Australia's National Science Agency

Proposed methods report for the Roper catchment

A report from the CSIRO Roper River Water Resource Assessment to the Government of Australia

Department of Infrastructure, Transport, Regional Development and Communications

Australian Government

Department of Infrastructure, Transport, Regional Development and Communications

National Water Grid Authority

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CSIRO Roper River Water Resource Assessment acknowledgements

This report was prepared for the Department of Infrastructure, Transport, Regional Development and Communications. The Roper River Water Resource Assessment is part of the Australian Government's Agricultural Competitiveness White Paper, the government's plan for stronger farmers and a stronger economy. Important aspects of the Roper River Water Resource Assessment will be undertaken in conjunction with the Northern Territory Government.

This report was reviewed by Dr Mila Bristow.

Photo

Fieldwork, Roper catchment

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Note: Assessment team as at December 1, 2019. All contributors are affiliated with CSIRO unless indicated otherwise. Activity Leaders are underlined.

1. Northern Territory Government

Shortened forms

SHORT FORM	FULL FORM
APSIM	Agricultural Production Systems sIMulator
AWRA-R	Australian Water Resource Assessment – River model
CLEM	Crop Livestock Enterprise Model
cLHS	Latin hypercube sampling
CSSHREC	CSIRO Social Science Human Research Ethics Committee (CSSHREC)
DEM	digital elevation model
DIWA	Directory of Important Wetlands in Australia
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
FAO	Food and Agriculture Organization of the United Nations
FSL	full supply level
GBA	Geological and Bioregional Assessment
GIS	geographic information system
GM	gross margin
GRASP	Grass Production Model
IPCC	Intergovernmental Panel on Climate Change
LiDAR	light detection and ranging
MODIS	Moderate Resolution Imaging Spectroradiometer
NABSA	North Australian Beef Systems Analyser
NASY	Northern Australia Sustainable Yields Project
NAWRA	Northern Australia Water Resource Assessment
SGG	soil generic group
SRTM	Shuttle Radar Topography Mission
WOfS	Water Observations from Space

Units

UNIT	DESCRIPTION
GL	gigalitre (1,000,000,000 litres)
km	kilometre (1000 metres)
L	litre
m	metre
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. 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 2000 and 2050, the world's population is projected to grow from 6 to 9 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 from this part of the world.

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 (a greenfield development opportunity in a first-world country) 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 (Western Australia), four small catchments between Darwin and Kakadu known collectively as the 'Darwin catchments' (Northern Territory) and the Mitchell catchment (Queensland). 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. This work covers an area of about 350,000 km^2 (approximately 12%) of 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 Roper 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.

Summary

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

- evaluate the climate, soil and water resources
- identify and evaluate water capture and storage options
- identify and test the commercial viability of irrigated agricultural, forestry and aquaculture opportunities
- assess potential environmental, social and economic 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 Roper 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 Roper 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 6) and key ecological assets (Chapter 8) will inform the structure of the river system model. The latter will inform the domain of the hydrodynamic model.

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 8).

Availability of suitable soil

The land suitability activity (Chapter 4) will develop digital land suitability maps of the entire Roper catchment, showing areas that are more and less suitable under different combinations of land use and irrigation systems, and aquaculture. The activity will employ statistically based digital soil mapping methods to rapidly and objectively generate 90 m × 90 m, or finer grids of a wide range of soil attributes (e.g. depth of soil, texture, pH). The digital soil mapping will be informed by a limited soil sampling campaign. The current set of rules for different combinations of land use and irrigation systems, and aquaculture will be refined. 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 5) will provide an overview of key Indigenous values, rights, interests and aspirations with respect to water and irrigated agricultural development in the Roper 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 7) and the ecology activity (Chapter 8). 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 6) will provide a comprehensive overview of the different surface water storage options in the Roper 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 7) 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 Roper catchment will be estimated using regional economic multipliers, following the approach used in the Northern Australia Water Resource Assessment. 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 6) activities.

Freshwater, riparian and near-short marine ecology

The ecology activity (Chapter 8) 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 study experiments

The Assessment will also undertake a small number of case studies in the Roper catchment (Chapter 9). 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 Roper 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

1 Introduction

1.1 Roper River Water Resource Assessment

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

- evaluate the climate, soil and water resources
- identify and evaluate water capture and storage options
- identify and test the commercial viability of irrigated agricultural, forestry and aquaculture opportunities
- assess potential environmental, social and economic 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 Roper River Water Resource Assessment commenced on 1 July 2019 and will be completed by 30 June 2022.

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 they 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 is 'blind' to 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 Roper 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 Roper 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 Roper 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.

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
Methods report	31 December 2019
Technical report 1: Surface water storage report	31 December 2021
Technical report 2: Socio-economic-agricultural-productive report	31 December 2021
Technical report 3: Digital soil mapping and land suitability report	31 December 2021
Technical report 4: Surface water dependent assets report	31 December 2021
Technical report 5: River modelling report (calibration and simulation) and delivery of model to jurisdiction	31 December 2021
Technical report 6: Indigenous aspirations and water values report	31 March 2022
Catchment report	30 April 2022
Case study report	30 April 2022

DELIVERABLE	DATE FOR COMPLETION
20-page summary report	30 April 2022
Final fact sheet	30 April 2022

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, Cities and Regional Development for final approval.

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 ROPER RIVER WATER RESOURCE ASSESSMENT AREA

The Assessment area is defined by Roper River catchment as defined by the 1" Shuttle Radar Topographic Mission (Figure 1-1). It encompasses an area of about 79,630 km^2. The largest towns in the Roper catchment are Mataranka and Ngukurr.

The Roper catchment is wet–dry tropical, and rainfall is highly seasonal. The wet season (November to April) accounts for 96% of annual rainfall and 96% of annual runoff (CSIRO, 2009). Annually, potential evaporation is greater than precipitation, and approximately 14% of precipitation is transformed to runoff. 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.

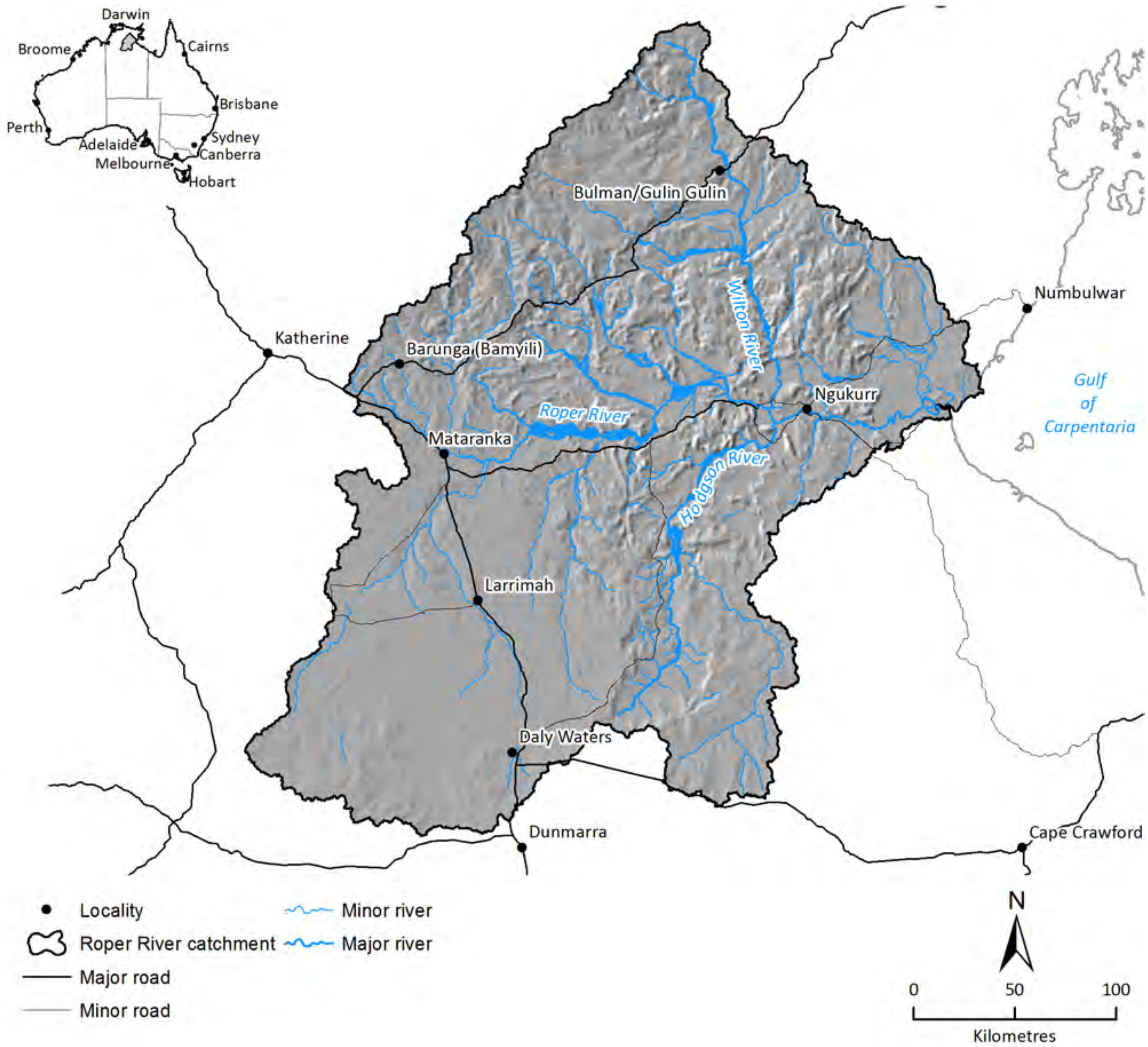

Figure 1-1 The Roper catchment in the Northern Territory

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 Roper 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
- 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 5 –Indigenous water values, rights, interests and development aspirations and water values
  - Chapter 6 – Surface water storage
  - Chapter 7 – 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 chapters present methods in Part IV:
  - Chapter 8 – 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 9 – Case studies
  - Chapter 10 – Reports, products, protocols and standards.

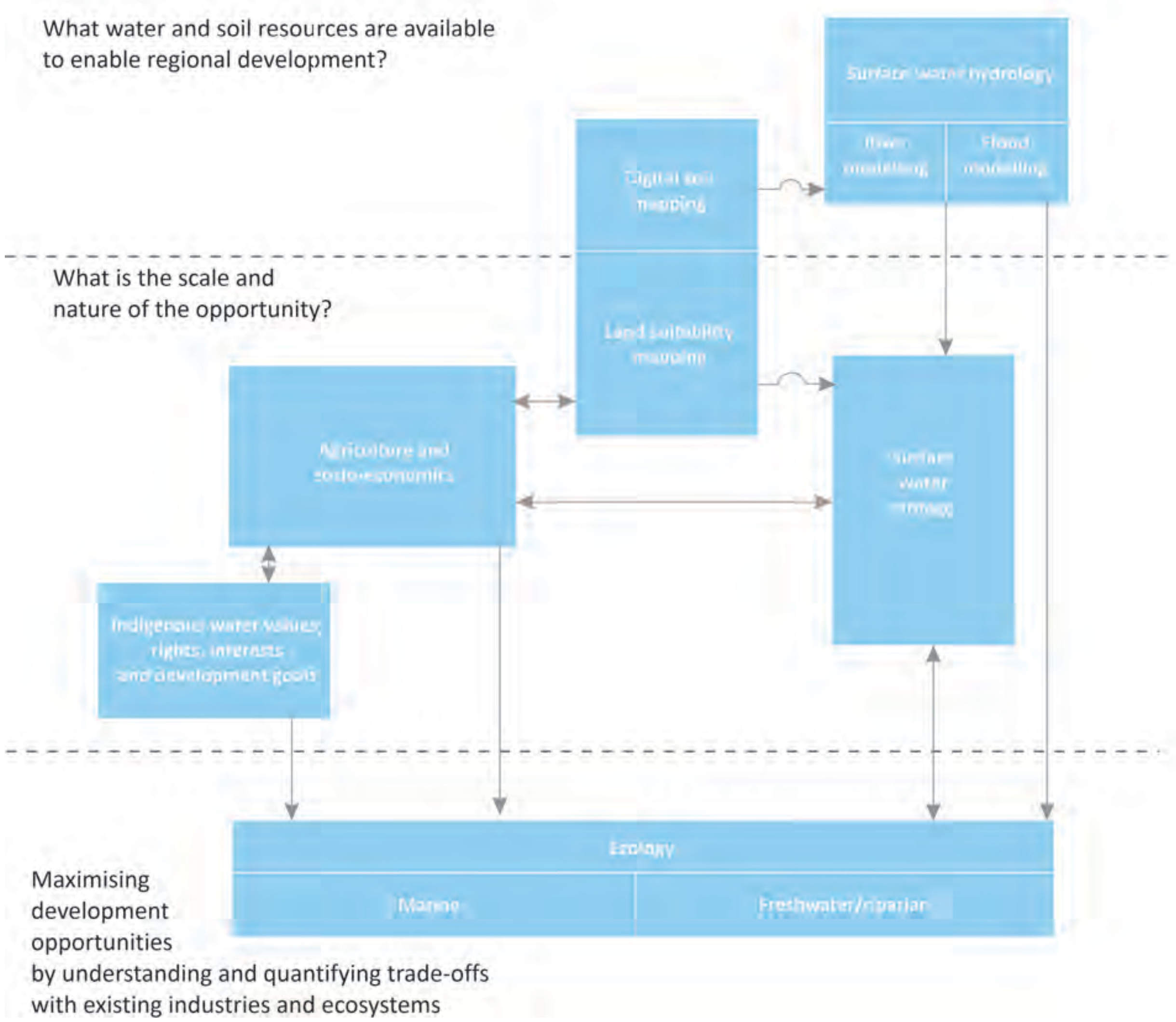

Figure 1-2 Schematic diagram illustrating the high-level linkages between the nine activities

1.6 References

CSIRO (2009) Water in the Roper Region. In: Water in the Gulf of Carpentaria 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 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 110 years (water years from 1 September 1910 to 31 August 2019) 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 at 31 August 2019. 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 9). 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. It will be based on the 110-year climate data sequence, scaled for conditions in about 2060. These climate data will be derived from a range of global climate model (GCM) projections for a 2.2 °C global temperature rise scenario, which encompasses different GCMs from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) under an RCP8.5 emissions scenario (RCP8.5 is one of four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its Fifth Assessment Report (AR5) in 2014). The projections will then be used to modify the observed historical daily climate sequences using a simple scaling technique as outlined in Charles et al., (2016). Like Scenario A, current development is the level of surface water, groundwater and economic development as at 31 August 2019.

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 Roper 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 Roper 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 9.

2.4 References

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Part II

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

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 Roper catchment.

The key questions that this activity seeks to address in the Roper 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 Roper 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 Roper 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 Roper catchment is highly seasonal, reflecting contrasting wet and dry seasons. The catchment is relatively flat and features extensive floodplains of low relief. The lower portions of the river are tidally affected. The Roper River shows a tidal influence upstream as far as Roper Bar (150 km from Roper River mouth).

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 web-link and graphical user interface, allowing anyone to run scenario analysis of the Roper 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 Roper 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 Roper 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 Roper 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 are now available since the NASY project was completed in 2008. The Roper 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 Roper catchment will be assessed for use; however, landscape modelling may also include nearby gauges. In the Roper catchment, 11 separate gauge records of variable quality and duration have been identified. These will be assessed for their inclusion in the river system node–link network. Gauge locations for the Roper catchment are shown in Figure 3-1.

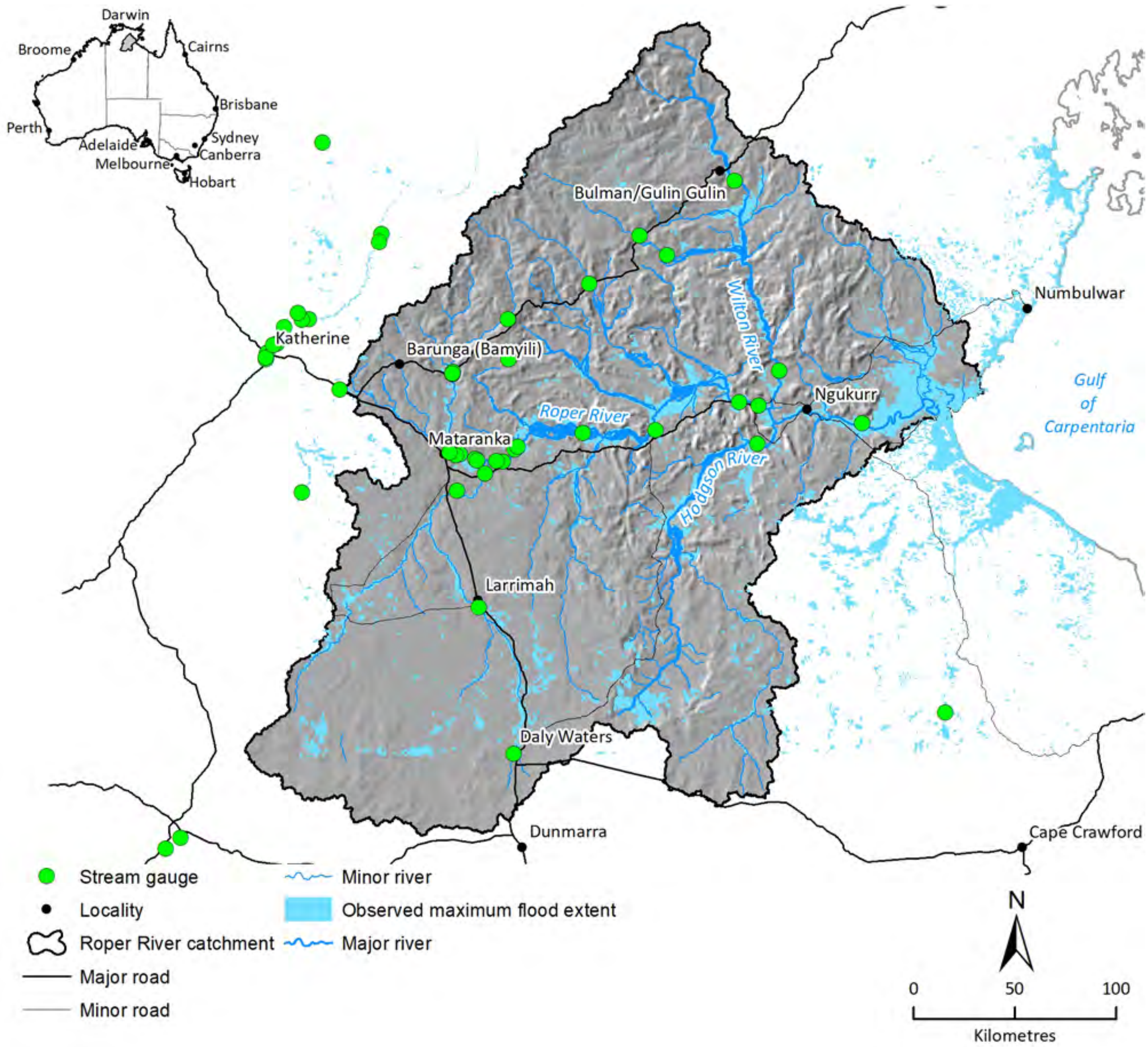

Figure 3-1 Roper catchment showing stream gauge locations and maximum flood extent (MODIS)

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 Roper catchment. Waterholes will be selected in consultation with the ecology activity (Chapter 8) 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 Roper 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 Roper 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 Roper 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 Roper 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 Roper 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 activity), and 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:

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

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:

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

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 Groundwater analysis

No new fieldwork will be undertaken for the Assessment; however, a desktop study of groundwater resources and opportunities will be conducted. This investigation will rely on studies and data currently available.

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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, field collected data and modelled outputs and 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 3 arc-seconds (approx. 90 m) or finer. 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 90 m resolution or finer. 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 Roper catchment (e.g. Aldrick and Wilson, 1992; Burgess et al., 2015; Day and Wood, 1976; McGrath and Andrews, 2019) 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).

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

- 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?
- What is the estimated reliability of the information provided above?

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.

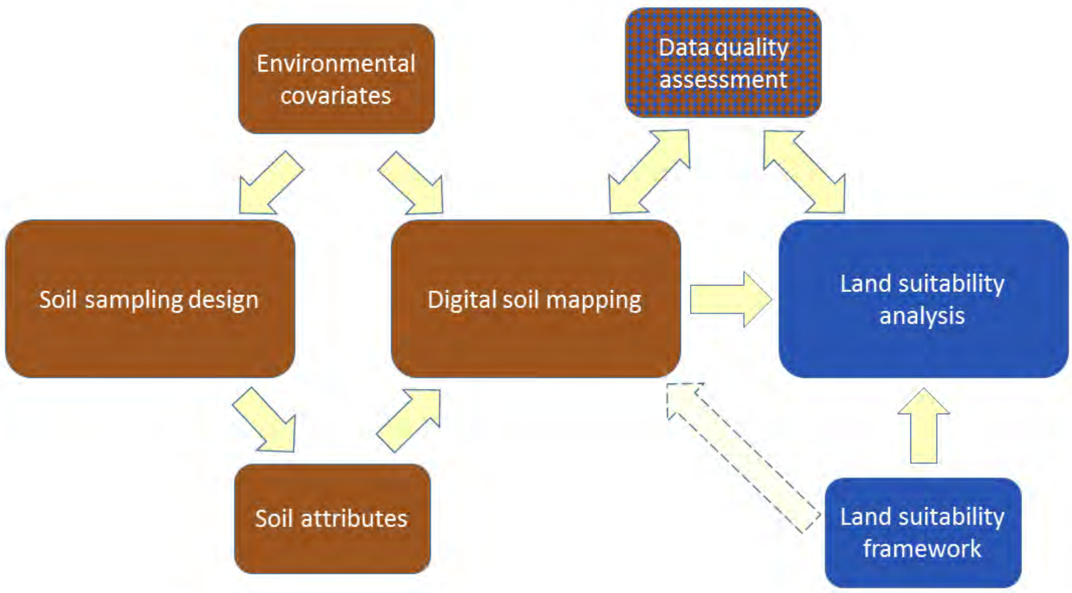

Figure 4-1 Land suitability analysis workflow, key inputs and processes (Thomas et al., 2018a)
Brown components reflect the Digital Soil Mapping component (as described in Thomas et al., 2018a) while blue components reflect the land suitability component (as described in Thomas et al., 2018b). The 'data 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 at approximately 200 new sites (Figure 4-2). The number of sampling points is determined a priori as a function of the budget and logistical considerations, such as access.

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

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[1] chosen to represent the full variability of soils across the Assessment area.

4.2.2 Environmental covariates

The covariates will be selected as proxies for factors of soil formation (i.e. climate, parent material, biota and topography) (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

[1] Environmental covariates (or simply *covariates*) are spatial geographic information system (GIS) raster format datasets that bear functional relationships to on-ground soil attributes, and so can contribute to prediction of soil attributes. For example, slope may support prediction of soil depth, relief patterns for soil water accumulation, or remote sensing for soil colour.

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 references).

Attribute data collected in the field include those which 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 and data at points and covariates (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 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 statistical 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; a mix of continuous and categorical 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 3 arc-second resolution or finer) 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 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, estimating the reliability of the model outputs, collecting independent external validation data (Brus et al., 2011), and (ii) on-ground expert (qualitative) examination of outputs during a validation field trip in the late dry season of 2020. 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 don’t appear credible.

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 (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 later dry-season 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 Roper 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.
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.

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Part III

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

5 Indigenous water values, rights, interests and development goals

5.1 Introduction

The Roper 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 Roper 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 Roper catchment
  - local Indigenous residence and tenure regimes in the Roper catchment
  - key issues in Indigenous water values, rights, interests and development goals in the Roper 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 Roper 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?

5.2 Linkages to other Assessment activities

Components of the Roper Indigenous values, rights, interests and development goals activity will have close connections with components of the agriculture and socio-economic (Chapter 7), land suitability (Chapter 4) and the ecology (Chapter 8) 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 Roper 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 Roper River Water Resource Assessment activities will also be identified as the study progresses.

5.3 Linkages to other research projects in the Roper catchment

There are a range of other research initiatives being undertaken in the Roper catchment that provide important context for the research undertaken through the Roper River Water Resource Assessment. A key research initiative relevant to the Indigenous activity is the CSIRO Geological and Bioregional Assessment (GBA) Program in the Beetaloo Sub-basin to assess the potential environmental impacts of shale and light gas development to inform regulatory frameworks and appropriate management approaches. The Assessment results are useful to the Northern Territory Government in developing water allocation plans that are directly relevant to Indigenous communities. An understanding of the key research activities at Beetaloo Sub-basin, and the types of research results being produced, including access to fact sheets and other communication products will be important in addressing questions and directing Traditional Owners and Indigenous residents to information about the study.

The Indigenous activity of the Assessment builds on previous work undertaken by Barber and Jackson (Barber and Jackson, 2011; Barber and Jackson, 2012) in the upper Roper River, on the 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.

5.4 Context and consultation

The Roper 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.

5.5 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 Roper 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.

5.6 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 had 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.

5.7 Methods

5.7.1 Review of existing information

The review of existing documented information will encompass:

- the historical and contemporary context for Indigenous people living in the Roper 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.

5.7.2 Fieldwork and direct consultation

The fieldwork will emphasise direct consultation with Traditional Owners of, and Indigenous residents in, the Roper 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.

5.7.3 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 Northern Australia Water Resource Assessment (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.

5.7.4 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 Northern Territory (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 Northern Territory.

The analysis will focus on rights and interests recognised in the Australian Commonwealth and Northern Territory 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.

5.8 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.

5.9 Staff and collaboration

The Indigenous activity team includes Peci Lyons, the project lead, and Marcus Barber as project advisor. Peci Lyons led the Mitchell catchment Indigenous sub-project of the NAWRA project and Marcus Barber was the overall project lead for all three catchments of NAWRA. Together they bring over 20 years of research experience on Indigenous water issues in northern Australia. 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.

5.10 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.

5.11 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.

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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.

6 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 Roper 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 Roper 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.

6.1 Introduction

In a highly seasonal climate such as the Roper 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 Roper catchment, nor have any previous studies on surface water storage in the Roper catchment been identified.

6.2 Large instream and offstream storages

This section describes the methods by which potential dam sites will be selected (Section 6.2.1) for pre-feasibility analysis (Section 6.2.2). Section 6.2.4 describes the additional analysis that is intended for the short-listed sites.

6.2.1 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; the best available DEM across the Roper catchment), gridded climate data and gridded runoff data from the surface water hydrology activity.

6.2.2 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 Roper 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 criteria will be evaluated are described in Table 6-1.

Table 6-1 Proposed methods for assessing potential dam sites in the Roper 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.
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, 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 Roper 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,

PARAMETER	DESCRIPTION
	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.

6.2.3 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.

6.2.4 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 Roper 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.

6.3 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 6-2). 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 6-2 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
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 Roper 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 Roper catchment, as well as a relevant list of references on farm dam planning, construction and maintenance.

6.4 References

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Petheram C, Rogers L, Eades G, Marvanek S, Gallant J, Read A, Sherman B, Yang A, Waltham N, McIntyreTamwoy 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.

Read AM, Gallant JC and Petheram C (2012) DamSite: an automated method for the regional scale identification of dam wall locations. 34th Hydrology and Water Resources Symposium, Sydney, Australia, 19–22 November 2012. Engineers Australia, Canberra.

7 Agriculture and socio-economics

The approach used to analyse the viability of agricultural development options in the Roper 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 Roper 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 Roper catchment region?

The agriculture and socio-economics activity will take a multi-scale approach (Figure 7-1), 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 Roper catchment.

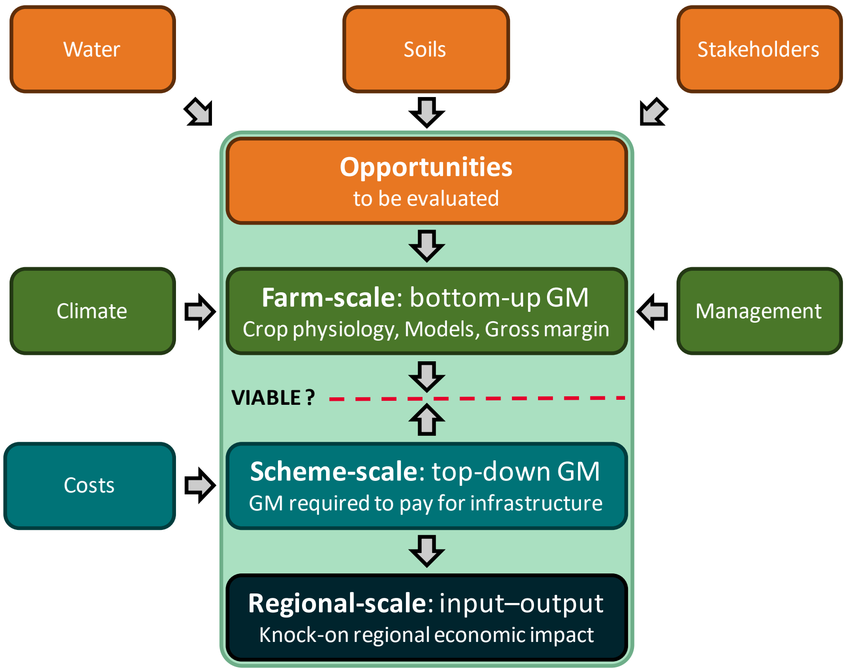

Figure 7-1 Overview of the approach for assessing the agricultural and economic viability of agricultural development options in the Roper catchment
Note: In the figure, GM = gross margin.

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 6) and land suitability (Chapter 4) activities, and stakeholder input (including the Indigenous activity, Chapter 5) to define the scale, location, costs and nature of 'development opportunities'.

7.1 Farm-scale analyses

7.1.1 Overview

Assessing the viability of different farming options requires bringing together information and knowledge on climate, soils, water resources, agronomy, natural resource management, pests and diseases, 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 Roper catchment due to the lack of broadacre cropping or horticulture experience in the catchment.

7.1.2 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 Roper catchment, a range of crops and forages are potentially suitable, including broadacre crops (e.g. sorghum, pulses), horticultural crops (e.g. mangoes, melons), root crops (e.g. peanuts, cassava), 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. It will be important to link with the ecology activity (Chapter 8) 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.

APSIM may not have the capability to simulate all the development options of interest in the Roper 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 existing cropping systems (e.g. mango and melon) operate in north Queensland, Western Australia and Northern Territory, 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). Validated crop models have been used in previous assessments of cropping potential for a range of prospective crops in northern Australia (Carberry et al., 1991; 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). 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 Roper catchment, based on similar work that was done in NAWRA.

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.

7.2 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. 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 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.

7.3 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 Roper 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 Northern Territory region (Murti, 2001)), following the approach used in NAWRA (Stokes et al., 2017).

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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?

8 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 trade-offs between different water resource development scenarios in the Roper catchment using a set of prioritised water-dependent assets. The analysis focuses on understanding outcomes resulting from changes in the flow regime.

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

- What is the main environmental context of the Roper 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 Roper 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 potential changes in flow?

8.1 Regional overview

The Roper River is a large perennial flowing river with one of the largest catchment areas draining into the western gulf (82,000 km^2) (Faulks, 2001). Due to the very flat topography of the upper catchment, the river braids into smaller channels that provide a diverse habitat structure (CSIRO, 2009). The wet-dry tropical climate of the catchment results in highly seasonal flow, with high flows occurring during the wet season. During the dry season river flows are reduced and much of the streams in the catchment recede to pools. Streams and waterholes that persist provide critical refuge habitat for many species (Barber and Jackson, 2011) where dry-season flow is largely supported by the groundwater discharge from the Tindall Limestone Aquifer of the Daly Basin. Important springs between Mataranka and the Red Lily Lagoon provide habitat and enrich the river flow by seepage through the river banks (Northern Territory Government, 2010).

About 2% of the Roper catchment is under protection. There are two national parks (Elsey and Limmen), one Indigenous Protected Area (South East Arnhem Land Indigenous Protected Area), a private nature reserve (Wongalara Sanctuary) and a management area (St Vidgeon). The catchment contains two wetlands of national significance (Directory of Important Wetlands in Australia (DIWA) listed), being the Limmen Bight (Port Roper) Tidal Wetlands System and the Mataranka Thermal Pool (Department of the Environment, 2010). The Limmen Bight Tidal

Wetlands System is the second-largest area of saline coastal flats in the Northern Territory (185,000 ha), forming one of the most important habitat systems of tidal wetlands (intertidal mud flats, saline coastal flats and estuaries) for migratory shorebirds in the Northern Territory (Department of the Environment, 2010). This wetland system provides important habitat for species listed in the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) including the northern Siberian bar-tailed godwit (*Limosa lapponica menzbieri*; critically endangered), eastern curlew (*Numenius madagascariensis*; critically endangered) and the Australian painted snipe (*Rostratula australis*; endangered). Mataranka Thermal Pool in the upper catchment is maintained by permanent thermal springs located within Elsey National Park in an area of less than 10 ha (Department of the Environment, 2010). Listed species in this national park include the red goshawk (*Erythrotriorchis radiatus*; vulnerable) and the Mertens' water monitor (*Varanus mertensi*; vulnerable for the Northern Territory).

Overall the Roper catchment contains a high diversity of flora and fauna including about 270 vertebrate species (Dasgupta et al., 2019). Freshwater crocodiles (*Crocodylus johnstoni*) are very common within the Roper River and its tributaries (CCNT, 1994), while the saltwater crocodile (*C. porosus*) occurs upstream along the Roper River to Elsey Station (Griffiths, 1997). Extensive seagrass beds in nearby coastal Gulf of Carpentaria waters are an important feeding area for dugongs (*Dugong dugon*) and turtles and support a major juvenile habitat for tiger and endeavour prawns (*Penaeus* spp. and *Metapenaeus* spp.) (Department of the Environment, 2010, Kenyon et al. 1999). Additionally, the near-coastal waters and estuaries support six listed species of marine turtles and a major commercial barramundi (*Lates calcarifer*) fishery, while harvest of mud crabs (mainly *Scylla serrata*) also occurs at Port Roper and along nearby coasts (Northern Territory Government, 2019).

Only a relatively small proportion of the catchment is occupied by riparian habitats. These habitats however, frequently have a higher abundance and species richness compared to surrounding habitats (Lynch and Catterall, 1999). The riparian vegetation mainly consists of *Livistona mariae* subsp. *rigida*, although *Pandanus* spp. and *Melaleuca* spp. also occur. The distribution of *L. mariae* palm community is very restricted in northern Australia and, as such, is considered a special community (Faulks, 2001). This vegetation community contains a rich frog fauna and the little red flying-fox (*Pteropus scapulatus*) often use it as a maternity colony. The gulf snapping turtle (*Elseya lavarackorum*), which is listed as endangered in the EPBC Act, has been associated with sections of river with riparian areas. Other EPBC Act-listed vertebrate species in the study area include the critically endangered speartooth shark (*Glyphis glyphis*) and the endangered northern quoll (*Dasyurus hallucatus*) and the Gouldian finch (*Erythrura gouldiae*). The freshwater sawfish (*Pristis pristis*), the dwarf sawfish (*Pristis clavata*) and the green sawfish (*Pristis zijsron*) are listed as vulnerable and migratory in the EPBC Act and the dugong as marine and migratory.

8.2 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 Roper 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.

8.2.1 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 Roper catchment, building upon the asset descriptions developed by Pollino et al. (2018b). 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 Roper 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.

8.2.2 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 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, 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 Roper catchment to understand their distribution and important habitat associations. By considering their distribution across the catchment, we can identify where they will be exposed to changes in the flow associated with different water resource developments. A range of data sources will be explored to develop maps and spatial relationships of these assets in the Roper catchment.

8.2.3 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 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.

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 (hydrometrics – statistical properties of the long-term flow regime) assessment identifies the key components of the hydrograph important for each asset. This assessment calculates the change in these asset-specific hydrometrics occurring between the baseline and the model scenarios. 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 will be 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, considering 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.

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Part V

Case studies, reports, key protocols and standards

9 Case studies

9.1 Rationale

By its nature, the Assessment will produce information from a very broad range of disciplines. This is as it should be 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 Roper 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 Roper catchment, which are often difficult to capture in discipline-based information.

9.1.1 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 Roper catchment should unfold.

9.2 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 Roper 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 (Petheram et al., 2018).

9.3 References

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10 Reports, products, protocols and standards

10.1 Reports, products and protocols

The Assessment management team will provide quality assurance for all data and reports produced from the Roper 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.

SharePoint is a website that provides a central storage for the Assessment team to share documents that require version control. The Assessment team will store all versions of the catchment and summary report documents on the CSIRO SharePoint website. All final versions of the technical reports will be stored on the SharePoint https://teams.csiro.au/units/ROWRA/_layouts/15/start.aspx#/.

A OneDrive site has been established for the Assessment team. This will 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 Roper 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.

10.2 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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