This means that a 4% higher GM would be required to achieve a target IRR (and irrigators’ capacity to pay for water would be ~4% lower) than if water could be supplied at 100% reliability. For crops where the quality of produce is more important than the quantity, such as annual horticulture, the approach of reducing planted land area in proportion to available water in ‘failed’ years would be reasonable. However, for perennial horticulture or tree crops it may be difficult to reduce (or increase) areas on an annual basis. Farmers of these crops would therefore tend to opt for systems with a high degree of reliability of water supply (e.g. 95%). For many broadacre crops, deficit irrigation could partially mitigate impacts on farm performance in years with reduced water availability, as could carry over effects from inputs (such as fertiliser) in a failed year that reduce input costs the following year.

Table 8-9 summarises how timing of periodic impacts affects scheme viability, providing risk adjustment factors for a range of reliabilities for an impact that had 50% severity with late timing, early timing and random (long-term frequency, weighted mean performance) timing.

These results show that any negative disturbances that reduce farm performance will have a larger effect if they occur soon after the scheme is established, and that this effect is greater at higher target IRRs. For example, at a 7% target IRR and 70% reliability with 'late' timing (where setbacks occur in the last 3 of every 10 years), the GM multiplier is 1.13, meaning the annual farm GM would need to be 13% higher than if farm performance were 100% reliable. In contrast, for the same settings with 'early' timing, the GM multiplier is 1.23, the farm GM would have to be 23% higher than if farm performance were 100% reliable. The impacts of early setbacks are more severe than the impacts of late setbacks.

Table 8-9 Risk adjustment factors for target farm gross margins (GMs) accounting for the effects of reliability and the timing of periodic risks
Assumes 50% farm performance during 'failed' years, in which 50% farm performance means 50% of the GM at 'full' potential production. IRR = internal rate of return.

TARGET IRR (%)	TIMING OF FAILED YEARS	RISK ADJUSTMENT MULTIPLIER FOR TARGET FARM GROSS MARGINS (VS BASE 100% RELIABILITY TABLES) (unitless ratio)								
		Reliability (proportion of 'good' years)								
		1.00	**0.90**	**0.80**	**0.70**	**0.60**	**0.50**	**0.40**	**0.30**	**0.20**
3	**Late**	1.00	1.05	1.10	1.16	1.22	1.30	1.39	1.50	1.63
	Random – no bias	1.00	1.05	1.11	1.18	1.25	1.33	1.43	1.54	1.67
	Early	1.00	1.06	1.13	1.20	1.28	1.37	1.47	1.58	1.70
7	**Late**	1.00	1.04	1.08	1.13	1.19	1.26	1.35	1.46	1.59
	Random – no bias	1.00	1.05	1.11	1.18	1.25	1.33	1.43	1.54	1.67
	Early	1.00	1.07	1.15	1.23	1.32	1.41	1.51	1.62	1.74
10	**Late**	1.00	1.03	1.07	1.12	1.17	1.24	1.32	1.42	1.56
	Random – no bias	1.00	1.05	1.11	1.18	1.25	1.33	1.43	1.54	1.67
	Early	1.00	1.08	1.16	1.25	1.35	1.45	1.55	1.66	1.77

8.6.2 Risks from initial 'learning' period

Another form of risk arises from the initial challenges in establishing new agricultural industries in the Victoria catchment; it includes setbacks from delays, such as gaining regulatory approvals, and adapting farming practices to Victoria catchment conditions. Some of these risks are avoidable if investors and farmers learn from past experiences of development in northern Australia (e.g. Ash et al., 2014), avoid previous mistakes and select farming options that are already well-proven in analogous northern Australian locations. However, even well-prepared developers are likely to face initial challenges in adapting to the unique circumstances of a new location. Newly developed farmland can take some time to reach its productive potential as soil nutrient pools are established, soil limitations are ameliorated, suckers and weeds are controlled, and pest and weed management systems are established.

'Learning' (used here to broadly represent all aspects of overcoming initial sources of farm underperformance) was assessed in terms of two simplified generic characteristics:

1. initial level of performance – the proportion of the long-term mean GM that the farm achieves in its first year
2. time to learn – the number of years taken to reach the long-term mean farm performance.

Performance was represented as increasing linearly over the learning period from the starting level to the long-term mean performance level (100%).

The effect of learning on scheme financial viability was considered for a range of initial levels of farm performance and learning times. As described above, learning had consistent proportional effects on target GMs, so results were simplified as a set of risk adjustment factors (Table 8-10). As expected, the impacts on scheme viability are greater the lower the starting level of farm performance and the longer it takes to reach the long-term performance level. Since these impacts, by their nature, are weighted to the early years of a new development, they have more impact at higher target IRRs. To minimise risks of learning impacts, there is a strong incentive to start any new irrigation development with well-established crops and technologies, and to be thoroughly prepared for the anticipatable agronomic risks of establishing new farmland. Higher-risk options (e.g. novel crops, equipment or practices that are not currently in profitable commercial use in analogous environments) could be tested and refined on a small scale until locally proven.

As indicated in the examples above, the influence of each risk individually can be quite modest. However, the combined influence of all foreseeable risks must be accounted for in planning, and the cumulative effect of these risks can be substantial. For example, the last question in Table 8-1 shows the combined effect of just two risks, and see Stokes and Jarvis (2021) for the effects of a common suite of risks on the financial performance of a Bradfield-style irrigation scheme.

Table 8-10 Risk adjustment factors for target farm gross margins (GMs), accounting for the effects of learning risks

Learning risks were expressed as the level of initial farm underperformance and time taken to reach full performance levels. Initial farm performance is the initial GM as a percentage of the GM at 'full' performance. IRR = internal rate of return.

TARGET IRR (%)	INITIAL FARM PERFORMANCE (%)	RISK ADJUSTMENT MULTIPLIER FOR TARGET FARM GROSS MARGINS (VS BASE 100% RELIABILITY TABLES) (unitless ratio)					
		Learning time (years to 100% performance)					
		2	**4**	**6**	**8**	**10**	**15**
3	**85**	1.01	1.02	1.03	1.03	1.04	1.05
	75	1.02	1.03	1.04	1.05	1.07	1.10
	50	1.04	1.06	1.09	1.12	1.14	1.21
	25	1.06	1.10	1.14	1.19	1.23	1.35
	0	1.08	1.14	1.20	1.26	1.33	1.53

TARGET IRR (%)	INITIAL FARM PERFORMANCE (%)	RISK ADJUSTMENT MULTIPLIER FOR TARGET FARM GROSS MARGINS (VS BASE 100% RELIABILITY TABLES) (unitless ratio)					
7	**85**	1.02	1.03	1.04	1.05	1.05	1.07
	75	1.03	1.05	1.06	1.08	1.09	1.13
	50	1.06	1.10	1.13	1.17	1.21	1.29
	25	1.09	1.15	1.22	1.28	1.35	1.51
	0	1.12	1.21	1.31	1.41	1.52	1.83
10	**85**	1.02	1.03	1.05	1.06	1.07	1.09
	75	1.04	1.06	1.08	1.10	1.11	1.15
	50	1.08	1.12	1.17	1.21	1.26	1.35
	25	1.12	1.20	1.28	1.36	1.44	1.65
	0	1.16	1.28	1.41	1.55	1.69	2.10

8.7 Achieving financial viability in a new irrigation development

Four key factors determine the financial performance and viability of irrigation schemes: capital costs of development, farm performance (that determines trajectories of future water demand and associated benefits from increased gross value of agricultural production (GVAP)), risk (and associated required level of investment return), and value adding beyond the farm gate (Stokes et al., 2017). Designing a new irrigation project would require balancing these four factors to find combinations that might collectively constitute a viable investment. As demonstrated by lessons from recent dam developments in Australia (Chapter 6), it can be difficult to fully balance the costs of new water infrastructure with the direct new benefits they generate. In concluding this chapter, the broad principles for balancing each of the factors analysed is discussed below.

Lowest capital costs of development – cheapest water

As highlighted in the companion technical reports in this Assessment, developing water resources suitable for irrigation in northern Australia is technologically challenging and opportunities are limited. The costs of developing these resources vary widely (Devlin, 2024), such that even when technically feasible options are found, many of these are likely to be too expensive for irrigation schemes. Capital costs of developing new water sources are high and a key determinant of scheme financial viability. Results suggest broadacre farms with GMs of $4000 per hectare per year would generate sufficient revenue (while providing a 10% IRR to farmers) to cover the costs of about $20,000 to $30,000/ha of off-farm water infrastructure, before accounting for the negative effects of risks. This would cover about 50% of the costs of the most cost-effective large dam development option in the Victoria catchment (about $50,000/ha off-farm water infrastructure cost; at a 7% target IRR for the public investor). Although irrigators are therefore unlikely to be able to pay the full costs of a publicly developed large dam, they may be able to cover a greater proportion of costs (>25%) than in many existing irrigation developments (Vanderbyl, 2021). On-farm water sources appear to provide good opportunities for affordable water that could support broadacre and cost-efficient horticulture but developing these resources would need to concentrate on the most cost-effective sites.

Highest farm gross margins – best crops, soils, and niche opportunities

The companion report on digital soil mapping and land suitability (Thomas et al., 2024) highlights where the best soils for various farming options are likely to be found (summarised in Section 3.2), and Chapter 5 assessed a range of farming options, including opportunities and constraints on maximising farm performance (including farm GMs). There are likely to be niche opportunities for farmers to improve GMs by taking advantage of cost savings and price premiums, but these are unlikely to be scalable. Periods of high prices for agricultural commodities (such as the recent high prices for cotton) provide opportunities for new industries to establish by creating a buffer for learning during the crucial start-up years when farms and associated supply chains will not yet be performing at their full sustainable potential.

Reducing investor risk – making lower investor returns acceptable

There are numerous risks that confront large infrastructure projects, such as new irrigation schemes. The higher these risks, the higher the return an investor would likely require, raising the performance thresholds a project would have to attain to be commercially viable. Conversely, lowering those risks lowers the target revenues that scheme investors would need to generate, which could contribute to making a potential investment viable. One of those risks is the paucity of background information required to develop new irrigation schemes in northern Australia. The information provided in the companion technical reports in this Assessment is targeted at addressing this information gap and reducing the uncertainty about the physical resources in the Victoria catchment, and how they might be developed.

Some risks can be avoided through careful planning, learning from past cropping experiences in northern Australia, and starting with well-established crops, technologies and management practices. Risks that cannot be avoided need to be managed, mitigated where possible and accounted for in determining the realistic returns that can be expected from a scheme. This would include having adequate capital buffers to survive through challenging periods that may exacerbate negative cashflows in the initial years of establishment.

Another perceived risk for investors is that of uncertainty around future policy, regulation changes, and tenure rights for land and water. Reducing this, or any other sources of risk, would contribute to making marginal investment opportunities more attractive.

Value adding and synergies

Value adding and synergies could contribute to the viability of a new irrigation scheme. The establishment of a new cotton gin near Katherine provides opportunities for local processing and provides natural synergies for the local use of cotton seed as a cattle feed supplement within the Victoria catchment. Other synergies that could also be considered to improve scheme revenues or reduce costs would include: (i) sequential cropping systems (increasing net farm revenue by growing two or more compatible crops from the same field each year; Section 5.3); (ii) integration of irrigated forages into existing beef enterprises (Section 5.4); (iii) including small-scale, high-value crops in the mix of farms in a scheme; (iv) expanding the scale of a scheme with extra rainfed/opportunistic cropping around the irrigated core; and (v) improving transport infrastructure and supply chains (reducing the disadvantages of remote locations). Location-appropriate production systems would need to be developed and proven for some of these options.

Conclusion

Ultimately no single one of the above factors is likely to provide a silver bullet to meet the substantial challenge of designing a commercially viable new irrigation scheme. Achieving financial viability will likely require contributions from each of the above factors, with careful selection to piece together a workable combination.

9 Regional economics

9.1 Multiplier and input–output (I–O) approach

When new economic activity begins in a region, such as with the development of a water infrastructure project, there will be knock-on effects to the wider regional economy, over and above the impacts directly related to the development scheme itself, through the way the new activities affect the flows of local goods and services. These effects can be both positive and negative. This section uses regional multiplier and input–output (I–O) analysis to estimate the regional economic benefits that could arise if new irrigated development were to occur in the catchment of the Victoria River. When evaluating the regional economic impact of new irrigated agricultural development within the Victoria catchment, there are two separate analyses required for each of the two distinct phases of the scheme. Firstly, the initial temporary impact from the construction activity at the start of the project. This is followed by the ongoing impacts arising from the increased agricultural production within the region once the development becomes operational and the new farming operations are up and running. The approach closely follows the regional economic analyses used in previous similar water resource assessments (Stokes et al., 2017; Stokes and Jarvis, 2021; Stokes et al., 2023), and further details of the approach, including discussion of the relative strengths and weakness of I–O analyses, are covered in those reports.

To briefly summarise, I–O multipliers are widely used to quantify economic impacts of projects (at regional or national level), offering clear advantages of transparency and ease of use compared to other methods. Simplistically, the method enables an estimate to be made of the total regional or national impact of the development project including the direct spend of the project itself, plus all the production and consumption-induced (knock-on) impacts on other businesses and households within the region.

The I–O multiplier approach recognises that the full impact of the economic stimulus provided by an irrigated agricultural development project extends far beyond the impact on those businesses and workers directly involved in either the short term (the construction phase) or longer term (the ongoing agricultural production phase). Those businesses directly benefitting from the increased construction (short term) and agricultural activity (longer term) would need to increase their purchases of goods and services, which would stimulate economic growth in the regions where those products were purchased. These impacts are known as production-induced effects. Furthermore, household incomes increase when local residents are employed as a consequence of the direct and/or production-induced business stimuli. A proportion of this additional income is spent within the region, creating additional demand, which serves to further stimulate regional economic activity. This additional economic activity is known as a consumption-induced effect.

The size of the production-induced and consumption-induced benefits can be quantified by the economic multiplier. Regional (or national) I–O multipliers are summary measures used to estimate the total economic impact on all industries within a region (or nation), from a change in demand for the output of any particular industry (McLennan, 1996). The key output from the I–O models is the estimated value of the increased economic activity (including, when focusing on an irrigated agricultural development, the original increase to construction or agriculture), where larger multipliers generate larger regional benefits. The models also estimate the increase in household incomes in the region. From this estimate the approximate number of jobs represented by this increased economic activity can be calculated (including those directly related to the increase in construction or agriculture and those generated by the indirect production and consumption effects). Thus, I–O models can be used to estimate the impact of new irrigation development on employment, income and regional economic activity during each phase (development and operational), encompassing all of the direct and indirect impacts expected as a result of the development.

I–O tables and associated multipliers can be constructed at a national or regional scale. With national models, inputs and outputs by industry sector reflect national production and spending patterns, while additional data reflect international imports and exports. For Australia, the Australian Bureau of Statistics (ABS) releases national I–O tables at regular intervals, with the latest release being for the financial year 2020–21 (ABS, 2023b). However, despite publishing the national I–O tables, the ABS has not compiled and published national I–O multipliers based on these tables since 1998–99 (leaving such a step to data users who can use the published national I–O tables to calculate multipliers at national level) due to concerns that provided multipliers could be used for purposes where they are unsuitable, or where lack of consideration is given to their inherent shortcomings and limitations; these limitations are discussed further below (Section 9.1.2). The ABS does not prepare or publish I–O tables at sub-national scale.

Regional models focus on a specific region and thus contain a spatially delimited subset of the expenditure patterns used in national models. They also require additional data to identify inter-regional imports and exports and to quantify other regional-specific spending patterns (Jarvis et al., 2018). This is necessary as relationships between industries within a region are not identical to those at the national scale. Typically, smaller and more remote geographic areas have smaller multipliers as inter-industry linkages tend to be shallow and the region's capacity to produce a wide range of goods is low, meaning that inputs and final household consumption are less likely to be locally sourced than in regions with larger urban centres (Jarvis et al., 2018; Stoeckl and Stanley, 2009). Furthermore, firms in rural and remote areas may have disparate access to production technologies, are often less able to take advantage of economies of scale, and face different relative input prices than their counterparts in developed urban areas (Stoeckl, 2012). In addition to differences in economic scales between regions, different industries are also more or less prominent in different regions; these differences can have an impact on the relative size of multipliers comparing region to region and industry to industry (Jarvis et al., 2018). Accordingly, where available, regional-specific models should be selected for use in the analysis. The regional context is vital, particularly in rural remote areas that likely have different characteristics compared with the rest of the country. Unfortunately, regional I–O tables are rare, and infrequently prepared; the lack of a recent and regionally specific model is accepted as a limitation of this work.

When considering the regional economic impact of such a development it is important to be aware that not all of the expenditure generated by the scheme will occur within the local region. The greater the leakage (that is the amount of direct and indirect spend made outside the region), the smaller the resulting economic benefit that will be enjoyed by the region. Conversely, the more of the initial spend, and subsequent indirect spend, that is retained within the region the greater the economic benefit, and the number of jobs created, within the local region. Accordingly, where there is leakage to other regions the local knock-on benefits would be reduced, but there would be benefits in the other regions where the expenditure occurred instead; thus, the irrigated agricultural development would provide benefits to those other regions across Australia who were the recipients of the additional demand for goods and services stimulated by the irrigated agricultural development. However, in instances where the leakage is to other countries, such as when capital items are imported, the benefits would flow outside of Australia. Thus, the economic impact of the project that remains within the local region, or within the country, is dependent on the skills and resources available locally and nationally, and leakage issues can be mitigated by careful design of the project, in both the construction and operational phases. Leakage from the local region can be minimised if local resources, including local workers and local businesses, can be employed; leakage from the region to elsewhere in the nation represents lost benefit locally but is offset by benefit gains elsewhere which may be viewed as 'no net loss' overall if the project is funded at the national level. However, leakage from the local region to international suppliers is a true loss, which may be minimised by careful project design but may be unavoidable if particular resources and skills can only be sourced overseas.

Another important consideration for model selection, beyond the specific geographic location, was the demographic characteristics of the region. The Victoria catchment population includes a much larger proportion of people identifying as Indigenous compared to Australia as a whole, and this characteristic can have a significant effect of any development in the region. Research based on small, remote communities has found that the expenditure patterns of Indigenous communities differ from the typical patterns elsewhere in Australia (Stoeckl et al., 2013). Additionally, Indigenous Australians are less likely to be in formal employment (government-sponsored employment schemes often involve a transfer of public funds from outside the region) and are proportionally more likely to be employed in the public and health sectors than non-Indigenous residents (Stoeckl et al., 2011). Accordingly, the greater proportion of Indigenous Peoples within the region compared to the national average further underpins the necessity of using I–O tables derived from local data, or from data as close to local as possible, rather than basing analyses on models drawn from dissimilar regions.

As noted above, recent regional I–O models are rare, and unfortunately no model exists that is specific to the Victoria catchment. Hence, there was a need to source model(s) that could provide an approximation of the likely impact of this development for this region. The analyses used two different I–O models to reflect the nature of the region (rural, remote and with a significant proportion of the population identifying as Indigenous). These models were prepared independently at different times and using different approaches. Each model is used to provide insights into the likely economic impact of this development, and to reinforce the robustness of the findings by triangulating results. Details of each of these models, and the appropriateness of each for providing insights into the likely regional economic impacts from a development within the Victoria catchment is discussed in more detail in the following section (Section 9.1.1).

This report focuses on the total output multipliers (referred to as Type II multipliers). Type II multipliers consider initial (direct) expenditure and intra-industrial 'knock-on' benefits along the business supply chain (as measured by simple output Type I multipliers) as well as 'knock-on' effects linked to the local expenditure of (household) wages and income (McLennan, 1996; Gretton, 2013).

9.1.1 Description of the two regional models used for I–O analysis

For the analysis presented here, regional multipliers were derived and modified from two separate publicly available sources: (i) a regional I–O table developed by the Office of Resource Development of the NT Government providing coverage for the entire NT region (Murti and NT Office of Resource Development, 2001); and (ii) a regional I–O table developed specifically for the catchment of the Daly River, adjacent to the Victoria River catchment in the NT (Stoeckl et al., 2011). Figure 9-1 shows the relative geographic locations of these I–O regions and Table 9-1 summarises their socio-economic characteristics for comparison.

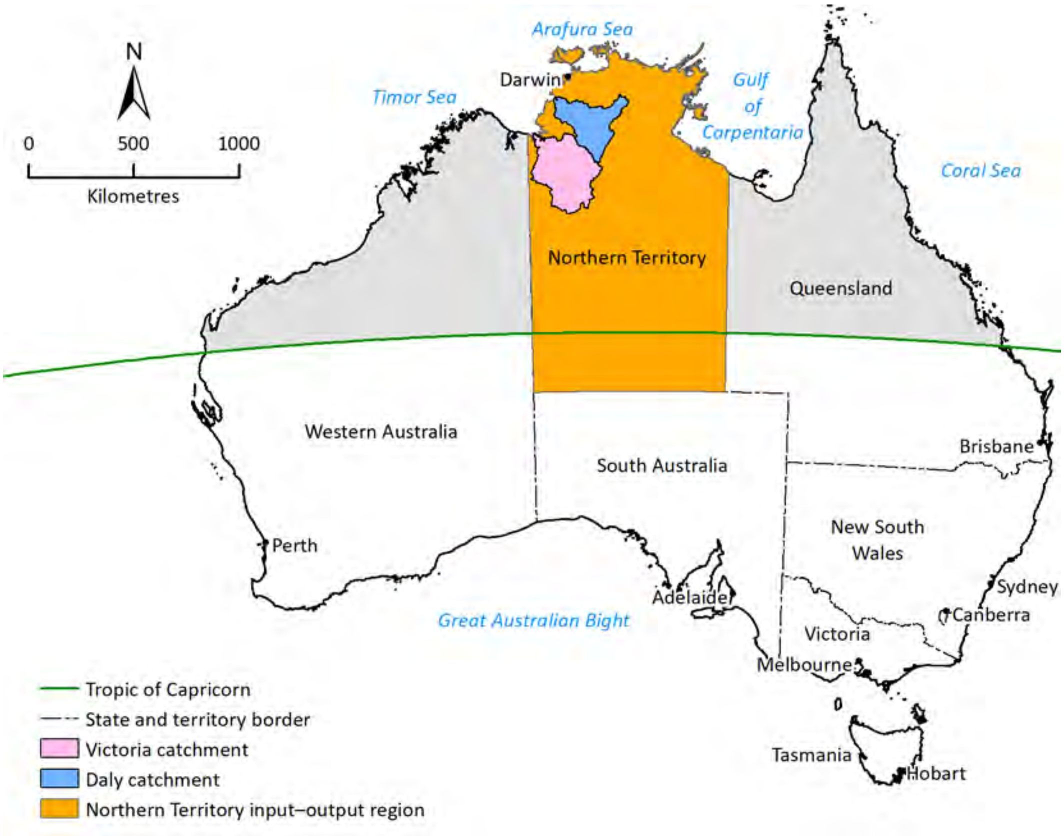

Figure 9-1 Regions used in the input–output (I–O) analyses relative to the Victoria catchment Assessment area

The first model covers a much wider geographic scale (1,348,094 km^2 for NT compared to 82,400 km^2 for Victoria) and also includes a large city, the NT capital Darwin (population 122,207 as at 2021 Census for the urban centre). These differences can have an impact on the relative complexity of the economic structures in each region. Agriculture is far more important to the Victoria catchment than to the whole of the NT, providing 29.2% and 2.3%, respectively, of employment within each region based on 2021 Census data (ABS, 2021). Due to the larger scale (on geographic, population and level of economic activity measures), the multipliers estimated using the whole of NT model will likely be larger than the multipliers for a small region within the NT. This is because of a number of factors (including less opportunities to take advantage of economies of scale, increased input prices and reduced access to production technologies, as described above), compared to firms in developed urban centres such as Darwin (Stoeckl, 2012). Accordingly, the estimated multipliers are likely to provide upper bounds estimates of the multipliers for the Victoria catchment region. However, it is likely to be a more appropriate estimate of the magnitude of the impact of a water development on the economic activity within the wider region, including Darwin; it is likely that the potentially lower impact within the Victoria catchment itself will 'leak' into the more urbanised locations within the NT.

Table 9-1 Key 2021 data comparing the Victoria catchment with the related input–output (I–O) analysis regions

Population statistics for Victoria and Daly regions have been estimated based on the weighted average of 2021 Census data (ABS, 2021) obtained by SA2 statistical region, with weighting based on the proportion of relevant ABS SA2 statistical regions falling within each of the catchment regions.

	VICTORIA CATCHMENT†	DALY CATCHMENT I–O REGION†	NT I–O REGION‡
Land area (km²)	82,232.0	53,088.5	1,348,094.3
Population	1,600	11,233	232,605
Percentage male	50.35%	51.56%	50.53%
Percentage Indigenous	74.68%	32.29%	26.27%
Median age	25	32	33
Median household income	$57,026	$104,505	$107,172
Contribution of agriculture, forestry and fishing to employment in the region	29.2%	6.6%	2.3%
Major industries of employment – top three industries in region (by % of employment 2021)			
Largest employer in region	Agriculture, forestry and fishing	Public administration and safety	Public administration and safety
2nd largest employer in region	Public administration and safety	Healthcare and social assistance	Healthcare and social assistance
3rd largest employer in region	Education and training	Education and training	Education and training
Gross value of total agriculture in region§	$110 million	$93 million	$746 million

†Statistics for Victoria catchment (ABS, 2021) and Daly catchment (ABS, 2021) regions have been estimated using the weighted mean of ABS 2021 Census data obtained by SA2 statistical region, with weighting based on the proportion of relevant ABS SA2 statistical regions falling within each catchment region.
‡ABS 2021 Census data (ABS, 2021).
§ABS Value of agricultural commodities produced 2020–21 by region, report VACPDCASGS202021 (ABS, 2022a).

The NT I–O table was originally prepared by the Centre for International Economics (CIE, 1997), and subsequently updated by Murti and the NT Office of Resource Development (2001). This I–O table utilises data from 1997–98 and incorporates inputs and outputs relating to 50 industry sectors operating within the region. See Murti and NT Office of Resource Development (2001) for additional detail on the methods and data used to prepare this table. While more recently compiled I–O table data would have been desirable, in general industry relationships within regions change slowly and the multipliers generally remain fairly stable over time (McLennan, 1996). The analyses presented here aggregated the 50 industries in the model to a smaller subset of 22 industry classes, both to reflect the nature of economic activity in the Victoria catchment and for consistency with similar previous analyses done for northern Australian catchments that used the same industry aggregations (Stokes et al., 2017; Stokes and Jarvis, 2018; Stokes et al., 2023). The agricultural sectors included in this aggregated model were 'beef cattle'; 'agriculture excluding beef cattle'; and 'aquaculture, forestry and fishing'. For this study the NT I–O model used by Stokes and Jarvis (2018) was further amended to disaggregate of the impacts on household incomes and job creation between Indigenous and non-Indigenous households, using disaggregation methods established by Jarvis et al. (2018).

The second I–O model focuses on the smaller geographic region of the Daly catchment, which is directly adjacent to the Victoria catchment and of similar geographic size (Daly catchment ~53,100 km^2, Victoria ~82,400 km^2). This I–O model was developed using a different methodology to the NT model, being based on survey data; prior research has established the appropriateness of such an approach (Stoeckl, 2007, 2012). Further, this model was specifically developed to explore the economic impacts of different types of development in remote, sparsely populated regions of northern Australia; such regions generally include a far greater proportion of Indigenous Peoples compared to Australia as a whole. The model was developed based on highly aggregated industry sectors, containing one agriculture sector, rather than any subdivision of the economic impacts of different types of agriculture within the region. As with the NT model, the Daly catchment model separately estimates the impacts on incomes for Indigenous and non-Indigenous households.

Although the Daly and Victoria catchments are comparable in terms of their geographic location and demography, there are also some notable differences. The Daly catchment is physically located closer to the major city of Darwin (see Figure 9-1), suggesting the Daly region is more likely to realise spill-over benefit from Darwin's regional economic activity than is the Victoria catchment. The Daly includes the important regional centre of Katherine (population 6303), while the Victoria catchment's largest settlement is Kalkarindji with a population of 383 people, based on the 2021 Census data. Agriculture is economically more important to the Victoria catchment than to the Daly catchment, providing, respectively, 29.2% and 6.6% of employment within each region, although this is likely due to the impact of those employed and residing in Katherine. Annual agricultural production in the Victoria catchment is similar in value to that of the Daly catchment ($110 million and $93 million gross value of agricultural production (GVAP), respectively). Thus, overall, while the Daly catchment may not be a perfect comparator to the Victoria catchment, the regions are sufficiently similar that it is likely that the use of this model will provide a good estimate of the impact of the development to the Victoria catchment and the surrounding regions overall; that is spill-overs from the Victoria catchment to the adjacent catchments are likely to be reflected in the results.

Using each of these models in turn, the total regional benefits from the operations of an irrigation development including all multiplier effects (indirect production effects, and the consumption effects linked to the local expenditure of (household) wages and income, in addition to initial direct effects) is estimated using I–O analysis. The regional economic impact from the construction phase and from the ongoing agricultural production phase of the development are estimated separately. The I–O analysis incorporates the value of the anticipated additional agricultural output directly driven by new development as an exogenous shock to the appropriate industry, then estimates how much additional activity is generated within each I–O region as a result of the exogenous shock.

The I–O analysis also estimates the likely increases to household incomes in the region. This increase in income was used to estimate the increase in jobs created in the I–O region (directly, and indirectly through production and consumption effects), by dividing the total increase in household incomes by the average income in the I–O region. Specifically, the estimated number of jobs was calculated as follows:

$$\text{Estimated additional jobs} = \frac{\text{Total estimated increase in household incomes}}{\text{Estimated mean employee income in NT}} \tag{1}$$

Where ‘Estimated mean employee income in NT’ has been calculated based on latest available mean employee income data for the NT (as at December 2023) from the ABS (ABS, 2023d) updated using wage price indices to more current wage rates based on the ABS wage price index data series (ABS, 2023c). Specifically, the estimated mean employee income in the NT was calculated to be $73,643 for September 2023 based on the following calculation:

$$\text{Estimated mean employee income} = \text{Employee income Jun ‘20} \times \frac{\text{Wage index Sept ‘23}}{\text{Wage index Jun ‘20}} \quad (2)$$

Because the purpose of the analysis was to estimate the number of new jobs created, incomes were specifically estimated only for employees (because including income from pensions or other non-employment sources would distort job estimates).

It should be noted that this method results in an imperfect estimate of the number of jobs created and is affected both by the limitations of I–O analysis and by the assumption that the mean income from additional direct and indirect jobs created will be the same as the current mean income level in the NT. However, it provides some guidance to the likely employment opportunities that could result from development within the region. As with all estimates resulting from I–O analysis, this should be considered as an upper-bound estimate.

9.1.2 Strengths, limitations and inherent weaknesses of using I–O multipliers to assess regional economic impacts

When using I–O analysis and I–O-derived multipliers for analysis of regional economic impact of developments, such as an irrigated agriculture development within the Victoria catchment, it is important to be aware of the inherent weaknesses and limitations of the approach, in addition to the factors that make the approach appropriate for use in such a location.

Firstly, the approach fails to recognise or incorporate any supply-side constraints or budget constraints, the omission of which results in estimates overstating the likely economic impacts, particularly when capital and/or labour are scarce (Gregg and Hill, 2023; Gretton, 2013). Secondly, the approach assumes the structure of the regional economy, including interlinkages between different sectors of the economy and ratios of leakages from the region, does not change either over time or as a result of policy or technological advancements. That is, the approach assumes fixed prices, fixed ratios for intermediate inputs and production, and makes no allowance for purchasers’ marginal responses to change. Relatedly, the analysis does not reflect any removal or substitution effects if expanding one sector (for example beef cattle) results in the reallocation of resources across sectors. Again, such omissions are likely to result in biased estimates of economic impacts. More detailed discussion of the limitations of I–O multiplier analysis can be found in Stokes et al. (2017, 2023) and ABS (2023e). These inherent limitations should be borne in mind when considering the results set out below. Specifically, the limitations and weaknesses inherent in the assumptions underpinning the approach results in multipliers providing biased estimates of the benefits or costs of a project.

However, despite these acknowledged limitations, there are aspects of the I–O multiplier approach that make it well-suited for scoping assessments of the potential regional benefits of greenfield developments in remote parts of Australia, which is how multipliers are used here.

Firstly, alternate approaches to estimating regional economic impacts, such as computable general equilibrium (CGE) models, are also imperfect and frequently suffer from similar limitations. Furthermore, models using alternate approaches are generally unavailable for small rural and remote regions such as the Victoria catchment, and CGE modelling has proven unsuitable, or to offer little benefit compared to I–O models, in previous similar applications for estimating the regional impacts of small agricultural developments that represent such a minor perturbation to regional economies. To provide two examples:

- The use of The Enormous Regional Model (TERM) dynamic multi-regional CGE model was trialled for assessing the impact of water resource developments within the Flinders and Gilbert catchments (Brennan McKellar et al., 2013). This model has been described in great detail (see Wittwer, 2012), and when developed was theoretically an improvement on prior models due to providing finer regional divisions and disaggregating the economy across a wider number of industrial sectors, and indeed, appears to have been successfully used in a number of examples such as within the southern Murray–Darling Basin (Wittwer, 2012). However, in practice, for small remote data-poor regions such as the Victoria catchment, the model suffers limitations similar to the simpler (and less costly) I–O approach. For example, the model was developed based on historical data (a national I–O table supplemented with some regional data, with a base year of 1997) and, despite the model disaggregating Australia into 57 different regions, these regions are insufficiently fine scale to match northern river catchments (the NT as a whole, for example, forms one region in the model) (Horridge, 2012).
- The use of the Australian Bureau of Agricultural and Resource Economics and Science (ABARES) AusRegion dynamic regional CGE has been trialled for assessing the regional economic impact of water resource developments across a number of different water resource developments (Ash et al., 2014), seeking to demonstrate the impact of development compared to a reference scenario, on output, employment and wages at the regional level, and on output at state and national levels. This approach offered the advantage of providing bottom-up estimates of impact at different scales (regional, state, national), but suffered limitations similar to the I–O approach, in that the model was based on historical data (2005–06) regarding the structure of the economy and interrelationships between industries and regions, and also that the model failed to disaggregate regional data to the fine scale required to match northern river catchments. Further, the usefulness of the approach was limited by the model outputs, which represented, for one future time period only (2029–30) the percentage difference between the economic indicators for that year under the development scenario compared to the reference scenario. These results appeared to emerge from the complex model as if from a 'black box' approach, with no quantification, or indication of relative importance, of the different drivers underpinning the cumulative effect of construction and operational phases over time, or of the changing impacts over time; thus the results provide little to no guidance on how these component regional economic impacts could change in response to variations in the assumptions underpinning the scenario (Ash et al., 2014).

Thus, taking into account the practical considerations of working with a small, remote region, I–O analysis is the most suitable approach for assessing regional economic impacts in the Victoria catchment (and similar river catchments in northern Australia).

Secondly, a region such as the Victoria catchment provides a data-sparse environment with few local precedents or alternate developments that can act as proxies to guide the likely outcomes from irrigated agricultural developments within the region. Alternate approaches to I–O, such as the CGE models, are data intensive, requiring detailed information on the structure of the economic system in the region under study to enable the regional economic model to be specified and parameterised. This includes structural information on production, consumption and trade, for example, and additionally, further data on behaviours, describing how this system will respond to changes; this usually requires information in the form of elasticities of demand, production and trade. The problems of gathering reliable data for remote regional areas are well known. Beyond the physical challenges of collecting data from remote, hard-to-access regions (due to poor transport and communication infrastructure, difficult terrain and extreme/variable weather conditions), the reporting of socio-economic data is also frequently suppressed or distorted for confidentiality purposes.[8] These data problems are exacerbated for regions with smaller and highly Indigenous populations. Taylor (2013) describes some of the flaws in data relating to Indigenous Peoples and their communities, which raise questions of data accuracy and also comparability of data over time. Some of the reasons noted as underpinning data issues include a changing propensity of individuals to identify as Indigenous over time and more frequent mobility of Indigenous Peoples (Taylor, 2013); these problems are exacerbated by the acknowledged significant undercounting of Indigenous Peoples in official statistics such as Census data, thought to be 17.4% for the 2021 Census (ABS, 2022c), similar to 17.5% for the 2016 Census (ABS, 2018). In such scenarios, the less data hungry I–O approach can be reasonably robust, compared to theoretically preferred but more data hungry approaches such as CGE, thus making the approach attractive in such a region as the Victoria catchment (data-sparse, remote and with a large proportion of the population identifying as Indigenous).

Finally, I–O approaches can usefully provide an estimate of the upper bound of regional knock-on effects at relatively low cost. By indicating the likely upper bound of these added benefits, they enable the easy identification of schemes that are likely to produce benefits too small to be able to justify substantial public subsidies for schemes that are not close to being financially viable in the first place. For such schemes, a more precise measure of regional benefits would be unlikely to change substantive decisions about whether a scheme would go ahead or not (e.g. even if the knock-on benefit was 50% lower or 50% higher this would not be enough to tilt a decision on a financially non-viable scheme becoming viable or vice versa). For situations where CBA indicated that a scheme was very close to being viable and regional benefits were to be a critical deciding factor, then it would be appropriate to go beyond indicative I–O analysis and invest in additional bespoke regional economic analysis in those specific cases. This is in line with the activities in the other parts of this Assessment which, as a combined scoping study, is primarily aimed at assisting investors and government planners in identifying where potential opportunities lie (distinguishing development options that might be viable from those that can easily be ruled out), with the expectation that specific project proposals would need to conduct additional feasibility analysis.

[8] An explanation from the ABS can be found at https://www.abs.gov.au/statistics/detailed-methodology-information/concepts-sources-methods/survey-income-and-housing-user-guide-australia/2019-20/using-survey#confidentiality.

In summary, the lack of better alternate approaches for many rural and remote Australian regions, combined with their adaptability and ease of use, makes I–O multipliers a popular and suitable tool for scoping-level economic impact analysis. When used appropriately, I–O multipliers can provide valid and useful information, provided results are carefully interpreted with due consideration for the key assumptions and limitations that underpin the models (Gregg and Hill, 2023; Gretton, 2013; Office of the Government Statistician Queensland Government, 2004). Accordingly, when using the results presented in the section below (Section 9.2) it is important to recognise the effect of the limitations is that regional benefit values are likely to represent an upper-bound estimate of potential outcomes (ABS, 2019). This becomes a more significant issue with larger and more complex developments, as smaller and fairly simple developments are less likely to distort current markets, place price pressures on supply chains and labour markets, and require imports (materials, equipment, skilled labour) from overseas.

9.2 Regional economic benefits

I–O analysis was applied to two distinctly separate streams of benefits: the 'one-off' benefits that arise during the construction phase of a new irrigation scheme and the ongoing benefits that arise during the operational phase when new farming production begins. Accordingly, the multipliers and estimated regional impacts of the two distinct phases are considered separately below. Estimates of regional benefits included all Type II multiplier effects (indirect production-induced effects, and the consumption-induced effects linked to the local expenditure of household wages and income, in addition to initial direct effects). The analysis is not based on any specific construction project and subsequent irrigated agricultural operations. Rather, the analysis provides information illustrating potential regional outcomes from a range of alternate types/scales of construction projects and the agricultural operations that could flow from these.

The initial source of funding for the capital cost of the water infrastructure development is not addressed in this analysis, that is, the analysis does not explicitly address the upfront source of the capital funding (be it private sector, public sector or public–private partnership). Similarly, the analysis during the operational phase doesn't explicitly address the size/proportion of contribution to construction cost required from farmers compared to possible public subsidies provided. However, the implications of funders and funding mechanisms are discussed in each of the sections below.

9.2.1 Regional economic benefits arising during construction phase (one-off)

While there is an initial cost of building infrastructure (and other related infrastructure such as new roads), by creating additional expenditure within a region (thus putting additional cash into people's/firm's pockets) this increases regional economic activity. Thus, this creates a fairly short-term (non-recurring) economic benefit to the region during the construction phase.

Construction industry multipliers should be applied to the annual expenditure on construction over the duration of the construction phase of the project, that is, they estimate the impact on the regional economy of the construction activity for the year in which that construction activity takes place. This regional economic impact will be of a 'one-off' nature; that is, the benefit will not be repeated in subsequent years.

The regional impacts of the construction phase of potential developments were estimated using a scenario approach for the scales of development. The analyses modelled regional impacts for four different indicative sizes of developments in the Victoria catchment. Total capital costs, including costs of labour and materials required by the project, ranged from $250 million to $2 billion. The smallest scale of development in Table 9-2, with a capital cost of $250 million, broadly represents about 20 new farm developments with their own on-farm water sources enabling around 10,000 ha of irrigation for horticulture and broadacre farming (based on the costing information previously presented for on-farm establishment costs in Table 7-1 and for on-farm water source developments in Table 7-2). The second-smallest scale scenario, with a $500 million capital cost, could represent a similar development to the first but with 20,000 ha of new irrigated farmland; this level of investment could also include a new processing facility (such as a cotton gin) that could be required and supported from this scale of agricultural development. Alternatively, the $500 million scale of development could represent a large *off-farm water* infrastructure development (based on indicative costings for the most cost-effective dam locations in the Victoria catchment, Table 7-3) along with related farm establishment costs (Table 7-1). The larger scales of development, at $1 billion or $2 billion shown in Table 9-2, indicate outcomes from combining potential developments in different ways (such as one large off-farm dam and multiple on-farm water sources). They also include investment in indirect supporting infrastructure across the region, such as roads, electricity and community infrastructure (as described in sections 7.5, 7.6 and 7.7).

Careful consideration was given to estimating the appropriate proportions of initial spend during the construction phase that would actually be spent within the region. The costs incurred during this phase would include labour, materials and equipment costs. It is likely that wages would be paid to workers sourced both from within the region and from elsewhere. The likely proportion of labour costs for each source of workers depends on the availability of appropriately skilled labour within the region. For example, a highly populated region with a high unemployment rate is likely to be able to supply a large proportion of the workers required from within the region; however, a sparsely populated region like the Victoria catchment with fewer trained construction workers would likely to need to attract many workers from outside the region, on a fly-in fly-out (FIFO) and/or drive-in drive-out (DIDO) basis. Similarly, some regions may be better able to supply a large proportion of the required materials and equipment from within the region whereas construction projects in other locations may not be able to source what they need locally and instead import a significant proportion into the region from elsewhere.

A scenario approach was again adopted, indicating the impact that would result from three different proportions of local construction spend (labour, equipment and materials) that could be sourced within the region (as opposed to being imported which has no impact on the regional economy): 65% (i.e. low leakage scenario), 50% and 35% (i.e. high leakage scenario) spent locally. For a very remote region such as the Victoria catchment, the potential exists for leakage to be higher than this high leakage scenario (i.e. <35% spent locally), resulting in a lower benefit to the local Victoria catchment regional economy; however, when considering the wider region encompassing the Victoria and adjacent regions within the northern NT, this range of likely leakage scenarios is likely reasonable. In cases of high leakage, the knock-on benefits would instead occur in the regions supplying the goods and services (like the wider NT I–O region).

Utilising four possible scales for development capital construction costs together with three possible levels of spend to be made locally resulted in 12 different construction scenarios. Each of these scenarios was processed through the two separate I–O models to estimate the potential regional benefit from the construction phase (including the Type II multiplier effects). The results of this analysis are set out in Table 9-2. The values are the total benefits over the duration of construction, so annual benefits would be split according to the expenditure in each year and would cease once the construction phase was complete.

Table 9-2 Regional economic impact estimated by input–output (I–O) analysis for the total construction phase of an irrigated agricultural development based on estimated Type II multipliers determined from two independent I–O models

Estimates represent an upper bound, because some assumptions of I–O analysis are violated in the case of such a large public investment in a region where existing economic (including agricultural) activity is so low. Leakage to other regions and other countries is accounted for by reducing the proportion of expenditure (and benefits) within the region.

DEVELOPMENT CAPITAL COST ($ billion)	TOTAL REGIONAL ECONOMIC ACTIVITY WITHIN I–O REGION AS A RESULT OF THE CAPITAL COST OF THE DEVELOPMENT ($ billion)					
	Victoria catchment based on NT I–O model			**Victoria catchment based on Daly catchment I–O model**		
	Proportion of total scheme-scale capital cost made locally within the I–O region					
	65%	**50%**	**35%**	**65%**	**50%**	**35%**
0.250	0.33	0.26	0.18	0.35	0.27	0.19
0.500	0.67	0.52	0.36	0.71	0.55	0.38
1.000	1.34	1.03	0.72	1.42	1.09	0.76
2.000	2.68	2.06	1.44	2.83	2.18	1.53

As can be seen from these results, the proportion of scheme construction costs spent within the region (indicating how much of the initial exogenous shock is retained within the region rather than being lost in leakage to elsewhere) has a significant impact on the size of the regional economic benefit experienced. If a large proportion of the initial spend leaks from the region, then the benefit of the initial construction investment will be less concentrated in the local Victoria catchment economy and would spread to other locations from where goods and services are sourced.

Comparing the results of the two separate I–O models reveals the estimates to be fairly similar: the construction multiplier for the Daly catchment model estimates 5.8% higher regional benefits than the NT model (noting that rounding slightly affects comparisons of presented values). It is clear that the more significant differences relate to the proportion of spend that is spent locally, and the absolute capital cost of construction; differences resulting from use of the different regional multiplier models are relatively minor in comparison.

The combined direct and indirect impacts on household incomes resulting from each of the scenarios were also estimated using the two models. Based on the NT I–O model, only 6% of the increased household incomes flows to Indigenous households, despite Indigenous Peoples comprising around 25% of the population of the NT. Based on the Daly catchment model, 8% of the increased household incomes flow to Indigenous households, despite Indigenous Peoples comprising around 29% of the population of that region. Thus, both models clearly indicate that the benefits flow disproportionately towards non-Indigenous households. This reflects the lower level of Indigenous engagement (compared to that of non-Indigenous Peoples) with the economic activity of these regions; this is not unexpected based on findings of previous research. This indicates that if the irrigated agricultural development is to contribute towards the government's Indigenous Advancement Strategy (NIAA, 2021), and contribute towards achieving the 'closing the gap' targets (Australian Government, 2021) then specific interventions are likely to be required to increase Indigenous involvement in the construction phase of the project by specifically seeking to provide employment opportunities to the Indigenous Peoples of the region where possible.

Based on the estimated increase in household incomes, the number of direct and indirect jobs created during the construction phase were estimated (Table 9-3). The estimated number of jobs has been presented in total, rather than presenting the additional jobs likely to be created for Indigenous and non-Indigenous workers separately due to the many additional assumptions that would be required for such an analysis (over and above the assumptions on which the I–O analysis are based). Note, however, that Indigenous workers are likely to only fill a small proportion of new jobs created, because only 6% to 8% of additional household incomes is estimated by the I–O models to flow to Indigenous households.

Table 9-3 Estimated full-time equivalent (FTE) number of jobs created for the construction phase of an irrigated agricultural development

Based on estimates of impact on household incomes calculated from I–O analysis (using Type II multipliers determined from two independent I–O models) and average incomes per person, for the construction phase of an irrigated agricultural development. Analyses assume the construction phase and duration of jobs would be within one year: for longer construction periods the annual FTE would be lower but spread over more years. Estimates represent an upper bound because some assumptions of I–O analysis are violated in the case of such a large public investment in a region where existing agricultural activity is so low. Leakage to other regions and other countries is accounted for by reducing the proportion of expenditure (and benefits) within the region.

SCHEME COST CAPITAL COST ($ billion)	ADDITIONAL JOBS ESTIMATED TO BE CREATED AS A RESULT OF THE CAPITAL COST OF THE SCHEME (FTE)					
	Victoria catchment based on NT I–O model			**Victoria catchment based on Daly catchment I–O model**		
	Proportion of total scheme-scale capital cost made locally within the I–O region					
	65%	**50%**	**35%**	**65%**	**50%**	**35%**
0.250	623	479	336	574	441	309
0.500	1,246	959	671	1,147	883	618
1.000	2,493	1,918	1,342	2,295	1,765	1,236
2.000	4,986	3,835	2,685	4,590	3,531	2,471

As expected, the estimated employment outcomes are closely related to those for impacts on regional economic activity, with a larger number of jobs created when there is assumed to be lower leakage rates and when the initial capital spend is larger. The analysis based on each of the two separate I–O models present different but similar results. Employment predictions based on the Daly catchment model are 8% smaller than the predictions based on the NT model; such differences are less significant than the differences due to assuming different leakage rates. The similarity between the estimated levels of economic activity that could result from the Victoria catchment development from the two independently developed I–O models provides some reassurance of the robustness of the findings presented here.

The regional benefits from the construction phase are estimated based on the assumption that the capital funding is an exogenous injection of spending into the region rather than some (or all) of the funding representing a diversion of current spend away from other construction projects within the region towards the new development; that is, the capital funding is treated as new expenditure over and above current activity. The benefits to the region under this assumption would be unaffected by whether the funding was derived from the public sector (federal or state) or private sources, or a combination. Should any of the construction represent a diversion from current regional spend, then the analysis should be considered to be based on the net injection (total spend on new project less current regional spend diverted) rather than gross expenditure to avoid overstatement of regional benefits. Further, the opportunity cost of the capital spend is not incorporated in this analysis, but the best alternate use(s) of the funding should also be evaluated before scarce available funding is committed to the development.

9.2.2 Regional economic benefits during the operational phase (recurrent)

For assessing the regional economic benefits arising during the operational (farming) phase of an irrigated agricultural development, analyses used four scenarios as indicators of the possible scales of investment and types of development. These scenarios evaluated the impacts of increases in gross value of agricultural production from new agricultural development of $25, $50, $100 and $200 million per year. At the low end ($25 million/year), this could represent 10,000 ha of new plantation timber, while the high end ($200 million/year) could represent 10,000 ha of mixed broadacre cropping and horticulture (based on farm financial estimates for these crops presented in Section 5.2) with other crop options falling in between the two ends of this range. In each scenario, the additional agricultural output is considered once developments have reached their full potential.

The different scales of increased economic output from agriculture, resulting from new water development, are stated net of any contribution the farmers are required to make towards the costs of building *off-farm* infrastructure. In practice farmers may be charged for the infrastructure development as part of their cost of acquiring a water entitlement and/or ongoing payments for water extraction, and these contributions may be subsidised to some extent by government grants towards the construction.

Impacts were quantified in terms of the total increased economic activity (Table 9-4) in the region, followed by analysis based on the associated impact on household incomes and employment (using the approach described above). The multipliers estimated from the I–O analysis that were used to estimate the increased economic activity are summarised in Table 9-5. The estimated impact on household incomes, disaggregated between Indigenous and non-Indigenous households, is shown alongside the estimated increased number of jobs represented by that increased income (Table 9-6). Note that all results scale linearly as the economic output of each type of agricultural activity increases; likewise, a linear decrease in economic activity would result from a decrease in agricultural activity.

As before, estimates were made based two independent I–O models: (i) the wider NT model estimated economic impacts from increased activity from within each of three categories of agricultural activity (beef cattle, agriculture excluding beef cattle, and aquaculture, forestry and fishing), and (ii) the Daly catchment model estimated economic impacts from increased activity from within a general category of agriculture of all types, encompassing all different possible agricultural activities.

Table 9-4 Estimated regional economic impact per year resulting from four scales of direct increase in agricultural output (rows) in the Victoria catchment, for the different categories of agricultural activity for two input–output (I–O) models (columns)

Increases in agricultural output are assumed to be net of the annualised value of contributions towards the construction costs. Estimates are based on Type ll multipliers determined from two independent I–O models for each year of agricultural production. Estimates represent an upper bound because some assumptions of I–O analysis are violated in the case of such a large public investment in a region where existing agricultural activity is so low. Leakage to other regions and other countries is accounted for by reducing the proportion of expenditure (and benefits) within the region.

DIRECT INCREASE IN AGRICULTURAL OUTPUT PER YEAR NET OF CONTRIBUTION TO CONSTRUCTION COSTS ($ million)	TOTAL ANNUAL VALUE OF INCREASED ECONOMIC ACTIVITY IN I–O REGION – DIRECT, PRODUCTION-INDUCED AND CONSUMPTION-INDUCED ($ million)			
	Victoria catchment based on NT I–O model			**Victoria catchment based on Daly catchment I–O model**
	Type of agricultural development			
	Beef cattle	**Agriculture excluding beef cattle**	**Aquaculture, forestry and fishing**	**Agriculture of all types**
25	51	37	70	51
50	103	73	141	102
100	205	146	282	203
200	411	292	563	406

Table 9-5 Type II regional economic multipliers applicable to the ongoing agricultural production phase of the Victoria catchment development

Estimates represent an upper bound because some assumptions of input–output (I–O) analysis are violated in the case of such a large public investment in a region where existing agricultural activity is so low. Leakage to other regions and other countries is accounted for by reducing the proportion of expenditure (and benefits) within the region.

	ECONOMIC MULTIPLIER ($/$)
Estimated using the NT I–O model	
Beef cattle	2.05
Agriculture excluding beef cattle	1.46
Aquaculture, forestry and fishing	2.82
Estimated using the Daly catchment I–O model	
Agriculture of all types	2.03

When applying the results of this analysis to a new irrigation scheme, based on the estimated increased value of agricultural output, it is important to be aware of all underlying assumptions, as explained previously. For example, the actual outcome may be quite different to that predicted by the analysis if the mix of agricultural activities within the I–O region is changed significantly from that in existence when the original I–O table was derived. Furthermore, the I–O method is generally considered to over estimate economic impacts, so the results are best used for relative comparisons among development options, or for providing an indication of the upper bound of the absolute magnitude of the regional benefit.

Table 9-6 Estimated impact on annual household incomes and full-time equivalent (FTE) jobs within the Victoria catchment resulting from four scales of direct increase in agricultural output (rows) for the various categories of agricultural activity (columns)

Increases in agricultural output are assumed to be net of the annualised value of contributions towards the construction costs. Estimates are based on Type II multipliers determined from two independent input–output (I–O) models for each year of agricultural production. Estimates represent an upper bound, because some assumptions of I–O analysis are violated in the case of such a large public investment in a region where existing agricultural activity is so low. Leakage to other regions and other countries is accounted for by reducing the proportion of expenditure (and benefits) within the region.

DIRECT INCREASE IN AGRICULTURAL OUTPUT PER YEAR NET OF ANY CONTRIBUTION TO CONSTRUCTION COSTS ($ million)	TOTAL ANNUAL VALUE OF INCREASED ECONOMIC ACTIVITY IN I–O REGION – DIRECT, PRODUCTION-INDUCED AND CONSUMPTION-INDUCED ($ million or FTE)			
	Victoria catchment based on NT I–O model			**Victoria catchment based on Daly catchment I–O model**
	Type of agricultural development			
	Beef cattle	**Agriculture excluding beef cattle**	**Aquaculture, forestry and fishing**	**Agriculture of all types**
	Additional incomes expected to flow to Indigenous households from development ($ million)			
25	0.8	0.1	0.9	0.5
50	1.6	0.2	1.7	1.0
100	3.3	0.4	3.4	2.0
200	6.5	0.8	6.8	4.0
	Additional incomes expected to flow to non-Indigenous households from development ($ million)			
25	7.1	1.7	14.3	6.75
50	14.2	3.3	28.7	13.5
100	28.4	6.7	57.4	27.0
200	56.8	13.4	114.7	54.0
	Additional jobs estimated to be created (FTE)			
25	108	24	206	98
50	215	48	413	197
100	430	97	825	394
200	860	193	1,650	788

As can be seen from the estimated regional economic impacts (Table 9-4), based on the model for the NT as a whole, an irrigation scheme that increases the output of the ‘beef cattle’ industry could have a larger impact on regional economic activity than a scheme that promotes ‘agriculture excluding beef cattle’, while the largest regional economic benefit would derive from an aquaculture, forestry and fishing focused development. These differences result from the different multipliers estimated for the different types of activities, as set out in Table 9-5. Using the alternate model for the Daly catchment, the estimated benefits from an agricultural development are similar, but slightly below, the estimates for a beef cattle focused development from the NT model. This finding is as expected, as the agricultural activity within the Daly catchment was heavily skewed towards beef cattle rather than other types of agriculture, as is the Victoria catchment currently. Further, the estimate using the Daly catchment I–O model is smaller than that from the NT model, which is also as expected based on economic theory (described above), as it is based on a much smaller (in geographic, population and existing level of economic activity scales) and more rural and remote region (including no major town or city). Given the most common type of agricultural activity across the Daly catchment (and the Victoria catchment) is beef cattle, it is not surprising that the estimates from the Daly model are closest to the estimates arising from the NT model for beef cattle; the estimates from the Daly model are only 1% below the beef cattle estimates from the NT model. The similarity between the estimates of the level of economic activity that could result from Victoria catchment development from the two independently developed I–O models provides some reassurance of the robustness of the presented findings.

The analysis also estimated increases to household incomes within the region that would result from the exogenous boost in demand (assumed to equal the increased production facilitated by the development) to the agricultural industries using each of the I–O models. This increase in income was used to estimate the increase in jobs created in the region (directly, and indirectly through production and consumption effects), by dividing the total increase in household incomes by the estimated mean annual incomes in the region (calculated using ABS wage price index data for the NT and the mean income within the NT region for the year ended June 2020, being the most recent regional data available, as described in Section 9.1.1 above). The disaggregated impact on Indigenous and non-Indigenous household incomes was estimated using each model; these disaggregated income effects are set out in Table 9-6; the same table also reflects the estimated number of jobs (Indigenous and non-Indigenous combined) that could be created directly and indirectly by such developments. Based on the Daly catchment model, 7% of the increase in household incomes is estimated to flow to Indigenous households, despite Indigenous Peoples representing around 29% of the population within the region. Using the NT model, where around 25% of the population identify as Indigenous, the proportion of household income increase flowing to Indigenous households varies according to agricultural type. A beef cattle based agricultural development would result in 10% of the increase in household incomes flowing to Indigenous households, compared to 6% for the other two categories (agriculture excluding beef cattle, and aquaculture, forestry and fishing). This is not unexpected, as Indigenous Peoples are known to have been involved in working with cattle on cattle stations across the country since colonisation, and thus have higher levels of involvement within this sector compared to others. Accordingly, it should be noted that a proportion of these jobs are unlikely to be filled by people currently residing within the Victoria catchment as it is unlikely that a sufficient pool of suitable workers is currently available in the catchment. A proportion of the jobs could be filled by people from the wider region, that is, people could migrate from other parts of northern Australia to take up some of these opportunities, however, foreign and domestic migratory workers from outside the region may also take up some of these opportunities. Accordingly, some of the benefits would accrue to people currently outside the catchment, and potentially outside of Australia, which could increase the leakage of benefits from the scheme outside of the region, and potentially, outside of the country.

9.2.3 Summary of estimated regional economic impact of a Victoria catchment irrigated agriculture development

While I–O based methods result in imperfect estimates, the approach provides some useful guidance to the likely upper bounds of the regional economic activity and employment opportunities that could result from development within the Victoria catchment region, in both the construction and operational phases.

Based on the Daly catchment model (as providing slightly lower estimates and representing a region with greater similarity to the Victoria catchment than the NT as a whole), a large agricultural development providing $200 million of ongoing net additional output each year (after subtracting any payments farmers are required to contribute to the capital costs of the development to enable the scheme to be fully self-funded) could provide up to $406 million of regional benefit (with almost half of this representing the direct benefit of the new farming) (Table 9-4) and create about 780 jobs (Table 9-6) (considering just irrigated cropping; higher regional benefits could be possible from aquaculture). This represents $1.03 of additional benefit to the direct benefit of each dollar of new agricultural production generated by such a scheme (Table 9-5). Should the Australian and/or NT governments choose to cover part of the costs of the development then the value of additional output will increase by the amount of the subsidy and the total regional economic benefit (direct and indirect) would increase by just over double the amount of that publicly funded contribution. Policy makers would need to consider the benefit generated by such a public investment compared to alternate uses of public funds (the opportunity cost) when determining the amounts and value of public contributions to new developments.

In the construction phase, based on the consideration of the results of both I–O models, a medium-scale agricultural development requiring a capital cost of $2 billion could provide a one-off (temporary) regional benefit of $2.7 billion, based on an optimistic estimate of the likely leakage outside the region (with the majority of this representing the direct benefit of the construction work) (Table 9-2), and create about 4800 jobs (Table 9-3). This represents around $0.35 of additional benefit to the direct benefit of each dollar invested in the construction of the scheme.

It should be noted that the above approach of summarising regional benefits of both the construction and agricultural phases of the project essentially represent upper-bound estimates for the likely outcomes, and particularly, that the magnitude of regional benefits arising during the construction phase is likely to be small relative to the actual capital cost of a development. Regional benefits, in terms of sustained increases in economic activity, incomes and jobs from new farming, are expected to flow during the operational phase.

Part IV Concluding comment

Forage crop grown under centre pivot

Source: CSIRO – Nathan Dyer

10 The ‘sweet spot’ for northern development

The purpose of this report was to provide information on the costs, risks and benefits of new irrigated development in the catchment of the Victoria River, at farm to scheme and regional scales, and supply chains beyond. The overall conclusion is that large public dams would be marginal, but on-farm water sources, suitably sited, could provide good prospects for viable new enterprises. There is a range of cropping options that could be suitable, of which the most likely to be profitable (if development costs can be kept low enough) are annual horticulture, cotton, forages and peanut.

Sequential cropping systems present opportunities for combining crops that might not be profitably grown alone and/or to generate additional net revenue from the same capital investment. There are many potential cropping sequences that show agronomic potential for matching back-to-back crop requirements with Victoria catchment growing conditions, particularly on well-drained loamy soils (Kandosols in the arable areas of the southern Victoria catchment) and Dermosols with good soil structure, moderate to high chemical fertility and water-holding capacity (scattered throughout the Victoria catchment), but these would need to be developed and proven locally. Trafficability constraints and poor drainage on some areas of finer-textured clay soils (Vertosols on flood and alluvial plains) would make scheduling back-to-back crops in the same season more difficult, so would restrict the choice of crops to those with shorter growing seasons and would likely be opportunistic. The farm-scale performance of cropping systems will be determined by:

- finding markets and supply chains that can provide a sufficient price and reliability of demand, while being able to supply those markets at adequate scale and an affordable cost (see Section 2.2 and Chapter 7 of this report)
- the skill of farmers and investors in managing the operational and financial complexity of adapting crop mixes and production systems to Victoria catchment environments (including soils, water resources and climates), particularly in managing cashflows and ‘learning’ through the challenging establishment years (see parts II and III of this report)
- the nature of water resources in terms of their costs to develop, the volume and reliability of supply, and the timing of when water is available relative to optimal planting windows (particularly for sequential cropping) (see companion technical reports on river model scenario analysis (Hughes et al., 2024a), surface water storage (Yang et al., 2024) and hydrogeological assessment (Taylor et al., 2024)
- the nature of the soil resources in terms of their scale and distribution, their proximity to water sources and supply chains, their farming constraints, crops they can support with viable yields, and their costs to develop; where the best opportunities are supported by Kandosols (which provide good wet-season trafficability, but require higher fertiliser inputs and more expensive pressurised irrigations systems), Dermosols (which have good soil structure, moderate to high chemical fertility and water-holding capacity, and Vertosols (which are less expensive to develop but have poor trafficability and in some areas poor drainage in the wet season) (see companion

technical reports on digital soils mapping and land suitability (Thomas et al., 2024) and flood modelling (Karim et al., 2023), and Part III of this report).

Long supply chains and distant processing facilities have typically put northern Australia agriculture at a competitive disadvantage (relative to southern farming regions). However, some of those constraints have recently been alleviated creating new opportunities from: (i) the opening of a new cotton gin near Katherine in December 2023, providing closer processing for possible new enterprises in the Victoria catchment; (ii) recent high cotton prices, that provide a financial buffer while farmers learn to grow the crop to its full potential, and develop supply chains to process and market their product; and (iii) recently built phytosanitary facilities at Darwin Airport, which makes export of horticultural produce easier.

As market, regulatory, infrastructure and other conditions in the Victoria catchment change from those prevailing at the time this report was written, growers would be expected to adapt and respond to opportunities and challenges accordingly. Ultimately the crops (if any) that can be successfully and sustainably grown will have to find sweet spots where investors can simultaneously address all three of the following questions (Stokes et al., 2019) (Figure 10-1; Table 10-1):

- Markets: Where is the investor going to sell their produce and how are they going to set up the supply chains to get their products, at low-enough cost, from the Victoria catchment to those who want to buy them?
- Production systems: What is the investor going to grow and do they understand how this needs to be grown differently in tropical Australia (and the soils, water resources and climates of Victoria catchment environments specifically) to where they have gained their previous experience?
- Competition: Why is it better to grow the chosen product(s) in tropical Australia, relative to alternative options of growing the same product elsewhere, or growing different products in the chosen location?

There is a wide variety of potential investors in northern Australia agriculture, each of whom will come with different strengths and blind spots (Stokes et al., 2017; Stokes et al., 2023). Each may initially be drawn by an opportunity in a particularly strong area of competence for one of the three criteria above (be it a new market where they can fill an unmet demand, a crop product with particular promise, or identifying a prospect for gaining a competitive advantage within an industry) but will likely not initially be completely aware of the full scale of the challenge in one of the other areas. Successful investments have typically been able to address all three of the above criteria, while failures have not.

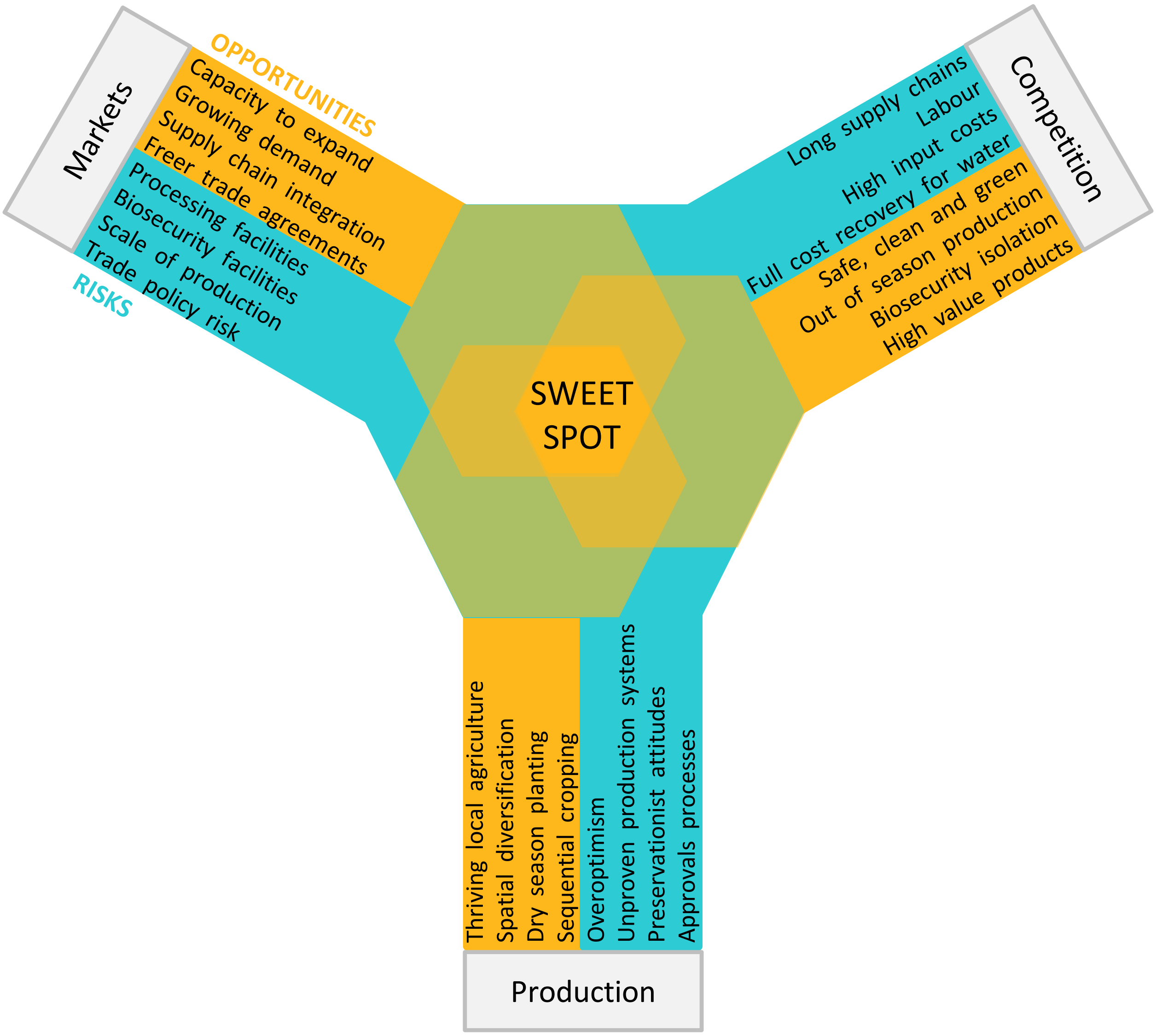

Figure 10-1 Viable irrigated agriculture investments in the Victoria catchment require a combination of capturing opportunities and mitigating risks in three critical areas: markets, production systems and competition

Adapted from Stokes et al. (2019). Details for each risk and opportunity are expanded in Table 10-1.

Table 10-1 Opportunities and risks across three key criteria for the success of irrigated development in the Victoria catchment

Adapted from Stokes et al. (2019), which provides details of the methods and supporting literature. These points are further supported by analyses and literature presented in this Assessment.

MARKETS	PRODUCTION SYSTEMS	COMPETITION
Where is the investor going to sell their produce and how are they going to set up the supply chains, at low-enough cost, to get their products to those who want to buy them?	*What is the investor going to grow and do they understand how this needs to be grown differently in tropical Australia to where they have gained their previous experience?*	*Why is it better to grow the chosen product(s) in tropical Australia, relative to alternative options of growing the same product elsewhere, or different products in the chosen location?*
Opportunities/Strengths	**Opportunities/Strengths**	**Opportunities/Strengths**
Capacity to expand	Thriving local agricultural industries	Safe, clean and green produce
Northern Australia is relatively undeveloped with capacity and natural resources to expand	Intensive agricultural businesses are growing and maturing in the NT	Gives access to markets with high health and environmental standards that some competitors are unable to meet; also meets consumer preferences in some markets
Growing demand from Asia and Middle East	Spatial diversification	Timing of seasonal production
Market analyses have identified a range of products with unmet demand that northern Australia could produce from horticulture and broadacre crops, including cotton, grain sorghum and sesame seeds	More uniform supply of agricultural products by spreading exposure to weather events, such as floods, destructive winds, drought, temperatures, climate change (e.g. offset risks for melon production concentrated in Queensland)	Out-of-season production (relative to the rest of Australia), broadens the national seasonal supply and can provide price premiums for local produce (e.g. early season mangoes from Katherine/Mataranka)
Production system/supply chain integration	Dry-season planting allows better seasonal planning	Biosecurity advantages of isolation
Opportunities to integrate agricultural production systems and supply chains with other regions/countries (e.g. live export of cattle to South-East Asia for fattening and supply chains with little refrigeration)	Planting at end of wet season in the north (vs start of wet in south) allows better seasonal planning (available soil and stored water are known at time of planting)	Remoteness from other areas growing the same crop reduces the risks of spreading diseases between them (e.g. Panama TR4 fungus in Cavendish bananas)
Freer trade agreements	Sequential cropping	High-value horticulture and aquaculture
Opportunities in 17 markets from free trade agreements, including recent agreements with Indonesia and India (with ongoing initiatives for additional potential agreements)	Advantage of tropics is *length*, not *quality*, of growing season; sequential broadacre cropping systems can make use of the longer seasons, but require tuning to local conditions (e.g. Cerrado in Brazil)	Proportionally less affected by higher costs of remoteness, and better suited to niche, small-scale, localised opportunities
Risks/Weaknesses	**Risks/Weaknesses**	**Risks/Weaknesses**
Processing facilities	Greenfield risks (overoptimism)	Length and quality of supply chains
Processors require assured scale and reliability of primary produce for investment in new processing infrastructure to be viable	An entrepreneurial spirit is required, but enthusiasm can exceed capacity and planning (e.g. under estimating development costs and time required to learn and adapt to local greenfield conditions, and over estimating farm production and profitability)	Higher transport costs and spoilage overall resulting from large distances to market and poorer quality of many regional roads and some storage/processing facilities
Biosecurity facilities for export	Novel/adapted production systems required for greenfield development	Labour availability and capacity

MARKETS	PRODUCTION SYSTEMS	COMPETITION
To meet quarantine requirements and certification for some target markets (e.g. irradiation of mangoes); as with processing facilities, this requires assured scale and reliability of primary produce and market demand	Novel elements are required to enable and adapt production systems for the particular challenges of northern agriculture (e.g. tropical vs subtropical agronomy, sequential cropping, variability in climates and prices, and biosecurity)	Intensive production has high, seasonal demands for labour relative to local population (e.g. demand in peak week of NT mango fruiting requires equivalent of ~2% of resident working population in Greater Darwin)
Scale of production	Preservationist attitudes	High input costs
Chicken-and-egg: need to achieve scale of production to cover required infrastructure costs and establish new markets and supply chains, but hard to scale production efficiently until that infrastructure is built	Attitudes from intensively developed parts of the south inappropriately exported and applied to sparsely developed north: irrigated agriculture in tropical Australia west of the Great Dividing Range only occupies about the same area as mining (both <0.1%)	Input costs are high relative to competitors (generally Australia vs international, and remote Australia vs regions closer to dominant southern markets and labour sources)
Trade policy risk (market access)	Approvals process	Full cost recovery for new public water infrastructure development
Access to foreign markets can become more restricted (e.g. live cattle export restrictions and policy changes by major trading partners)	Approvals process can be protracted, costly and inefficient: a definitive decision in a reasonable time frame, either way, provides investors with certainty	It is challenging for new irrigated development to compete on the basis of full cost recovery against existing developments where water costs are subsidised

This Assessment (including companion technical reports) has focused primarily on ‘production system’ challenges by filling knowledge gaps on the land and water resources in the Victoria catchment. This report has evaluated the farming options that could be sustainably and profitably developed on that resource base, and has provided additional supporting information for overcoming the competitive disadvantages and market constraints for northern Australia. Widespread expansion of agriculture in the Victoria catchment is unlikely to occur in the near term. However, smaller-scale opportunities will continue to emerge (as they have done throughout northern Australia before) for those able to find niches for cost savings and suitable markets, and who have the capital and capacity to persist through the challenging establishment years.

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Part V Appendices

Barramundi fish

Appendix A Aquaculture opportunities and viability

A.1 Introduction

There are considerable opportunities for aquaculture development in northern Australia given its natural advantages of a climate suited to farming valuable tropical species, large areas identified as suitable for aquaculture, political stability and proximity to large global markets. The main challenges to developing and operating modern and sustainable aquaculture enterprises are regulatory barriers, global cost competitiveness and the remoteness of much of the suitable land area. A comprehensive situational analysis of the aquaculture industry in northern Australia (Cobcroft et al., 2020) identifies key challenges, opportunities and emerging sectors. This appendix draws on a recent assessment of the opportunities for aquaculture in northern Australia (Irvin et al., 2018), summarising: the three most likely candidate species (Section A.2); an overview of production systems (Section A.3); and the financial viability of different types of aquaculture developments (Section A.4).

A.2 Candidate species

The three species with the most aquaculture potential in the catchment of the Victoria River are black tiger prawns (*Penaeus monodon*), barramundi (*Lates calcarifer*), and red claw (*Cherax quadricarinatus*). The first two species are suited to many marine and brackish water environments of northern Australia and have established land-based culture practices and well-established markets for harvested products. Prawns could potentially be cultured in either extensive (low density, low input) or intensive (higher density, higher inputs) pond-based systems in northern Australia, whereas land-based culture of barramundi would likely be intensive. Red claw is a freshwater crayfish that is currently cultured by a much smaller industry than the other two species.

Black tiger prawns

Black tiger prawns are found naturally at low abundances across the waters of the western Indo-Pacific region, with wild Australian populations making up the southernmost extent of the species. Within Australia, the species is most common in the tropical north, but does occur at lower latitudes.

Barramundi

Barramundi is the most highly produced and valuable tropical fish species in Australian aquaculture. Barramundi inhabit the tropical north of Australia from the Exmouth Gulf in WA through to the Noosa River on Queensland's east coast. It is also commonly known as the 'Asian sea bass' or 'giant sea perch' throughout its natural areas of distribution in the Persian Gulf, the western Indo-Pacific region and southern China (Schipp et al., 2007). The attributes that make barramundi an excellent aquaculture candidate are fast growth (reaching 1 kg or more in 12 months), year-round fingerling availability, well-established production methods, and hardiness (i.e. they have a tolerance to low oxygen levels, high stocking densities and handling, as well as a wide range of temperatures) (Schipp et al., 2007). In addition, barramundi are euryhaline (able to thrive and be cultured in fresh and marine water), but freshwater barramundi can have an earthy flavour.

Red claw

Red claw is a warm-water crayfish species that inhabits still or slow-moving water bodies. The natural distribution of red claw ranges from the tropical catchments of Queensland and the NT to southern New Guinea. The name ‘red claw’ is derived from the distinctive red markings present on the claws of the male crayfish. The traits of red claw that make them attractive for aquaculture production are: a simple life cycle, which is beneficial in that complex hatchery technology is not required (Jones et al., 1998); their tolerance of low oxygen levels (<2 mg/L), which is beneficial in terms of handling, grading and transport (Masser and Rouse, 1997); their broad thermal tolerance, with optimal growth achievable between 23 and 31 °C; and their ability to remain alive out of water for extended periods.

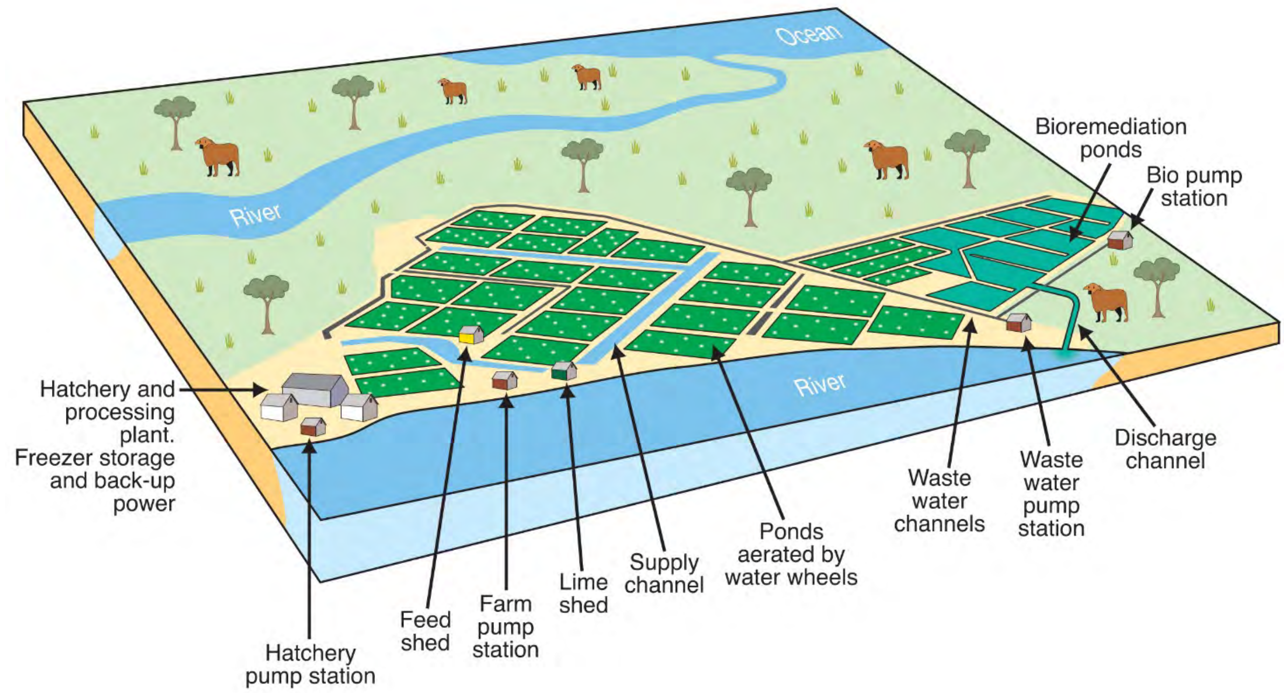
A.3 Production systems

Overview

Aquaculture production systems can be broadly classified into extensive, semi-intensive and intensive systems. Intensive systems require high inputs and expect high outputs: they require high capital outlay and have high running costs; they require specially formulated feed and specialised breeding, water quality and biosecurity processes; and they have high production per hectare (in the order of 5,000 to 20,000 kg/ha per crop). Semi-intensive systems involve stocking seed from a hatchery, routine provision of a feed, and monitoring and management of water quality. Production is typically 1000 to 5000 kg/ha per crop. Extensive systems are characterised by low inputs and low outputs: they require less sophisticated management and often require no supplementary feed because the farmed species live on naturally produced feed in open-air ponds. Extensive systems produce about half the volume of global aquaculture production, but there are few commercial operations in Australia.

Water salinity and temperature are the key parameters that determine species selection and production potential for any given location. Suboptimal water temperature (even within tolerable limits) will prolong the production season (because of slow growth) and increase the risk of disease, reducing profitability.

The primary culture units for land-based farming are purpose-built ponds. Pond structures typically include an intake channel, production pond, discharge channel and a bioremediation pond (Apx Figure A-1). The function of the pond is to be a containment structure, an impermeable layer between the pond water and the local surface water and groundwater. Optimal sites for farms are flat and have sufficient elevation to enable ponds to be completely drained between seasons. It is critical that all ponds and channels can be fully drained during the off (dry-out) season to enable machinery access to sterilise and undertake pond maintenance.



Apx Figure A-1 Schematic of marine aquaculture farm

Most production ponds in Australia are earthen. Soils for earthen ponds should have low permeability and high structural stability. Ponds should be lined if the soils are permeable. Synthetic liners have a higher capital cost but are often used in high-intensity operations, which require high levels of aeration – conditions that would lead to significant erosion in earthen ponds.

Farms use aerators (typically electric paddlewheels and aspirators) to help maintain optimal water quality in the pond, provide oxygen, and create a current that consolidates waste into a central sludge pile (while keeping the rest of the pond floor clear). A medium-sized 50-ha prawn farm in Australia uses around 4 GWh annually, with pond aeration accounting for most of an enterprise's energy use (Paterson and Miller, 2013). Back-up power capacity sufficient to run all the aerators on the farm, usually via a diesel generator, is essential to be able to cope with power failures. Extensive production systems do not require aeration in most cases.

Black tiger prawns

For black tiger prawns, a typical pond in the Australian industry would be rectangular in shape, about 1 ha in area and about 1.5 m in depth. The ponds are either wholly earthen, lined on the banks with black plastic and earthen bottoms, or (rarely in Australia) fully lined. Pond grow-out of black tiger prawns typically operates at stocking densities of 25 to 50 individuals per square metre (termed 'intensive' in this report). These pond systems are fitted with multiple aeration units (that could double from 8 to 16 units as the biomass of the prawn crop increases) (Mann, 2012).

At the start of each prawn crop, pond bottoms are dried, and unwanted sludge from the previous crop is removed. If needed, additional substrate is added. Before filling the ponds, lime is often added to buffer pH, particularly in areas with acid sulfate soils. The ponds are then filled with filtered seawater and left for about 1 week prior to postlarval stocking. Algal blooms in the water are encouraged through addition of organic fertiliser to provide shading for prawns, discourage benthic algal growth, and stimulate growth of plankton as a source of nutrition (QDPIF, 2006). Postlarvae are purchased from hatcheries and grow rapidly into small prawns in the first month after stocking, relying mainly on the natural productivity (zooplankton, copepods and algae) supported by the algal bloom for their nutrition. Approximately 1 month after the prawns are stocked, pellet feed becomes the primary nutrition source. Feed is a major cost of prawn production; around 1.5 kg of feed is required to produce 1 kg of prawns. Prawns typically reach optimal marketable size (30 g) within 6 months. After harvest, prawns are typically processed immediately, with larger farms having their own production facilities that enable grading, cooking, packaging and freezing activities.

Effective prawn farm management involves maintaining optimal water quality conditions, which becomes progressively complex as prawn biomass and the quantity of feed added to the system increase. As prawn biomass increases, so too does the biological oxygen demand required by the microbial population within the pond that is breaking down organic materials. This requires increases in mechanical aeration and water exchanges (either fresh or recycled from a bioremediation pond). In most cases water salinity is not managed, except through seawater exchange, and will increase naturally with evaporation and decrease with rainfall and flooding. Strict regulation of the quality and volume of water that can be discharged means efficient use of water is standard industry practice. Most Australian prawn farms allocate up to 30% of their productive land for water treatment by pre-release containment in settlement systems.

Barramundi

The main factors that determine productivity of barramundi farms are water temperature, dissolved oxygen levels, effectiveness of waste removal, expertise of farm staff, and the overall health of the stock. Barramundi are susceptible to a variety of bacterial, fungal and parasitic organisms. They are at highest risk of disease when exposed to suboptimal water quality conditions (e.g. low oxygen or extreme temperatures).

Due to the cost and infrastructure required, many producers elect to purchase barramundi fingerlings from independent hatcheries, moving fish straight into their nursery cycle. Regular size grading is essential during the nursery stage to minimise aggressive and cannibalistic behaviour: size grading helps to prevent mortalities and damage from predation on smaller fish, and it assists with consistent growth.

Ponds are typically stocked to a biomass of about 3 kg per 1000 L. Under optimal conditions barramundi can grow to over 1 kg in 12 months and to 3 kg within 2 years (Schipp et al., 2007). The two largest Australian aquafeed manufacturers (located in Brisbane and Hobart) each produce a pellet feed that provides a specific diet promoting efficient growth and feed conversion. The industry relies heavily on these mills to provide a regular supply of high-quality feed. Cost of feed transport would be a major cost to barramundi production in the Victoria catchment. As a carnivorous species, high dietary protein levels, with fishmeal as a primary ingredient, is required for optimal growth. Barramundi typically require between 1.2 and 1.5 kg of pelleted feed for each kilogram of body weight produced.

Warm water temperatures in northern Australia enable fish to be stocked in ponds year round. Depending on the intended market, harvested product is processed whole or as fillets and delivered fresh (refrigerated or in ice slurry) or frozen. Smaller niche markets for live barramundi are available for Asian restaurants in some capital cities.

Red claw

Water temperature and feed availability are the variables that most affect crayfish growth. Red claw are a robust species but are most susceptible to disease (including viruses, fungi, protozoa and bacteria) when conditions in the production pond are suboptimal (Jones, 1995). In tropical regions, mature females can be egg bearing year round. Red claw breed freely in production ponds, so complex hatchery technology (or buying juvenile stock) is not required. However, low fecundity and the associated inability to source high numbers of quality selected broodstock are an impediment to intensive expansion of the industry. Production ponds are earthen lined, rectangular in design and on average 1 ha in size. They slope in depth from 1.2 to 1.8 m. Sheeting is used on the pond edge to keep the red claw in the pond (they tend to migrate), and netting surrounds the pond to protect stock from predators (Jones et al., 2000).

At the start of each crop, ponds are prepared (as for black tiger prawns above), then filled with fresh water and left for about 2 weeks before stocking. During this period, algal blooms in the water are encouraged through addition of organic fertiliser. Ponds are then stocked with about 250 females and 100 males that have reached sexual maturity. Natural mating results in the production of around 20,000 advanced juveniles. Red claw are omnivorous, foraging on natural productivity such as microbial biomass associated with decaying plants and animals. Early-stage crayfish rely almost solely on natural pond productivity (phytoplankton and zooplankton) for nutrition. As the crayfish progress through the juvenile stages, the greater part of the diet changes to organic particulates (detritus) on the bottom of the pond. Very small quantities of a commercial feed are also added on a daily basis to assist with the weaning process and provide an energy source for the pond bloom. Providing adequate shelters (net bundles) is essential at this stage to improve survival (Jones, 2007). Approximately 4 months after stocking, the juveniles are harvested and graded by size and sex for stocking in production ponds.

Juveniles are stocked in production ponds at 5 to 10 per square metre. Shelters are important during the grow-out stage, with 250/ha recommended. During the grow-out phase, pellet feed becomes an important nutrition source, along with the natural productivity provided by the pond. Current commercial feeds are low cost and provide a nutrition source for natural pond productivity as much as for the crayfish. Most Australian farmers use diets consisting of 25% to 30% protein. Effective farm management involves maintaining water quality conditions within ranges optimal for crayfish growth and survival as pond biomass increases. As with barramundi, management involves increasing aeration and water exchanges, while strictly managing effluent discharges. Red claw are harvested within 6 months of stocking to avoid reproduction in the production pond. At this stage the crayfish will range between 30 and 80 g. Stock are graded by size and sex into groups for market, breeding or further grow-out (Jones, 2007).

Estimated water use

An average crop of prawns farmed in intensive pond systems (8 t/ha over 150 days) is estimated to require 127 ML of marine water, which equates to 15.9 ML of marine water for each tonne of harvested product (Irvin et al., 2018). For pond culture of barramundi (30 t/ha over 2 years), 562 ML of marine water, or fresh water, is required per crop, equating to 18.7 ML of water for each tonne of harvested fish. For extensive red claw culture (3 t/ha over 300 days), 240 ML of fresh water is required per pond crop, equating to 16 ML of water for each harvested tonne of crayfish (Irvin et al., 2018).

A.4 Aquaculture viability

This section provides a brief, generic analysis of what would be required for new aquaculture developments in the Victoria catchment to be financially viable. The analyses follow the same approach as those conducted in Irvin et al. (2018) but have been updated. First, indicative costs are provided for a range of four possible aquaculture enterprises that differ in species farmed, scale and intensity of production. The cost structure of the enterprises is based on established tools available from the Queensland Government for assessing the performance of existing or proposed aquaculture businesses (https://publications.qld.gov.au/dataset/agbiz-tools-fisheries-aquaculture). Based on the ranges of indicative capital and operating costs for the four types of enterprises, gross revenue targets that a business would need to attain to be commercially viable are then calculated.

Enterprise-level costs for aquaculture development

Costs of establishing and running a new aquaculture business are divided here into the initial capital costs of development and ongoing operating costs. The four enterprise types analysed were chosen to portray some of the variation in cost structures between potential development options, not as a like-for-like comparison between different types of aquaculture (Apx Table A-1).

Capital costs include all land development costs, construction, and plant and equipment, accounted for in the year production commences. The types of capital development costs are largely similar across the aquaculture options with costs of constructing ponds and buildings dominating the total initial capital investment. Indicative costs were derived from Guy et al. (2014), and consultation with experts familiar with the different types of aquaculture, including updating to December 2023 dollar values (Apx Table A-1).

Operating costs cover both overheads, which do not change with output, and variable costs that increase as the yield of produce increases. Fixed overhead costs in aquaculture are a relatively small component of the total costs of production. Overheads consist of costs relating to licensing, approvals and other administration (Apx Table A-1).

The remaining operating costs are variable (Apx Table A-1). Feed, labour and electricity typically dominate the variable costs. Aquaculture requires large volumes of feed inputs, and the efficiency with which this feed is converted to marketed produce is a key metric of business performance. Labour costs consist of salaries of permanent staff and casual staff who are employed to cover intensive harvesting and processing activities. Aerators require large amounts of energy, increasing as the biomass of produce in the ponds increase, which accounts for the large costs of electricity. Transport, although a smaller proportional cost, is important because this puts remote locations at a disadvantage relative to aquaculture businesses that are closer to feed suppliers and markets. In addition, transport costs may be higher at times if roads are cut (requiring much more expensive air freight or alternative, longer road routes) or if the closest markets become oversupplied. Packing is the smallest component of variable costs in the breakdown categories used here.

Revenue for aquaculture produce typically ranges from $10 to $25/kg (on a harvested mass basis), but prices vary depending on the quality and size classes of harvested animals and how they are processed (e.g. live, fresh, frozen or filleted). Farms are likely to deliver a mix of products targeted to the specifications of the markets they supply. Note that the mass of sold product may be substantially lower than the harvested product (e.g. fish fillets are about half the mass of harvested fish), so prices of sold product may not be directly comparable to the costs of production below (which are on a harvest mass basis) (Apx Table A-1).

Apx Table A-1 Indicative capital and operating costs for a range of generic aquaculture development options

Costs are provided both per hectare of grow-out pond and per kilogram of harvested produce, although capital costs scale mostly with the area developed and operating costs scale mainly with crop yield at harvest. Capital costs have been converted to an equivalent annualised cost assuming a 10% discount rate and that a quarter of the developed infrastructure was assets with a 15-year life span and the remainder had a 40-year life span. Indicative breakdowns of cost components are provided on a proportional basis. Costs derived from Guy et al. (2014) and adjusted to December 2023 dollar values.

PARAMETER	UNITS	PRAWN (EXTENSIVE)	PRAWN (INTENSIVE)	BARRAMUNDI	RED CLAW (SMALL SCALE)
Scale of development					
Grow-out pond area	ha	20	100	30	4
Total farm area	ha	25	150	100	10
Yield at harvest	t/y	30	800	600	32
Yield at harvest per pond area	t/ha/y	1.5	8.0	20.0	3.0
Capital costs of development (scale with area of grow-out ponds developed)					
Land and buildings	%	56	26	23	30
Vehicles	%	5	2	2	11
Pond-related assets	%	27	66	70	41
Other infrastructure and equipment	%	11	6	5	17
Total capital cost (year 0)	$/ha	74,000	142,000	147,000	163,000
Equivalent annualised cost	$/kg	5.41	1.94	0.81	5.95
	$/ha/y	8,108	15,558	16,106	17,859
Operating costs (vary with yield at harvest, except overheads)					
Nursery/juvenile costs	%	12	9	7	1
Feed costs	%	0	26	30	8
Labour costs	%	47	13	12	57
Electricity costs	%	16	24	30	9
Packing costs	%	2	4	3	2
Transport costs	%	6	16	16	11
Overhead costs (fixed)	%	17	8	1	12
Total annual operating costs	$/kg	19.31	12.47	12.46	17.80
	$/ha/y	28,966	99,783	249,211	53,402
Total costs of production					
Total annual cost	$/kg	24.72	14.42	13.27	23.75
	$/ha/y	37,100	115,300	265,300	71,300

Commercial viability of new aquaculture developments

Capital and operating costs differ between different types of aquaculture enterprises (Apx Table A-2), but these costs may differ even more between locations (depending on case-specific factors such as remoteness, soil properties, distance to water source and type of power supply). Furthermore, there can be considerable uncertainty in some costs, and prices paid for produce can fluctuate substantially over time.

Apx Table A-2 Gross revenue targets required to achieve target internal rates of return (IRRs) for aquaculture developments with different combinations of capital costs and operating costs

All values are expressed per hectare of grow-out ponds in the development. Gross revenue is the yield per hectare of pond multiplied by the price received for produce (averaged across products and on a harvest mass basis). Capital costs were converted to an equivalent annualised cost assuming a quarter of the developed infrastructure was assets with a 15-year life span and the remainder had a 40-year life span. Targets would be higher after taking into account risks such as initial learning and market fluctuations. IRR = internal rate of return.

OPERATING ($/ha/y)	GROSS REVENUE REQUIRED TO ACHIEVE TARGET IRR ($/ha/y)								
	Capital costs of development ($/ha)								
	60,000	**70,000**	**80,000**	**90,000**	**100,000**	**110,000**	**125,000**	**150,000**	**175,000**
7% target IRR									
20,000	25,022	25,859	26,696	27,533	28,371	29,208	30,463	32,556	34,648
50,000	55,022	55,859	56,696	57,533	58,371	59,208	60,463	62,556	64,648
100,000	105,022	105,859	106,696	107,533	108,371	109,208	110,463	112,556	114,648
150,000	155,022	155,859	156,696	157,533	158,371	159,208	160,463	162,556	164,648
100,000	105,022	105,859	106,696	107,533	108,371	109,208	110,463	112,556	114,648
200,000	205,022	205,859	206,696	207,533	208,371	209,208	210,463	212,556	214,648
250,000	255,022	255,859	256,696	257,533	258,371	259,208	260,463	262,556	264,648
10% target IRR									
20,000	26,574	27,669	28,765	29,861	30,956	32,052	33,695	36,434	39,174
50,000	56,574	57,669	58,765	59,861	60,956	62,052	63,695	66,434	69,174
100,000	106,574	107,669	108,765	109,861	110,956	112,052	113,695	116,434	119,174
150,000	156,574	157,669	158,765	159,861	160,956	162,052	163,695	166,434	169,174
100,000	106,574	107,669	108,765	109,861	110,956	112,052	113,695	116,434	119,174
200,000	206,574	207,669	208,765	209,861	210,956	212,052	213,695	216,434	219,174
250,000	256,574	257,669	258,765	259,861	260,956	262,052	263,695	266,434	269,174
14% target IRR									
20,000	28,776	30,238	31,701	33,163	34,626	36,089	38,283	41,939	45,596
50,000	58,776	60,238	61,701	63,163	64,626	66,089	68,283	71,939	75,596
100,000	108,776	110,238	111,701	113,163	114,626	116,089	118,283	121,939	125,596
150,000	158,776	160,238	161,701	163,163	164,626	166,089	168,283	171,939	175,596
100,000	108,776	110,238	111,701	113,163	114,626	116,089	118,283	121,939	125,596
200,000	208,776	210,238	211,701	213,163	214,626	216,089	218,283	221,939	225,596
250,000	258,776	260,238	261,701	263,163	264,626	266,089	268,283	271,939	275,596

Given the variation among possible aquaculture developments in the Victoria catchment, a generic approach was taken to determine what would be required for new aquaculture enterprises to become commercially viable. The approach used here was to calculate the gross revenue that an enterprise would have to generate each year to achieve a target internal rate of return (IRR) for given operating costs and development costs (both expressed per hectare of grow-out ponds). Capital costs were converted to annualised equivalents on the assumption that developed assets equated to a mix of 25% 15-year assets and 75% assets with a 40-year life span (using a discount rate matching the target IRR). The target gross revenue is the sum of the annual operating costs and the equivalent annualised cost of the infrastructure development (Apx Table A-2).

In order for an enterprise to be commercially viable, the volume of produce grown each year multiplied by the sales price of that produce would need to match or exceed the target values provided above. For example, a proposed development with capital costs of $90,000/ha and operating costs of $200,000 per hectare per year would need to generate gross revenue of $213,695 per hectare per year to achieve a target IRR of 10% (Apx Table A-2). If the enterprise received $12/kg for produce (averaged across product types, on a harvest mass basis), then it would need to sustain mean long-term yields of 18 t/ha (= $213,695 per hectare per year ÷ $12/kg × 1 t/1000 kg) from the first harvest. However, if prices were $20/kg, mean long-term yields would require 11 t/ha (= 213,695 per hectare per year ÷ $20/kg × 1 t/1000 kg) for the same $125,000 capital costs per hectare, or only 6 t/ha harvests if the capital costs were lowered to $100,000/ha. Target revenue would be higher after taking into account risks, such as learning and adapting to the particular challenges of a new location and periodic setbacks that could arise from disease, climate variability, changes in market conditions or new legislation.

Key messages

From this analysis, a number of key points about achieving commercial viability in new aquaculture enterprises are apparent:

- Operating costs are very high, and the amount spent each year on inputs can exceed the upfront (year zero) capital cost of development (and the value of the farm assets). This means that the cost of development is a much smaller consideration for achieving profitability than ongoing operations and costs of inputs.
- High operating costs also mean that substantial capital reserves are required, beyond the capital costs of development, as there will be large cash outflows for inputs in the start-up years before revenue from harvested product starts to be generated. This is particularly the case for larger size classes of product that require multi-year grow-out periods before harvest. Managing cashflows would therefore be an important consideration at establishment and as yields are subsequently scaled up.
- Variable costs dominate the total costs of aquaculture production, so most costs will increase as yield increases. This means that increases in production, by itself, would contribute little to achieving profitability in a new enterprise. What is much more important is increasing production efficiency, such as feed conversion rate or labour efficiency, so inputs per unit of produce are reduced (and profit margins per kilogram are increased).
- Small changes in quantities and prices of inputs and produce would have a relatively large impact on net profit margins. These values could differ substantially between different locations (e.g. varying remoteness, available markets, soils and climate) and can depend on the

experience of managers. Even small differences from the indicative values provided above could render an enterprise unprofitable.

- Enterprise viability would therefore be very dependent on the specifics of each particular case and how the learning, scaling up and cashflow were managed during the initial establishment years of the enterprise. It would be essential for any new aquaculture development in the Victoria catchment to refine the production system and achieve the required levels of operational efficiency (input costs per kilogram of produce) using just a few ponds before scaling any enterprise.

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Appendix B Mining and petroleum

Author: Kaylene Camuti, James Cook University

Mining includes extraction of minerals (including coal), petroleum and gas, and quarrying. The largest contributor to the NT's Gross State Product in 2022–23 (28%) was the mining (minerals) industry, providing $4.4 billion to the NT economic output (Department of Treasury and Finance, 2023). Petroleum production (including onshore crude oil, liquefied natural gas as well as condensate and natural gas) also contribute significantly to the NT's economic output, and expenditure on exploration totalled $228.1 million in 2023 – an increase of 14.1% from 2022. Mining alone employed 4093 people in 2022–23, accounting for 3% of total NT employment. These industries are key to the NT's economic future (NT Government, 2023) with the need for critical minerals set to build (Apx Table B-1). Mining, however, is not among the major industries of employment in the Victoria catchment (Table 2-3).

Water is central to the mining and petroleum industries, with 10% of all water abstracted in Australia used for industrial purposes (including mining). The main uses for which water is abstracted are agricultural (70%) and urban (20%) (ABS, 2020). Indicative volumes of water consumption by commodity are presented in Apx Table B-2. Water infrastructure associated with mining (small- to large-scale) includes but is not limited to purpose-built dams for water supply; transport and processing; tailings dams; and de-watering practices.

B.1 Overview

Mining practices are well established in Australia. Records indicate that before European settlement Indigenous Peoples quarried different types of stone (particularly gurabaan) and trading materials. Following European settlement were periods of rapid population and industrial growth during the mineral rushes, particularly the gold rushes of the 1850s (Australian Museum, 2024). The first discovery of a petroleum-related product in Australia is attributed to the crew of HMS *Beagle* in 1839, who described a bituminous material in a water well near the tidal extent of the Victoria River in the NT (Resources Victoria, 2022). The mining and petroleum industries, and associated exploration activities, are major contributors to Australia's economy through exports, revenue, taxes, investment and jobs (APPEA, 2023).

In February 2024 the Australian Government released an updated list of Australia's critical minerals (Department of Industry, Science and Resources, 2024) to include minerals:

- essential to Australia's modern technologies, economies and national security, specifically the priority technologies set out in the *Critical Minerals Strategy 2023–2030* (Department of Industry, Science and Resources, 2023)
- for which Australia has geological potential for resources
- in demand from strategic international partners
- vulnerable to supply chain disruption.

The Strategic Materials List, also updated in February 2024, includes minerals:

- important for the global transition to net zero and broader strategic applications, specifically the priority technologies set out in the Critical Minerals Strategy
- for which Australia has geological potential for resources
- in demand from strategic international partners.

The supply chains for strategic materials are not currently vulnerable enough for these materials to meet the criteria for the Critical Minerals List (Department of Industry, Science and Resources, 2024).

The NT Government's program 'Resourcing the Territory' (https://resourcingtheterritory.nt.gov.au) aims to attract and support increased investment in exploration for critical minerals. The program provides high-quality geoscience data to explorers and grant funding to support eligible industry exploration programs (NT Geological Survey, 2023).

Critical minerals and strategic materials targeted by recent and current exploration programs in the Victoria catchment include copper, zinc, nickel, vanadium, manganese, platinum and palladium (Apx Table B-1) (NT Government Geoscience and Mining Exploration System, 2012, 2022a, 2022b; Transition Minerals, 2023).

Global demand for refined copper has been forecast to rise steadily to 2030 (Apx Figure B-1). A 2021 report by the Minerals Council of Australia notes that drivers of demand include the shift towards zero-emissions energy sources, increased spending on consumer electronics in emerging markets, higher urbanisation rates and growth in the use of electric vehicles (Minerals Council of Australia, 2020).

The Minerals Council of Australia reports that the outlook for zinc is linked to growth in galvanised steel products, with global demand forecast to rise gradually to 2030 (Apx Figure B-1) (Minerals Council of Australia, 2020). A potential significant future use may be in zinc-based batteries, which are being offered as alternatives to lithium batteries for grid storage (Crownhart, 2023).

The demand for nickel is forecast to grow to 2030 due to demand for stainless steel, and the rising demand for battery-grade nickel, with the battery sector predicted to consume more than 1 Mt of nickel/year (Apx Figure B-1) (Minerals Council of Australia, 2020).

Vanadium demand is largely driven by its inclusion in steel production, but the growing demand for energy storage has seen increasing interest in the use of vanadium in rechargeable batteries for use in grid-scale applications. Vanadium is also used to produce ceramics and electronics, textile dyes, fertilisers and synthetic rubber, in welding, and in alloys used in nuclear engineering and superconductors (Geoscience Australia, 2024; Project Blue, 2023).

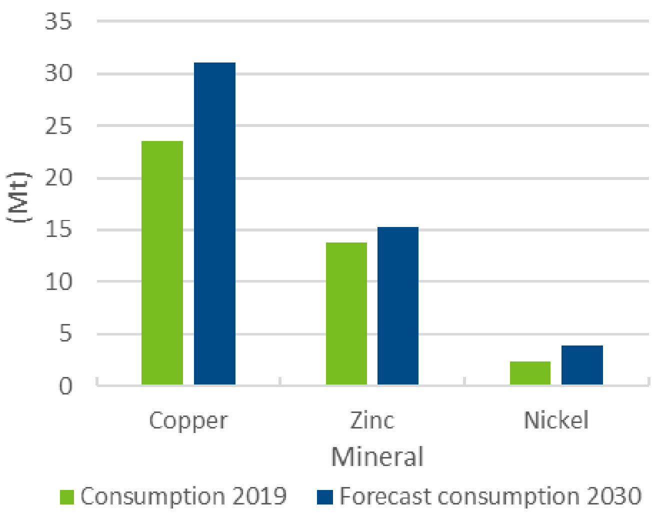
Manganese is Australia's most mined metal (in tonnes) after iron, aluminium and copper. Most manganese is used as an alloying agent in the production of steel; it is also used in the production of rechargeable electric vehicle batteries, and the growth in battery technology and demand is stimulating interest in the metal (Summerfield, 2020).

Platinum and palladium are two of the platinum group elements used in catalytic converters and as catalysts in renewable energy production (Geoscience Australia, 2024; Lasley, 2023; World Platinum Investment Council, 2022).

Apx Table B-1 Critical mineral status and strategic material status for commodities identified as mineral occurrences in the Victoria catchment, and examples of metals targeted during exploration activities

COMMODITY	CRITICAL MINERAL STATUS†	STRATEGIC MATERIAL STATUS†
Amethyst‡		
Barite‡		
Cobalt*	Y	
Copper‡		Y
Diamond‡		
Gold§		
Iron ore‡		
Lead‡		
Nickel*	Y	
Manganese‡	Y	
Platinum§	Y	
Palladium*	Y	
Prehnite‡		
Titanium‡	Y	
Vanadium*	Y	
Zinc‡		Y
Zirconium§	Y	

†Australian Government Department of Industry, Science and Resources. Australia's Critical Minerals List and Strategic Materials List, 20 February 2024 (Department of Industry, Science and Resources, 2024).
‡Main commodity from Mineral Occurrence Database (MODAT), NT Geological Survey Database (MODAT, 2024).
§Minor associated commodity from MODAT, NT Geological Survey Database (MODAT, 2024).
*Example of target metal for mineral exploration activities over the past two decades (NT Government Geoscience and Mining Exploration System, 2012; Transition Minerals, 2023).



Apx Figure B-1 Forecast global growth in consumption for copper, zinc and nickel

Source: Minerals Council of Australia (2020)

B.2 Water use and mining

Water is used by the minerals industry for many purposes (Prosser et al., 2011), which can include:

- transport of ore and waste in slurries and suspension
- separation of minerals by chemical or physical processes
- cooling systems for power generation
- dust suppression
- washing equipment
- potable water for areas that house mining staff.

Water is also extracted or 'used' during de-watering at mines that extend below the water level. Petroleum companies, which use relatively small volumes of water, produce water as a by-product of extraction. Water extracted during de-watering or as a by-product of petroleum extraction must be safely discharged and may need treatment.

Water consumption at mining operations is highly variable. The variations are due to a range of factors including different mining methods, ore types, ore grades, processing treatments and different definitions of water usage. The key variables that influence direct water consumption for metal production processes are the grade of the ore being processed, the tailings solids density and the rate of re-use or recycling within concentration facilities.

The processing of mineral ores to produce metal concentrates is usually carried out at the site of the mining operation. The overall water balance on a site is highly dependent on climate conditions, which affect water availability and inflows into the site, and the ability to re-use and recycle water within process facilities (Northey and Haque, 2013). While not mined in the Victoria catchment, coal is by far the largest user of water in the mining sector. The water used by mining enterprises does not need to be of potable quality.

The water consumption values in Apx Table B-2 are from a dataset compiled from an extensive global literature review by Meissner (2021), which noted the wide variation of water consumption values reported for many commodities. The dataset includes minimum and maximum values as well as calculated mean specific water consumption values/tonne of metal equivalent in the concentrates or refined metals (Meissner, 2021).

Because water is typically a very small fraction of total input cost, and mining produces high-value products, mining enterprises usually develop their own water supplies, which are often regulated separately to the water entitlement system (Prosser et al., 2011). Based on the mineral occurrences in the Victoria catchment (Apx Figure B-2), potential water demands by mining are likely to be modest.

Apx Table B-2 Global water consumption in the mining and refining of selected metals

PROCESSING STAGE	MEAN WATER CONSUMPTION (m³/tonne of metal)	RANGE OF WATER CONSUMPTION (m³/tonne of metal)
Copper concentrate†	43.235	9.673–99.550
Lead concentrate†	6.597	0.528–11.754
Zinc concentrate†	11.93	11.07–24.65
Manganese concentrate†	1.404	1.390–1.410
Uranium concentrate (U_3O_8)†	2746	46.2–8207
Gold metal‡	265,861	79,949–477,000
Platinum metal‡	313,496	169,968–487,876
Palladium metal‡	210,713	56,779–327,874

†Metal concentrates are typically produced at the site where the ore is mined.
‡Includes mining, smelting and refining of pure metals, assuming mining and processing are all located within a single region or separate regions but with similar water characteristics.

Source: Meissner (2021)

Regulatory instruments for water development are discussed in Section B.4.

B.3 Current Victoria catchment setting

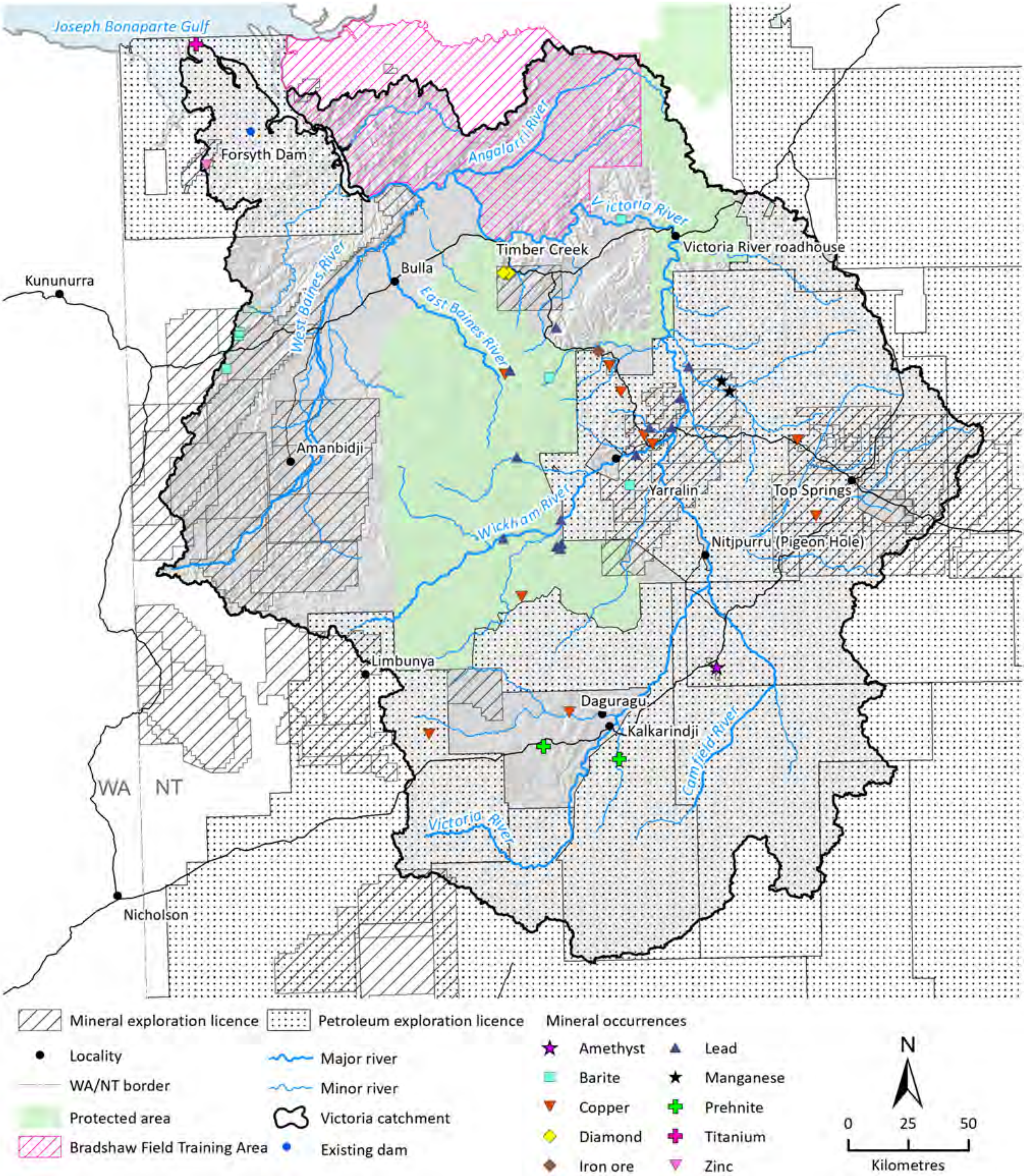
The Victoria catchment has a number of mineral occurrences, mainly in the centre of the catchment as well as on the western margin (Apx Figure B-2). Commodities identified in the mineral occurrences are mainly lead and copper (centrally located), manganese in the east and zinc in the far north-west. Several occurrences of barite have been identified in the catchment.

Approximately 61% of the Victoria catchment is covered by either mineral or petroleum exploration licences. Exploration tenements are largely outside Judbarra National Park and the Bradshaw Field Training Area. Mineral exploration tenements are located mostly through the middle of the catchment in the east and the west, and tenements for petroleum exploration are located mainly in the east and south (Apx Figure B-2).

Two boreholes were drilled for petroleum exploration in the north-west of the catchment – one in 1984 and one in 2014 – but no hydrocarbons were reported (NT Government,2024a).

Target metals for mineral exploration activities over the past two decades include nickel, platinum group elements (platinum and palladium), vanadium, zinc and manganese (NT Government Geoscience and Mining Exploration System, 2012, 2022a, 2022b; Transition Minerals, 2023).

No mine or petroleum projects are currently operating in the Victoria catchment.



Apx Figure B-2 Main commodity mineral occurrences and exploration tenements in the Victoria catchment

Source: Mineral Occurrence Database (MODAT), NT Geological Survey Database (MODAT, 2024).

B.4 Regulatory frameworks and reforms

The NT Government, with the aim of achieving economic, social and environmental goals, has regulatory mechanisms in place for governance of development, including operational requirements. These cover many aspects of proposed developments from clearing native vegetation and building approvals to ongoing environmental monitoring and reporting obligations. An overview of regulatory instruments applicable to the mining and petroleum industries relating to water development and the environment is presented in the companion technical report on regulatory requirements for land and water development (Speed and Vanderbyl, 2024) and water planning arrangements (Vanderbyl, 2024).

Environmental reforms

In November 2023, following a period of consultation and feedback, (via: public consultation; individual members of the public; environment groups; mining companies; industry associations; land councils; special interest groups: https://haveyoursay.nt.gov.au/environmental-reforms) the NT Government passed reforms to the Northern Territory *Environment Protection Act 2019* (NT Government, 2024b). The reforms aim to improve the environmental management of mining activities and introduce a risk-based licensing system, extend compliance and enforcement powers under the Act, and consolidate environmental impact management under one licence (NT Government, 2023). Relevant guidance material is being updated, and amendments commenced in early March 2024 (NT Government, 2024b).

Under the current system an exploration, mining or extractive activity that could have a significant impact on the environment may need to undergo an environmental impact assessment (EIA) through the NT Environment Protection Authority (NT EPA) (NT Government, 2024c).

An EIA must address the NT EPA environmental factors and objectives relevant to the proposed activity. These are classified under five themes: land, water, sea, air and people (NT Environment Protection Authority, 2021).

Water development

Several aspects of mining activities can affect surface and groundwater resources (Office of the Queensland Mine Rehabilitation Commissioner, 2022), including:

- permanent or temporary diversion of waterways or overland flow
- construction of dams or weirs for storage of raw or mine-affected water
- de-watering of aquifers during mining, and long-term rebound after mining
- capture and release of mine-affected water from a mine lease area.

The factors to be considered for an EIA when addressing impacts on water are hydrological processes, inland water environmental quality and aquatic ecosystems (NT Environment Protection Authority, 2022).

Regulatory framework for legacy or abandoned mines

The NT Government considers legacy mines to be areas where mining activities have occurred but there is no financial security to cover costs associated with site rehabilitation (NT Government, 2024d, 2024e). As part of the NT Government's legacy mines and remediation projects, mining operators in the NT pay an annual levy to support a Mining Remediation Fund to address the impacts of legacy mines (NT Government, 2024f, 2024g). In November 2023 the NT Government passed the Legacy Mines Remediation Bill 2023 to provide a new regulatory framework for the Mining Remediation Fund (NT Government, 2024b).

The NT Government Small Mines Safety Program addresses risks to public safety from early mines. The impacts of these small mines are commonly associated with mine workings or open shafts (NT Government, 2024h).

The NT Government's legacy mines webpage does not identify any legacy mines in the Victoria catchment undergoing remediation (NT Government, 2024d).

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Contact us

1300 363 400
+61 3 9545 2176
csiroenquiries@csiro.au
www.csiro.au

For further information

Environment
Dr Chris Chilcott
+61 8 8944 8422
chris.chilcott@csiro.au

Environment
Dr Cuan Petheram
+61 467 816 558
cuan.petheram@csiro.au

Agriculture and Food
Dr Ian Watson
+61 7 4753 8606
Ian.watson@csiro.au