Proposed methods report for the Victoria catchment

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

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CSIRO Victoria River Water Resource Assessment acknowledgements

This report was funded through the National Water Grid Authority's Science Program, which sits within the Australian Government's Department of Climate Change, Energy, the Environment and Water.

Aspects of the Assessment have been undertaken in conjunction with the Northern Territory 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 Authority (Department of Climate Change, Energy, the Environment and Water); NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Qld Department of Agriculture and Fisheries; Qld 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 Authority (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Cattlemen's Association; NT Department of Environment, Parks Australia; Parks and Water Security; NT Department of Industry, Tourism and Trade; Regional Development Australia; NT Farmers; NT Seafood Council; Office of Northern Australia; Roper Gulf Regional Council Shire

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 its release.

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

Plant life in a lagoon in the Northern Territory. Source: Geoff Whalan

Director’s foreword

Sustainable regional development is a priority for the Australian and Northern Territory governments. Across northern Australia, however, there is a scarcity of scientific information on land and water resources to complement local information held by Indigenous owners and landholders.

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

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 provide data and insight to support consideration of the use of land and water resources for development in the Victoria River catchment. While the Assessment focuses mainly on the potential for agriculture, the detailed information provided on land and water resources, their potential uses and the impacts of those uses are relevant to a wider range of regional-scale planning considerations by Indigenous owners, landholders, citizens, investors, local government, the Northern Territory and Australian governments.

Importantly, the Assessment will not recommend one development over another, nor assume any particular development pathway. 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.

C. Chilcott

Chris Chilcott

Project Director

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Note: Assessment team as at 1 June 2021. All contributors are affiliated with CSIRO unless indicated otherwise. CSIRO contributors are part of the Victoria, Roper and/or Southern Gulf Water Resource Assessment. Activity Leaders are underlined.

[1]Northern Territory Government; [2]Charles Darwin University

Shortened forms

SHORT FORM	FULL FORM
AHD	Australian Height Datum
APSIM	Agricultural Production Systems sIMulator
AWRA-L	Australian Water Resources Assessment – Landscape
AWRA-R	Australian Water Resource Assessment – River model
BE	barometric efficiency
BoM	Bureau of Meteorology
BRF	barometric response functions
CLEM	Crop Livestock Enterprise Model
cLHS	Latin hypercube sampling
CMB	chloride mass balance
CSSHREC	CSIRO Social Science Human Research Ethics Committee (CSSHREC)
DCF	Dook Creek Formation
DEM	digital elevation model
DEPWS	Northern Territory Government Department of Environment, Parks and Water Security
DES	Department of Environment and Science
DRDMW	Department of Regional Development, Manufacturing and Water
DSM	digital soil mapping
ETa	actual evapotranspiration
EVI	enhanced vegetation index
FAO	Food and Agriculture Organization of the United Nations
FSL	full supply level
GAB	Great Artesian Basin
GBA	Geological and Bioregional Assessment
GCM	global climate model
GDE	groundwater-dependent ecosystems
GIS	geographic information system
GM	gross margin
GRASP	Grass Production Model
GRF	Gilbert River Formation
GVMI	global vegetation moisture index
IPCC	Intergovernmental Panel on Climate Change
LiDAR	light detection and ranging
MODIS	Moderate Resolution Imaging Spectroradiometer
MRT	mean residence time

SHORT FORM	FULL FORM
NABSA	North Australian Beef Systems Analyser
NASY	Northern Australia Sustainable Yields Project
NAWRA	Northern Australia Water Resource Assessment
NT	Northern Territory
PBC	prescribed body corporate
SAR	Synthetic Aperture Radar
SGG	soil generic group
SRTM	Shuttle Radar Topography Mission
SVAT	soil vegetation atmosphere transfer
SWL	standing water levels
TDS	total dissolved solids
TLA	Tindall Limestone Aquifer
WA	Western Australia
WOfS	Water Observations from Space
WRA	Water Resource Assessment

Units

UNIT	DESCRIPTION
µS	microsecond
cm	centimetre
GL	gigalitre (1,000,000,000 litres)
km	kilometre (1000 metres)
L	litre
m	metre
mBGL	metres below ground level
mg	milligrams
ML	megalitre (1,000,000 litres)

Preface

Sustainable regional development is a priority for the Australian, Western Australian, Northern Territory and Queensland governments. Governments and many rural communities in northern Australia see irrigated agriculture as a means of reversing the long-term trend in population decline and as a critical element of broader regional development aspirations, with the National Farmers' Federation recently aspiring for the value of Australian agriculture to exceed $100 billion by 2030. This belief is supported by evidence from the southern Murray–Darling Basin, where studies have shown that irrigation production generates a level of economic and community activity that is three to five times higher than would be supported from rainfed (dryland) production.

Development of northern Australia is not a new idea; there is a long history of initiatives to develop cultivated agriculture in the tropical north of Australia. Many of these attempts have not fully realised their goals, for a range of reasons. Most recently, it was highlighted that although northern Australia's environment poses challenges for irrigated agriculture, the primary reason that many of the schemes did not fully realise their goals is that they had insufficient capital to overcome the failed years that inevitably accompany every new irrigation scheme. The only large schemes still in operation in northern Australia had substantial government financial support at the construction phase, as well as ongoing support during establishment and learning phases.

Northern Australia, however, is now seen to be located in the right place at the right time. Between 2022 and 2050, the world's population is projected to grow from 8 to 10 billion people, and growth in food and fibre production is needed to meet an anticipated increase in demand.

The majority of this growth is projected to occur in the tropics, particularly sub-Saharan Africa and South-East Asia. With two-thirds of the world's food insecurity in Asia, sharp upward price movements in food have been identified as having the potential to result in political and social unrest. At the same time, it is projected that Asia will become home to the majority of the world's middle class, which will result in an increasing demand for high-quality food produce.

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

Most of northern Australia's land and water resources have not been mapped in sufficient detail to support reliable resource allocation, mitigate investment or environmental risks, or provide policy settings that can support such decisions. Better data are required to enable private investment and government expenditure on development to be soundly targeted and designed, to account for intersections between existing and potential resource users, and to ensure that net development benefits are maximised.

In 2013, the Australian Government commissioned CSIRO to undertake the Flinders and Gilbert Agricultural Resource Assessment in north Queensland, and then in 2016 the Northern Australia Water Resource Assessment (NAWRA) in three priority areas – the Fitzroy catchment (WA), four small catchments between Darwin and Kakadu known collectively as the 'Darwin catchments' (NT) and the Mitchell catchment (Queensland). A similar assessment is currently being undertaken in the Roper River catchment (NT). These assessments developed fundamental soil and water datasets and provided a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of agricultural development in five catchments of northern Australia. The assessments provide a blueprint of the data and analysis required to identify and support actionable development opportunities in northern Australia. The outcome of the assessments was to reduce the uncertainty of investors and regulators, and to give the base information to allow development to occur in a sustainable manner. The work in the Victoria catchment covers an area of about 80,000 km^2 (third largest catchment in northern Australia). Acquiring a similar level of data and insight across northern Australia's more than 3 million km^2 would require more time and resources than are currently available.

As a consequence, the 2015 'Our North, Our Future: White Paper on Developing Northern Australia' prioritised about a dozen regions in northern Australia where more detailed water and agriculture resource assessments should be undertaken. One of the regions identified was the Victoria catchment. The information from this Assessment will:

- evaluate the soil and water resources
- identify and evaluate water capture and storage options, and supply reliability
- identify and test the commercial viability of agricultural opportunities, including irrigated agriculture, aquaculture and forestry
- assess potential environmental, social and economic impacts and risks.

Executive summary

The Victoria River Water Resource Assessment will provide a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water resource development in the Victoria catchment (NT). The Assessment seeks to:

- identify and evaluate potential water capture and surface and groundwater storage opportunities
- evaluate the climate, soil and water resources
- identify and assess the commercial viability of irrigated agricultural and horticulture opportunities, and other uses of the available water
- assess potential environmental, social, economic and cultural (including Indigenous water values) impacts and risks of water resource and irrigation development.

In addition, each Assessment is designed to:

- address explicitly the needs and aspirations of local development
- meet the information needs of governments as they assess sustainable and equitable management of public resources, with due consideration of environmental and cultural issues
- meet the due diligence requirements of private investors by exploring questions of profitability and income reliability of agricultural and other developments.

The objective of this report is to broadly outline the methods proposed for the Assessment. The purpose is to openly communicate the scope of the Assessment and the proposed methods to a wide range of stakeholders, to allow them to provide feedback and engage with the Assessment team. The report also provides a mechanism for the Assessment team to acquire feedback on the proposed methods, to ensure that they are fit for purpose. The actual methods that the Assessment will use may differ as more information becomes available and local nuances are better understood. The final methods will be documented in technical detail in the final technical reports.

The Assessment comprises the following interrelated activities, which are discussed below.

Availability of water

The availability of surface water across the Victoria catchment will primarily be assessed using three types of hydrological models: (i) a conceptual rainfall-runoff model (Sacramento), (ii) river system model, and (iii) hydrodynamic model (MIKE FLOOD) (see surface water hydrology activity, Chapter 3). The conceptual rainfall-runoff model will be used to quantify water fluxes across the Victoria catchment. These fluxes will be used as inputs to the river system and hydrodynamic models. River system models are well suited to modelling regulated systems and exploring how streamflow may be perturbed under future development, management and climate scenarios. The river system modelling provides an integrating framework for analysing the opportunities by which surface water development may enable regional development. Hydrodynamic models are physically based models that explicitly model the movement of water across the landscape. These models will be used to examine how large and small flood events, and the connectivity of offstream wetlands and the main river channel, are affected by future development and climate scenarios. Interim digital land suitability maps (Chapter 4), potential dam locations (Chapter 7) and key ecological assets (Chapter 9) will inform the structure of the river system model. The latter will inform the domain of the hydrodynamic model.

The groundwater hydrology activity (Chapter 5) seeks to provide a comprehensive assessment of the most promising intermediate to regional-scale aquifers in the Victoria catchment, in the context of identifying opportunities for, and risks associated with, groundwater resource development to enable regional development. The groundwater activity will conduct a combination of desktop, field and modelling investigations based on the current level of existing information for different aquifers across the catchment. Investigations will be targeted to the most prospective aquifers and/ or geological formations. Investigations will likely: (i) assess the important hydrogeological attributes (i.e. spatial extent, saturated thickness, water quality, bore yield, aquifer properties) that identify aquifers as suitable for future development; (ii) characterise the scale and residence time of key groundwater flow processes, the degree of inter-aquifer connectivity and groundwater–surface water connectivity for key aquifers; (iii) estimate groundwater recharge and discharge across the catchment; and (iv) evaluate the quantity of potential available groundwater for future development and identify the potential risks of groundwater extraction on known groundwater-dependent ecosystems and existing users.

One of the challenges of working in northern Australia is the scarcity of data and the remoteness of the landscape. For these reasons, the Assessment will seek to use remotely sensed imagery (i.e. satellite imagery) where it can meaningfully inform the information needs of the Assessment. This will include use of the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra and Aqua satellites, and archival multi-temporal Landsat imagery from the Australian Geoscience Data Cube. The work will involve mapping flood inundation (to help constrain the hydrodynamic modelling), identifying persistent waterholes (key ecological refuge Chapter 9).

Availability of suitable soil

The land suitability activity (Chapter 4) will develop digital land suitability data and maps of the entire Victoria catchment, showing areas that are more and less suitable under different combinations of land use and irrigation systems, as well as for aquaculture. The activity will employ statistically based digital soil mapping methods to rapidly and objectively generate 30 m × 30 m grids of a wide range of soil attributes (e.g. depth of soil, texture, pH). The digital soil mapping will be informed by a field sampling campaign and will also use data previously collected by the Northern Territory Government. The current set of rules for different combinations of land use and irrigation systems, and aquaculture will be refined and harmonised with those used by the Northern Territory Government. The rules will be applied to the digital soil mapping attributes, and landscape and climate raster data to generate land suitability maps of the catchment.

Indigenous aspirations and water values

The Indigenous values, rights, interests and development goals (Chapter 6) will provide an overview of key Indigenous values, rights, interests and aspirations with respect to water and irrigated agricultural development in the Victoria catchment. This analysis is intended to assist, inform and underpin future discussions between developers and Indigenous people about particular developments, and their potential positive and negative effects on Indigenous populations. The activity will closely align with components of the agriculture and socio-economics activity (Chapter 8) and the ecology activity (Chapter 9). The fieldwork component of this activity will emphasise direct consultation with Traditional Owners of, and residents in, the Assessment area. This will be undertaken through a variety of means, including telephone discussions, face-to-face interviews, group meetings and workshops. Other key components of the activity include a cultural heritage assessment, and a legal and policy analysis.

Surface water storage options

The surface water storage activity (Chapter 7) will provide a comprehensive overview of the different surface water storage options in the Victoria catchment, to help decision makers take a long-term view of water resource development and to inform future allocation decisions. The construction of inappropriate storages and incremental releases of water can preclude the development of more appropriate water storages and water development options. The work will include a pre-feasibility assessment of large instream and offstream dams. The activity will also include a study of large on-farm (e.g. 2 to 8 GL) hillside dams and ringtanks. The river system models (Chapter 3) will be used to explore how the reliability of harvesting water into ringtanks decreases with increasing catchment allocation and extraction, and other factors such as pumping capacity and the threshold above which water can be taken. Digital soil maps (Chapter 4) will be used to provide information on areas that are suitable for on-farm storage, such as ringtanks.

Agriculture viability and socio-economics

The agriculture and socio-economics activity (Chapter 8) will fully integrate biophysical agriculture production with an economic assessment. The activity will include crop and forage modelling and analysis using the Agricultural Production Systems sIMulator (APSIM), the Grass Production Model (GRASP), and expert knowledge and experience. Some limited field studies may be undertaken as part of this activity to assist in validating crop and forage models and estimates of crop and forage production. Although the agricultural and socio-economics activity will analyse individual crops and forages to help provide fundamental information on potential yields, water use, growing seasons and gross margins, for example, the aim is not to be prescriptive about cropping systems for particular locations; rather, the aim is to provide insights into the issues and opportunities associated with developing integrated cropping or crop–livestock systems, as opposed to individual crops.

This activity will extend the economic analysis to the scheme scale, using industry standard cost–benefit analysis methods. The impact of an irrigation development on the regional economy of the Victoria catchment will be estimated using regional economic multipliers, following the approach used in the Northern Australia Water Resource Assessment (NAWRA). Information on the possible locations and scale of water resource development will be provided by the surface water hydrology (Chapter 3), land suitability (Chapter 4) and surface water storage (Chapter 7) activities.

Freshwater, riparian, and near-shore marine ecology

The ecology activity (Chapter 9) seeks to assess the potential for possible changes in flow regimes associated with new infrastructure across the Assessment area to affect aquatic ecosystems, including freshwater and freshwater-dependent marine ecosystems. The Assessment focuses on water-related ecosystems because water developments, particularly irrigation, can result in substantial changes to streamflow, although typically water developments occupy only a small proportion of the landscape (<1% of a catchment). Key tasks in the ecology activity will include identifying and prioritising assets in the Assessment area, for which conceptual models that capture flow–ecology relationships will be developed. A multiple lines of evidence approach will be used to develop relationships between flow and ecology. These will be qualitative where information is poor and semi-quantitative or quantitative where information is sufficient. The activity will use hydrological outputs from the surface water hydrology modelling (Chapter 3) to which the flow–ecology relationships will be applied to identify likely ecological changes to freshwater and marine ecosystems as a result of different types and scales of water resource development.

Case studies

The Assessment will also undertake a small number of case studies in the Victoria catchment (Chapter 10). Their purpose is to show the reader how to ‘put everything together’ to answer their own questions about water resource development. As well, they aim to help readers understand the types and scales of opportunities for irrigated agriculture in selected geographic parts of the Assessment area and explore some of the nuances associated with greenfield developments in the catchments, and northern Australia in general. Importantly, they are not designed to demonstrate, recommend or promote particular development opportunities being proposed by individual development proponents, nor are they recommendations on how development in the Victoria catchment should unfold. They are, however, designed to be realistic representations, and will explore a variety of potential water resource development options and scales of development. The case studies will draw on information, expertise and models from all activities in the Assessment.

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Part I

Introduction


Photo: Magpie geese (Geoff Whalan)

1 Introduction

1.1 Victoria River Water Resource Assessment

The Victoria River Water Resource Assessment will provide a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water resource development in the Victoria catchment (NT). The Assessment seeks to:

- identify and evaluate potential water capture and surface and groundwater storage opportunities
- evaluate the climate, soil and water resources
- identify and assess the commercial viability of irrigated agricultural and horticulture opportunities, and other uses of the available water
- assess potential environmental, social, economic and cultural (including Indigenous water values) impacts and risks of water resource and irrigation development.

It is important to note that, although these four points appear in sequence, activities in one part of the Assessment will often inform (and hence influence) activities in an earlier part. For example, understanding ecological requirements (the third part of the Assessment, described in Part IV of this report) is particularly important in setting rules around water extraction and diversion (i.e. how much water can be taken and when it should be taken – the second part of the Assessment, described in Part III of this report). Thus, the procedure of assessing a site will inevitably include iterative steps, rather than a simple linear process.

In covering the above points, the Assessment is designed to:

- address explicitly the needs and aspirations of local development by providing objective assessment of resource availability, with consideration of the environmental and cultural issues
- meet the information needs of governments as they assess sustainable and equitable management of public resources, with due consideration of environmental and cultural issues
- meet the due diligence requirements of private investors, by exploring questions of profitability and income reliability of agricultural and other developments.

Drawing on the resources of all three tiers of government, the Assessment will build on previous studies, draw on existing stores of local knowledge, and employ world-class scientific expertise, with the quality of the studies assured through peer-review processes.

The Victoria River Water Resource Assessment commenced on 1 June 2021 and will be completed by 1 December 2024.

1.1.1 Scope of assessments

In stating what the Assessment will do, it is equally instructive to state what they will not do.

The Assessment will not advocate irrigation development. It will identify the resources that could be deployed in support of irrigation and aquaculture enterprises, and the scale of the opportunity that might exist. They are designed to evaluate the feasibility of development (at a catchment scale), not to enable particular developments. The Assessment will quantify the monetary and non-monetary values associated with existing use of resources, to enable a wide range of stakeholders to assess the likely costs and benefits of given courses of action. The Assessment is fundamentally a resource assessment, the results of which can be used to inform planning decisions by citizens; councils; investors; and the state, territory and Australian governments. The Assessment does not seek to replace any planning processes, and it will not recommend changes to existing plans or planning processes.

The Assessment will not invest or promote investment in infrastructure that may be required to support irrigation enterprises. It seeks to lower barriers to investment in the Assessment area by exploring many of the questions that potential investors might have about production systems and methods, yield expectations and benchmarks, and potential profitability and reliability. This information will be established for the Assessment area, not for individual paddocks or farms.

The Assessment does not assume that particular areas within the Assessment areas are in or out of scope. For example, the Assessment deliberately ignores issues such as land tenure that may exclude land parcels from development. The Assessment will identify those areas that are best suited for new agricultural and aquaculture developments and industries, and, by inference, those that are not well suited.

The Assessment does not assume particular types or scales of water storage or water access. It will identify the types and scales of water storage and access arrangements that might be possible, and the likely consequences (both costs and benefits) of pursuing these possibilities. Having done that, it will not recommend preferred development possibilities, nor comment on the required regulatory requirements to make those water resources available.

The Assessment will not assume a given regulatory environment. It will evaluate the availability and use of resources in accordance with existing regulations, but will also examine resource use unconstrained by regulations, to ensure that the results can be applied to the widest possible range of uses for the longest possible time frame.

It is not the intention – and nor will it be possible – for the Assessment to address all topics related to irrigation and aquaculture development in northern Australia, due to time and/or resource constraints. Important topics that are not addressed by the Assessment (e.g. impacts of irrigation development on terrestrial ecology) are discussed with reference to, and in the context of, the existing literature. No attempt has been made to identify such topics in this report.

Functionally, the Assessment will adopt an activities-based approach to the work (which is reflected in the content and structure of the outputs and products, as per Section 1.2), with the following activity groups: surface water hydrology; land suitability; agriculture viability and socio-economics; surface water storage; Indigenous values, rights, interests and development goals; and aquatic and marine ecology.

1.1.2 Program governance framework

The Program Governance Committee will provide high-level governance and leadership to the Victoria River Water Resource Assessment. The Program Governance Committee will meet every 6 months and act as a conduit to government stakeholders.

The Assessment will also have a steering committee, which will guide the Victoria River Water Resource Assessment Team. The committee will regularly report to key stakeholders on the program and ensure that the expectations of stakeholders are considered and responded to appropriately.

The Victoria River Water Resource Assessment Team will plan, manage and deliver the Assessment. The team will consist of CSIRO staff, augmented with contracts to jurisdictions, universities and private contractors, where necessary.

1.2 Reporting schedule

The contracted deliverables for the Assessment are a suite of reports:

- Technical reports present scientific work at a level of detail sufficient for technical and scientific experts to understand the work. Each of the activities of the Assessment has a corresponding technical report.
- A catchment report – synthesises key material from the technical reports, providing well-informed but non-scientific readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture.
- An overview report – is provided for a general public audience.
- A fact sheet – is provided to explain key findings for a general public audience.

A video for social media and data layers will also be released.

The dates for completion of key deliverables are listed in Table 1-1.

Table 1-1 Key deliverables for the Assessment

DELIVERABLE	DATE FOR COMPLETION
Contract signing and establishment of Governance and Steering committees	May 2021
Proposed methods report	15 June 2021
Technical report 1: Floodplain inundation mapping and modelling	30 June 2022
Communications protocol	30 September 2021
Technical report 2: Surface water storage report	31 December 2022
Technical report 3: River and flood modelling report (calibration and simulation, and delivery of model to the jurisdiction)	31 December 2023
Technical report 4: Hydrogeological assessment	31 December 2023
Technical report 5: Digital soil mapping and land suitability report	31 December 2023

DELIVERABLE	DATE FOR COMPLETION
Technical report 6: Ecology	31 December 2023
Technical report 7: Socio-economics-agricultural opportunities	31 March 2024
Technical report 8: Groundwater flow modelling	31 March 2024
Case study report	31 March 2024
Technical report 9: Indigenous aspirations, water values and use options	30 June 2024
Catchment report	30 June 2024
20-page summary report	30 June 2024
Final fact sheet	30 June 2024
Final video for social media	30 June 2024
Updated NAWRA explorer tool and data access layers	30 June 2024

1.3 Review process

As part of CSIRO's internal quality assurance process, all reports produced by the Assessment will be reviewed. CSIRO will manage the review process in accordance with CSIRO's ePublish protocols.

Technical reports will be reviewed by at least two reviewers. Additional comment will be sought from the Northern Territory Government, depending on the topic and content. A combination of external and internal reviewers will be used.

After review and revisions in response to the review, each report will be sent to the Department of Infrastructure, Transport, Regional Development and Communications.

1.4 Past studies and links to relevant current projects

A key component of the Assessment will be the collation and review of relevant literature, which will be a prerequisite for all activities. The methods described in this report will be modified to take into account the availability (and sometimes lack) of information on the Assessment area. The Assessment team will rely in part on the Program Steering Committee to ensure that all relevant literature is captured and to help identify local experts who should be consulted.

1.4.1 The Victoria River Water Resource Assessment area

The Assessment area defined by the Victoria River catchment is shown in Figure 1-1. It encompasses an area of about 79,630 km^2. The largest towns in the Victoria catchment are Timber Creek and Kalkarindji.

The Victoria catchment is wet–dry tropical, and rainfall is highly seasonal. Large variability in annual runoff occurs, and the strong seasonality in rainfall results in large wet-season flows and small dry-season flows (CSIRO, 2009). The ecology of the catchments is adapted to the high seasonality and variability typical of tropical river systems.

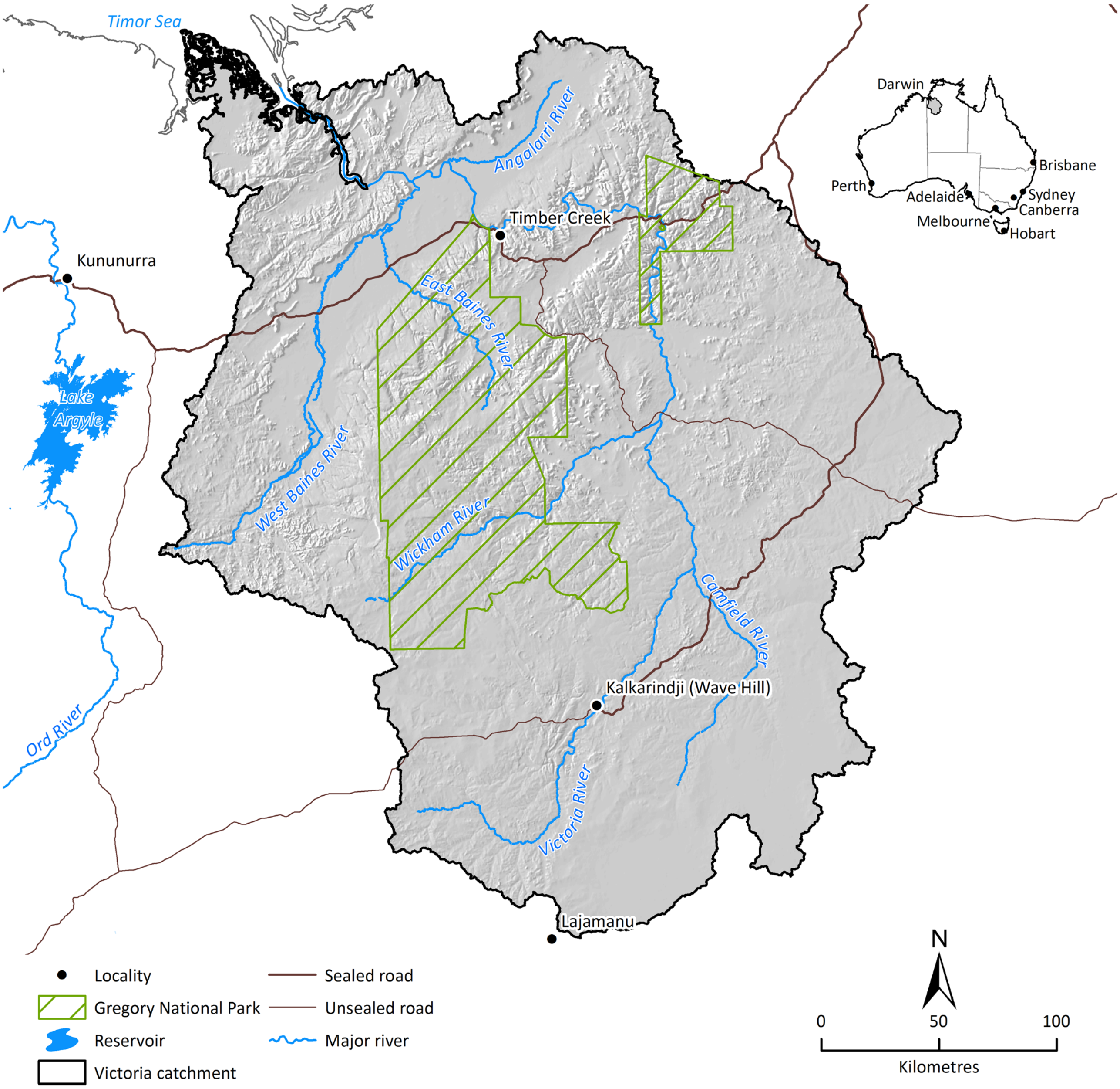

Figure 1-1 The Victoria catchment in the Northern Territory
Neighbouring Ord catchment also shown for context.

1.5 Objectives and contents of this report

The objective of this report is to broadly outline the methods that the Assessment intends to employ. The purpose is to openly communicate the scope of the Assessment and the proposed methods to a wide range of stakeholders, to allow them to provide feedback and engage with the Assessment team. The report also provides a mechanism for the Assessment team to acquire feedback on the proposed methods, to ensure that they are fit for purpose. The actual methods that the Assessment will use may vary as more information becomes available, and will be documented in detail in the technical reports.

The Assessment is divided into six activities. Figure 1-2 illustrates the high-level linkages between the activities (in blue boxes) and the general flow of information in the Assessment. The figure does not seek to capture all linkages and dependencies between activities.

This report is structured to align with the following three central questions (in italics below) that encompass the four deliverable points listed in Section 1.1, as well as the activities shown in Figure 1-2:

- Part I – Introduction provides an overview of the Victoria catchment and defines the Assessment area and key concepts:
  – Chapter 1 – Introduction
  – Chapter 2 – Key concepts
- Part II – Resource assessment addresses the question '*What soil and water resources are available to support regional development?*' by describing the information and methods needed to identify, map and quantify the available soil and water resources. The following chapters present methods in Part II:
  – Chapter 3 – Surface water hydrology
  – Chapter 4 – Land suitability
  – Chapter 5 – Groundwater hydrology
- Part III – Economic viability addresses the question '*What are the opportunities by which water resource development may enable regional development?*' by evaluating the opportunities for agriculture and aquaculture, water storage, and supply of water for multiple uses, including urban and hydro-electric power generation. It also evaluates the economic costs and benefits, and regional socio-economic impacts of these opportunities. The following chapters present methods in Part III:
  – Chapter 6 –Indigenous water values, rights, interests and development goals
  – Chapter 7 – Surface water storage
  – Chapter 8 – Agriculture and socio-economics
- Part IV –Achieves a balance between competing priorities by addressing the question '*What are the likely risks and opportunities to the natural environment due to changes in the river flow regime as a result of water resource development?*' The following chapter presents methods in Part IV:
  – Chapter 9 – Ecology
- Part V – Case studies, reports, key protocols and standards describes the rationale for undertaking case studies, summarises the reports that will be delivered by the Assessment and outlines key protocols for data management:
  – Chapter 10 – Case studies
  – Chapter 11 – Reports, products, protocols and standards.

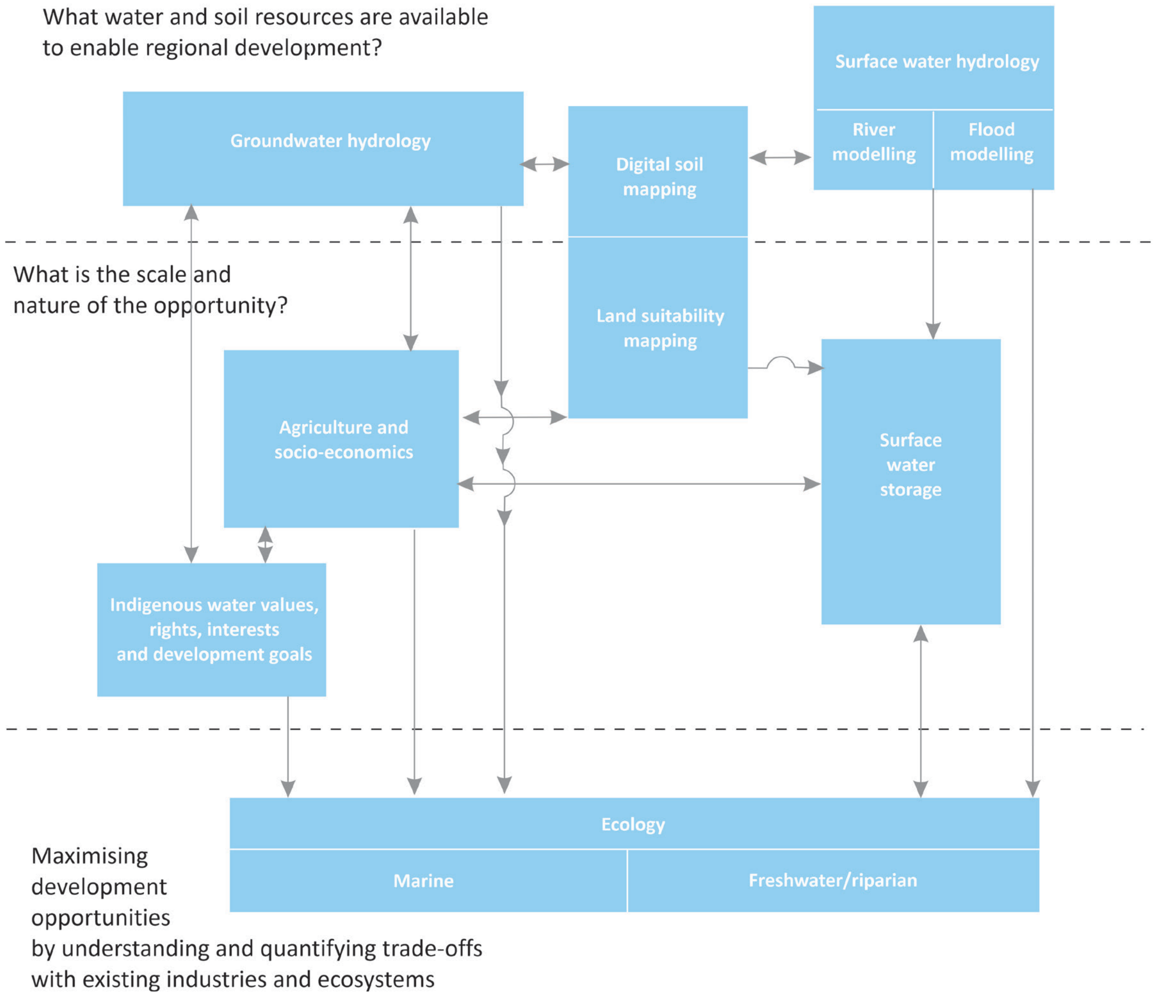

Figure 1-2 Schematic diagram illustrating the high-level linkages between the seven activities and general flow of information in the Assessment

1.6 References

CSIRO (2009) Water in the Ord-Bonaparte Region of the Timor Sea Drainage Division. A report to the Australian Government from the CSIRO Northern Australia Sustainable Yields Project. CSIRO Water for a Healthy Country Flagship, Australia.

2 Key concepts

2.1 Water year, and wet and dry seasons

The Assessment area experiences a highly seasonal climate, with the majority of rain falling between December and March. Unless specified otherwise, the wet season is defined as the 6-month period from 1 November to 30 April and the dry season as the 6-month period from 1 May to 31 October. All results in the Assessment are reported over the 'water year', defined as the period 1 September to 31 August, which allows each wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons). This is the usual convention for reporting climate statistics in northern Australia, as well as from a hydrological and agricultural assessment viewpoint.

2.2 Scenario definitions

The Assessment will consider four different scenarios of climate, surface water, groundwater and economic development, as used in the Northern Australia Sustainable Yields (NASY) Project (CSIRO, 2009):

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

2.2.1 Scenario A

Scenario A will include historical climate and 'current' development. The historical climate data will be for 112 years (water years from 1 September 1910 to 31 August 2021) of observed climate (rainfall, temperature and potential evaporation for water years). All results will be presented over this period, unless specified otherwise. Current development is defined here as the level of surface water, groundwater and economic development as 31 August 2021. The Assessment will assume that all current water entitlements are being fully used.

Scenario A will be used as the baseline against which assessments of relative change are made.

2.2.2 Scenario B

Scenario B will include historical climate and future water resource development. Scenario B will use the same historical climate data as Scenario A. Future water resource development will be described by each case study storyline, and river inflow and water extractions will be modified accordingly. Case study storylines will be developed in consultation with key stakeholders (see Chapter 10). The impacts of changes in flow regime due to future development will be assessed and compared to other scenarios including:

- impacts on instream, riparian and near-shore ecology
- impacts on Indigenous water values
- economic costs and benefits
- opportunity costs of expanding irrigation
- institutional, economic and social considerations that may impede or enable adoption of irrigated agriculture.

2.2.3 Scenario C

Scenario C will include future climate and current development. These climate data will be derived from a range of global climate model (GCM) projections from the Sixth assessment Report. The method for developing future climate sequences is under discussion. Like Scenario A, current development is the level of surface water, groundwater and economic development as 31 August 2021.

2.2.4 Scenario D

Scenario D is future climate and future development. It will use the same future climate series as Scenario C. River inflow, groundwater recharge and flow, and water extraction will be modified to reflect proposed future development, in the same way as in Scenario B.

2.3 Case studies

The case studies in the Assessment will be used to provide examples of how information produced by the Assessment can be assembled to help readers 'answer their own questions'. They will also help readers understand the type and scale of opportunity for irrigated agriculture or aquaculture in selected geographic parts of the Assessment area, and explore some of the nuances associated with greenfield developments in the Victoria catchment.

Importantly, the case studies are illustrative only. They are not designed to demonstrate, recommend or promote particular development opportunities being proposed by individual development proponents, nor are they CSIRO's recommendations on how development in the Victoria catchment should unfold. However, they are designed to be realistic representations. That is, the case studies will be 'located' in specific parts of the Assessment area, and use specific water and land resources, and realistic intensification options. For more information on the case studies, see Chapter 10.

2.4 References

Charles S, Petheram C, Berthet A, Browning G, Hodgson G, Wheeler M, Yang A, Gallant S, Vaze J, Wang B, Marshall A, Hendon H, Kuleshov Y, Dowdy A, Reid P, Read A, Feikema P, Hapuarachchi P, Smith T, Gregory P and Shi L (2016) Climate data and their characterisation for hydrological and agricultural scenario modelling across the Fitzroy, Darwin and Mitchell catchments. A technical report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure

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Part II

What water and soil resources are available to support regional development?

Photo: Victoria River panorama (cropped, (Michael Whitehead)

3 Surface water hydrology

The surface water hydrology activity uses a modelling framework to obtain water storage and flux estimates over various spatial and temporal scales across the Victoria catchment.

The key questions that this activity seeks to address in the Victoria catchment include:

- How much water has discharged from the catchment each day, month and year since 1910?
- What are the opportunities to use surface water for multiple uses?
- Where is most runoff generated?
- How does the persistence of waterholes relate to streamflow in different river reaches?
- With what degree of reliability can increasing volumes of water be extracted in different parts of the Victoria catchment, and how will streamflow be perturbed downstream?
- What is the maximum flood extent, and how do flood extent and duration vary with different sized events?
- How do flood extent and duration change under different levels of water harvesting and large dam development?
- How would changes in future climate potentially affect streamflow and water resource development in the Victoria catchment?

This chapter provides an overview of the key surface water modelling frameworks to be used in the Assessment. This is followed by a brief description of the available data, and an overview of the model calibration and model experiment process. Examples of use of the model output are then provided, and surface water quality is discussed briefly.

3.1 Introduction

Streamflow in the Victoria catchment is highly seasonal, reflecting contrasting wet and dry seasons. The catchment is relatively flat and features extensive floodplains of low relief.

3.2 Model overview

Three types of interdependent models will be used: (i) landscape, (ii) river system, and (iii) hydrodynamic. Broadly speaking, the landscape model simulates fluxes that will be used as input to the river system model and the hydrodynamic model. Output from the river system model will be used as an upstream boundary condition for the hydrodynamic model.

Landscape models

Landscape models are used to estimate the hydrological response of landscapes (at the scale of interest). The most widely used and recognisable landscape model is a rainfall-runoff model, which features calibrated parameters, and typically estimates runoff at a point or grid cell from daily precipitation and potential evaporation inputs. The Sacramento model (Burnash et al., 1973) will be used in the Assessment to simulate a range of landscape water fluxes, but the output of primary interest for the purposes of the Assessment is runoff.

River system models

The river system models aggregate runoff estimates obtained from the conceptual rainfall-runoff model and routs the water along a stream network. Streamflow is usually estimated at various points along the river system. These points are typically referred to as nodes, with connecting stream lines referred to as 'links' or reaches. Each link features various sub-models to estimate in-reach processes such as routing, irrigation diversion, losses to groundwater, losses to floodplains, anabranch flow and reservoirs. Each reach or link uses inflows from reaches upstream, climate data, configuration information and calibrated parameters to estimate states related to configured processes and estimate flow at the end of the reach. The models could be used with or without a loss function to improve goodness of fit. The river system modelling activity will use an extended version of the Australian Water Resource Assessment – River (AWRA-R) model, (Dutta et al., 2015a). AWRA-R can be used with a conceptual rainfall-runoff model such as Sacramento (Burnash et al., 1973). The AWRA-R model is very flexible, enabling it to be quickly modified, as a result of its simple reach-by-reach operation where each reach is simulated in full before the simulation of the next reach. The AWRA-R model is also designed to enable fast run times and can be used in conjunction with a variety of auto-calibration routines (Dutta et al., 2015b). This will enable modelling experiments to be rapidly undertaken to ascertain the most appropriate conceptualisation and calibration strategies.

Models will be formulated with input from Northern Territory Government hydrologists to ensure that the river system models have utility for jurisdictional needs. Additionally, finalised models will be made available via weblink and graphical user interface, allowing anyone to run scenario analysis of the Victoria catchment.

Hydrodynamic models

Hydrodynamic models are physically based models that explicitly simulate the movement of floodwaters through waterway reaches, storage elements and hydraulic structures. The Victoria River floodplain inundation modelling will be implemented using MIKE FLOOD (DHI, 2007; DHI, 2009) which is a coupled one-dimensional–two-dimensional model developed by DHI. The floodplain will be represented by a two-dimensional flexible triangular mesh and simulated using MIKE 21, while the river channel will be modelled with a one-dimensional model called MIKE 11. The benefit of using this approach over MIKE 21 alone is that it allows more control over the river dynamics and therefore should give more accurate representations of overbank flows.

The data requirements for the floodplain modelling activity will be a recently collected and corrected light detection and ranging (LiDAR) digital elevation model (DEM) for two-dimensional flexible mesh generation, and river bathymetry for the cross-section input used in the one-dimensional component. MIKE FLOOD also allows for hydrological processes such as infiltration, rainfall and evaporation; however, these modules require soil property data as well as climate data. Importantly, gauged stream level and flow data are used as inputs to the simulations and are also used to calibrate/evaluate the model. Finally, satellite imagery such as Landsat (various satellites) is used to evaluate the predicted inundation. The availability of the data is likely to determine the flood events that are used for calibration and evaluation.

3.3 Data availability

The surface water storage activity will build on work previously undertaken in the Victoria catchment, namely the Northern Australia Sustainable Yields (NASY) Project (CSIRO, 2009). As part of the NASY project, runoff was generated using an ensemble of conceptual rainfall-runoff models (Petheram et al., 2009). In the Victoria River Water Resource Assessment, a more complex suite of hydrological models will be used than were used in NASY because more detailed modelling is required. Furthermore, a greater length of streamflow data is now available since the NASY project was completed in 2008. The Victoria River Water Resource Assessment will have greater data requirements than the NASY project because more detailed analysis and modelling are required to address the objectives of the Assessment, and more physically based models will be used.

The primary dataset used for all surface water model calibration is stream gauge data. For the river system modelling, all available gauges in the Victoria catchment will be assessed for use; however, landscape modelling may also include nearby gauges. In the Victoria catchment, the number of gauge records will be assessed, and the data quality and duration have been identified. These will be assessed for their inclusion in the river system node–link network. Gauge locations for the Victoria catchment are shown in Figure 3-1.

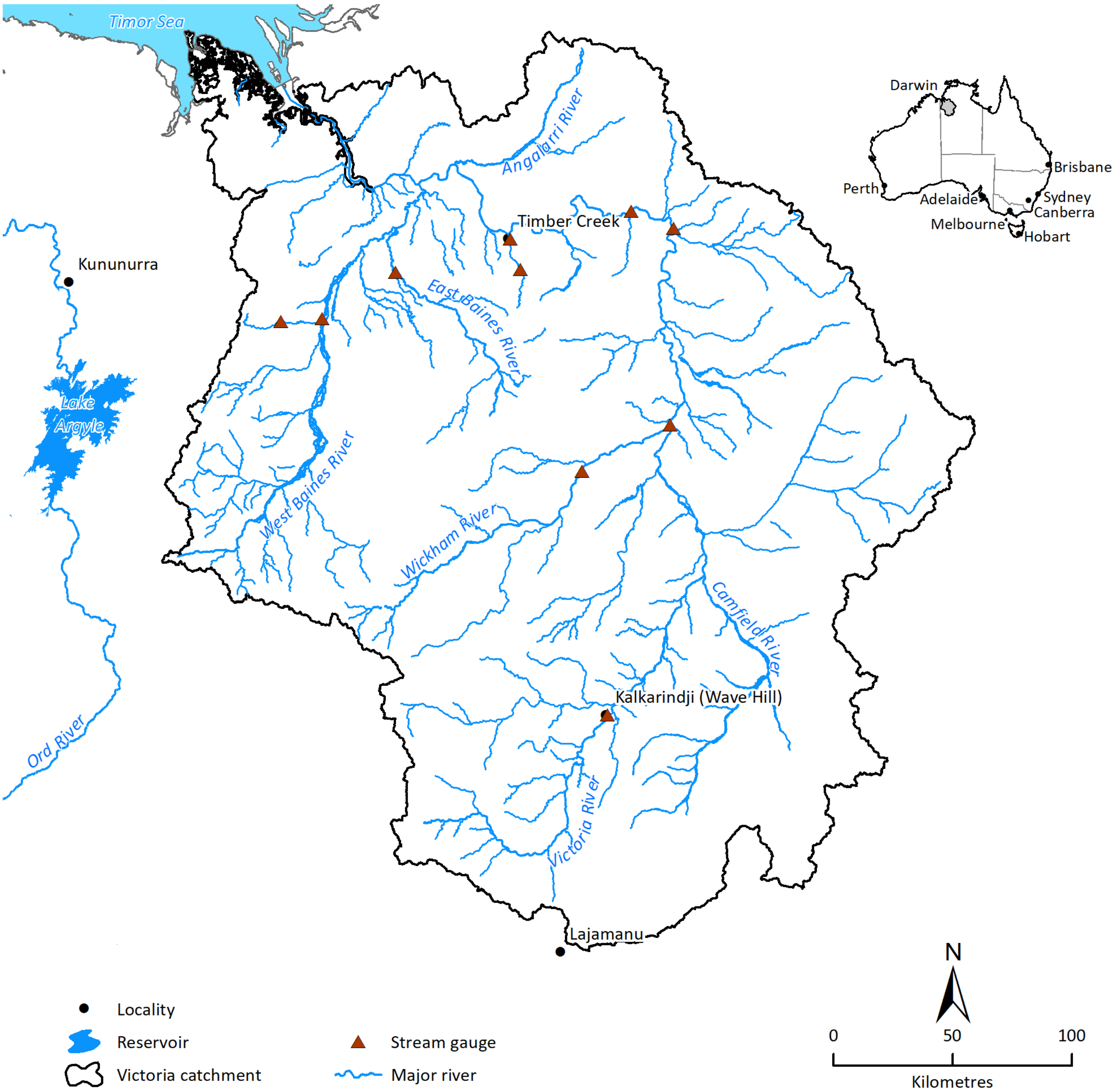

Figure 3-1 Victoria catchment showing stream gauge locations

3.4 Model calibration and modelling experiments

3.4.1 Input data and data collection

Climate data will be sourced from the SILO database, subject to data quality checks.

The Assessment will use the hydrologically corrected Shuttle Radar Topography Mission (SRTM-H) DEM as the baseline elevation dataset. It is supplemented with LiDAR data, which has been acquired by CSIRO. Stream bathymetry data may be acquired within the main stream channel (subject to budget and time constraints). These data will be spliced back into the SRTM DEM-H. These high-resolution elevation data are particularly useful in helping to parameterise channel features in the MIKE FLOOD model.

Roughness information is required to parameterise the MIKE FLOOD model. This will be derived from vegetation mapping data and, potentially, satellite radar data.

A limited number of pressure sensors may be deployed in selected persistent waterholes in the Victoria catchment. Waterholes will be selected in consultation with the ecology activity (Chapter 9) and the Northern Territory Government, and by analysis of the Water Observations from Space (WOfS) dataset. The on-ground sensors will be used to try to establish 'commence to fill' discharge and the flow required to fill selected waterholes after each dry season. This information can be used to make the output from the river system models (typically daily time series of water fluxes) more ecologically meaningful.

In consultation with the Northern Territory Government and the surface water storage activity, field data may be collected to help establish the physical (minimum) limits to water extraction (i.e. minimum depth and discharge at which water could be pumped) in key reaches of the Victoria catchment.

3.4.2 Model calibration

Sacramento

The following modelling experiments to support the calibration of the Sacramento model will be undertaken:

- The Assessment will investigate various strategies for making best use of the available streamflow data. These will include modelling experiments to determine an appropriate data quality and length threshold for use in the calibration process.
- A variety of objective functions will be explored using the data from the Victoria catchment, to best simulate both low and high flows.
- A single set of parameters will be determined for the Sacramento model for each of two approaches:
  - parameters calibrated to gauges in the vicinity of the Victoria catchment
  - parameters calibrated to a subset of gauges based on either perennial streams or ephemeral streams, since dry-season groundwater discharge is obvious in some parts of the catchment, but not others.

The parameter set that proves to have the best predictive capacity will be used to estimate runoff at all locations across the Victoria catchment at a 5-km grid. The model parameters will be evaluated on an independent subset of catchments, using various goodness-of-fit measures and compared to the result of a conceptual rainfall-runoff models.

AWRA-R

Calibration of the AWRA-R model will proceed as follows:

- A baseline node–link network will be established for the Victoria catchment. This is simply the physical connection of river reaches with each other and is required to enforce the calculation order for each reach (reach models are run upstream to downstream in a workflow). This step will be influenced by the availability and suitability of gauge data, and physical aspects of the river system. The model will be structured so that nodes are also situated at sites potentially suitable for surface water storage (surface water storage activity), adjacent to land suitable for irrigated agriculture (land suitability activity), near locations of ecological interest (ecology activity), and of interest to Traditional Owners (Indigenous water values, rights, interests and development goals activity), so as to simulate streamflow at the boundary of the modelled floodplains.

- If experimental results warrant, gauge data will be filtered to remove any data with unacceptable quality codes.
- Sub-models that enable various processes (e.g. overbank flow, groundwater loss) can be switched on or off.
- Sacramento runoff estimates will be aggregated to provide estimates of ungauged flow (i.e. residual inflow) for each river reach, or where gauge data are available, Sacramento will be calibrated locally in conjunction with AWRA-R parameters.
- The observed streamflow record in the headwater catchments will be 'patched' with Sacramento aggregated runoff estimates (i.e. simulated runoff will be used where there are gaps in the headwater observed time series). Calibration against observed flows will be undertaken using a 'shingle' approach where all reaches in a portion of the catchment will be calibrated simultaneously. Each portion of the catchment overlaps to ensure that parameters transition smoothly between upstream and downstream shingles.

The differential evolution algorithm (Mullen et al., 2011) will be used for calibration parameters search. The objective function will be a combination of Nash–Sutcliffe efficiency on root transformed values and mean annual absolute bias:

$$OF_{multi} = (2 - E_d^{0.5}) * (1 + |\varepsilon_{365}|) * (1 + |\varepsilon_{hf}|) * (1 + EPD_{90}) * (1 + |\beta|) \quad (1)$$

where $E_d^{0.5}$ is the Nash–Sutcliffe efficiency of the root transformed daily flow, ε_{365} is the normalised annual error, ε_{hf} is the normalised error in the highest 20 flow days, EPD_{90} is the exceedance probability difference of the 90%, non-zero exceedance value of the observed data in comparison to the simulated data:

$$EPD_{90} = |P_{90}(Q_{obs}) - P_{90}(Q_{sim})| \quad (2)$$

where P_{90} refers to the 90% exceedance probability. High flow error calculates the normalised difference between the 20 highest observed flows and the 20 highest simulated flows.

3.5 References

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4 Land suitability

4.1 Introduction

A fundamental input to the study of water resource development, principally for agricultural purposes, is an understanding of the soil and landscape resources available, their spatial distribution and the limitations to their use. Primarily, an understanding of the potential suitability of soils for a range of crops, planting seasons and irrigation management will be explored, although land suitability estimates will also be made within the Assessment for aquaculture and for earthen ringtanks.

The activity will use a combination of existing national data and data previously collected by the Northern Territory Government, field collected data as part of the Assessment and modelled outputs. It is the largest single activity within the Assessment.

A digital soil mapping (DSM) approach will be taken to produce a set of raster attribute data (which can be displayed as maps) at a pixel resolution of 1 arc-second (approx. 30 m). These attributes will then be used within a land suitability framework to produce an estimate of land suitability for a range of specific land uses using a 5-class scale from highly suitable to unsuitable, again in data and map form at 30 m resolution. Estimates of reliability for these data will also be produced using novel methods.

The land suitability rule framework will be built on a combination of existing frameworks within CSIRO and the Northern Territory Government, both of which are compatible with the land evaluation approach of the Food and Agriculture Organization (FAO) of the United Nations.

The outputs of this activity can be considered useful at a regional (broad) scale (approx. 1:250,000 scale) rather than for individual property or enterprise planning.

The activity will make use of the rich history of soil and landscape investigation by the Northern Territory Government within the Victoria catchment (e.g. Brocklehurst et al., 1996; Lewis et al., 2010; Napier and Hill, 2012; Napier et al., 2018) and will make use of these legacy data wherever possible. The work also draws heavily on the methods and practices for broad-scale land evaluation from the Flinders and Gilbert Agricultural Resource Assessment (Bartley et al., 2013; Harms et al., 2015; Thomas et al., 2015) and the Northern Australia Water Resource Assessment (NAWRA) (Thomas et al., 2018a; Thomas et al., 2018b) and ongoing refinement in the Roper River Water Resource Assessment (RoWRA).

The key questions that this activity seeks to address in the Victoria catchment include:

- What are the soil and landscape attributes for the catchment?
- What is the total area of land with characteristics suitable for a particular land use, principally irrigated and dryland cropping, and where in the catchment can this land be found?
- What is the total area of different soil types and where in the catchment can they be found?

- What are the soil limitations for specific land uses, such as irrigated agriculture, and where are they located?

4.2 Workflow

Figure 4-1 shows the broad workflow undertaken for this activity. The workflow highlights the tasks of soil sampling design, DSM and land suitability analysis, while also showing the dependencies feeding into these, including environmental covariates, soil attribute data, data quality metrics, and the land suitability rule framework that drives the land suitability analysis.

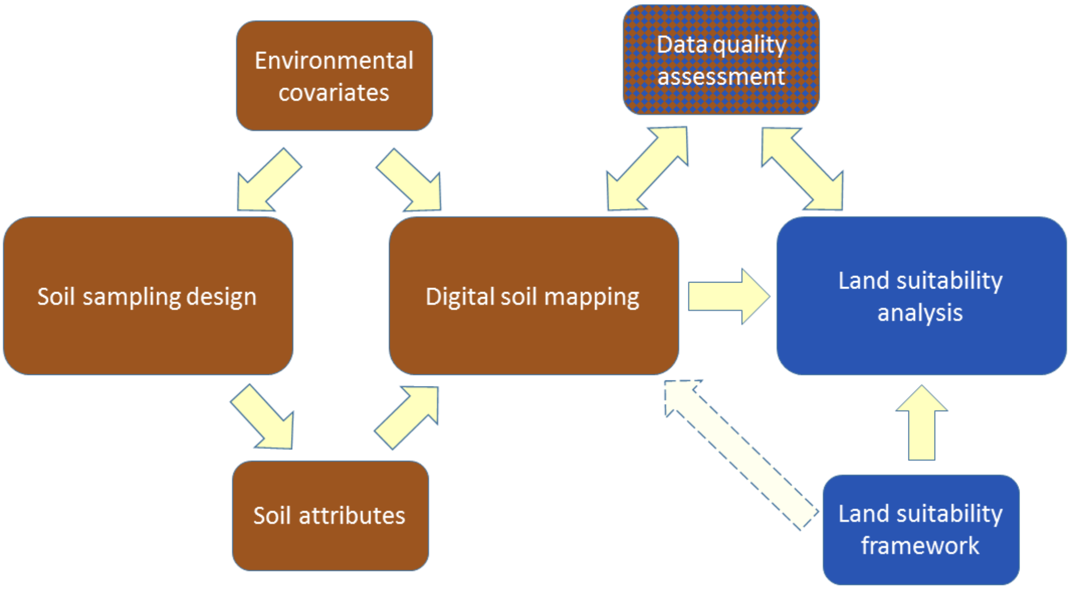

Figure 4-1 Land suitability analysis workflow, key inputs and processes (Thomas et al., 2018a)
Brown components reflect the DSM component (as described in Thomas et al., 2018a), while blue components reflect the land suitability component (as described in Thomas et al., 2018b). The 'data quality assessment' sits across both components.

4.2.1 Soil sampling design

As well as using legacy soil data, new soil data will be collected in the field (Figure 4-2). The number of sampling points and their precise locations are determined a priori as a function of the budget and logistical considerations, such as access.

A stratified random sampling approach (McKenzie et al., 2008) will be used to remove human bias in the selection of soil sampling sites, and to maximise the spread of sites so the full range of soil–landscape variability across the catchment is sampled. A non-biased soil sampling design is a prerequisite of reliable DSM. The sampling design will use conditioned Latin hypercube sampling (cLHS) described in full in Minasny and McBratney (2006). Use of cLHS ensures sampling points capture the empirical distribution of the environmental covariates chosen to represent the full variability of soils across the Assessment area.

Figure 4-2 Collecting soil cores in the field using a vehicle-mounted push core rig. The collected soil will be analysed in the field and a subset subjected to laboratory analysis

Photo: CSIRO

4.2.2 Environmental covariates

The covariates will be selected as proxies for factors of soil formation (i.e. climate, parent material, biota, topography and time) (Jenny, 1941). They will then be used in two tasks within the DSM approach: (i) the selection of new sampling sites, and (ii) predicting new soil attributes using DSM (Figure 4-1). More than 30 covariates will be tested, including those related to soils, climate, vegetation and bare ground, relief, parent material and landscape age. Selection of covariates will be based on those in Table 2-2 from Thomas et al. (2018a) using the framework of Jenny (1941) and McBratney et al. (2003) but will also consider several newly released datasets.

4.2.3 Soil attributes (properties)

Soil attribute, or soil property, information will be collected directly in the field and through subsequent lab analysis (Figure 4-3). For this Assessment, these data will come from newly collected soil data and from legacy data collected previously by the Northern Territory Government (see Section 4.1 for some references).

Attribute data collected in the field include those that indicate soil physical properties (e.g. soil depth, field texture), soil chemistry (e.g. field pH, dispersion, surface salinity), and risk (e.g. erosion) while lab analyses provide estimates of such things as particle size (% sand, % silt, % clay), cation exchange capacity, sodicity, and pH at each depth within the profile.

Figure 4-3 Soil sample being extracted from coring tube in the field

Photo: CSIRO

4.2.4 Digital soil mapping (soil attribute layers)

The DSM modelling approaches rely on correlative models that establish statistical relations between soil observations at points and covariate layers (McKenzie and Ryan, 1999). DSM models can be expressed as statistically based rules representing the relationship between: (i) soil data at the sampling sites, and (ii) the values of the covariates at these sites. Multiple, co-registered covariates are used in environmental correlation – effectively in a stack of raster covariates (predictors). The soil attribute to be mapped is predicted at an unsampled location using the data values of the covariates in the stack and the model rules. This process of rule-to-covariate matching is applied to the whole area of interest (raster stack area) to compile the complete final soil map. The environmental correlation approach can be thought of as a digital analogue of the traditional soil mapping method, which relies on experts to build models (rules) from patterns of relief, drainage or vegetation (Hudson, 1992). In the DSM analogue, the expert is represented by the machine learning modelling process.

A random forest approach (Breiman, 2001) will be used. The approach constructs a multitude of decision trees during the algorithm training phase. Decision trees are ideally suited for the analysis of high-dimensional environmental data; continuous covariates that exhibit non-linear relationships, high-order interactions, and missing values can be used to predict continuous soil attributes (regression trees) or categorical ones (classification trees).

A number of modelled soil attribute layers will be produced (at 1 arc-second resolution) including soil pH, clay content, A-horizon depth, soil depth, plant available water capacity, permeability, drainage, rockiness, erodibility, exchangeable sodium percentage, surface condition, structure, surface salinity, texture and microrelief.

A data layer (which can be displayed as a map) will be used to produce soil generic groups (SGGs), principally as a communication product. The SGGs represent the main soil types of northern Australia. Soils within a group share a similar profile morphology and soil chemical and physical characteristics. Their agricultural land management requirements are also similar in terms of general land use potential. The approach used to allocate the SGG will be to classify the soil at each field site according to the Australian Soil Classification (Isbell and National Committee on Soil and Terrain, 2016) and then allocating the soil to an SGG.

4.2.5 Data quality assessment

An iterative process of data quality assessment will allow for improvements in the attribute layers and the SGG layer produced within the DSM process and in the land suitability analysis.

The DSM approach allows for production of companion maps of reliability in the prediction surfaces that show where the soil attribute data are more or less reliable, so that people making decisions or modelling users (e.g. hydrologists, agronomists) can make objective decisions about how to apply the data for their requirements. A major benefit of DSM compared to traditional soil mapping is that it is possible to statistically quantify and map the uncertainty associated with the soil attribute prediction at each pixel.

Quality assessment of the DSM will be conducted using: (i) statistical (quantitative) methods i.e. testing the quality of the DSM models using data withheld from model computation, and estimating the reliability of the model outputs (Brus et al., 2011); and (ii) on-ground expert (qualitative) examination of outputs during a validation field trip planned for the second or third year. This validation trip will use a set of independent sites, again chosen using a statistical approach based on cLHS. Furthermore, expert knowledge will be used to highlight, and amend where necessary, any attribute layers that do not appear credible. An estimate of reliability will also be produced.

4.2.6 Land suitability framework

The land suitability framework will be built on a combination of existing frameworks within CSIRO and the Northern Territory Government. It will provide the set of rules for determining the potential of land for specific land uses on the basis of the local range of environmental attributes and qualities (Rossiter, 1996), collectively termed limitations. In this Assessment, the land uses will be principally agricultural (i.e. crop by season by irrigation type) but will also be applied to aquaculture and to earthen ringtanks.

The soil attribute layers will be combined into approximately 20 limitations. These limitations will include such things as permeability, rockiness, irrigation efficiency, nutrient balance, plant available water capacity and soil physical restrictions. These edaphic components of land suitability mostly relate to soil attributes that have a key bearing on the growth and productivity of irrigated and rainfed crops, or the amount of land preparation and maintenance of farming infrastructure needed that may affect the financial viability of the irrigation enterprise. For example, soil permeability affects the rate of water application, and rockiness relates to the intensity of rock picking required in land preparation, root crop harvesting and wear on machinery.

A further limitation, which can be applied retrospectively, will be the consideration of landscape complexity. That is, the extent to which the size and shape of contiguous pixels of suitable land follow spatial patterns that might allow or prohibit development.

While the framework generally follows the FAO approach to land evaluation (FAO, 1976; FAO, 1985) it differs from the strict FAO approach, which also includes a range of social (e.g. land tenure), environmental (e.g. water availability, flooding risk) and farm-scale economic (e.g. production and industry development) aspects considered elsewhere in the Assessment.

4.2.7 Land suitability analysis

The land suitability analysis is the final step in the process of determining the suitability of each pixel of land for a range of land uses and forms the basis for summary statistics showing the amount and location of land suitable for specific land uses.

The analysis is done on a pixel-by-pixel basis for each individual land use to compile the corresponding 5-class suitability map. For each pixel, for each land use, for each limitation, the analysis uses the rules from the land suitability framework to allocate one class from a 5-class land suitability rating (Table 4-1). The classes range from Class 1 (highly suitable) to Class 5 (unsuitable). The overall suitability for that pixel, for that land use, is taken as the limitation with the highest class (most unsuitable) rating. That is, the overall land suitability class at that location (for that land use) is based on the most limiting factor for that land use.

In places where the suitability class does not match expert expectations and/or experience (e.g. experienced on-ground during the validation field trip), the limitations at that location are interrogated. Where the most limiting factor does not conform to the expectations of the experts (i.e. the influence of the limitation appears too great on the mapped outcome because the limitation setting is too conservative), the thresholds used in the rule may be adjusted. This process may be repeated numerous times for numerous limitations until the final implementation of the rule set satisfies expert expectations and evidence.

Finally, a land versatility map will be generated for the Victoria catchment that scores the suitability ratings for each land use for each pixel. High scoring areas of the map indicate that numerous crops may be grown there (i.e. there is greatest versatility for cropping in these areas).

Table 4-1 Land suitability classes based on FAO (1976) and adapted from DSITI and DNRM (2015) and van Gool et al. (2005)

CLASS	SUITABILITY	LIMITATIONS	DESCRIPTION
1	Highly suitable land	Negligible	Highly productive land requiring only simple management practices to maintain economic production.
2	Suitable land	Minor	Land with limitations that either constrain production or require more than the simple management practices of Class 1 land to maintain economic production and minimise land degradation.
3	Moderately suitable land	Considerable	Land with limitations that either further constrain production or require more than those management practices of Class 2 land to maintain economic production and minimise land degradation.

CLASS	SUITABILITY	LIMITATIONS	DESCRIPTION
4	Currently unsuitable land	Severe	Currently considered unsuitable land due to severe limitations that preclude successful sustained use of the land for the specified land use. In some circumstances, the limitations may be surmountable with changes to knowledge, economics or technology.
5	Unsuitable land	Extreme	The limitations are so extreme that the specified land use is precluded. The benefits would not justify the inputs required to maintain production and prevent land degradation in the long term.

4.3 References

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5 Groundwater hydrology

The purpose of the groundwater hydrology activity is to examine opportunities for future groundwater development to support primary industries in the Victoria catchment, principally irrigated agriculture but potentially also aquaculture. At the scale of the Victoria catchment, the activity will identify and assess the most promising intermediate to regional-scale aquifers and where sufficient information exists, quantify the potential opportunities for, and risks associated with, future groundwater development.

In this chapter, methods are described by which groundwater resources will be assessed across the catchment involving a combination of desktop analyses, targeted field investigations, and modelling at a variety of spatial and temporal scales. It is anticipated that this work will be carried out through engagement and collaboration with the Northern Territory Government Department of Environment, Parks and Water Security (DEPWS); the Power and Water Corporation (PWC); various Indigenous communities in the catchment; and potentially other hydrogeological consultants if required. Much of the contextual hydrogeological information presented in the chapter has been summarised from publicly available data collated by the Northern Territory Government (DEPWS, 2021) as well as some previous hydrogeological studies including: (i) the Water Resources Survey of the Western Victoria River District (Tickell and Rajaratnam, 1998), (ii) the Northern Australia Sustainable Yields (NASY) project (CSIRO, 2009), and (iii) relevant regional and local groundwater studies conducted by the Northern Territory Government and other agencies and consultancies.

The key questions that this activity seeks to address in the Victoria catchment include:

- What types of aquifers exist and what is the nature of the flow systems they host?
- What are the important attributes that help identify aquifers in the catchment as promising for future groundwater resource development and how do they vary spatially?
- Can a range in recharge for these aquifers be estimated and are these ranges reasonable when considering rainfall, runoff, evapotranspiration and groundwater levels?
- Which river or creek reaches have evidence of strong groundwater–surface water connectivity and which aquifers support their persistence?
- What types of vegetation are utilising groundwater for transpiration, where do they occur, and which aquifers support their water use?
- For the most promising aquifers identified, what component of their water balance can be estimated with some level of confidence and what components remain uncertain?
- What are the ranges in potential extractable volumes for the most promising aquifers and what are the key risks posed by future groundwater extraction?
- What areas pose a risk of irrigation-induced watertable rise and secondary salinisation?

5.1 Regional geology and hydrogeology of the Victoria catchment

5.1.1 Regional geology

The Victoria catchment has a complex geological history with geological units hosted in several different geological basins coinciding with the Victoria catchment. The most important of these basins are the: (i) stacked Birrindudu and Victoria basins, and (ii) Wiso Basin. The rocks and sediments of the Birrindudu and Victoria basins are the oldest and most dominant rock types across the catchment. These Precambrian aged weathered and fractured sandstones, siltstones and dolostones outcrop and subcrop in the central parts of the catchment (Carson, 2013) (Figure 5-1). The harder more resistive sandstones form ranges in these central parts of the catchment and the softer dolostones (Proterozoic carbonate rocks) form valleys (CSIRO, 2009; Tickell and Rajaratnam, 1998). Overlying the sandstones, siltstones and dolostones in the western, eastern and southern areas of the catchment are the Antrim Plateau Volcanics, which are mostly comprised of basalt and basalt breccia (Geoscience Australia and Australian Stratigraphy Commission, 2021; Tickell and Rajaratnam, 1998). In the east of the catchment, the Cambrian Limestone of the Wiso Basin is prominent, which is mostly comprised of limestone, dolomite and siltstone (Randal, 1973) (Figure 1-1). The youngest rocks across the catchment are the: (i) Cretaceous sandstone and claystone, which overlie the Cambrian Limestone in the east of the catchment; and (ii) minor Cenozoic sediments including alluvium that occurs along the river/creek valleys and floodplains, which are most prominent in the north of the catchment near the coast (CSIRO, 2009; Tickell and Rajaratnam, 1998).

5.1.2 Regional hydrogeology

There are three main types of aquifers across the Victoria catchment: (i) fractured and weathered rocks; (ii) fractured, fissured and karstic carbonate rocks; and (iii) fractured and porous sandstones (Tickell, 2013; Tickell and Rajaratnam, 1998). These aquifer types occur in a variety of hydrogeological units (geological units hosting aquifers) across the catchment and host groundwater flow systems of varying scales. That is, some hydrogeological units host local-scale flow systems (fractured and weathered rocks) while others host intermediate to regional-scale flow systems (fractured, fissured and karstic carbonate rocks). Local-scale flow systems have very short distances between recharge areas where water enters the groundwater system and discharge areas where water exits the system (i.e. a few hundred metres to a few kilometres). Whereas, intermediate to regional-scale flow systems have much larger distances between recharge and discharge areas (i.e. several kilometres to tens or hundreds of kilometres). It is these larger groundwater flow systems that provide greater opportunities for groundwater development because they often: (i) store and transmit larger amounts of water, (ii) provide opportunities for development away from existing users and groundwater-dependent ecosystems GDEs, and (iii) have greater potential to coincide with larger areas of soils that may have potential for agricultural intensification.

Data and information for different hydrogeological units and the groundwater flow systems they host vary significantly across the Victoria catchment. Groundwater resources across the entire catchment support stock and domestic water use and numerous community water supplies (i.e. Bulla, Daguragu, Kalkarindji, Pigeon Hole and Yarralin). Unlike other parts of the NT, extensive highly productive aquifers are limited in the Victoria catchment because of the geological setting, and there are no existing groundwater models. However, there are three hydrogeological units with groundwater systems where indicative hydrogeological data from existing groundwater bores (i.e. aquifer depth and extent, water quality and bore yields) indicate that they could potentially be suitable for developing groundwater-based irrigation (DEPWS, 2021; Tickell and Rajaratnam, 1998). Indicative data exists for potentially promising aquifers including: (i) the Montejinni Limestone hosted in the Cambrian Limestone in the east of the catchment, (ii) the Campbell Springs Dolostone hosted in the Proterozoic carbonate rocks in the centre of the catchment, and (iii) various fractured and porous sandstone units throughout the catchment. However, further investigations are required to confirm their suitability for future development. For example, most bores have been constructed for stock water supplies, limiting bore yields, though it is anticipated that larger diameter, deeper and appropriately constructed bores such as those constructed for community water supplies could yield >10 L/second (Karp, 1987; Tickell and Rajaratnam, 1998). In addition, there has also been little work to characterise the nature of the flow systems at a broader scale, quantify their groundwater balances and evaluate the risks of future development to existing users (i.e. community water supplies) and groundwater-dependent ecosystems (GDEs), including springs and groundwater-dependent streams and vegetation (DEPWS, 2021; Jackson and Jolly, 2004; Tickell and Rajaratnam, 1998). Springs and groundwater-fed streams occur at various places throughout the Victoria catchment, some of which are associated with the more promising aquifers (Jackson and Jolly, 2004; Tickell and Rajaratnam, 1998) (Figure 1-1).

For those hydrogeological units that could potentially support development of primary industry (and potentially other unidentified local/intermediate-scale units), the groundwater hydrology activity would seek to provide a better understanding of: (i) key hydrogeological characteristics (i.e. aquifer extent and thickness, aquifer properties, bore yields and water quality), and (ii) where possible, important components of the groundwater balance (i.e. recharge rates and sources of discharge). It is anticipated that more detailed information for these hydrogeological units would not only provide information to private or government proponents seeking to develop groundwater but could equally be used to underpin future groundwater planning, investment and management.

For the most prospective hydrogeological units identified, and where resources are sufficient to adequately characterise the system, the groundwater hydrology activity will seek to acquire a range of more detailed information related to better understand the costs and economics of groundwater development in specific units, including information on:

- depth to water-bearing formation – strongly correlated to the cost of drilling
- depth of potentiometric head – strongly correlated to the cost of pumping
- yield – influences number of bores required to meet water demand, influencing cost of development
- aquifer drawdown in response to pumping – correlates to cost of pumping (increases head required to pump), but also very important to understand in terms of the potential available resource when considering hydrological impacts to existing users, GDEs and aquifer integrity (i.e. depletion of storage or degradation of water quality).

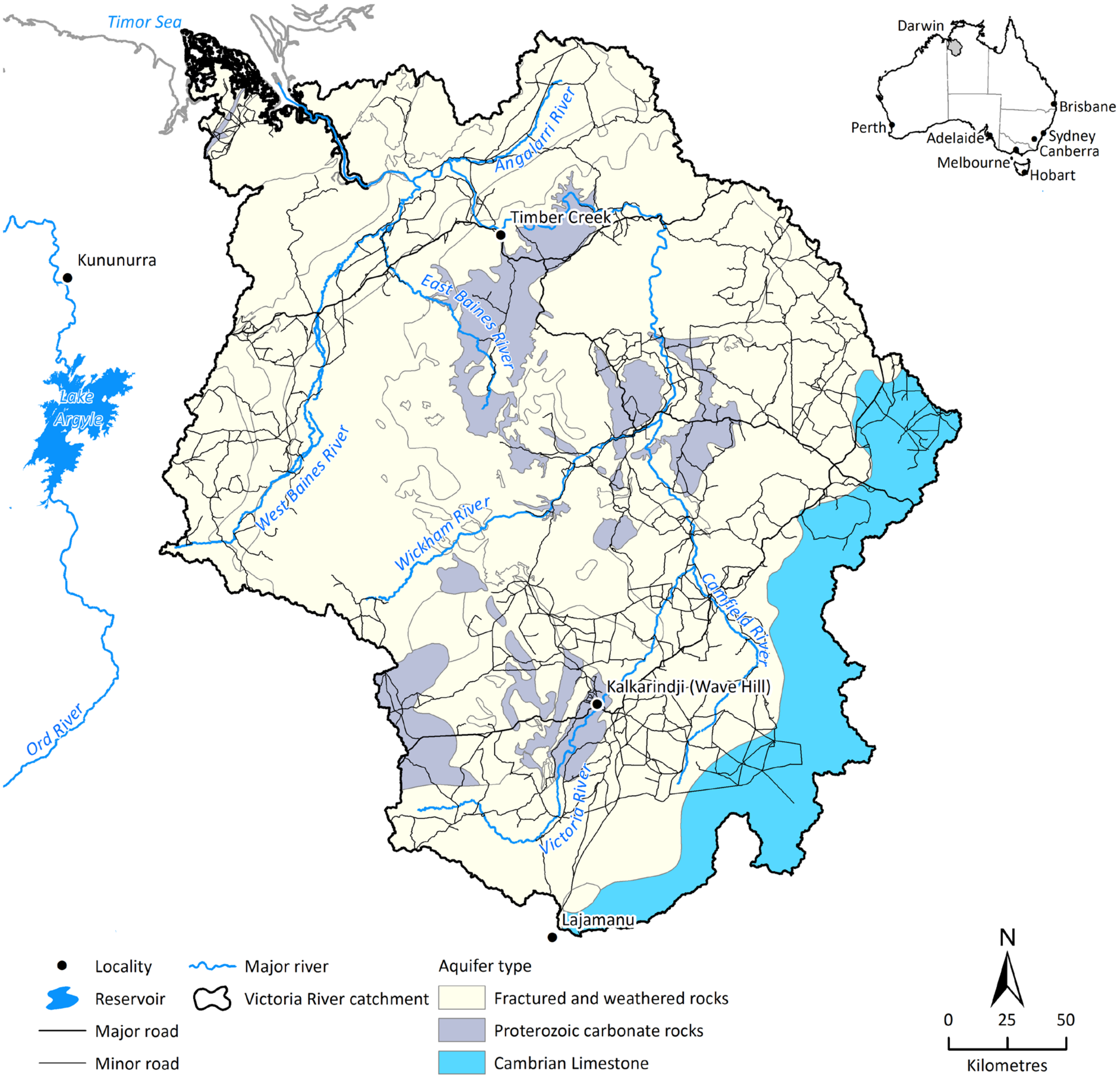

Figure 5-1 Regional hydrogeology of the Victoria catchment

Data source: Hydrogeological units (Tickell, 2013)

5.2 Regional hydrogeological desktop assessment

A regional hydrogeological desktop assessment will be undertaken across the entire catchment. This assessment will provide an aquifer attribution to publicly available groundwater data available through the DEPWS web mapping tool (DEPWS, 2021). Aquifer-specific hydrogeological data including water levels and quality, water chemistry, bore yield and aquifer properties, will then be collated and summarised along with data published in existing literature to evaluate the amount of available information for all aquifers in different hydrogeological units. In addition, the available information for the catchment's more promising hydrogeological units hosting intermediate to regional-scale groundwater flow systems (Cambrian Limestone and Proterozoic carbonate rocks) will then be used to identify: (i) potential areas where further targeted field investigations (drilling and/or ground-based geophysics) can be conducted to better characterise aquifer extents, geometries, saturated thickness and properties (Section 5.3); (ii) candidate groundwater bores to implement hydrological monitoring and groundwater sampling programs;

and (iii) springs and potential reaches of groundwater-fed streams for surface water sampling programs. The monitoring and sampling programs will assist in further characterising, conceptualising and quantifying groundwater flow processes (i.e. recharge, throughflow and discharge) and where possible, seek to evaluate their potential for future development (Section 5.6). In addition, information from existing literature will be used to design other desktop, field and modelling investigations to fill key knowledge gaps that will assist in underpinning future groundwater planning, investment and management of the catchment's key groundwater resources (Section 5.5).

5.3 Hydrogeological framework

Refinement of the hydrogeological framework for the Cambrian Limestone and Proterozoic carbonate rocks will be determined following an evaluation of the publicly available hydrogeological data, and through discussions with hydrogeologists at DEPWS and PWC. In addition, consultation will be undertaken with relevant Indigenous communities and the Aboriginal Areas Protection Authority prior to undertaking any proposed drilling programs or geophysical surveys. If drilling programs are warranted, drilling techniques to be employed (i.e. rotary mud, rotary air, sonic, etc.) will be selected based on previous successful drilling in areas with similar hydrogeological settings. The combination of production and monitoring bores will be constructed and installed for addressing specific hydrogeological questions such as determining aquifer hydraulic properties, discrete water level monitoring and discrete hydrogeochemistry and environmental tracer sampling to characterise groundwater flow processes. Any ground-based geophysical survey to be undertaken will also employ methods (i.e. time domain electromagnetics, surface nuclear magnetic resonance, etc.) for addressing specific hydrogeological questions such as depth of the watertable, aquifer depth, aquifer geometry and spatial extent, and groundwater–surface water interactions.

5.3.1 Cambrian Limestone

The Montejinni Limestone hosted in the Cambrian Limestone Aquifer occurs on the eastern edge of the catchment on the western margin of the Wiso Basin. Regional hydrogeological data specific to the Montejinni Limestone have been collated and reviewed for both the development and update of the FEFLOW groundwater model for the Cambrian Limestone Aquifer, though is quite sparse in this part of the Wiso Basin (Knapton, 2009). A recent review of this data for the current Geological and Bioregional Assessment (GBA) program (https://www.bioregionalassessments.gov.au/assessments/geological-and-bioregional-assessment-program/beetaloo-gba-region), in conjunction with estimates of actual evapotranspiration (ETa) in this part of the catchment, have potentially identified a groundwater discharge area not previously mapped for the Montejinni Limestone. The groundwater hydrology activity will seek to utilise and value add to this work by evaluating all available hydraulic head data for the Montejinni Limestone in the west of the Wiso Basin. Data-sparse areas will be identified to implement a hydrological monitoring and groundwater sampling program, which may also be supported by a targeted ground-based geophysical survey. These investigations will be used to better map and understand the scale and direction of groundwater flow in the vicinity of the eastern boundary of the Victoria catchment.

Lithological logs and stratigraphic picks from groundwater bores, mineral exploration holes and petroleum wells will be used to generate two-dimensional hydrogeological cross-sections of the Montejinni Limestone. These cross-sections will be compared to the Leapfrog geological model that is the framework for the FEFLOW groundwater model of the Cambrian Limestone Aquifer. In addition, to further characterise the scale and direction of flow and thickness, geometry and extent of the limestone unit, multiple techniques will be employed to analyse the hydraulics and hydrogeochemical and environmental tracer composition of groundwater to characterise and quantify groundwater flow processes. This information will then be used to estimate the groundwater balance for the limestone unit in this part of the catchment (see sections 5.4.2, 5.4.3 and 5.6).

5.3.2 Proterozoic carbonate rocks and other sandstone units

Other than indicative hydrogeological data (i.e. water quality, bore yields, etc.), very little is currently known about the spatial extent, thickness, depth and geometry of the Proterozoic carbonate rocks and other sandstone units of the Birrindudu and Victoria basins. The groundwater hydrology activity will evaluate the available hydrogeological data for these units to identify data-sparse areas for implementing a hydrological monitoring and groundwater sampling program. These investigations will be used to better map and understand the scale and direction of groundwater flow and underpin the development of a refined hydrogeological conceptual model for these hydrogeological systems.

Lithological logs and stratigraphic picks from groundwater bores, mineral exploration holes and petroleum wells will be used to generate two-dimensional hydrogeological cross-sections focused on the dolostone and sandstone units. In addition, to further characterise the scale and direction of flow and thickness, geometry and extent of the dolostone unit, multiple techniques will be employed to analyse the hydraulics and hydrogeochemical and environmental tracer composition of groundwater to characterise and quantify groundwater flow processes. This information will then be used to estimate the groundwater balance for these systems in various parts of the catchment (see sections 5.4.2, 5.4.3 and 5.6).

5.3.3 Aquifer hydraulic properties

The collation and, where applicable, reinterpretation of historical pumping test data from bores drilled, installed and tested across the Montejinni Limestone, and multiple units of the Proterozoic carbonate rocks and fractured and porous sandstones, will provide an understanding of the physical properties of aquifers and their ability to supply water at a sufficient rate and volume to support irrigation. As part of the current GBA program, transmissivity values have been collated from all available (188) historical pumping tests conducted in the Cambrian Limestone aquifers located across the Daly, Wiso and Georgina basins. The data relevant to the Montejinni Limestone in the east of the catchment will be collated, reviewed and reinterpreted where possible. In addition, historical pumping tests conducted in the carbonate aquifers of the Proterozoic rocks and various fractured and porous sandstone units will also be collated, reviewed and reinterpreted from the dataset collated by Tickell and Diem Phuong Nguyen (2014). Additional test data may also be available from bore reports across the Victoria catchment accessible from the DEPWS web mapping tool but not yet digitised (DEPWS, 2021). Where a tested aquifer was not recorded, this will be interpreted from bore construction and lithological or stratigraphic information.

Time-drawdown data from historical pumping tests will be digitised from bore reports and reinterpreted using a range of appropriate drawdown solutions. Diagnostic plots (Renard et al., 2009) of both the raw data and their temporal derivatives will be used to identify aquifer type(s) and therefore appropriate pumping test solution(s). Reinterpretation of these data will be undertaken to provide new estimates of aquifer transmission and storage parameters, providing useful information on how productive the aquifers are. The latter are rarely available from historical pumping test interpretations. The industry standard software AQTESOLV (Duffield, 2007) will be used to perform pumping test reinterpretation. This software package incorporates a broad range of pumping test solutions, including for both single and dual bore tests, from drawdown responses measured in one or more aquifers. Pumping test solutions will be fitted to measured time-drawdown data using a least squares optimisation algorithm.

5.3.4 Time series analyses of groundwater pressure data

Groundwater pressures are commonly measured at a high temporal resolution (e.g. hourly or by the minute) using automated loggers, which can be deployed for many months before data are collected. Logger data that are already publicly available across parts of the Victoria catchment specific to the Montejinni Limestone, Proterozoic carbonate rocks and potentially other aquifers will be collated from the DEPWS web mapping tool (DEPWS, 2021). In addition, new logger data will be obtained through the implementation of a hydrological monitoring program across the Montejinni Limestone, Proterozoic carbonate rocks and potentially other aquifers. These data will be useful for a range of activities including conceptualisation of groundwater flow systems using groundwater-level mapping and hydrograph analyses (Section 5.4.1), which can also be used for quantifying gross recharge (Section 5.4.2). In addition to responses to typical hydrological drivers (such as rainfall, evapotranspiration and groundwater extraction), the time series data obtained from loggers often contain responses to ambient drivers of relatively smaller magnitude, such as atmospheric pressure and Earth tides. Analyses of groundwater responses to these two ambient drivers provide alternative, low-cost means of: (i) identifying aquifer types, including the degree of confinement (i.e. unconfined, semi-confined or confined); and (ii) estimating aquifer hydraulic properties.

Groundwater responses to variations in atmospheric pressure can be characterised by barometric response functions (BRFs), which quantify the time lags associated with measured responses. Aquifer types and hydraulic properties can subsequently be interpreted from BRFs. Instantaneous responses are indicative of confined conditions. The degree of aquifer confinement can be characterised by a metric known as barometric efficiency (BE), from which estimates of specific storage can be derived. Regression deconvolution (Rasmussen and Crawford, 1997) will be used to calculate BRFs. Where possible, aquifer transmission and storage parameters will be estimated by fitting additional solutions to BRFs. The method presented by Acworth et al. (2015) and improved by Rau et al. (2020) will be used to calculate BE values. Specific storage estimates will be calculated from BE values using the definition provided by Jacob (1940). Where suitable, additional poroelastic parameters will be estimated using the method presented by McMillan et al. (in review).

Earth tides are driven by the movements of the Sun and Moon and the planets Mercury, Venus, Mars, Jupiter and Saturn. These cause vertical compression and extension of the Earth's surface. This can be observed as micrometre-scale groundwater pressure fluctuations in the subsurface below (Godin, 1972). Five frequencies, ranging from 0.8 to 2.0 cycles per day, typically account for about 95% of the total Earth tide potential (Cutillo and Bredehoeft, 2011). The amplitudes of these signals attenuate (decrease) as they propagate downward through the subsurface. Similarly, the velocity at which these signals propagate decreases with distance travelled into the subsurface; this is typically described by the phase lag of a signal. Reductions in both the amplitude and phase of Earth tide components at these five known frequencies can be interpreted to provide estimates of vertical hydraulic diffusivity. Theoretical Earth tide potential values will be calculated using the Hartmann and Wenzel (1995) tidal catalogue using the ETERNA software (Wenzel, 1996) via the PyGTide package (Rau, 2018) for the Python language. The amplitude and phase values of groundwater responses will be estimated using both the discrete Fourier transform (Kanasewich, 1981) and harmonic least squares (Schweizer et al., 2021), both implemented as part of the HydroGeoSines package (Rau et al., 2021) for the Python language. Where appropriate, hydraulic diffusivity values will be estimated using the solution presented by Boldt-Leppin and Hendry (2003), which will be converted to vertical hydraulic conductivity values where independent estimates of specific storage values are available.

5.4 Groundwater recharge and flow

5.4.1 Groundwater-level mapping

Spatial and temporal groundwater-level observations provide information such as variations to: (i) the depth to groundwater, (ii) the physical properties of aquifers or aquitards, (iii) the saturated thickness of aquifers, (iv) the degree to which an aquifer is confined or unconfined, and (iv) the hydraulic gradient and hydrological connectivity between different bores and different aquifers compared with surface water levels. This information is useful for conceptualising groundwater flow both locally (i.e. at a given bore) or at an intermediate (i.e. a kilometre to a few kilometres) to regional (i.e. tens to hundreds of kilometres) scale, providing information about the nature of groundwater flow systems.

The groundwater hydrology activity will utilise both static (i.e. manual standing water level (SWL)) and temporal (i.e. logged data) data publicly available via DEPWS (DEPWS, 2021) as well as new data from the implementation of a hydrological monitoring program for characterising:

- the depth to groundwater at given locations
- groundwater flow directions across different aquifers
- the scale of groundwater flow
- the hydraulic gradient between different aquifers
- spatial changes in the saturated thickness of different aquifers
- recharge to and discharge from different aquifers (Section 5.4.2)
- the physical properties of the aquifers at different locations (Section 5.3.3).

Water level data from a combination of suitable bores identified from publicly available data as well as any new bores drilled and installed by the groundwater hydrology activity will be used to map the water levels across the Montejinni Limestone, Proterozoic carbonate rocks and potentially other sandstone aquifers. Mapping will combine static SWL data available from the Department of Environment, Parks and Water Security (DEPWS, 2021) and PWC, as well as manual SWL measurements undertaken as part of a hydrological monitoring program across different aquifers. Suitable bores for monitoring water levels will be identified as part of the regional desktop assessment (Section 5.2). SWL measurements taken as part of the hydrological monitoring will be conducted using a variety of portable submersible hand-operated electronic water level meters. The SWL at each location will be measured periodically and referenced to the Australian Height Datum (AHD) from either surveyed data, light detection and ranging (LiDAR) data collected in the Assessment, or an existing digital elevation model (DEM). A variety of groundwater-level products will be produced, to indicate the direction and scale of groundwater flow in the most promising intermediate to regional-scale aquifers. Depending on the amount, quality and location of data, products to be produced include: (i) hydrographs; (ii) piezometric cross-sections, at the kilometre scale; and (iii) intermediate to regional-scale interpolated groundwater-level maps. Groundwater-level mapping will be produced using spatial analyses. These analyses will include a review of different geostatistical interpolation methods (inverse distance weighting, triangulated irregular network, spline interpolation and kriging or co-kriging) appropriate for the amount of spatial groundwater data as well as other spatial attributes of importance. Interpolations will be conducted with geographic information system (GIS) software.

5.4.2 Recharge modelling

Recharge is an important component of the groundwater balance and crucial for understanding the potential availability of water from different aquifers. While recharge to the Cambrian Limestone aquifers has previously been investigated at the basin scale (Crosbie and Rachakonda, 2021; Knapton, 2009), it is poorly understood for the western part of the Wiso Basin in the east of the Victoria catchment. Furthermore, only very preliminary estimates of recharge have been derived for the carbonate aquifers of the Proterozoic rocks and other sandstone aquifers across the Victoria catchment (Tickell and Rajaratnam, 1998). The groundwater hydrology activity will undertake a range of recharge investigations, including desktop and modelling analyses as well as deriving estimates from environmental tracer interpretation (Section 5.4.3).

Methods of regional-scale recharge estimation will include: (i) a catchment water balance analysis using remotely sensed ETa data (Crosbie et al., 2015); (ii) the Australian Water Resources Assessment – Landscape (AWRA-L) model (Vaze et al., 2013); (iii) soil vegetation atmosphere transfer (SVAT) modelling using WAVES (Zhang and Dawes, 1998); (iv) regionally upscaled chloride mass balance (CMB) (Crosbie and Rachakonda, 2021); and (v) the watertable fluctuation method (Crosbie et al., 2019). Regional estimates of recharge will be constrained using point-scale estimates of recharge inferred from field data and used to evaluate recharge to aquifers in the most prospective hydrogeological units identified.

Excess water

The catchment water balance method relies on a water balance where net recharge can be estimated as the difference between rainfall and ETa. The non-transpired component of rainfall, also referred to as the ‘excess water’, is a combined estimate of water exported from the grid cell as either groundwater recharge or runoff. For the runoff component to be used as an estimate of recharge, it would need to be able to be independently estimated. Excess water has been used as a constraint on the probabilistic estimate of recharge using the watertable fluctuation method in the catchments around Darwin (Crosbie et al., 2019) and the CMB method for the Cambrian Limestone aquifers (Crosbie and Rachakonda, 2021). MODIS data will be used to produce scaled ETa estimates on a 250-m resolution grid using an algorithm developed by Guerschman (2009) (CMRSET) that incorporates a relationship derived from the enhanced vegetation index (EVI) and the global vegetation moisture index (GVMI). The MODIS reflectance, EVI and GVMI datasets will be sourced from the remote sensing activity; the CMRSET data will be calibrated locally to flux towers in northern Australia. Precipitation data will be sourced from the climate activity.

AWRA-L

The AWRA system of models was developed by CSIRO for the Bureau of Meteorology (BoM) for their Water Resource Assessments and Water Accounts (Vaze et al., 2013). The BoM provide the outputs of AWRA-L online (http://www.bom.gov.au/water/landscape/) using a single parameter set that has been calibrated at a continental scale. AWRA-L is a landscape-scale water balance model that is capable of simulating runoff, recharge, evapotranspiration and soil water storage on a daily time step, on a regular grid, at a spatial resolution of 0.05 × 0.05 degrees (~5 × 5 km) (Viney et al., 2015). Within the model the recharge is the addition of water to the groundwater store after having passed beyond the root zone and through a 6-m soil column. Many of the parameters in the model are spatially variable based upon mapped vegetation, soil, terrain and geological properties. There are also 21 parameters that are calibrated to observed streamflow in unimpeded catchments. Outputs from AWRA-L will be collated, reviewed and summarised in terms of gross recharge across the Victoria catchment.

WAVES

The WAVES model described by Zhang and Dawes (1998) is a physically based model that achieves a balance in its modelling complexity between soil physics, plant physiology, energy and solute balances. WAVES has previously been used on multiple occasions to model recharge across northern Australia, including modelling of the impacts of a future climate (Crosbie et al., 2009). The WAVES model will be parameterised using pedotransfer functions based on grids of parameters generated by the digital soil mapping undertaken in the land suitability activity (Chapter 4 Land Suitability). Default vegetation parameters will be assigned based on available vegetation mapping. The WAVES recharge modelling will be constrained using MODIS-derived leaf area index data and point estimates of recharge derived from field data.

Upscaled chloride mass balance

The CMB method has recently been used to estimate recharge across the Cambrian Limestone aquifers (Crosbie and Rachakonda, 2021), part of which are in the east of the Victoria catchment. This work will be extended to cover the entire Victoria catchment. The CMB requires the chloride deposition due to rainfall (Davies and Crosbie, 2018) and the chloride concentration of the groundwater. The Northern Territory Government has analysed thousands of samples of groundwater for chloride concentration that can be used to estimate recharge as well as any new bores sampled as part of the groundwater sampling program (Section 5.4.3). The recharge estimates are upscaled using regression kriging with rainfall, soil clay content and normalized difference vegetation index as a measure of vegetation density as covariates. The uncertainty in the probabilistic upscaled recharge estimates is then constrained using excess water at the high end and groundwater discharge as baseflow at the low end of the recharge distribution.

Watertable fluctuation

The watertable fluctuation method (WTF method) of estimating recharge requires a time series of groundwater-level measurements and an estimate of the specific yield at the location of the watertable. A combination of existing data from monitoring bores in the Victoria catchment (DEPWS, 2021), as well as any new bores where water level loggers will be installed as part of a hydrological monitoring program, could be ideal for estimating recharge using the WTF method. Any new bores where water level loggers will be installed as part of a hydrological monitoring program will be identified as part of the regional desktop assessment (Section 5.2). The specific yield is usually poorly known and is the major source of uncertainty in this method. The uncertainty in the recharge estimates using the WTF method was recently constrained using excess water and CMB estimates of recharge in the catchments around Darwin (Crosbie et al., 2019). This same method will be applied to the suitable bores in the Victoria catchment.

5.4.3 Hydrogeochemistry and environmental tracers

To characterise groundwater suitability for irrigation use, as well as characterise, conceptualise and quantify groundwater flow processes, samples for chemistry and environmental tracers will be collected from both groundwater and surface water and be analysed and interpreted. Candidate bores with a suitable bore construction and an aquifer attribution will be identified from the regional desktop assessment (Section 5.2) to be used in a groundwater sampling program across the different aquifers (Montejinni Limestone, Proterozoic carbonate rocks and potentially other sandstone units). Characterising the general chemistry of different water sources (i.e. rainfall, surface water and groundwater) provides a basis for understanding the sources of salinity, acidity or alkalinity in water samples resulting from processes occurring in different components of the hydrological cycle. For example, different dissolved constituents may include salts and/or metals (ions) that may be present in water as a result of the cycling of salts with a contemporary marine origin, connate salts with a historical marine origin and salts and/or metals resulting from either terrestrial and/or hydrogeochemical weathering (rock–water interaction). Characterising the hydrogeochemical evolution of groundwater when coupled with other hydrogeological information will assist in refining the conceptual model of groundwater flow in different aquifers. The conceptual model and hydrogeological framework for different aquifers are fundamental for underpinning water balance, analytical and numerical modelling of water availability in different aquifers. In addition, the chloride concentration in groundwater and rainfall can be used as input for the CMB method (Section 5.4.2).

Environmental tracers are substances that naturally occur in the water cycle and have proved very useful for characterising groundwater systems in a variety of hydrogeological settings in northern Australia (Deslandes et al., 2019; Taylor et al., 2018a; Turnadge et al., 2018). The interpretation of environmental tracer concentrations in groundwater and surface water provides a way of tracing the evolution of groundwater flow in aquifers (i.e. sources and locations of recharge, areas of throughflow and locations and sources of discharge) including the scales, directions and rates of flow. When coupled with information including climate data, groundwater levels, aquifer type and geometry they can provide multiple lines of evidence to support a hydrogeological conceptual model. In addition to characterising and conceptualising groundwater systems, the sampling and application of multiple tracers under appropriate circumstances (i.e. using specialised sampling techniques and at groundwater infrastructure with adequate bore construction) can be used to quantify groundwater flow processes. A common application of tracers is to characterise and quantify mean residence times (MRTs) for groundwater flow processes including recharge, throughflow and discharge. Residence times for groundwater can vary significantly (i.e. a few years to tens of thousands of years) depending on the scale and physical properties of different hydrogeological units as well as changes in hydraulic gradients.

There are a range of different tracers available to characterise and quantify groundwater flow, each providing a unique application, covering a different range in MRT and exhibiting a different susceptibility to contamination, degradation and geochemical alteration. Ideal tracers are part of the water molecule itself (such as the stable hydrogen (^{2}H) and oxygen (^{18}O) isotopes of water and radioactive isotope of hydrogen (^{3}H)), or inert gases such as the noble gases (helium (He), neon (Ne), argon (Ar), krypton (Kr) and xenon (Xe) and their isotopes) because these can characterise groundwater recharge and flow processes without any geochemical alteration. Anthropogenic gases such as chlorofluorocarbons (CFCs), sulfur hexafluoride (SF_6) and bromotrifluoromethane (Halon 1301 or H-1301) can be used to characterise short MRTs for groundwater, for example, for flow ranging from years to decades that can occur in high rainfall zones like northern Australia (Taylor et al., 2018a; Turnadge et al., 2018). However, careful sampling is required to avoid atmospheric contamination. Anthropogenic gases can also be susceptible to degradation in certain hydrogeological settings. The concentrations of these anthropogenic gases are known from global atmospheric monitoring, they are soluble in water and represent the air–water equilibrium at the time of recharge.

Tritium (^{3}H) and carbon-14 (^{14}C) are radioactive isotopes with half-lives of 12.32 and 5730 years respectively (Godwin, 1962; Lucas and Unterweger, 2000). They are present in the atmosphere both naturally from the interaction of nitrogen with cosmic rays and by release from nuclear weapons testing in the mid-1900s (Kalin, 2000). Given the respective half-lives of ^{3}H and ^{14}C and their known concentrations in rainfall and the atmosphere, they have been used in a variety of hydrogeological systems to characterise MRTs for groundwater flow of up to about 70 and 40,000 years (Harrington and Harrington, 2016a; Suckow et al., 2020; Taylor et al., 2018a; Taylor et al., 2018b). Carbon-14 requires careful interpretation depending on the nature of the hydrogeological system due to the potential addition of dead carbon from either CO_2 in the unsaturated zone or carbonate mineral weathering in the saturated zone. Helium-4 is produced by the radioactive decay of uranium and thorium in the aquifer and therefore increases with long residence times typical in regional flow systems. Its concentration in groundwater can vary over five orders of magnitude, which makes ^{4}He the most sensitive tracer to detect the presence of old groundwater in an aquifer (Deslandes et al., 2019; Taylor et al., 2018a; Torgersen and Stute, 2013).

The groundwater hydrology activity is currently discussing the suite of tracers to be used as part of characterising aquifers of the Victoria catchment and it is likely to include most of the tracers mentioned above. There are numerous methods for the interpretation of environmental tracer concentrations in groundwater, from simple one-dimensional analytical solutions (Vogel, 1967), via conceptional two-dimensional cross-sections (Harrington and Harrington, 2016b; Taylor et al., 2018a), to complex numerical groundwater flow and solute transport models (Salamon et al., 2006). Depth profiles through an aquifer have shown to be extremely useful for both constraining recharge estimates but also characterising inter-aquifer connectivity (Taylor et al., 2018a; Taylor et al., 2018b; Turnadge et al., 2018). In this Assessment, the hydrogeological conceptual model derived from existing data and new field investigations will dictate the interpretation approach to be used, starting with a simple model, and building in complexity as knowledge and process understanding are acquired.

5.5 Groundwater discharge

Groundwater discharge is also an equally important component of the groundwater balance and crucial for understanding the potential availability of water from different aquifers. Groundwater discharge, depending on the hydrogeological and climate settings, can provide water that supports a range of different ecologically and culturally significant environmental assets at the surface, for example, springs, spring-fed vegetation, phreatophytes (i.e. vegetation accessing the watertable), rivers and creeks. In addition, it can be a source of recharge to other aquifers via upward or downward leakage or a source of water to the marine environment where aquifers discharge near the coast. The groundwater hydrology activity will undertake a range of field investigations to further characterise the sources, processes and locations of groundwater discharge across the Victoria catchment. These activities will be designed based on the current available information for: (i) GDEs including mapped springs and groundwater-fed streams, (ii) existing records of gauged spring flow and streamflow, (iii) surface areas where perennial water is detected by remote sensing techniques, and (iv) the outputs of the existing FEFLOW model for the Montejinni Limestone (Knapton, 2009). Where appropriate, there will be close links with both the surface water storage activity (Chapter 7) and the ecology activity (Chapter 9). Furthermore, groundwater extraction/use will also be quantified for key aquifers where information is available.

Preliminary spatial analyses of ETa indicate there is potentially a previously unmapped regional groundwater discharge zone at the western edge of the Cambrian Limestone of the Wiso Basin (eastern part of the Victoria catchment) where clusters of springs are prominent as vigorous perennial vegetation. While previously inferred regional flow paths for the Wiso Basin indicate flow from the western boundary of the basin to the north, the simulated hydraulic heads of the basin are based on sparse monitoring data and are influenced by defined boundary conditions set for the FEFLOW groundwater model (Knapton, 2009). Furthermore, ephemeral and perennial spring discharge from the carbonate aquifers of the Proterozoic rocks are known to support significant spring discharge (i.e. >15 L/second) in some places throughout the dry season, though few investigations of these springs have occurred (Jackson and Jolly, 2004; Tickell and Rajaratnam, 1998).

Present knowledge gaps on groundwater discharge across the Victoria catchment include:

- the location and extent of groundwater discharge zones in the east of the catchment on the boundary of the Cambrian Limestone and Antrim Plateau Volcanics
- the extent to which the Proterozoic carbonate aquifers and other fractured and porous sandstone aquifers support baseflow to the Victoria River and its tributaries

- the lack of aquifer attribution to mapped springs occurring across multiple hydrogeological units across the catchment.

Environmental tracer and chemistry surveys will be used to further identify the sources of water contributing to key springs that can be accessed and are thought to be associated with the more extensive and productive carbonate and sandstone aquifers of the catchment. In addition to key springs, environmental tracers will be sampled in existing groundwater bores with suitable bore construction installed in the Montejinni Limestone, Antrim Plateau Volcanics, Proterozoic carbonates and fractured and porous sandstone to characterise the composition of groundwater (Section 5.4.3). Environmental tracers to be sampled in springs and groundwater are still being discussed but will 'likely' include major and minor ions, ^{2}H and ^{18}O, ^{3}H, ^{13}C, ^{14}C, $^{87}Sr/^{86}Sr$ and noble gases (including ^{4}He).

5.5.1 Seepage/baseflow to rivers and creeks

A number of stream reaches within the Victoria catchment were classified as having a high potential of being GDEs, based on national-scale assessment of MODIS imagery (250 m); however, none of these were field validated within the Victoria catchment (Doody et al., 2017). Dry-season baseflow to the Victoria River and its tributaries has been previously reported by Jackson and Jolly (2004) and Tickell and Rajaratnam (1998) but is poorly understood at a broader scale. Some of the discharge is ephemeral and ceases to occur by the middle of the dry season, whereas in other places it is perennial, for example, Stirling Creek and the Wickham River (Jackson and Jolly, 2004; Tickell and Rajaratnam, 1998). Where discharge from the more promising aquifers of the Proterozoic carbonate rocks and fractured and porous sandstone units occur, it may be possible to undertake a longitudinal dry-season survey to further characterise and map discharge. For example, if locations are accessible, a survey for electrical conductivity, dissolved inorganic carbon concentration, temperature and radon-222 (^{222}Rn) activity and major ion chemistry in surface water could be adopted. The sampling design for any surface water survey will follow similar studies in the NT and elsewhere in northern Australia (Cook et al., 2003; Cook, 2003; Harrington et al., 2011; Smerdon et al., 2012; Taylor et al., 2018a).

5.5.2 Groundwater-dependent vegetation

National-scale mapping of GDEs (based on MODIS) indicates that there is high potential that groundwater-dependent vegetation exists along the banks of many of the river reaches in the Victoria River catchment (Doody et al., 2017). This activity provides the opportunity to validate the remotely sensed interpretations of field-based hydrogeological evidence and further refine remote sensing analyses. Synthetic Aperture Radar (SAR) is one remote sensing technique (e.g. Castellazzi et al., 2019) that will be considered for identifying where GDEs exist across the landscape at finer scales and during different seasons than were previously available. Unlike remotely sensed imagery, SAR has the advantage that it is not obscured by cloud cover.

Key hydrogeological information that is required to identify where GDEs exist and to understand how the hydrogeological environment supports them includes:

- depth to groundwater in surficial aquifer systems

- conceptual hydrogeological understanding of surface water and groundwater interactions, including recharge and discharge processes
- where potential evapotranspiration exceeds precipitation (Section 5.4.2)
- spring and perennial surface water body identification.

5.6 Assessing the opportunities and risk for future groundwater development

The groundwater hydrology activity will be working closely with hydrogeologists at DEPWS to provide new sources of information for use in future water resource planning, investment and management. A particular focus will be on providing new information in relation to system conceptualisation and hydrogeological frameworks and, where possible, deriving groundwater balances for groundwater flow systems hosted in the more promising hydrogeological units (Montejinni Limestone, Proterozoic carbonate rocks and potentially other sandstone units). Where appropriate (i.e. an existing model is available or enough geological data, a well-constrained conceptual model and initial water balance components exist), hypothetical groundwater extraction scenarios will be simulated using the existing model or by constructing a numerical groundwater flow model to evaluate the potential availability of water for future groundwater development. However, it should be noted that only the FEFLOW model for the Cambrian Limestone exists in the Victoria catchment and the construction of a new model may not be possible for other groundwater systems. Where there is insufficient information available (i.e. no existing model or a lack of geological data, a poorly constrained system conceptualisation and rough water balance components), other analytical models that simulate drawdown propagation, springflow depletion and streamflow depletion 'may' be considered. However, their use will be governed by whether or not they are deemed appropriate for answering questions in relation to evaluating the potential water availability for different aquifers given the amount of available hydrogeological information for a particular aquifer. In the absence of modelling, arithmetic groundwater balances will be derived where information is sufficient for the most promising aquifers identified. The potentially available groundwater resource for future development will be summarised in the context of contingent allocation rules stated in the Northern Territory Water Allocation Planning Framework (DENR, 2020).

5.7 References

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Part III

What are the opportunities by which water resource development may enable regional development?

Photo: Dryland cotton (CSIRO)

6 Indigenous water values, rights, interests and development goals

6.1 Introduction

The Victoria River Water Resource Assessment Indigenous activity will provide an overview of key Indigenous values, rights, interests and development goals with respect to water, irrigated agriculture and other potential non-agricultural opportunities. This analysis is intended to assist, inform and underpin future discussions between developers, government and Indigenous people about particular developments and their potential positive and negative effects on Indigenous populations.

The key questions that this activity will seek to address in the Victoria catchment include:

- What is the existing documented information pertaining to Indigenous people in the Assessment area, and to Indigenous water and development issues more generally? This will emphasise:
  - the historical and contemporary context for Indigenous people living in the Victoria catchment
  - local Indigenous residence and tenure regimes in the Victoria catchment
  - key issues in Indigenous water values, rights, interests and development goals in the Victoria catchment
  - key issues for Indigenous people regarding water, irrigated agricultural development and other water-related development opportunities in the catchment.
- How do current Traditional Owners of, and Indigenous residents in, the Victoria catchment perceive water resource assessment and development?
- What potential issues regarding cultural heritage arise from water resource assessment and development?
- What are the key legal and policy issues with respect to Indigenous people, water and irrigated agricultural development?
- What are the barriers to, and enablers of, Indigenous people participating in water resource development?
- What are the barriers to, and enablers of, Indigenous people deriving social and economic benefits from water resource development?

6.2 Linkages to other Assessment activities

Components of the Victoria Indigenous values, rights, interests and development goals activity will have close connections with components of the agriculture and socio-economic (Chapter 8), land suitability (Chapter 4), and ecology (Chapter 9) activities. The Indigenous activity will, through consultations with Traditional Owners and Indigenous corporations and their partners, provide a guiding framework to support the agriculture and socio-economic activity with an economic analysis of selected bush foods from the catchment. This framework will also guide the selection of bush foods for the land suitability activity. Considerations of Traditional Owners' intellectual property and control of knowledge and potential future business opportunities are critical considerations in this work.

The Indigenous activity will support the ecology activity through the collaborative identification of key natural and cultural assets of significance to Indigenous people of the Victoria catchment. Indigenous knowledge will be crucial in understanding how particular assets have human ecological significance, and how they function as nodes in interconnected networks supporting biocultural diversity and sustainability. Connections with other Victoria River Water Resource Assessment activities will also be identified as the study progresses.

6.3 Linkages to other research projects in the Victoria catchment

There is a range of other research initiatives being undertaken in the Victoria catchment that provide important context for the research undertaken through the Victoria River Water Resource Assessment.

The Indigenous activity of the Assessment will build on any previous work where there was inclusion of Indigenous knowledge in water planning. In addition, it will incorporate principles for sustainable development, barriers and enablers of participation in water planning, and whole-of-catchment and inter-generational impacts.

6.4 Context and consultation

The Victoria catchment is unique in terms of its:

- governance and tenure regimes
- population size and demographics
- levels of pre-existing development including water-related development
- existence of previous research
- ongoing current and proposed future research, etc.

This context makes ongoing consultation with key stakeholders crucial to determining the exact scope of the Indigenous activity. This consultation is expected to continue throughout the conduct of the research and is likely to include stakeholders from:

- Australian Government
- state and territory governments

- local governments
- Northern Land Council
- regional councils
- local Indigenous landholders and prescribed bodies corporate (PBC)
- local Indigenous land trusts
- Aboriginal Areas Protection Authority
- catchment management agencies
- Indigenous development agencies.

6.5 Scope

Previous experience from the Flinders and Gilbert Agricultural Resource Assessment (Barber, 2013) and the Northern Australia Water Resource Assessment (NAWRA) (Barber, 2018; Barber and Woodward, 2018; Lyons and Barber, 2018) within the project team suggests that consultations about project scope and methods in the Victoria catchment are likely to be iterative, and that maintaining some flexibility in project scope is important in the initial planning stages. The research will not seek to directly enable or facilitate Traditional Owner group consensus about water and irrigation development in general, or specific development scenarios considered by the Assessment. Rather, the project will focus on generating a representative set of Indigenous issues, perspectives and aspirations regarding water development that can be used as a guide and foundation for subsequent discussions between public and private developers and Indigenous interests. The evaluation and refinement of development options undertaken by the other components of the Assessment provides further shared foundations for this process. Further refinements in project scope, including jurisdictionally specific refinements, are expected to be made following further consultation.

6.6 Research ethics

Prior to the commencement of the fieldwork component of the project, the research aims and proposed methods will be reviewed by the CSIRO Social Science Human Research Ethics Committee (CSSHREC). Project information sheets and a free, prior and informed consent form will also be submitted for approval by CSSHREC as part of the application. CSSHREC oversight will continue throughout the project.

Following initial consultations and briefings, a one-year whole-of-Assessment research permit has been approved by the Northern Land Council. The project will make annual submissions to the Northern Land Council for a reissue of the research permit during the project life. Further consultation will be undertaken with local and subregional Indigenous organisations.

Participation in the project will be entirely voluntary. Potential research participants will be provided with clear explanations of the research process and outcomes through a combination of telephone, face-to-face, and written contact prior to them making any decision to participate. Wherever practicable, research participants will be afforded an extended period (of 1 month or more) after first contact by research staff to allow time for further consideration and consultation before making a decision to participate. During initial contact, the project information sheets and the written consent form will be supplied. After this process has taken place, verbal consent will be sought and then confirmed through the participant signing the consent form. These forms are to be retained by CSIRO staff in a secure location. Based on experience of past projects, it is expected that rather than participants being individually identified, comments that appear in any report will be identified through a more general group identifier. This retains anonymity but also provides a level of geographic specificity.

6.7 Methods

6.7.1 Review of existing information

The review of existing documented information will encompass:

- the historical and contemporary context for Indigenous people living in the Victoria catchment
- local Indigenous residence and tenure regimes
- key issues in Indigenous water values, rights, interests and aspirations
- key issues for Indigenous people regarding water, irrigated agricultural development and its interactions with other water-related development.

Relevant supporting data generated by other activities (for example, ecological data with biocultural implications) will also be integrated with the review.

6.7.2 Fieldwork and direct consultation

The fieldwork will emphasise direct consultation with Traditional Owners of, and Indigenous residents in, the Victoria catchment through a combination of:

- telephone and face-to-face interviews
- group meetings and workshops
- trips to key locations
- other research methods developed in consultation with local and regional stakeholders.

Local Indigenous organisations and individuals in each jurisdiction will influence the degree to which particular methods (e.g. individual interviews) are positioned with respect to other options (large workshops and groups).

Participants will be identified through a ‘snowball’ method of iterative consultation with key local and regional Indigenous organisations – Northern Land Council, local group-based Indigenous corporations, and catchment management agencies. The objectives and intended methods of the research will be explained, copies of project information and consent forms provided, and further direction taken about people and organisations who should be contacted in the preliminary scoping and identification stage of the Assessment. Key organisations and individuals nominated by these Indigenous organisations will then be approached for further consultation during planned field trips.

6.7.3 Cultural heritage assessment

The Assessment will provide regionalised, landscape-scale desktop information about cultural heritage based on information agreed with the Aboriginal Areas Protection Authority. It will also contain general commentary, drawn from past work in the NAWRA project, about the cultural heritage values and issues that are potentially significant in future water resource development. Particular attention will be paid to future water storage options identified through Assessment research.

6.7.4 Legal and policy analysis

This component of the activity will provide a desktop description of current legislative and policy requirements relevant to the inclusion of Indigenous interests in the Assessment and development of water resources in the NT (including water rights, cultural heritage, Aboriginal freehold and native title). It will also identify key legislative and policy challenges to, and opportunities for, recognising and valuing Indigenous interests associated with water resources in the NT.

The analysis will focus on rights and interests recognised in the Australian Commonwealth and NT legal systems including recent developments designed to better accommodate Indigenous water values and rights in the Northern Territory Government's allocation planning processes. The analysis will also note instances where Indigenous customary laws and cultural understandings of water are not currently recognised by the legal and regulatory system.

6.8 Data analysis and preliminary dissemination

The data from the literature and interviews will be iteratively analysed using NVivo qualitative analytical software to identify major themes and key findings. Key information and research participant comments from the interviews will be identified, extracted and then formally checked with the respective research participants as both an accurate reflection of their views and as able to be used in further analysis and public presentation.

The resulting information and analysis will then be combined into a draft research report. This will be disseminated to local Indigenous research participants and key Indigenous stakeholders for further comment, correction and confirmation. The report will be augmented by further presentations to group meetings. The resulting feedback will be incorporated into a revised draft report, which will then be subjected to scientific peer review and further community comment prior to finalisation.

6.9 Staff and collaboration

The Indigenous activity team includes Peci Lyons, the project lead, and Marcus Barber as project advisor. Peci Lyons led the Mitchell and Roper catchment Indigenous activities. Peci Lyons will coordinate the activity and its articulation with other Assessment activities, and undertake primary fieldwork. Additional CSIRO and non-CSIRO staff may be added on an as-needs basis.

6.10 Project governance and oversight

Project governance and oversight containing Indigenous representation will be established at the 'whole-of-project' level in consultation with the Northern Land Council. Specific governance and oversight for the Indigenous activity will be provided through regular reporting to the relevant regional councils of the Northern Land Council. Further reporting to the Northern Land Council Executive and Full Council will be at the direction of the Northern Land Council.

6.11 References

Barber M (2013) Indigenous water values, rights and interests in the Flinders and Gilbert catchments. A technical report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy. CSIRO Water for a Healthy Country and Sustainable Agriculture flagships, Australia.

Barber M (2018) Indigenous water values, rights, interests and development objectives in the Darwin catchments. A technical report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments, Australia.

Barber M and Woodward E (2018) Indigenous water values, rights, interests and development objectives in the Fitzroy catchment. A technical report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments, Australia.

Lyons I and Barber M (2018) Indigenous water values, rights, interests and development objectives in the Mitchell catchment. A technical report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments, Australia.

7 Surface water storage

The purpose of the surface water storage activity is to provide a comprehensive overview of the different surface water storage options in the Victoria catchment, to enable decision makers to take a long-term view of water resource development and to inform future allocation decisions. In this chapter, methods are described by which different surface water storage options will be assessed in the Assessment.

The key questions that this activity seeks to address in the Victoria catchment include:

- Where are the highest yielding and most geologically suitable farm-scale and large dam sites?
- How much water could dams yield and at what cost?
- Would the reservoir inundate endangered ecosystems?
- After how many years would large dam(s) infill with sediment?
- What is the opportunity for storing water in offstream farm-scale water storages, such as ringtanks?
- How much water is contained in naturally occurring wetlands and waterholes?
- Where are the best opportunities for hydro-electric power generation?

This chapter consists of two parts. The first part details the methods that will be undertaken as part of a scoping-level assessment and pre-feasibility assessment of large (i.e. >10 GL) instream and offstream storages. The second part examines opportunities for farm-scale water storage structures (i.e. <10 GL), such as hillside dams and ringtanks.

7.1 Introduction

In a highly seasonal climate such as the Victoria catchment, and in the absence of a suitable groundwater resource, industries that require year-round use of water will need to invest in surface water storage infrastructure. Currently no major surface water storages exist in the Victoria catchment, nor have any previous studies on surface water storage in the Victoria catchment been identified.

7.2 Large instream and offstream storages

This section describes the methods by which potential dam sites will be selected (Section 7.2.1) for pre-feasibility analysis (Section 7.2.2). Section 7.2.4 describes the additional analysis that is intended for the short-listed sites.

7.2.1 Initial scoping-level assessment using the DamSite model

Instream storages are highly contentious because they can affect existing environmental, cultural and recreational values. The process by which large dams are selected for investigation has often been unclear or seemingly subjective, and the decision-making process is not always transparent to all stakeholders. This section presents an open and transparent method by which sites will be selected for a pre-feasibility analysis. The first step involves running the DamSite model over the entire catchment to identify those locations in the catchment likely to be more promising for large instream dams, farm-scale gully dams and offstream storages.

DamSite model

The DamSite model (Read et al., 2012; Petheram et al., 2013) uses a digital elevation model (DEM) to assess all locations on a river network and test simulated dam walls of varying heights, to produce a comprehensive dataset of sites with relevant attributes, including catchment area, runoff, reservoir volume, reservoir surface area, dam height, dam width and dam face area. Saddle dams are included in the Assessment if required by the terrain. This dataset will include an exhaustive set of potential dam locations – more than 100,000 potential sites in each catchment (based on previous experience with DamSite). These sites are then filtered to identify approximately 5000 of the most suitable sites, using a combination of criteria including yield, construction cost, and yield per dollar construction cost.

Yield is initially calculated at every location and every metre increment height using the Gould–Dincer Gamma method, and then refined for the subset of around 5000 sites using a behaviour analysis model. Construction cost is calculated using a cost algorithm that serves to penalise higher and longer dam walls. The cost algorithm will be refined as part of the Assessment to improve its accuracy. Key input data to the DamSite model are the SRTM DEM-H (Shuttle Radar Topography Mission digital elevation model; the best available DEM across the Victoria catchment), gridded climate data and gridded runoff data from the surface water hydrology activity.

7.2.2 Pre-feasibility analysis

The pre-feasibility analysis is largely a detailed desktop analysis of a selection (approximately six) of the more promising potential dam sites in the Victoria catchment. It involves a comprehensive review of past studies, a reassessment of each site using a consistent set of methods and models, and a site investigation by an experienced infrastructure planner and engineering geologist. Each site will be evaluated and the results reported against a consistent set of criteria. The criteria and the methods by which each criterion will be evaluated are described in Table 7-1.

Table 7-1 Proposed methods for assessing potential dam sites in the Victoria catchment

PARAMETER	DESCRIPTION
Previous investigations	Literature documenting previous dam site investigations will be obtained from a variety of sources.
Description of proposal	Based on review of past reports. Where no documents are identified, this will be noted. For the short-listed potential dam sites, the original proposals will be modified to reflect more recent data and methods, and contemporary thinking.
Regional geology	The regional geology for each dam site will be assessed using the 1:100,000 geology series, and other finer scale geological data where available.
Site geology	The site geology for each dam site will be assessed using the 1:100,000 geology series, and other finer scale geological data where available, and a site visit by a dam geologist.

PARAMETER	DESCRIPTION
Reservoir rim stability and leakage potential	These parameters will be assessed by overlaying inundated area at full supply level (FSL) on available geology data.
Proposed structural arrangement	Based on review of past reports. Where no documents are identified, this will be noted. For the short-listed potential dam sites, new conceptual arrangements will be developed that better reflect contemporary thinking and more recent data.
Availability of construction materials	Based on review of available literature, site visits and proximity to quarry locations.
Catchment area	Catchment areas will be derived from SRTM DEM-H. In the majority of cases, the SRTM-H data are considered to be superior to historical topographic data for the purposes of deriving catchment areas and computing reservoir volumes.
Flow data	Mean and median flows will be computed using observed data from the nearest streamflow gauging station.
Capacity	Dam capacity will be derived from SRTM DEM-H, unless stated otherwise. For potential dams, the dead storage volume will be assumed to be 2% of the reservoir capacity at FSL.
Reservoir yield assessment	A behaviour analysis model will be used to assess the reliability of different yields under the historical climate and future climate.
Open water evaporation	Morton's wet environment areal potential evaporation (Morton, 1983) and a stability corrected bulk aerodynamic formula (Liu et al., 1979).
Potential use of supply	Based on review of past studies.
Impacts of inundation on existing property and infrastructure	Based on review of past studies, satellite imagery, geographic information system (GIS) overlays and site visit.
Ecological and cultural considerations raised by previous studies	Based on review of past studies.
Estimated rates of reservoir sedimentation	Sedimentation rates will be calculated using estimated sediment yields and the FSL dam capacity for each site. Sediment yields will be computed from an empirical relationship derived from ten sediment yield studies across northern Australia. The rates of reservoir sedimentation will be presented for 1, 10, 30, 100 and 1000 years, as well as the number of years taken to 100% infill. Minimum (best-case), expected and maximum (worst-case) estimates will be provided.
Environmental considerations	**Barrier to fish movement** Mapped data on the ecological assets and the fish species distribution in the Victoria catchment will be sourced from the ecology activity. Data on the persistence of waterholes in both catchments will be sourced from remotely sensed imagery.
Cultural heritage considerations	A desktop Indigenous cultural heritage review will be undertaken by searching the available databases.
Estimated cost	For all potential dam sites that were previously investigated, the cost estimate reported in the literature will be adjusted for inflation using the Australian consumer price index. This will be compared with an estimate provided by the DamSite model automated dam cost algorithm, informed by local preliminary geology assessment. The uncertainty associated with these estimates is likely to be between –30% and +75%. For the short-listed potential dam sites, more detailed cost estimates will be calculated by developing conceptual arrangements for each of the dams, informed by flood design modelling. Cost rates applied for each item of work may be derived from earlier estimates for the Green Hills dam, Connors River dam and Wyaralong Dam (in Queensland). The uncertainty in cost of the short-listed sites is likely to be between –20% and +50%.
Estimated cost per ML of supply	Estimated capital cost divided by the yield at 85% reliability, as computed by the Assessment under the proposed structural arrangement.
Potential costs and benefits	Based on reviewed literature.
Summary comment	Provided by Assessment personnel.

7.2.3 Assessment of system yield

The system yield from of two or more reservoirs in series will be investigated as part of the river system scenario modelling.

7.2.4 Short-listed dam sites

Based on the pre-feasibility analysis, a short list will be compiled of approximately three of the more promising dam sites in the Victoria catchment. Short-listed sites will be primarily selected based on topography of the dam axis, geological conditions, proximity to suitable soils, water yield, and ecological and cultural considerations.

Additional studies undertaken for the short-listed dam sites will include a flood design study, a detailed cost estimate and a desktop cultural heritage assessment. High-resolution data will be acquired for the short-listed dam sites using laser altimetry or photogrammetry methods.

For any of these options to advance to construction, a feasibility analysis would need to be undertaken, which would involve several iterations of detailed (and expensive) studies, and ultimately development of a business case. Studies at this level of detail are beyond the scope of the current regional-scale resource assessment.

7.3 Farm-scale instream and offstream storages

This section describes the methods for assessing the opportunities for farm-scale instream and offstream water storage structures (i.e. <10 GL). Instream storages include gully dams and hillside dams, while offstream water storage facilities can take the form of ringtanks, turkey nest tanks and excavated tanks (described in more detail in Table 7-2). Weirs can also be used in conjunction with some offstream water storages, where the weir is used to raise the upstream water level to allow diversion into an offstream storage or the creation of a pumping pool. The most suitable type of farm-scale water storage depends on a number of factors, including topography, the availability of suitable soils, excavation costs and the source of water (e.g. groundwater or surface water pumping, flood harvesting).

Table 7-2 Types of offstream water storages (Lewis, 2002)

TYPE OF FARM-SCALE STORAGE	DESCRIPTION	STORAGE TO EXCAVATION RATIO
Gully dam	An earth embankment built across a drainage line. Dams are normally built from material located in the storage area upstream of the dam site.	10:1 (favourable conditions)
Hillside dam	An earth dam located on a hillside or slope and not in a defined depression or drainage line.	5:1 (on flatter terrain) 1:1 (on steeper slopes)
Ringtank	A storage confined entirely within a continuous embankment built from material obtained within the storage basin.	1.5:1 (small tank) 4.5:1 (large tank)
Turkey nest tank	A storage confined entirely within a continuous embankment but built from material borrowed from outside the storage area. All water is therefore held above ground level.	Usually smaller than ringtanks, and lower storage to excavation ratio

TYPE OF FARM-SCALE STORAGE	DESCRIPTION	STORAGE TO EXCAVATION RATIO
Excavated tank	Restricted to flat sites and comprise excavations below the natural surface. Excavated material is wasted. Generally limited to stock and domestic use, and irrigation of high-value crops.	Low storage to excavation ratio

The following analysis will be undertaken to assess the opportunities for farm-scale water storages in the Victoria catchment:

- The soil attribute grids (to a depth of 1.5 m) generated as part of the land suitability activity and locally specific rules will be used to identify those parts of the Assessment area that are more and less suitable for farm-scale water storages. The Assessment will draw on bore lithology logs, expert and local knowledge, and electromagnetic data to make assessments below 1.5 m.
- The DamSite model will be used to identify those parts of the Assessment area that are likely to be hydrologically and topographically favourable for instream farm dams (e.g. hillside dams).
- Likely physical constraints to water pumping in key river reaches (i.e. minimum pumping thresholds) will be estimated.
- Spatial analysis, remotely sensed imagery and local engineering expertise will be used to identify those parts of the landscape that are likely to be more suitable for diversion structures.
- Over those sections of river reach where there are opportunities to impound water running down flood-outs, a higher-resolution DEM will be obtained using laser altimetry flown by helicopter; the reliability with which the flood-outs run will be estimated using a one-dimensional hydraulic model. Acquisition of higher-resolution DEM cross-sections will primarily occur in those areas identified by the interim land suitability maps as having large continuous areas of land suitable for irrigated agriculture.

In assessing regional-scale economics of water harvesting schemes, local variations in scale and site-specific nuances can present challenges. These can result in considerably different construction and ongoing operational costs from one site to another (e.g. costs for different amounts of diesel required for pumping, removal of sediment deposited in diversion channels, replacement of worn and damaged equipment). Hence, operationally, each site would require its own specifically tailored engineering design. As a result, the Assessment will not produce individual engineering designs for water harvesting infrastructure for each landholder in the Assessment area; this is beyond the scope and resources of the Assessment. Besides, most landholders will have observed the way in which water moves across their land and will have given considerable thought to their most suitable water harvesting configurations. However, the Assessment will provide some overarching principles that could be used by individual landholders in designing, siting and costing water harvesting infrastructure in the Victoria catchment, as well as a relevant list of references on farm dam planning, construction and maintenance.

7.4 References

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Petheram C, Rogers L, Eades G, Marvanek S, Gallant J, Read A, Sherman B, Yang A, Waltham N, McIntyre Tamwoy S, Burrows D, Kim S, Podger S, Tomkins K, Poulton P, Holz L, Bird M, Atkinson F, Gallant S and Kehoe M (2013) Assessment of surface water storage options in the Flinders and Gilbert catchments. A technical report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy. CSIRO Water for a Healthy Country and Sustainable Agriculture flagships, Australia.

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8 Agriculture and socio-economics

The approach used to analyse the viability of agricultural development options in the Victoria catchment will draw on similar recent technical assessments (Petheram et al., 2013a; Petheram et al., 2013b; Ash et al., 2014; Ash et al., 2017; Ash et al., 2018a; Ash et al., 2018b; Stokes et al., 2017).

> The key question that this activity seeks to address in the Victoria catchment is:
>
> - What farming options are likely to be able to cover the costs of new development(s) and/or deliver the most economic benefit to the Victoria catchment region?

The agriculture and socio-economics activity will take a multi-scale approach (Figure 8-1), from farm to regional scale. Methods for key components of the activity are outlined below and expanded in this chapter.

- The emphasis of the 'farm-scale component' will be a bottom-up analysis, working from the biophysical and management determinants of crop productivity to indicative farm gross margins that could be achieved for a range of cropping and fodder options.
- The 'scheme-scale component' will initially take a generic top-down approach, working backwards from the costs of new developments to the farm gross margins that would have to be sustained to cover those costs.
- The 'regional-scale component' will look at the knock-on economic impacts that could occur if new agricultural areas were developed in the Victoria catchment.

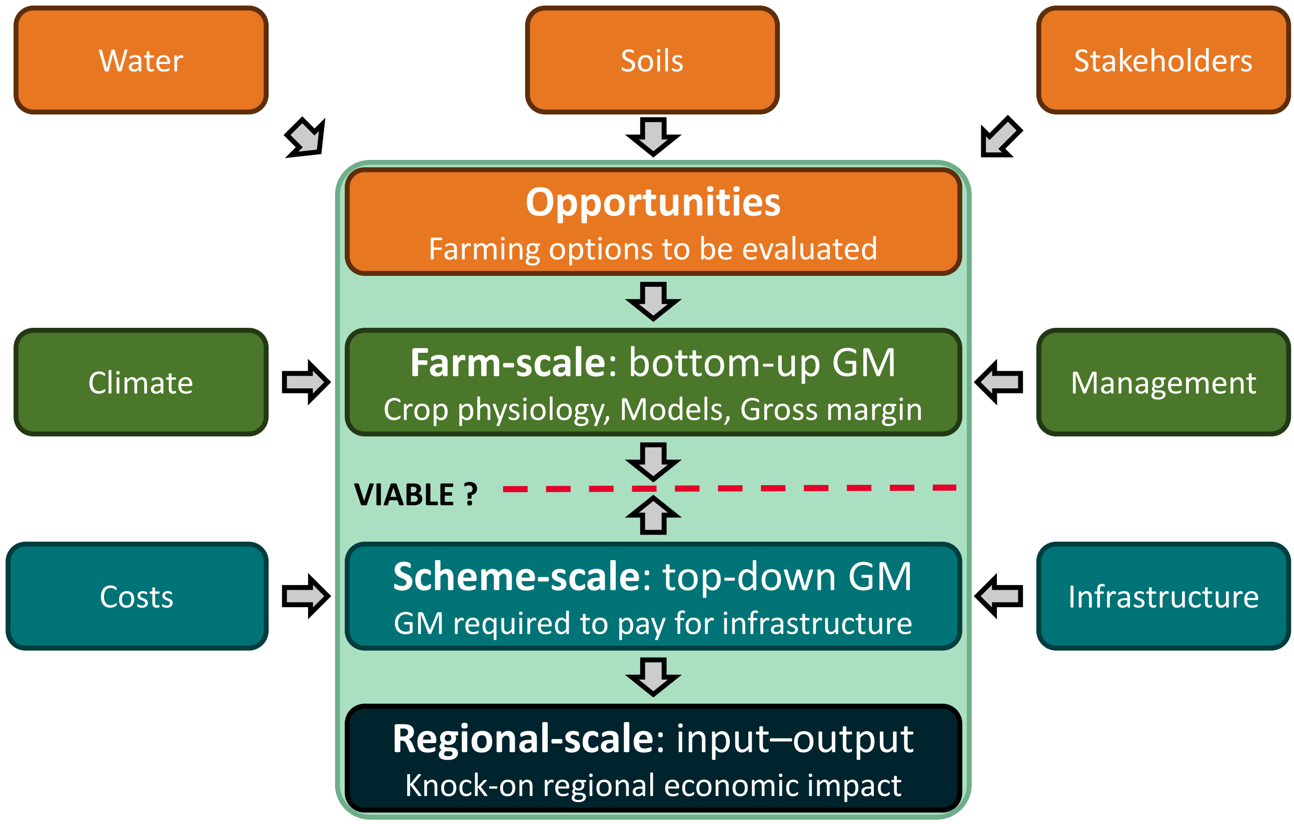

Figure 8-1 Overview of the approach for assessing the agricultural and economic viability of agricultural development options in the Victoria catchment

Note: In the figure, GM = gross margin.

The combined analytical framework will also allow 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 surface water storage options.

Rather than being prescriptive about cropping systems for particular locations, the aim is to provide insights on the issues and opportunities associated with developing integrated cropping or crop–livestock systems, which will be illustrated with a range of contrasting prospective cropping options. The set of crops that will be considered in the analyses will be determined as the project progresses and will rely heavily on the surface water hydrology (Chapter 3), surface water storage (Chapter 7) and land suitability (Chapter 4) activities, and stakeholder input (including the Indigenous activity, Chapter 6) to define the scale, location, costs and nature of development 'opportunities' (Figure 8-1).

8.1 Farm-scale analyses

8.1.1 Overview

Assessing the viability of different farming options requires bringing together information and knowledge on climate, soils, water resources, agronomy, natural resource management, and farm economics and using analytical tools to provide quantitative outputs for interpretation. This information will be used in the Assessment to drive an analysis of the type of cropping systems and/or crop–livestock systems to deliver the most favourable yields and farm gross margins, given the constraints of soils, environment, climate, and supply and reliability of irrigation resources. The approach requires an understanding of crop physiology and the sensitivity of crop growth to local climate as a precursor to individual crop and fodder assessment, using modelling, industry best practice and expert knowledge, as no field work is planned for model validation. Climate (temperature, rainfall and radiation) influences crop type, optimal growing windows and crop management not only in the context of individual crop needs but also in terms of how cropping and forage systems can be constructed to make the most effective use of available resources, such as water. Past publications and expert input will be sought and reviewed, covering cropping and livestock experience (either actual (trial, commercial) or desktop). Expert knowledge and local industry experience from existing agriculture in the Katherine and Douglas Daly regions will be particularly important in the Victoria catchment due to the limited broadacre cropping or horticulture experience in the catchment.

8.1.2 Agricultural viability

Crop and forage modelling and analysis

The cropping systems analysis will depend on having estimates of crop, forage and livestock production for individual components of the system and will require data and outputs from the land suitability and surface water storage activities. For the Victoria catchment, a range of crops and forages could be suitable, including broadacre crops (e.g. sorghum, pulses), horticultural crops (e.g. mangoes, melons), root crops (e.g. onions), forages (e.g. sorghum, lablab) and industrial crops (e.g. cotton, industrial hemp). Estimating crop and forage production relies on highly parameterised simulation models such as the Agricultural Production Systems sIMulator (APSIM) and the Crop Livestock Enterprise Model (CLEM). Initial estimates of production will be based on generic soils selected to match as closely as possible existing soils information in the Assessment area, but these will be adjusted as new information becomes available. The modelling work also provides estimates of water used for different crops and forages. Ultimately, this will link to water requirements for cropping systems, with feedback to water resource requirements, availability and reliability. Losses of water from irrigation land may affect water quality in streams and aquifers. There will be links with the ecology activity (Chapter 9) to consider possible off-site impacts. The influence of irrigated agriculture on Indigenous water values, rights and development goals may also need to be considered (Chapter 6).

APSIM may not have the capability to simulate all the development options of interest in the Victoria catchment, so a pluralistic approach will be taken, using simulation models, industry data, best practice and expert knowledge. For crops such as some cucurbits, tree crops, vegetables, some fodder or pastures and industrial crops such as hemp, expert and local experience from existing agricultural regions in northern Australia will be used to develop an assessment of production potential and water use. For some of these cropping systems, simple day degree models exist that have been designed to estimate harvest date and potential yield. These simple models will be compared with available data in each catchment to determine their utility. Where cropping systems (e.g. mango and melon) operate in similar northern Australian environments, production and water use data will be collected from the existing farming systems to inform the Assessment. Crop calendars will be developed for each crop and forage assessed.

Agricultural Production Systems sIMulator

APSIM is a modelling framework that has been developed to simulate biophysical process 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). Calibrated crop models have been used in previous assessments of cropping potential for a range of prospective crops in northern Australia (Carberry et al., 1991; Pearson and Langridge, 2008; Webster et al., 2013; Yeates, 2013; Ash et al., 2017). The APSIM simulation framework has been extensively employed in earlier agricultural assessments in northern Australia (Northern Australia Water Resource Assessment (NAWRA), Flinders and Gilbert Agricultural Resource Assessment, Northern Australia Food and Fibre Supply Chains Study), and is currently being used in the Roper River Water Resource Assessment (RoWRA). Although the focus of this work will be on fully irrigated crop and forage production, opportunistic dryland and supplementary irrigation options will be considered.

Crop Livestock Enterprise Model

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

Farm gross margins and overheads

The farm gross margin is the difference between the revenue received for the harvested produce and the variable costs incurred in growing the crop. Gross margin templates will be set up for each crop to calculate variable costs and revenue under a range of conditions and locations in the Victoria catchment, using a new tool currently being developed in RoWRA.

Farm overheads, the fixed costs that a farm incurs each year even if no crop were planted, will be calculated for a generic broadacre farm. Annual net farm revenue is the difference between the farm gross margin and the overhead costs.

8.2 Scheme-scale analyses

Scheme financial evaluations will use industry standard cost–benefit methods (OBPR, 2016), based on a discounted cashflow framework, to evaluate the commercial viability of irrigation developments. The framework, detailed in the NAWRA socio-economic technical report (Stokes et al., 2017), provides a purely financial evaluation of the conditions that would be required to produce an acceptable return from an investor’s perspective. Initially, a generic ‘top-down’ approach will be taken, working backwards from the costs of developing a new irrigation scheme to determine the farm gross margins that would be required to generate an acceptable rate of return on the investment (Figure 8-1). This will be compared against the 'bottom-up' indicative farm gross margins from the farm-scale analyses to identify which crop options could be potentially viable.

A discounted cashflow analysis considers the lifetime of costs and benefits following capital investment in a new project. Costs and benefits that occur at different times are expressed in constant real dollars, with a discount rate applied to streams of costs and benefits. Costs included will be the capital costs of developing the land and water resources, and the ongoing maintenance and operating costs. Cohorts of infrastructure assets will be tracked according to their lifespans to account for replacement and residual values over the evaluation period. Net farm revenue each year will be calculated by subtracting fixed overhead costs from the gross margin.

Additional analyses will quantify the effects of various risks and risk-mitigation measures on the farm gross margins that would be required for a scheme to break even.

8.3 Regional economic impacts

The full, catchment-wide impact of the economic stimulus provided by an irrigated development extends far beyond the impact on those businesses and workers directly involved both in the short term (construction phase) and longer term (operational phase). There are knock-on stimulus effects to other businesses in the region whose goods and services are purchased to support the new economic activity, and household incomes increase where local residents are employed (as a consequence of the direct and/or production-induced business stimuli) leading to increases in household expenditure that further stimulates the regional economy. The combined regional economic benefit would depend on the scale of the development, the type of agriculture that is established, and how much spending from the increased economic activities occurs within the region.

The size of the impact on the Victoria catchment regional economy will be estimated using regional economic multipliers (derived from input–output tables that summarise expenditure flows between industry sectors and households within the NT region (Murti, 2001)), following the approach used in NAWRA (Stokes et al., 2017).

8.4 References

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Part IV

What are the likely risks and opportunities to the natural environment due to changes in the river flow regime as a result of water resource development?

Photo: Victoria River escarpment (Geoff Crane)

9 Ecology

River flow regimes are regarded as a primary driver of riverine and floodplain wetland ecology (Bunn and Arthington, 2002; Junk et al., 1989; Poff and Zimmerman, 2010). Water resource development has the potential to change the flow regime leading to changes in important flow attributes such as the magnitude, timing, duration and rate of change of flow events to which the ecosystem is adapted. These changes create new conditions, thereby resulting in potential ecological changes and consequences for the biota and ecosystem processes of a catchment (Poff et al., 1997).

The ecology activity seeks to determine the relative risks between different water resource development scenarios in the Victoria catchment using a set of prioritised water-dependent assets. The analysis focuses on understanding ecological outcomes resulting from changes in the flow regime.

The key questions that this activity seeks to address in the Victoria catchment include:

- What is the main environmental context of the Victoria catchment that could influence water resource development?
- What are the key environmental drivers and stressors that are currently occurring or likely to occur in the Victoria catchment (including key supporting and threatening processes such as invasive species, water quality and habitat changes)?
- What are the known linkages between flow and ecology?
- What are the key ecological trade-offs between different water resource developments considering impacts from potential changes in flow on species and habitats?

9.1 Ecology activity breakdown

In order to understand the potential risks to the natural environment associated with water resource development, the ecology activity is using an ecological asset approach and building upon and adapting the methods used in the ecology synthesis and assessment component of the Northern Australia Water Resource Assessment (NAWRA) (Pollino et al., 2018a; Pollino et al., 2018b). This includes undertaking a prioritisation of assets, reviewing and updating asset knowledge bases, conceptual relationships and evidence narratives, including the flow–ecology relationships, and considering their context and application in the Victoria catchment.

The ecology activity will use a hierarchal modelling approach that utilises a range of assessment methods for a set of prioritised assets that transition from qualitative to more quantitative methods as sufficient relationships between flow and ecological outcomes are sufficiently known and can be suitably supported. The ecology activity modelling will use hydrology scenarios developed by the surface water hydrology activity and compare outcomes as relative differences between scenarios and a baseline.

9.1.1 Prioritisation of assets

For the purpose of the ecology activity, assets are classified as species, functional groups or habitats and can be considered as either partially or fully freshwater dependent, or marine dependent upon freshwater flows. To identify priority assets to undertake the ecological analysis, a review and prioritisation of assets will be undertaken for the Victoria catchment, building upon the asset descriptions developed by Pollino et al. (2018b) and continued in the Roper catchment (CSIRO, 2019). For the purposes of this Assessment, assets are defined as:

- being listed as threatened, vulnerable or endangered species or communities
- being wetlands, species or communities that are formally recognised in international agreements
- providing vital, near-natural, rare or unique habitat for water-dependent flora and fauna
- supporting significant biodiversity for water-dependent flora and fauna
- providing recreational, commercial or cultural value.

From the full range of potential assets occurring in the Victoria catchment, the process for selecting priority assets will consider if they are:

- representative – to capture a range of flow requirements for biota and ecological processes
- distinctive – to enable a broad representation of water requirements
- describable – with sufficient peer-reviewed evidence available to describe relationships with flow
- significant – considering ecological, conservation, cultural and recreational importance.

9.1.2 Conceptual modelling and evidence base

Conceptual models will be used to describe the ecological understanding of the assets, including flow relationships and other influences that may contribute to the sustainability, function, condition or health of the asset. The conceptual models provide a framework to underpin the analyses of the impacts of water resource development by providing a knowledge and evidence base linking key drivers to outcomes. Standardised conceptual models will be adapted or developed that synthesise the best available knowledge of flow–ecology relationships considering aspects such as life history, flow triggers, movement, refuge, productivity, water quality or connectivity requirements as relevant for each ecological asset.

The conceptual models will include key potential risks from a range of sources, as relevant to each asset, including water resource development and changes in land use, as well as physical changes (e.g. increases in sedimentation), water quality changes (e.g. increased nutrients) and invasive species (spread of pests and weeds), and articulate how these can result in changes in ecology or to the asset.

Assets will be mapped across the Victoria catchment to understand their distribution and/or important habitat associations. By considering their distribution across the catchment, assets that will be exposed to changes in the flow associated with different water resource developments can be identified. A range of data sources will be explored to develop maps and spatial relationships of these assets in the Victoria catchment.

9.1.3 Analysis of potential ecological impacts

The ecology activity will undertake an assessment of the potential impacts for the prioritised assets using a hierarchal modelling approach. This approach will provide a consistent framework to understand ecological impacts resulting from flow regime changes. The modelling approach will incorporate semi-quantitative and quantitative modelling methods, with application of each method considering the asset's knowledge base and the ability to support quantitative relationships between flow, ecological responses and outcomes.

The ecological analysis will utilise daily hydrology data generated with river system and hydrodynamic models to understand the relative differences between scenarios and a baseline, by considering the types of changes in the flow regime, the asset flow relationships and the distribution of assets within the catchment using the asset mapping or key spatial relationships.

The ecological analysis will include a 'flow requirements assessment', a 'habitat suitability assessment' and a 'connectivity assessment'. Each are described briefly below.

Flow requirements assessment

The flow requirements (quantified using hydrometrics – statistical properties of the long-term flow regime) assessment identifies the key components of the hydrograph important for each asset. Each asset has specific set of flow metrics that are important for supporting ecological function, life history or important habitat. The flow requirements assessment calculates the change in these asset-specific hydrometrics occurring between the model scenarios as change from the baseline. The relative differences between sites and scenarios can be compared to understand what scenarios are likely to impact which ecological assets and where.

Habitat suitability assessment

The habitat suitability (preference curve) assessment captures how components of flow meet the habitat needs of the selected assets. The preference curves relate an attribute of flow to a condition value of the asset. A set of preference curves are used for each asset to generate an overall condition score for the baseline and modelled hydrology scenarios. The preference curves consider ecological needs such as movement, breeding or survival requirements, and how changes in key flow attributes impact the asset, reporting relative outcomes such as population size or condition.

Connectivity assessment

The connectivity assessment uses hydrodynamic modelling to develop a time series of inundation extents for a range of scenarios. For these scenarios, across a sample of flood events, the pattern and extent of inundation will be used to quantify the connectivity of assets (wetlands) to the main river channel via connection across the floodplain or via flood runners. Differences in the connection or duration of connection between the scenarios will be quantified.

9.2 References

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Part V

Case studies, reports, key protocols and standards

10 Case studies

10.1 Rationale

By its nature, the Assessment will produce information from a very broad range of disciplines. This is as it should be expected because the development of northern Australia will require the integration of knowledge from a similarly broad range of disciplines.

The purpose of the case studies is to help readers:

- understand how to 'put the Assessment information together' to answer their own questions about water resource development in the Victoria catchment
- understand the type and likely scale of opportunity of different types of water resource development in selected geographic parts of the Assessment area
- explore some of the nuances associated with 'greenfield' developments in the Victoria catchment, which are often difficult to capture in discipline-based information.

10.1.1 What the case studies are designed to do and not do

Although the case studies are designed to be realistic representations – that is, they will be 'located' in specific parts of the Assessment area, and use specific water and land resources, and realistic intensification options – they are illustrative only. They are not designed to demonstrate, recommend or promote particular development opportunities being proposed by individual development proponents, nor are they CSIRO's recommendations on how development in the Victoria catchment should unfold.

10.2 Proposed case study framings

The specific case studies will be developed over time as the Assessment proceeds and the Assessment team begins to assemble information from a range of sources and disciplines. These sources will include ideas generated by stakeholders within the Assessment area and will be guided by current enterprise types found in the Assessment area. Proposed case studies will then be tested with the Program Steering Committee before being finalised.

Although the case studies are yet to be developed, the following framings can be used as a guide:

1. large schemes, privately funded (greater than about $500 million)
2. large schemes, publicly funded (greater than about $500 million)
3. medium-sized schemes, such as might be developed by pastoral corporates or large family businesses (from tens of millions of dollars to about $500 million)
4. small-scale schemes, such as an individual or family business might develop (from about $1 million to about $10 million).

Coupled to this framing, various methods of water capture and supply will be considered. Various agricultural systems will be included in the case studies.

The case studies will consider the costs and challenges of supplying water using various configurations of capture and distribution, the timing of water supply and demand, assumptions concerning annual water yield (at varying reliabilities), and conveyance and field application losses. Soil and landscape attributes will be considered in terms of their proximity to the water supply, risks such as secondary salinity, and suitability for various crop and aquaculture types. Interactions and links with other industries (e.g. the beef industry), processing facilities, transport logistics, and hard and community infrastructure requirements will be factored in. The case studies will be grounded within the social and cultural context of the Victoria catchment, including infrastructure availability and constraints. Economic analyses will consider gross margins, as well as the ability of the enterprise to service capital costs.

One way to envisage what these case studies will look like is to consider those used in previous land and water resource studies in the Flinders catchment (Petheram et al., 2013a), the Gilbert catchment (Petheram et al., 2013b) and the Northern Australia Water Resource Assessment (NAWRA) (Petheram et al., 2018).

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11 Reports, products, protocols and standards

11.1 Reports, products and protocols

The Assessment management team will provide quality assurance for all data and reports produced from the Victoria River Water Resource Assessment. To meet this objective, the team will:

- provide templates, standards, processes and workflows for reporting
- provide collaborative working spaces (including SharePoint, Google Drive)
- review all technical material
- ensure that sensitive and important modelling is undertaken within a best modelling practice framework – that is, a three-stage independent review process of (i) conceptual model, (ii) calibration model, and (iii) simulation model
- edit and produce catchment and summary reports
- develop processes and provide information sheets and training to Assessment members on data management protocols, the CSIRO metadata catalogue, and the CSIRO data access portal and data audit trails.

Microsoft Teams is a communications platform that provides a central storage for the Assessment team to share documents. Version control has been implemented for the 'reports' channel of the project's Teams site. The Assessment team will store all versions of the catchment and summary report documents on this site. All final versions of the technical reports will be available on the CSIRO website.

The project's Teams site will also be the team's primary collaboration space to share non-sensitive documents, calendars, photos, meeting minutes, guideline documents and videos, stakeholder contact information and other similar material.

Table 1-1 details key deliverables for the Victoria River Water Resource Assessment. These will be complemented by a minimum of six technical reports, which will provide the technical underpinning for the summary material.

Alternative (non-report) products for the delivery of information to key stakeholders will include incorporation of river models into NAWRA river (https://nawra-river.shinyapps.io/river/) and other datasets into the NAWRA explorer (https://nawra-exp.appspot.com/). The CSIRO data access portal will be used as the final repository for key datasets such as the land suitability grids.

11.2 Standards

The Assessment management team will define editorial standards to guide authors in reporting the findings of the Assessment. These standards will include map and figure conventions, and will be available in a document titled *Reporting standards*. These standards are based on:

- the Australian Government *Style manual for authors, editors and printers*

- CSIRO brand identity guidelines
- standards used in the Flinders and Gilbert Agricultural Resource Assessment and the Northern Australia Sustainable Yields (NASY) projects
- the *Australian Oxford dictionary*.

Since many specialist terms are not found in these resources, additional conventions specific to the Assessment will be developed in consultation with the Assessment team.

Reporting standards will be a ‘living document’ that changes as the Assessment progresses, to document decisions on language and formatting. Conventions specified in early drafts, however, will not be changed unless necessary; the aim is to add conventions, not to backtrack on earlier decisions. Reporting standards will be published as a report at the end of the Assessment.

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