Assessment of surface water storage options and reticulation infrastructure in the Roper catchment

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

Cuan Petheram[1], Ang Yang[1], Lynn Seo[1], Lee Rogers[1], Fred Baynes[2], Kevin Devlin[2], Steve Marvanek[1], Justin Hughes[1], Rocio Ponce Reyes[1], Peter Wilson[1], Danial Stratford[1], Seonaid Philip[1]

[1] CSIRO, [2] Independent consultant

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Important disclaimer

CSIRO Roper River Water Resource Assessment acknowledgements

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

The Assessment was guided by two committees:

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

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

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

This report was reviewed by Fazlul Karim (CSIRO)

Acknowledgement of Country

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

Photo

Farm-scale gully dam in Roper catchment. Source: CSIRO

Director’s foreword

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

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

In 2019 the Australian Government commissioned CSIRO to complete the Roper River Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to provide data and insight to support consideration of the use of land and water resources for development in the Roper catchment. While the Assessment focuses mainly on the potential for agriculture, the detailed information provided on land and water resources, their potential uses and the impacts of those uses are relevant to a wider range of regional-scale planning considerations by Indigenous owners, landholders, citizens, investors, local government, the Northern Territory and federal governments.

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

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

Chris Chilcott

Project Director

The Roper River Water Resource Assessment Team

Project Director	Chris Chilcott
Project Leaders	Cuan Petheram, Ian Watson
Project Support	Caroline Bruce
Communications	Chanel Koeleman/Kate Cranney, Siobhan Duffy, Amy Edwards
Activities	
Agriculture and socio-economics	Chris Stokes, Caroline Bruce, Shokhrukh Jalilov, Diane Jarvis[1], Adam Liedloff, Yvette Oliver, Alex Peachey[2], Allan Peake, Maxine Piggott, Perry Poulton, Di Prestwidge, Thomas Vanderbyl[7], Tony Webster, Steve Yeates
Climate	David McJannet, Lynn Seo
Ecology	Danial Stratford, Laura Blamey, Rik Buckworth, Pascal Castellazzi, Bayley Costin, Roy Aijun Deng, Ruan Gannon, Sophie Gilbey, Rob Kenyon, Darran King, Keller Kopf[3], Stacey Kopf[3], Simon Linke, Heather McGinness, Linda Merrin, Colton Perna[3], Eva Plaganyi, Rocio Ponce Reyes, Jodie Pritchard, Nathan Waltham[9]
Groundwater hydrology	Andrew R. Taylor, Karen Barry, Russell Crosbie, Phil Davies, Alec Deslandes, Katelyn Dooley, Clement Duvert[8], Geoff Hodgson, Lindsay Hutley[8], Anthony Knapton[4], Sebastien Lamontagne, Steven Tickell[5], Sarah Marshall, Axel Suckow, Chris Turnadge
Indigenous water values, rights, interests and development goals	Pethie Lyons, Marcus Barber, Peta Braedon, Kristina Fisher, Petina Pert
Land suitability	Ian Watson, Jenet Austin, Elisabeth Bui, Bart Edmeades[5], John Gallant, Linda Gregory, Jason Hill[5], Seonaid Philip, Ross Searle, Uta Stockmann, Mark Thomas, Francis Wait[5], Peter L. Wilson, Peter R. Wilson
Surface water hydrology	Justin Hughes, Shaun Kim, Steve Marvanek, Catherine Ticehurst, Biao Wang
Surface water storage	Cuan Petheram, Fred Baynes[6], Kevin Devlin[7], Arthur Read, Lee Rogers, Ang Yang

Note: Assessment team as at June 15, 2023. All contributors are affiliated with CSIRO unless indicated otherwise. Activity Leaders are underlined.

[1]James Cook University; [2]NT Department of Industry, Tourism and Trade; [3] Research Institute for the Environment and Livelihoods. College of Engineering, IT & Environment. Charles Darwin University; [4]CloudGMS; [5]NT Department of Environment, Parks and Water Security; [6]Baynes Geologic; [7]independent consultant; [8]Charles Darwin University; [9]Centre for Tropical Water and Aquatic Ecosystem Research. James Cook University.

Shortened forms

SHORT FORM	FULL FORM
AEP	annual exceedance probability
AHD	Australian Height Datum
ALOS	Advanced Land Observing Satellite
AMTD	adopted middle thread distances
ANCOLD	Australian National Committee on Large Dams
APE	areal potential evaporation
APSIM	Agricultural Production Systems sIMulator
AWRA-L	Australian Water Resources Assessment landscape model
AWRA-R	Australian Water Resources Assessment river system model
AWRC	Australian Water Resources Council
BHA	behaviour analysis
CC	conventional concrete
DEM	digital elevation model
DEM-H	national 1 second hydrological digital elevation model
DIWA	Directory of Important Wetlands in Australia
DOI	Digital Object Identifier
EPBC	Environmental Protection and Biodiversity Conservation act
FSL	full supply level
GDG	Gould–Dincer Gamma algorithm (or method)
GRP	glass reinforced plastic
EGM96	Earth Gravitational Model 1996 geoid, which is the datum upon which SRTM and DEM-H are based
PMF	probable maximum flood
RCC	roller compacted concrete
SGG	Soil generic group
SRTM	Shuttle Radar Topographic Mission
TDC	Total direct costs
TOC	Total out turn costs

Units

UNIT	DESCRIPTION
m^3	cubic metre
GL	gigalitre
ha	hectare
km	kilometre
mEGM96	EGM96 geoid height in metres
ML	megalitre
ML/year	megalitres per year (ML/y)
mm	millimetre
Mt	million tonnes
m^2	square metre
y	year
t	tonne

Preface

Sustainable regional development is a priority for the Australian and Northern Territory governments. For example, in 2023 the Northern Territory Government committed to the implementation of a new Territory Water Plan. One of the priority actions announced by the government was the acceleration of the existing water science program 'to support best practice water resource management and sustainable development'.

The efficient use of Australia's natural resources by food producers and processors requires a good understanding of soil, water and energy resources so they can be managed sustainably. Finely tuned strategic planning will be required to ensure that investment and government expenditure on development are soundly targeted and designed. Northern Australia presents a globally unique opportunity (a greenfield development opportunity in a first-world country) to strategically consider and plan development. Northern Australia also contains ecological and cultural assets of high value and decisions about development will need to be made within that context. Good information is critical to these decisions.

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

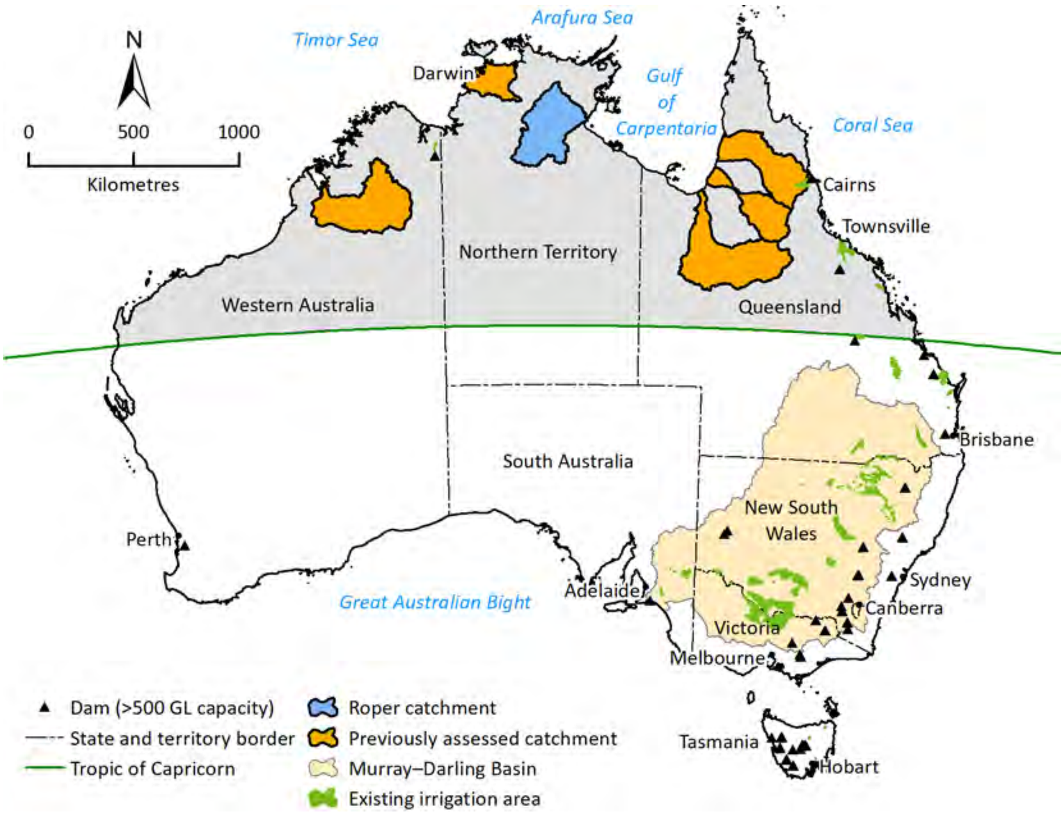
In consultation with the Northern Territory Government, the Australian Government prioritised the catchment of the Roper River for investigation (Preface Figure 1-1) and establishment of baseline information on soil, water and the environment.

Northern Australia is defined as the part of Australia north of the Tropic of Capricorn. The Murray–Darling Basin and major irrigation areas and major dams (greater than 500 GL capacity) in Australia are shown for context.

The Roper River Water Resource Assessment (the Assessment) provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water and agricultural development.

While agricultural developments are the primary focus of the Assessment, it also considers opportunities for and intersections between other types of water-dependent development. For example, the Assessment explores the nature, scale, location and impacts of developments relating to industrial and urban development and aquaculture, in relevant locations.

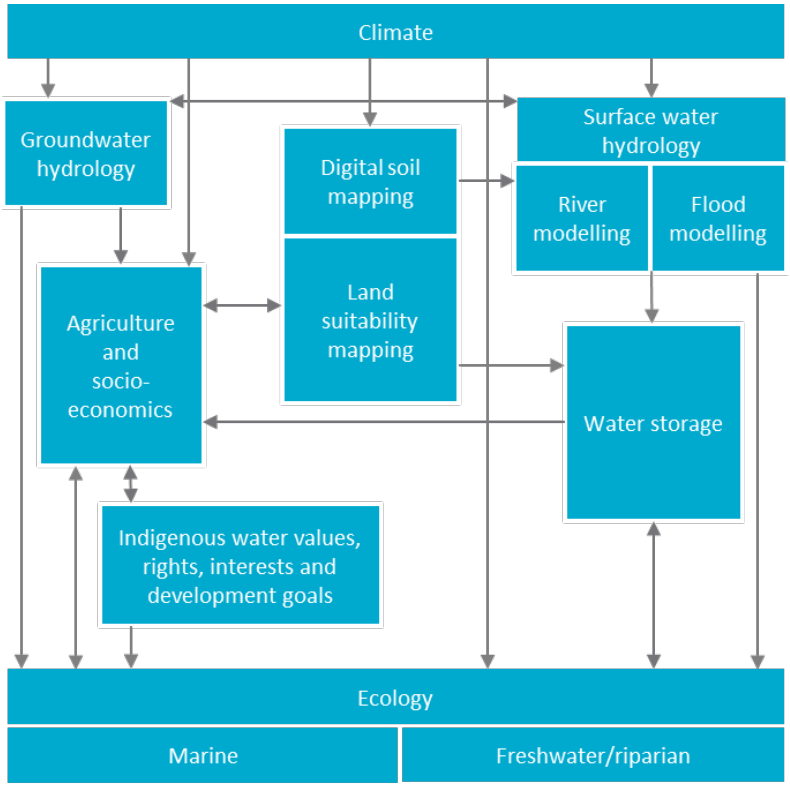
The Assessment was designed to inform consideration of development, not to enable any particular development to occur. As such, the Assessment informs – but does not seek to replace – existing planning, regulatory or approval processes. Importantly, the Assessment does not assume a given policy or regulatory environment. As policy and regulations can change, this enables the results to be applied to the widest range of uses for the longest possible time frame.



Preface Figure 1-1 Map of Australia showing Assessment area

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

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



Preface Figure 1-2 Schematic diagram of the high-level linkages between the eight activities and the general flow of information in the Assessment.

Assessment reporting structure

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

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

- Technical reports; that present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the eight activities has one or more corresponding technical report.
- A Catchment report; that for the Roper catchment synthesises key material from the technical reports, providing well-informed (but not necessarily-scientifically trained) readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture and other development options.
- A Summary report; that for the Roper catchment provides a summary and narrative for a general public audience in plain English.
- A Summary factsheet; that for the Roper catchment provides key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable the reader to better access information that is not readily available in a static form. All of these reports, information tools and data products are available online at https://www.csiro.au/roperriver. The website provides readers with a communications suite including factsheets, multimedia content, FAQs, reports and links to other related sites, particularly about other research in northern Australia.

Executive summary

Current allocations of surface water in the Roper catchment are low, relative to the catchment's median annual streamflow (<0.1%). The development of the surface water resources of this highly seasonal catchment to enable regional economic development, as has occurred in the south of Australia, would in many instances require rivers to be regulated and water stored. This report presents information on the broad-scale opportunities for and risks of storing surface water in the Roper catchment, including large engineered dams and large farm-scale offstream storages (i.e. ringtanks) and large farm-scale gully dams. The information is provided to support informed deliberations and discussions around the construction of dams in the Roper catchment.

Large instream dams

No previous studies of large dams in the Roper catchment have been undertaken. In order to undertake an objective analysis the DamSite model, a series of algorithms that automatically determines favourable locations in the landscape as sites for large instream and offstream dams was used to assess over 50 million potential dam sites in the Roper catchment. The more favourable sites in terms of cost per ML released from the dam wall in distinct geographic parts of the Roper catchment were evaluated together with broad-scale geological data and land suitability data to select dam sites for a desktop pre-feasibility analysis.

Potentially feasible damsites in the Roper catchment occur where resistant ridges of Proterozoic sandstone beds have been incised by the river systems and outcrop on both sides of river valleys. The sandstones are generally weathered to varying degrees and the depth of weathering and the amount of sandstone outcrop on the valley slopes is a fundamental control on the suitability of the potential damsites. Where the sandstones are relatively unweathered and outcrop on the abutments of the potential damsite less stripping will be required to achieve a satisfactory founding level for the dam. The other fundamental control on the suitability of potential dams in the Roper catchment is the extent and depth of the Quaternary alluvial sands and gravels in the floor of the valley as these materials will have to be removed to achieve a satisfactory founding level for any dam. In general, where stripping removes the more weathered rock, it is anticipated that the Proterozoic sandstones will form a reasonably watertight dam foundation requiring conventional grout curtains and foundation preparation.

In those parts of the catchment where potentially soluble dolomites occur within the Proterozoic sequences (soluble over a geological time scale) then it is possible that potentially leaky dam abutments and reservoir rims may be present requiring specialised and costly foundation treatment such as extensive grouting. In the lower reaches of the Roper River where the river is tidal, the presence of soft estuarine sediments has the potential to make dam design more challenging and construction more expensive, which may compromise the feasibility of a dam.

Four potential dam sites were selected based on their potential to supply water for irrigation and one potential dam site (on the Wilton River) was selected based in its potential to supply water for hydro-electric power generation. These sites are summarised in Preface Table 1. Two potential sites were short-listed to develop conceptual arrangements and preliminary manually derived cost estimates. The remaining costs were modelled using the dam cost algorithm used in the DamSite model.

Preface Table 1 Potential dam sites in the Roper catchment examined as part of this Assessment

NAME	DAM TYPE*	SPILLWAY HEIGHT ABOVE BED ** (M)	CAPACITY AT FSL (GL)	CATCHMENT AREA (KM^2)	ANNUAL WATER YIELD *** (GL)	CAPITAL COST# ($ MILLION)	UNIT COST## ($/ML)	EQUIVALENT ANNUAL UNIT COST & O&M### ($/Y PER ML/Y)
Waterhouse River West Branch dam site	RCC	23	128	795	48	415☐	8646	640
Waterhouse River	RCC	21	219	1,477	89	253◘	2,843	211
Flying Fox Creek	RCC	22	133	1,173	68	318◘	4,676	346
Jalboi River	RCC	25	174	828	40	463☐	11,575	857
Wilton River	RCC	39	4,541	12,073	926	849☐[&]	916	68

FSL = full supply level
* Roller compacted concrete dam (RCC).
** The height of the dam abutments and saddle dams will be higher than the spillway height.
*** Water yield is based on 85% annual time-based reliability using a perennial demand pattern for the baseline river model under Scenario A. This is yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These yield values do not take into account downstream existing entitlement holders or environmental considerations.
# ◘ Indicates manually derived preliminary cost estimate, which is likely to be –10% to +50% of 'true cost'. ☐ Indicates modelled preliminary cost estimate, which is likely to be –25% to +75% of 'true' cost. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher.
This is the unit cost of annual water supply and is calculated as the capital cost of the dam divided by the water yield at 85% annual time reliability.
Assuming a 7% real discount rate and a dam service life of 100 years. Includes operation and maintenance costs, assuming operation and maintenance costs are 0.4% of the total capital cost.
§§Note there is limited soil suitable for irrigated agriculture downstream of this potential dam site

Although there are potential dam sites in the lower Roper River, Hodgson River and Wilton River that could potentially supply large quantities of water at a relatively low levelized cost (i.e. ~$60/y per ML/y), there is limited land downstream of these sites suitable for irrigated agriculture. The site with the lowest levelized cost upstream of moderately large contiguous areas of soils suitable for irrigated agriculture is on the Waterhouse River. This site could potentially supply a modest amount of water at a levelized cost of $211/y per ML/y and the site is situated on Aboriginal Land scheduled under ALRA near the community of Beswick and is classified under 'inalienable freehold title', which means that it cannot be bought, acquired or mortgaged. Other sites with relatively low levelized cost on lease hold land, more favourable geology for roller compacted concrete dams and small to moderate contiguous areas of suitable soil downstream are on the upper Flying Fox Creek and Jalboi River. Situated on relatively small catchments these are relatively low yielding sites (68 and 40 GL in 85% of years respectively) and have levelized costs of about 346 and 857 per $/y per ML/y respectively.

Although the potential dam site on the Wilton River has capacity to generate large quantities of hydro-electric power there is no transmission line infrastructure in the Roper catchment to support the development of hydro-electric power.

No information relating to sacred sites or cultural heritage values of the potential dam sites was made available to the Assessment. The Roper catchment is very likely to contain a large number of

Indigenous cultural sites, including archaeological pre-contact sites some of which are likely to be of national scientific significance. Previous studies in northern and southern Australia clearly show that Indigenous people lived along major watercourses and drainage lines. The cultural heritage value of these landforms and their immediate surrounds is therefore assumed to be moderate to very high.

Potential dams in the Roper catchment, which were examined as part of the Assessment, were estimated to have less than 1% sediment infilling after 30 years and less than 3% sediment infilling after 100 years. If any of the potential dams examined in the Assessment were to be constructed, sediment yields would need to be recomputed by undertaking a detailed field measurement and modelling program of downstream impacts on river channels and an assessment of estuarine and coastal geomorphology.

A desktop assessment of potential environmental issues associated with large potential dam sites in the Roper catchment was undertaken. Assessment of potential impacts was based on fish distribution and passage, for which reasonable information exists, and consideration of general environmental issues that commonly arise in dam developments in similar habitats elsewhere, particularly the Burdekin Falls Dam (Lake Dalrymple) and the Ord River Dam (Lake Argyle).

A large dam constructed on the lower Wilton River may limit the migration, movement or colonisation of habitat by fish species. Potential dam sites in the headwaters of the Roper catchment (i.e. Waterhouse River, Flying Fox Creek and Jalboi River) will have less impact because the restriction on species movement is small relative to the downstream areas and the number of fish species typically decreases with distance from the coast.

It should be noted that the investigation of a potential large dam site generally involves an iterative process of increasingly detailed studies over a period of years, occasionally over as few as 2 or 3 years but often over 10 or more years. For any of the options listed in this report to advance to construction, far more comprehensive studies would be needed. Studies at that detail are beyond the scope of this regional-scale resource Assessment.

Farm-scale gully and hillside dams and offstream storages in the Roper catchment

This report provides a broad-scale assessment of the suitability of farm-scale gully and hillside dams and offstream water storage locations in the Roper catchments. It does not attempt to produce individual engineering farm-dam or water-harvesting infrastructure designs for individual producers.

A desktop assessment of the suitability of farm-scale offstream storages in the Roper catchment was undertaken based on soil parameter grids developed by the Assessment. These data were sourced from the companion technical report on digital soil mapping (Thomas et al., 2022). Because the Assessment only sampled soil to a depth of 1.5 m, this suitability assessment does not give consideration to the nature of subsurface material below 1.5 m depth. The largest areas suitable for farm-scale offstream storages in the Roper catchment are along the recent alluvial soils adjacent to the Roper River. This area is, however, susceptible to flooding. Elsewhere in the Roper catchment the soils are too sandy or landscape too steep and rocky for farm-scale offstream storages.

Farm-scale gully and hillside dams were modelled using the DamSite model. Those areas that are more topographically favourable for gully dams have the smallest areas of soil suitable for irrigated agriculture. The cumulative effect of water extraction for farm-scale ringtanks is examined in the companion technical report on river system simulation (Hughes et al., 2023) and the companion technical report on ecology (Stratford et al., 2023).

Assuming an average seepage loss of 2 mm/day a 4.25 m high ringtank in the Roper catchment was calculated to have a levelized cost of $135, 175 and $239/y per ML/y for irrigating crops with short, medium and long/perennial growing seasons. For crops with short and medium length growing seasons the levelized cost is considerably less than that for large engineered dams. For crops with a long growing season (i.e. double cropping system or perennial) the levelized cost of a 4.25 m high ringtank is slightly higher than the most cost-effective large engineered dams in the Roper catchment, however, the levelized cost of a 6.75 m ringtank is slightly less than the most cost-effective large engineered dam.

With a levelized cost typically between $50 and $75/y per ML/y gully dams were found to be considerably more cost effective than ringtanks and large engineered dams. However, this is under idealised conditions where suitable soils for construction are readily available, and the site is upstream of soils suitable for irrigated agriculture. The combination of suitable topography for gully dams, soils for construction and irrigated cropping in the Roper catchment are rare.

Contents

Figures

Tables

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Part I Introduction

1 Introduction

Current allocations of surface water in the Roper catchment are low relative to the catchment's median annual discharge (i.e. <1%). Large-scale development of the surface water resources of this highly seasonal catchment to enable regional economic development would generally require rivers to be regulated and water stored. In southern Australia, constructing large reservoirs (Preface Figure 1) has effectively delivered reliable water supplies in a dry and variable temperate climate. The elaborate series of dams and tunnels constructed as part of the Snowy Mountain Hydro-Electric Scheme has enabled watering of much of the irrigated land in the Murray–Darling Basin. A number of commentators have observed that no country or region in a tropical or sub-tropical climate has made significant economic progress without harnessing adequately its water resources (Bisawas, 2012).

Large instream dams are not the only methods of storing water. Although Petheram et al. (2014) found that large dams presented the greatest opportunity for enabling broad-scale irrigated agriculture across northern Australia, they also stated that other methods, while capable of supplying far smaller volumes of water than instream dams, may play a role in maximising the cost-effectiveness of water supply. Furthermore, the large, often public, capital expenditure requirements and often unpredictable environmental and social changes associated with large instream dams have led some sectors of the public to question whether they are an appropriate pathway for development (O'Donnell and Hart, 2016; International Rivers, 2014; WCD, 2000).

Thus, decisions around river regulation and water storage are complex, and the consequences of decisions are inter-generational – even small inappropriate releases of water may preclude possibly larger and more appropriate developments in the future.

The primary purpose of this report is to provide a comprehensive overview of the different surface water storage options available in the Roper catchment to help decision makers take a long-term view of water resource development (i.e. >20 years), which will also inform shorter-term allocation decisions.

Having a wide range of reliable information prior to making decisions, including on all the different ways water can be stored, can have long-lasting benefits to government and communities and facilitate an open and transparent debate. The broad types of dams and water storage options likely to be used in northern Australia are described in Section 1.1.

The first step in assessing potential water storage options in a catchment is to examine existing water storages. Any available unused water in these storages is likely to be the most cost-effective source of additional water. No large engineered dams exist in the Roper catchment.

It is important to note that this surface water storage analysis was of a pre-feasibility nature. The broad steps involved in investigating a large dam are described in Section 1.2.

Report objectives

The objectives of this report were to:

- review all previous studies (published and unpublished) on large dams in the Roper catchment

- identify and assess every location in the study area for its potential for the construction of large instream and offstream dams, including an estimate of water yield and modelled cost
- undertake a manual cost estimate (for 2 short-listed sites) at a nominated full supply level (FSL) height
- undertake a pre-feasibility assessment of the best opportunities for farm-scale instream (i.e. gully and hillside dams) and offstream (i.e. ringtank) storages
- identify the more promising surface water storage option in the study area in terms of yield per unit cost and proximity to soil suitable for irrigated agriculture.
- present the results in a consistent tabulated format that facilitates site comparisons
- provide a conceptual layout and indicative costs for two scheme-scale reticulations systems in more-promising parts of the catchment.

Site-specific field investigations of individual farm-scale storage sites were beyond the scope of this pre-feasibility assessment. However, the performance of hypothetical farm-scale storage is discussed, generalised cost estimates are provided and farm-scale storages were modelled using the best available information.

Report outline

This report is divided into four parts and two appendices.

Part I Introduction contains two chapters. Chapter 1 provides introductory material to aspects of large instream and offstream dams and farm-scale dams, key terminology and concepts, and Chapter 2 details the methods undertaken to assess dams in the Assessment area, including the DamSite modelling process.

Part II Large instream and offstream dams contains four chapters. Chapter 3 analyses a long-list of dams used to identify potential sites for pre-feasibility analysis. Chapter 4 presents detailed information on two short-listed dam sites in the Roper catchments. Chapter 5 contains general information on regulating structures, such as weirs and sand dams and Chapter 6 examines farm-scale storages in the Roper catchment.

Part III Scheme-scale reticulation infrastructure contains Chapter 7 which examines the scope for broad-scale irrigation developments serviced by the two short-listed dam sites.

Part IV Summary comments contains the summary comments in Chapter 8 and references in Chapter 9.

Appendix A provides detailed costings for the two short-listed potential dam sites in the Roper catchment.

Appendix B provides summary tables for the three potential dam sites selected for pre-feasibility analysis but were not short-listed for a more detailed costing.

Section outline

The remainder of this introductory chapter is structured so as to give well-informed but non-technical readers some of the background information on surface water storage infrastructure needed to understand subsequent technical sections of the report. Large parts of this section are reproduced from Petheram et al. (2017a) as the material is generic and provides good contextual information for the specific analysis of the Roper catchment presented in Part 2. Section 1.1, provides an overview of the different types of large dams and farm-scale water storage infrastructure in the Roper catchment. Section 1.2 outlines the broad steps in the investigation of a large dam site, which provides the context for the additional work needed in order to for a site to be considered 'shovel ready'. In Section 1.3 a brief overview of dam safety, provides the context for a discussion on who might build different types of dams, which influences their cost. Section 1.4 defines key terminology and concepts used in the report.

Introductory information on environmental and cultural heritage considerations and deriving dam axis elevation profiles and reservoir volumes using Shuttle Radar Topographic Mission (SRTM) data is provided in Petheram et al. (2013).

Key linkages with other activities of the Roper River Water Resource Assessment

This report draws heavily on information and models generated by other activities in the Assessment, in particularly the rivers system model calibration report (Hughes et al., 2023), ecology asset description report (Stratford et al., 2022), digital soil mapping and land suitability report (Thomas et al., 2022), agriculture and socio-economic viability report (Stokes et al., 2023) and the flood mapping and modelling report (Kim et al., 2023).

1.1 Types of water storages

The Assessment undertook a pre-feasibility level assessment of four types of surface water storage options. These were (i) large dams that supply water to multiple properties, (ii) farm-scale or on-farm dams that supply water to a single property, (iii) re-regulating structures such as weirs, and (iv) natural water bodies. Although the last does not require construction, their capacity may be enhanced with strategically constructed embankments.

Both large dams and farm-scale dams can be further classified as either instream or offstream water storages. In this Assessment, instream water storages are defined as structures that intercept a drainage line (creek or river) and are not supplemented with water from another drainage lines. Offstream water storages are defined as structures that (i) do not intercept a drainage line, or (ii) intercept a drainage line and are supplemented with water extracted from another larger drainage line. Ringtanks and turkey nest tanks are examples of offstream storages with a continuous earth embankment. Large dams, farm-scale dams, offstream storages, re-regulating structures and natural water bodies are briefly discussed below.

Large instream dams are usually constructed from earth, rock or concrete materials as a barrier across a river to store water in the reservoir created. They need to be able to safely discharge the largest flood flows likely to enter the reservoir, and the structure must be designed so the dam meets its purpose, generally for at least 100 years. Note, however, that some dams have been in continuous operation for over 1000 years. For example, the Kofini Dam in Greece and the Anfengtang Dam in China are still in operation 3300 and 2600 years, respectively, after their construction (Schnitter, 1994). Schnitter (1994) consequently described dams as 'the useful pyramids'.

The requirements of a good dam have long been established. For example, inscriptions near the Anantharaja Dam in southern India, completed in 1369, detail 12 requirements of a good reservoir (taken from Vadera (1965) in Schnitter (1994)), that could still be claimed as valid today:

1. A king (i.e. owner or client) endowed with righteousness, rich, happy and desirous of acquiring fame
2. A person well versed in hydrology
3. A reservoir bed of hard soil
4. A river conveying sweet water from a distance of about 40 km
5. Two projecting portions of hills in contact with the river
6. Between these projecting portions of hills a dam built of compact stone, not too long but firm
7. The two extremities of the hills to be devoid of fruit-bearing land (i.e. humus)
8. The bed of the reservoir to be extensive and deep
9. A quarry containing straight and long stones
10. Fertile low and level (i.e. irrigable) area in the neighbourhood
11. A watercourse having strong eddies in the mountain region
12. A group of men skilled in the art of dam construction.

The inscription also lists six faults that should be avoided:

1. Oozing of water from the dam
2. Saline soil
3. Site at the boundary of two kingdoms
4. High ground in the middle of the reservoir
5. Scanty water supply and an extensive area to be irrigated
6. Too little land to be irrigated and excessive supply of water.

An attraction of large dams is that if the reservoir is large enough relative to the demands on the dam (i.e. water supplied for consumptive use, evaporation and seepage), when the reservoir is full water can last two or more years. This has the advantage of providing water during dry seasons and mitigating against years with low inflows to the reservoir. For this reason large dams are sometimes referred to as carry-over storages.

An advantage of large instream dams is that they provide a very efficient way of intercepting the flow in a river, effectively trapping all flow until the FSL is reached. For this reason, however, they also provide a very effective barrier to the movement of fish and other species within a river system and can also inundate large areas of land.

Two types of dams are particularly suited to northern Australia: embankment dams and concrete gravity dams.

In the hazard framework outlined in Section 1.3, large dams fall within Category 3, and it is recommended that their construction be undertaken by an engineering consultant specialising in large dams.

Embankment dams

Embankment dams are usually the most economical, provided that suitable construction materials can be found locally, and are best suited to smaller catchment areas where the spillway capacity requirement is small. There are two major types of embankment dams: earthfill embankment dams and rockfill embankment dams. Earthfill embankment dams are the most popular dams worldwide (61%) because they can be built on a wide range of foundation conditions. In Australia, however, only 33% of large dams are classified as earthfill, while 40% are rockfill.

Like earthfill dams, rockfill dams can be built on a wide range of foundation conditions, but they require less material as they can be built with much steeper sides. They can also be constructed during rain and remain stable even under high seepage conditions. Rockfill embankment dams also have an advantage over earthfill embankment dams in that methods have been devised for reinforcing the downstream rockfill slope to protect it from erosion. Indeed several rockfill dams in Australia have survived overtopping during flood events with minimal damage.

Two common types of rockfill dams for which there are examples in northern Australia are shown in Figure 1-1 and Figure 1-2. In the first case the dam has a central earth core within the embankment that provides a watertight barrier to prevent water percolating through the rockfill (e.g. Belmore Creek Dam (officially known as Lake Belmore), Norman catchment). In the second case the seepage barrier is a thin reinforced concrete slab placed on the upstream face of the rockfill (e.g. Corella Dam, Flinders catchment).

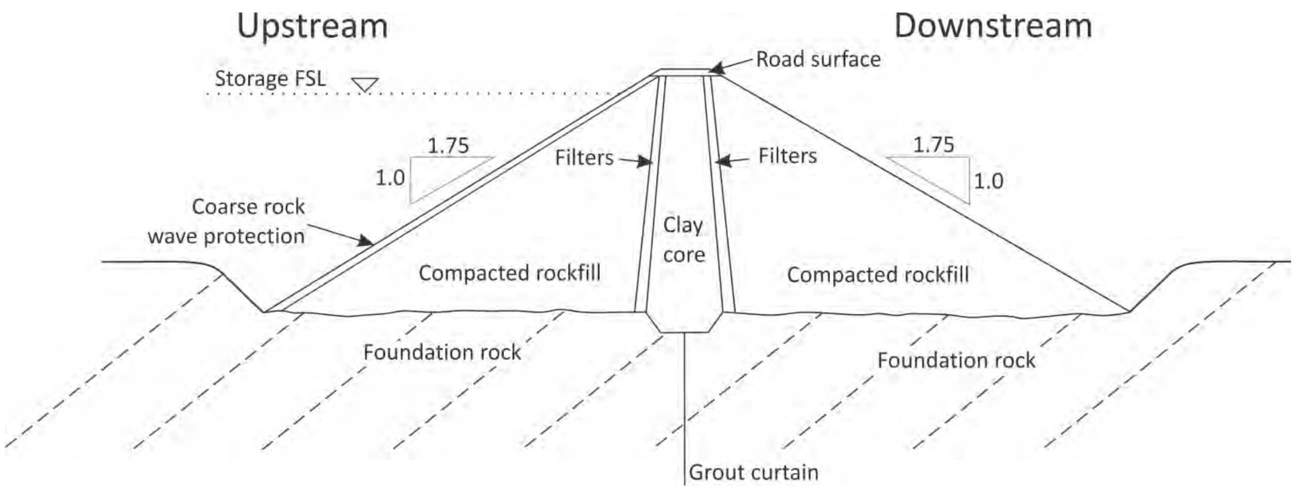

Figure 1-1 Schematic cross-section diagram of a rockfill embankment dam with a clay core

Source: Petheram et al. (2013)

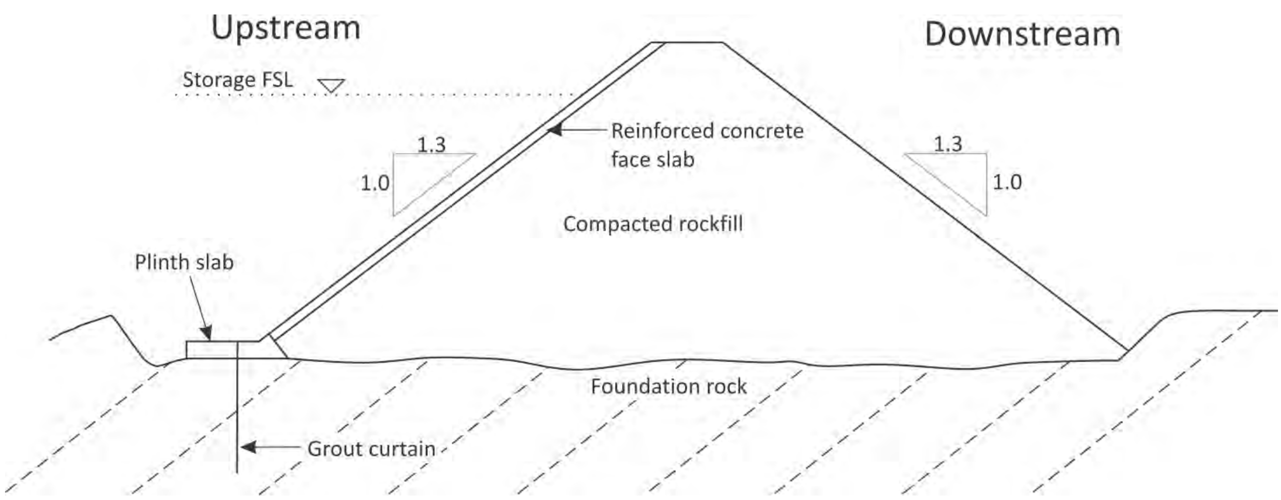

Figure 1-2 Schematic cross-section of a concrete-faced rockfill dam

Source: Petheram et al. (2013)

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

Concrete gravity dams

In contrast to embankment dams, concrete gravity dams require sound foundation rock because the leakage path through the foundation under the water barrier is short (Kinstler, 2000a). Where a large capacity spillway is needed to discharge flood inflows, a concrete gravity dam with a central overflow spillway is generally the most suitable type. Traditionally, concrete gravity dams were constructed by placing conventional concrete (CC) in formed 'lifts'. However, Kidston Dam (officially known as the Copperfield River Gorge Dam) in the Gilbert catchment was the first dam in Australia where roller compacted concrete (RCC) was used, with low-cement concrete placed in continuous thin layers from bank to bank and compacted with vibrating rollers. This approach allows large dams to be constructed in a far shorter time frame than is required for CC construction. The use of RCC over CC was estimated to reduce the cost of a concrete gravity dam at Copperfield Gorge by about 40% (Doherty, 1999), and the introduction of this technique resulted in an increase in the proportion of concrete gravity type dams built in Australia.

RCC is best used for high dams where a larger-scale plant can provide significant economies of scale. This is now the favoured type of construction in Australia whenever foundation rock is available within reasonable depth, and where a larger capacity spillway is required.

Other types of large dams

Two other major types of dams are concrete buttress and arch dams. Each can be favourable when concrete is expensive and labour is cheap (i.e. they require more formwork and are of greater complexity), such as occurred during the Great Depression and after World War II. However, in recent decades the high cost of labour has made these types of dams less economical than concrete gravity or embankment dams. Furthermore, arch dams are generally not very suitable in Australia due to a lack of suitable topography; they have the greatest benefits over concrete gravity dams where the valley width is narrow and the rock is structurally sound.

A note on offstream storages

Offstream water storages are not a new concept; they were among the first constructed water storages because people initially lacked the capacity to build structures that could block rivers and withstand large flood events. For example, in the 12th Dynasty of Ancient Egypt, water was diverted from the Nile River into the El Fayyum Depression (Nace, 1972), while one of the largest Mayan cities was constructed around offstream water storages (Scarborough and Gallopin, 1991). In Australia there is evidence that Indigenous people, prior to European settlement, engineered structures in the Roper catchment to divert dry-season baseflow into adjacent wetlands (Barber and Jackson, 2011).

Offstream water storages can take the form of farm-scale ringtanks (e.g. 100 to 10,000 ML storage capacity) or large dam structures (>10,000 ML). Figure 1-3 shows an example of an approximately 4000 ML ringtank. The most suitable type of offstream water storage depends on a number of factors, including topography, availability of suitable soils, excavation costs and source of water (e.g. groundwater or surface water pumping, flood harvesting).

One of the advantages of offstream storages is that, if properly designed, they can cause less disruption of the natural flow regime than do large instream dams, provided that water is extracted from the river using pumps or there is a diversion structure with raiseable gates that allow water and aquatic species to pass when not in use. However, raiseable gates are typically expensive to operate and maintain, particularly in remote areas, and the structures supporting the gates need to be designed to withstand large flood events, which increases the cost of the diversion structure considerably.

Weirs can also be used in conjunction with offstream water storages, whereby the weir is used to raise the upstream water level to allow diversion into an offstream storage or the creation of a pumping pool. However, an often-overlooked aspect of offstream storages is that the amount of water that can be diverted into an offstream storage using a diversion structure in a river depends on the relative difference of the height of water in the river and the height of water in the storage. Water must run downhill from the point of diversion to the storage location. To achieve adequate flow rates in the diversion channel, the diversion structure has to be sufficiently high to generate the required head of water. This is particularly the case in northern Australia where river water levels rise and fall very rapidly (Petheram et al., 2008) and there is little time for extraction or diversion. Kim et al. (2013) provide an example of a ‘hydraulic’ analysis for an offstream storage and diversion structure in the Flinders catchment.

Because the risk of failure of offstream storages due to overtopping is typically lower than for an instream dam, it is more feasible that a regionally based contractor overseen by a regionally based engineer (i.e. suitable to build a Category 2 dam) could construct a large offstream storage than a large instream dam.

Figure 1-3 Rectangular ringtank in the Flinders catchment

Photo: CSIRO

1.1.1 Farm-scale dams and water storages

Farm-scale dams, also referred to as on-farm dams, are typically used to supply water for stock and domestic purposes or for mosaics of small-scale irrigation supplying the one property. They can take the form of gully and hillside dams, ringtanks, turkey nest tanks and excavated tanks. A summary of the different types of on-farm dams and indicative storage-to-excavation ratios is provided in Table 1-1. These structures are evaluated in Chapter 6.

Table 1-1 Types of farm-scale water storages

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

Source: Adapted from Lewis (2002).

1.1.2 Re-regulating structures

Re-regulating structures such as weirs differ from dams in that they are lower barriers located entirely within stream banks and are totally overtopped during flood events. Weirs are typically used as re-regulating structures downstream of large dams to allow for more efficient releases from the storages and for some additional water yield from the weir storage itself, thereby reducing the transmission losses normally involved in supplemented river systems. Re-regulating structures can range from concrete gravity weirs to sheet piling weirs to simple sand dams – mounds of river sand within the bed of a river to create a pumping pool. These types of structures are discussed in more detail in Chapter 7.

1.2 Stages of investigation in design, costing and construction of dams

The investigation of a potential dam site involves an iterative process of increasingly detailed studies, sometimes occurring over as few as 2 or 3 years but often over 10 or more years. It is not unusual for the cost of the geotechnical investigations for a dam site alone to exceed several million dollars. Given the high costs and time involved and the likelihood of many potential dam sites in a catchment, an important stage of developing the surface water resources of a catchment is a pre-feasibility assessment.

The pre-feasibility assessment is the first of five stages of a dam project. Fell et al. (2015) outlined these five stages as pre-feasibility, feasibility and site selection, design and specification, construction, and operation.

The pre-feasibility stage, including this Assessment, typically involves a detailed desktop investigation and site visit to acquire significant information for numerous dam sites in an area, including determining whether the:

- topography favours the creation of a large storage volume by a dam of a height and length likely to be economically viable
- regional and local geology are likely to impose constraints or additional cost to construction
- streamflow characteristics are appropriate for a storage to meet the forecast demand
- dam site location is in the vicinity of the forecast demand for water and soils suitable for irrigation
- storage would affect existing land uses, existing infrastructure or environmental, social or cultural values
- impacts are likely to be acceptable to investors and other stakeholders. This is particularly relevant to the Darwin catchments which have a large amount of infrastructure development relative to other parts of northern Australia.

The geological assessment should include a visit to each site by an experienced infrastructure geologist.

The likelihood of dam sites being suitable for future detailed evaluation can often be determined from a preliminary assessment of available information including maps, geology and streamflow data, and particularly from site inspections. An initial desktop assessment of the impacts of a storage development on existing land uses, existing infrastructure and environmental values may indicate at an early stage whether the impacts are likely to be acceptable to investors or other stakeholders. More-promising potential dam sites may have been the subject of earlier investigations, in which case the available study reports can be particularly useful in any reassessment.

A pre-feasibility analysis commonly short-lists the better sites for a more detailed desktop analysis, including more time-demanding analyses such as preliminary flood design assessment (e.g. to assess the additional height above the FSL (or freeboard), which can significantly affect dam cost). One such preliminary assessment was recently undertaken in northern Australia in the Flinders and Gilbert catchments by Petheram et al. (2013). This process makes it possible to confidently select the most appropriate dam sites on which to undertake more detailed and costly ground-based investigations.

To progress a dam proposal from a desktop assessment to the commencement of construction requires a series of comprehensive and often iterative studies. These include:

- detailed topographic surveys
- detailed hydrological studies calculating the reservoir yield and reliability and the magnitude of flood inflows that could be experienced during the period of construction and operation of the dam
- geotechnical studies, including geological mapping of the site and inundated area, seismic surveys, trenching and drilling to assess foundation conditions for each of the proposed structural elements and to assess potential sources of construction materials. Geotechnical assessments are required at all five stages of a dam project (Fell et al., 2015)
- engineering studies of dam type and layout, including for the main cross-river wall, any necessary saddle dams, spillways and outlet works as well as provisions required to address impacts, particularly in the storage area
- impact assessment studies including environmental, social and cultural heritage impacts and the development of strategies to avoid or manage impacts
- consideration of needs and costs for processing, transport and marketing of the products of irrigated agriculture
- economic and financial studies that compare estimated costs and benefits and which develop proposals for funding the construction and operation of the works including the water supply charges proposed.

Ultimately the studies need to acquire the necessary level of detail and certainty to obtain the required approvals. The final step should consider how implementation of the project should proceed, including institutional arrangements for construction and ongoing operation and maintenance of the scheme, for the entire operational life of the dam.

1.3 Dam safety and models of dam labour construction

The Australian National Committee on Large Dams (ANCOLD) is an incorporated voluntary association of organisations and individual professionals with an interest in dams in Australia. It organises technical working groups and issues guidelines on topics related to dams. The ANCOLD dam consequence categories (ANCOLD, 2012) define seven hazard groups (Very low, Low, Significant, High C, High B, High A and Extreme), where the higher the hazard category assigned to a dam the more work is required to ensure the risk to downstream communities is mitigated to an acceptable level.

These seven hazard categories can be grouped into three categories that broadly reflect the amount of work required for the operation of a safe dam:

- Category 1. Dams in the 'Very low' or 'Low' hazard category. Depending upon the jurisdiction and the dimensions of the structure and reservoir, these dams may require a permit to undertake dam works, but in general, these require the least amount of detail to satisfy statutory planning, construction, maintenance and reporting requirements.
- Category 2. Dams that fall into a hazard category of 'Significant' and 'High C', or all dams that are over 10 m but less than 25 m in height and not in Category 3. These require considerably more detail to satisfy planning, construction, maintenance and reporting requirements than do dams in Category 1.
- Category 3. Dams that are at the higher end of the hazard category scale. These dams include 'High B', 'High A' and 'Extreme' hazard dams and dams that are over 25 m in height. These generally require the services of an engineering consultancy service specialising in the construction of large dams, require considerable planning and approval, and usually require an environmental impact statement and approval under the Commonwealth's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

In the context of the Assessment, these three categories are useful for helping to broadly categorise dam labour construction models, the capital costs and ongoing operation and maintenance costs.

Dam labour construction models and implications to cost

Most on-farm dams fall into Category 1, but larger farm-scale dams may be Category 2. It is technically feasible for farm dams that fall into Category 1 to be constructed by the landholder where they own their own plant or can purchase new or second-hand plant and compaction equipment, and the structure satisfies jurisdictional requirements.

There are no jurisdictional regulations covering construction of farm dams in the NT.

Construction by landholders using their own plant and equipment may often be a cheaper form of surface water storage construction because:

- landholders often employ lower design standards, preferring intermittent annual costs associated with maintaining a structure rather than high upfront costs (e.g. preferring to repair batter slopes with their own equipment as needed rather than use rock protection)
- contractor and other project overheads (e.g. ensuring access and operation of the structure comply with health and safety regulations) are substantially lower than if a regionally based contractor and engineer were used
- the cost of maintenance and repair of machinery and the opportunity cost of the landholder undertaking their own design, survey and project management of the structure are rarely considered by landholders.

Although farm dams constructed by a landholder may in some circumstances be cheaper than those using a regionally based contractor and engineer, the dam's service life is typically lower and the ongoing maintenance costs and risk of failure are typically higher. For example, ANCOLD (1992) report that a study in NSW found a 23% failure rate for farm dams in that state.

Dams that fall within Category 2 could feasibly be constructed by a regionally based contractor, with investigation and design being undertaken by a regionally based engineering consultant. Under this model of construction, the upfront cost of constructing the dam would be higher than for a Category 1 dam but probably less than for a Category 3 dam. Category 2 dams are generally cheaper than Category 3 dams because they require less technical design and investigation and typically have lower contractor overheads, such as project risk and site accommodation, because of the smaller scale and complexity of the operation.

Larger dams such as Darwin River Dam and Manton Dam in the Darwin catchments are Category 3 dams. These dams are the domain of professional engineering companies that specialise in the construction of large dams. Costs are usually high because investigation costs are expensive and the structures are generally designed and constructed to a very high standard, usually with at least a 100-year service life. Contingency is typically high because these structures carry the highest risk as considerable subsurface works are required.

1.4 Key terminology and concepts

1.4.1 Dam terminology

In this report the word 'dam' refers to the structure including the dam wall, primary and secondary spillways and outlet structures. 'Reservoir' is reserved for the water body upstream of the dam wall. Dam volume is defined here as the volume of material in the dam wall, and the reservoir capacity is the volume of the reservoir at FSL. The total freeboard is the sum of the wet freeboard and the dry freeboard, where the wet freeboard is the height above the FSL below which a design flood event may pass (also referred to as flood surge) and the dry freeboard is the height above the wet freeboard to account for wind-generated waves overtopping the structure.

1.4.2 Water yield

Yield is the amount of water that can be released in a controlled manner from a reservoir system. Yield values are accompanied by a reliability value where, for all other factors held constant, increasing the reliability decreases the yield. Other terms used synonymously with yield are release, draft and regulation. In this report all yield and reliability values are expressed in terms of annual time reliability, which is calculated as per Equation 1.

$$R_t = \frac{N_S}{N} \tag{1}$$

Where R_t is the time-based reliability, N_S is the total number of intervals during which the demand was met; and N is the total number of time intervals in the simulation. For annual time reliability N_S becomes the number of successful years and N becomes the number of years in the simulation period.

1.4.3 Water year and wet and dry seasons

Northern Australia has a highly seasonal climate, with most rain falling from December to March. Unless specified otherwise, this Assessment defines the wet season 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, unless specified otherwise. This allows each individual wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons). This is more realistic for reporting climate statistics from a hydrological and agricultural assessment viewpoint.

1.4.4 Scenario definitions

Four scenarios are presented in this report:

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

Scenario A

Scenario A is historical climate and current development. The historical climate series is defined as the observed climate (rainfall, temperature and potential evaporation for water years from 1 September 1910 to 31 August 2019). All results presented in this report are calculated over this period unless specified otherwise. The current level of surface water, groundwater and economic development were assumed (as at 2021). Scenario A was used as the baseline against which assessments of relative change were made. Historical tidal data were used to specify downstream boundary conditions for the flood modelling.

Historical climate data were sourced from the scientific information for landowners (SILO) data drill database, http://www.longpaddock.qld.gov.au/silo/ (Jeffrey et al., 2001). SILO provides surfaces of daily climate data interpolated and infilled from point measurements made by the observation network developed and maintained by the Bureau of Meteorology.

Scenario B

Scenario B is historical climate and future development, as generated in the Assessment. Scenario B used the same historical climate series as Scenario A. River inflow, groundwater recharge and flow, and agricultural productivity were modified to reflect potential future development. All price and cost information was indexed to mid-2021. The impacts of changes in flow due to this future development were assessed, including impacts on:

- instream, floodplain and near-shore ecology
- 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.

Scenario C

Scenario C is future climate and current levels of surface water and ground development assessed at ~2060. It will be based on the 109-year climate series (as in Scenario A) derived from GCM projections for an approximate 1.6°C global temperature rise (~2060) relative to the 1990 scenario, representing Shared Socioeconomic Pathway, SSP2-4.5. The GCM projections will be used to modify the observed historical daily climate sequences.

Scenario D

Scenario D is future climate and future development. It used the same future climate series as Scenario C. River inflow, groundwater recharge and flow, and agricultural productivity were modified to reflect potential future development, as in Scenario B. Therefore, in this report, the climate data for Scenarios A and B are the same (historical observations from 1 September 1890 to 31 August 2019) and the climate data for Scenarios C and D are the same (the above historical data scaled to reflect a plausible range of future climates).

1.4.5 Reporting DEM-H elevation and height data

Elevation data are fundamental to assessing dam design and evaluating water storage capacities. For the Roper catchment, the national 1 second hydrological digital elevation model (DEM-H) (~30 m horizontal grid), derived from the Shuttle Radar Topographic Mission (SRTM) data (Gallant et al., 2011), is the finest resolution digital elevation dataset available. This dataset covers the entire continent and constitutes the best available data over most of Australia, particularly northern Australia.

The SRTM is based on the Earth Gravitational Model 1996 (EGM96) geoid, for which there is a vertical datum difference with the Australian Height Datum (AHD). The difference between the datum of the two elevation datasets is poorly defined due to the lack of a well-defined AHD surface across the Australian continent; however, it is generally less than 1 m. For this reason, all heights and elevations derived using the DEM-H are reported here as EGM96 geoid height in metres (mEGM96). It is important to understand the strengths and weaknesses of any elevation dataset used, and the reader is referred to Petheram et al. (2013) for a brief discussion of the DEM-H.

2 Methods

2.1 Large instream and offstream dams

The first phase of the investigation into large dams involved (i) reviewing reports describing all large dam proposals that had been the subject of earlier or current investigations, and (ii) running the DamSite model to ensure no potential dam options had been overlooked. These two activities were undertaken concurrently and are described in Section 2.1.1 and Section 2.1.2, respectively.

Based on the review of existing literature and the DamSite model results, Section 2.1.3 lists the sites selected for pre-feasibility analysis and Section 2.1.4 summarises the methods for which each potential dam site was assessed and outlines the method by which potential dam sites were selected for pre-feasibility analysis.

2.1.1 Review of past literature

No previous studies examining dam sites in the Roper catchment have been identified.

2.1.2 DamSite modelling

To ensure that potential dam sites across the Roper catchment were objectively and consistently assessed, the DamSite model (Read et al., 2012; Petheram et al., 2017b) was applied across the entire study area. This model is a series of algorithms that automatically determines favourable locations in the landscape as sites for intermediate-to-large water storages and has been previously applied successfully to the Flinders and Gilbert catchments (Petheram et al., 2013).

Broadly, the approach involved calculating the potential dam and reservoir dimensions of every location in the Roper catchment at 1 m height increments, constructing saddle dams as required, and using the DEM-H, the best freely available DEM across northern Australia.

The DamSite model then calculated a ‘preliminary yield’ (85% annual time reliability) at the dam wall using the computationally efficient Gould–Dincer Gamma (GDG) method (McMahon and Adeloye, 2005; Petheram et al., 2008) for calculating the water yield of carry-over storages (i.e. large dams where water can be carried over from one year to the next) and a within-year storage yield method (Petheram et al., 2017b). This was done for each 1 m increment dam height at each site, and for over 100 heights at some sites. For each height increment, the ‘preliminary yield’ was selected from the larger of the GDG yield and within-year yield estimates. At each site and for each 1 m increment dam height, the model calculated an approximate unit cost for a dam structure based on the vegetation-corrected Advanced Land Observing Satellite (ALOS) DEM elevation profile along the dam and saddle dam axis and type, and the quantity of material required and their unit cost rates. The cost algorithm effectively applies a penalty to higher and longer dam wall structures.

More detail on the DamSite model is provided by Read et al. (2012), Petheram et al. (2013) and Petheram et al. (2017b). Since these publications, however, the DamSite model dam cost algorithm has been substantially revised. The new cost algorithm is described in Petheram et al. (2017a).

DamSite model parameters as applied to the Roper catchment

The DamSite model as applied to the Roper catchment for assessing large dams was parameterised as follows:

- The minimum catchment area assessed was 2 km^2.
- The minimum wall height was 6 m.
- Gridded runoff data were sourced from the Australian Water Resources Assessment landscape (AWRA-L) model runs for the catchment (see companion technical report on river model calibration (Hughes et al., 2023)).

The results of the DamSite model were summarised to identify the most cost-effective potential dam sites. This was done by presenting the results in terms of:

- the ratio of reservoir capacity (i.e. reservoir volume at FSL) to cost of dam construction, also referred to as maximum volume per unit cost ($VpUC_{max}$). This measure is useful for identifying parts of the landscape that are particularly topographically suitable for large offstream storages
- the ratio of reservoir yield to cost of dam construction, also referred to as maximum yield per unit cost ($YpUC_{max}$). This measure is particularly useful for identifying sites that are topographically and hydrologically suitable for the construction of large instream dams.

The results of the DamSite analysis in the Roper catchment is presented in Section 3.1.

Note that the DamSite model was also used to assess on-farm dams using a smaller catchment area and wall height. The method and parameters used to assess on-farm dams are detailed in Section 2.2.2.

2.1.3 Potential dam site selection

Based on the DamSite modelling, a ‘long list’ of approximately 20 potential dam sites geographically spread across the Roper catchment were selected for an initial cursory desktop geological evaluation. The sites were selected on the basis of having a relatively favourable ratio of reservoir yield to unit cost as calculated by the DamSite model. The geological desktop evaluation was undertaken using satellite imagery and 1:250,000 geological mapping data.

Based on the initial desktop geological evaluation, a smaller number of dam sites were selected for an evaluation of water yield based on inflows from the Roper River system model (Hughes et al., 2023) and a revised modelled cost using the ALOS DEM to extract the dam site axis elevation profile (as opposed to the DamSite model costing, which was based on the SRTM-H). Based on these data five sites were selected for pre-feasibility analysis.

For any of these options to advance to construction, far more comprehensive studies would be required, as outlined in Section 1.2. Studies of that level of detail were beyond the scope of this pre-feasibility level Assessment.

2.1.4 Summary of criteria used to assess large dams as part of pre-feasibility analysis and methods used to select sites

Five of the more favourable potential dam sites (in terms of topography of the dam axis, geological conditions, proximity to suitable soils, general geographic location and water yield) in different geographic regions of the catchment were selected for pre-feasibility analysis. To facilitate comparison of different sites, each site was assessed and reported against a standard set of 19 criteria listed in Table 2-1. This table summarises the methods by which the criteria were investigated and reported. Two of the more favourable sites selected for pre-feasibility analysis were short-listed (in terms of topography of the dam axis, geological conditions, proximity to suitable soils, general geographic location and water yield) for a manual detailed dam cost estimate for a nominal FSL. The tables summarising the characteristics of the two short-listed sites in Chapter 4 present the assessment criteria in the same structure as shown here. While these sites represent some of the more promising large instream and offstream dams in the Roper catchment, other sites may be more favourable depending upon the location and nature of the demand.

Table 2-1 Criteria used to assess potential dam sites

PARAMETER	DESCRIPTION
Previous investigations	Based on web-based searches and searches of NT Government databases, no literature on past dam studies in the Roper catchment were identified.
Description of potential dam configuration	An overview of a dam configuration based on recent data, methods and contemporary thinking.
Regional geology	The regional geology for each dam site was assessed using satellite imagery and the NT 1:250,000 geology series.
Site geology	The site geology for each dam site was assessed using the NT 1:250,000 geology series, and some sites where permission was granted were visited by the Assessment geologist.
Reservoir rim stability and leakage potential	These parameters were assessed by overlaying inundated area at the selected FSL and 1% AEP flood event on satellite imagery and 1:250,000 geology data, and some sites were inspected from helicopter by the Assessment geologist.
Potential structural arrangement	Potential conceptual arrangements were developed by the Assessment's water infrastructure planner, based on contemporary dam design concepts and thinking.
Availability of construction materials	Based on 1:250,000 geology data and proximity to known quarry locations.
Catchment area	Catchment areas were derived from DEM-H.
Flow data	Simulated streamflow metrics were calculated using output from the AWRA-R (river system) models produced by the Assessment (see river modelling companion technical report (Hughes et al., 2023)).
Storage capacity	Storage capacity was derived from the DEM-H, unless stated otherwise. For potential dams the dead storage volume was assumed to occur at 5 m above the river bed (typically 1 to 2% of the reservoir capacity at FSL).

PARAMETER	DESCRIPTION
Reservoir yield assessment at dam wall	A behaviour analysis (BHA) model (McMahon and Adeloye, 2005) was used to assess the relationship between yield, reliability and storage volume under Scenario B (historical daily climate data, potential dam development) for a range of dam wall heights (i.e. yield was assessed at 1 m height increments from 5 m above river bed to a maximum height beyond which a dam would not be feasible) and a perennial crop demand pattern (Figure 2-1) using the baseline river model (Hughes et al., 2023). Inflows to the BHA model were generated by the locally calibrated AWRA-R (river system) model and the AWRA-L (landscape) model (see companion technical report on river model calibration (Hughes et al., 2023)). Table 2-2 lists the AWRA-R nodes from which simulated streamflow data were extracted for input into the behaviour analysis model. The perennial crop demand pattern was based on the Agricultural Production Systems sIMulator (APSIM) (Keating et al., 2003) simulations using the sugarcane module (see companion technical report on agriculture (Stokes et al., 2023)). The performance of each reservoir was reported in terms of the annual time reliability and the volumetric reliability (McMahon and Adeloye, 2005). These performance criteria are sensitive to particular aspects of unsatisfactory operation during periods of low reservoir inflows. The inability of a reservoir or system of reservoirs to provide the target demand during a given period is commonly described as a supply failure.
Potential use of supply	Based on soil and land suitability information compiled by the Assessment (see companion technical report on digital soil mapping and land suitability for the Roper catchment, Thomas et al. (2022)).
Estimated rates of reservoir sedimentation	Sedimentation rates were calculated using estimated sediment yields and the FSL dam capacity for each site. Sediment yields were calculated using an empirical relationship derived from ten sediment yield studies across northern Australia (Tomkins, 2013). Rates of reservoir sedimentation are presented for 30 and 100 years and the number of years taken to 100% infill. Minimum (best-case), expected and maximum (worst-case) estimates are provided.
Storage impacts	Based on review of past studies, satellite imagery, GIS overlays and site visit.
Environmental considerations	Mapped data on the ecological assets and the fish species distribution for the Roper catchment were sourced from the companion technical report on aquatic ecology (Stratford et al., 2022) and complemented with datasets of endangered vertebrate and plant species at a national (Species and Ecological Communities of National Significance) and territory level. It should be noted that due to a range of factors, records of species are sparse across this catchment. Key datasets for the assessments were: • Atlas of Living Australia (Atlas of Living Australia, 2022) • Fish Atlas Database • CDU University- Fish dataset • NT Government Fauna Atlas (2019) • Species of National Environmental Significance Database (2019) • Ecological Communities of National Environmental Significance (public grids) Database 10 km Grids (Australian Government Department of the Environment, 2016) • Wildnet wildlife records (2021) • Department of Environment Parks and Water Security (2019) • OBIS (2022) • Directory of Important Wetlands in Australia (DIWA) Spatial Database (Public) (2018) • Important Areas for Birds (Birdlife International, year) • Ramsar Wetlands of Australia (2015) • Threatened animals and plants (Northern Territory Government, 2021). **Barrier to movement of aquatic species** The likely impacts of a dam wall in terms of creating a barrier to the movement of aquatic species was assessed by examining the distribution of species within the catchments and the relative position of the dam within the catchment. **Ecological implications of inundation**

PARAMETER	DESCRIPTION
	The ecological implications of inundation were assessed in terms of potential habitat loss for the local biodiversity. This was done intersecting the species datasets against the catchment boundary and the inundation region. Of special interest were species listed as 'of concern', 'vulnerable', 'endangered', 'critically endangered' or 'migratory' in national (EPBC), state or territory (NT, WA and Queensland) and/or international level (in particular, migratory birds). **Water quality and stratification considerations** No specific assessment of water quality and stratification was made as part of the Assessment. It has been assumed that selective withdrawal baulks will be provided in the intake works so that best quality water can be drawn from the storage when releases are made.
Indigenous land tenure, native title and cultural heritage considerations	No site-specific evaluation of cultural heritage considerations was possible as pre-existing Indigenous cultural heritage site records were not made available to the Assessment from the NT Government. Land tenure and native title information were derived from regional land councils and the National Native Title Tribunal.
Estimated cost	For the two short-listed potential dam sites, cost estimates were calculated manually by the Assessment's water infrastructure planner. This was done by developing conceptual arrangements for each of the storages. Dam and saddle dam profile axes were calculated using the ALOS DEM. Unit cost rates applied for each item of work were originally derived from earlier estimates for studies the proposed Green Hills and Connors River dams and the existing Wyaralong Dam and then using more recent estimates from Hells Gates and Palmer River dam studies. The uncertainty in cost associated with the quantity of material for short-listed sites was estimated to be between −20% and +50%. However, if non-trivial geological issues were identified as part of a feasibility analysis or during dam construction then the final cost of construction could be increased by considerably more than 30%. For those three pre-feasibility dams that were not short-listed, modelled dam costs were obtained using the cost algorithm in the DamSite model (see Section 2.1.2) using a dam axis elevation profile derived from the ALOS DEM. The uncertainty in cost associated with the quantity of material estimated by the DamSite model is estimated to be between −25% and +75%. However, if non-trivial geological issues were identified as part of a feasibility analysis or during dam construction then the final cost of construction could be increased by considerably more than 50%.
Estimated cost / ML of supply	Estimated capital cost divided by the water yield at 85% reliability as computed by the Assessment under the nominated structural arrangement.
Summary comment	As provided by Assessment personnel.

Table 2-2 AWRA-R nodes from which simulated streamflow data were extracted for use in the behaviour analysis model at the five potential dam sites selected for pre-feasibility analysis

ROPER POTENTIAL DAM SITES	NODE IDENTIFIER
Wilton River at ATMD 33 km	90301460
Waterhouse River at ATMD 70.5 km	90300890
Flying Fox Creek at ATMD 105 km	90301080
Waterhouse River West Branch	90300890
Jalboi River at ATMD 53 km	90302505

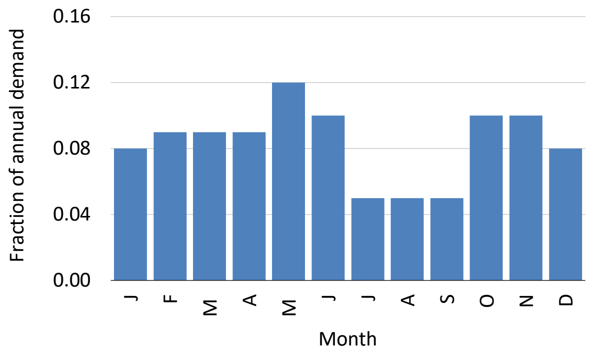

Figure 2-1 Constant monthly demand pattern used in the BHA modelling for the Roper catchment

2.2 Farm-scale storages

Because large farm-scale water storages are typically no more than several gigalitres in capacity and are constructed to serve one farm or paddock/location, they could feasibly occur at multiple locations within a landscape. For a catchment-scale investigation of farm-scale water storages, it was not feasible to visit and assess the many hundreds of possible locations.

Rather, the Assessment used a broad-scale analysis to identify areas with the greatest (and least) potential for farm-scale storages, to help focus on-ground assessments and guide policy and planning decisions related to farm-scale storages.

The high-level catchment-scale investigations analysed:

- earth embankment offstream storage suitability
- locations most suitable for gravity drainage
- topographic and hydrological characteristics of suitable locations for gully dams.

The methods employed in these investigations are briefly discussed in turn below.

2.2.1 Identification of areas suitable for farm-scale offstream storages

The suitability of landscapes and soil for the construction of earth embankment farm dams (both ringtanks and gully or hillside dams) was assessed using 30 m by 30 m gridded data of selected soil attributes generated for the Roper catchment (see companion technical report on digital soil mapping attributes (Thomas et al., 2022)). These gridded datasets were generated using a relatively new approach called digital soil mapping, which makes use of advances in computing and statistics.

Digital soil mapping allows soil properties (variables), such as clay content, sampled at specific locations, to be related to an expanding Australian database of national covariates. Covariates, which are GIS-format datasets, are selected because they directly correlate to landscape and soil properties. Examples of covariates are slope, correlating to soil depth, and rainfall deficit, correlating to leaching intensity and pH. Digital soil mapping (i) enables discovery of relationships at the geographic intersection of the sampled variable (e.g. pH) and multiple 'stacked' covariate datasets, (ii) builds statistical models from these relationships, and then (iii) applies the models to predict (map) the variable values at all other unsampled locations in the Assessment area from the covariates (McBratney et al., 2003). Unlike traditional soil mapping used to map soil types, digital soil mapping produces maps of individual soil properties (e.g. pH or permeability). As a result, the approach is especially suited to land suitability assessment. A particular strength of digital soil mapping methods over the traditional mapping methods is that the former produces spatial statistical measures of the quality of the mapped parameter that can be readily displayed.

The assessment of the suitability of earth embankment structures across the study area was undertaken on a grid cell by grid cell basis and by examining all possible combinations of four gridded soil parameters. The four parameters and the categories, listed from least to most favourable, used for each parameter are:

- clay content – 0 to 10%, 10 to 25%, 25 to 35%, 35 to 50% and greater than 50%
- permeability – rapid, moderate, slow and very slow NCST (2009)
- soil depth – <1 m, 1 to 1.5 m and >1.5 m
- slope – >5%, 2 to 5%, 1 to 2% and <1%.

Those grid cells characterised as being most suitable for the construction of farm-scale earth embankment structures were assigned a suitability score of 1, and those least suitable were assigned a 4 (Table 2-3). A subset of rules to illustrate the concept is provided in Table 2-4.

Table 2-3 Suitability scores for the construction of farm-scale earth embankment structures

SUITABILITY SCORE	DESCRIPTION
1	Likely to be suitable
2	Possibly suitable
3	Unlikely to be suitable
4	Not suitable

Table 2-4 Subset of rules used to assess suitability of land for construction of farm-scale earth embankment structures

CLAY CONTENT	PERMEABILITY	SOIL DEPTH	SLOPE	SUITABILITY SCORE
25 to 35%	Slow	1 to 1.5 m	<1%	2
25 to 35%	Slow	1 to 1.5 m	1 to 2%	2
25 to 35%	Slow	1 to 1.5 m	2 to 5%	3
25 to 35%	Slow	1 to 1.5 m	>5%	4
25 to 35%	Moderate	1 to 1.5 m	<1%	3
25 to 35%	Moderate	1 to 1.5 m	1 to 2%	3
25 to 35%	Moderate	1 to 1.5 m	2 to 5%	3
25 to 35%	Moderate	1 to 1.5 m	>5%	4

Irrespective of the values of the other parameters, a grid cell was assigned a suitability score of 4 if at that location the:

- soil depth was less than 1 m
- slope was greater than 5%
- permeability was rapidly draining, or
- clay content was between 0 and 10%.

In total there were 240 possible permutations of the clay content, permeability, soil depth and slope classes. Eight of these permutations resulted in a suitability score of 1, 19 permutations resulted in a suitability score of 2, 41 permutations resulted in a suitability score of 3, and 172 permutations resulted in a suitability score of 4.

2.2.2 Topographic and hydrological analysis of suitable locations for gully and hillside dams

The topographic and hydrological potential for gully and hillside dams across the study area was assessed using the DamSite model. As outlined in Section 2.1.2 for large instream and offstream dams, the DamSite model requires hydro-climate data (i.e. runoff, rainfall and evaporation), a DEM and an algorithm for costing the structure.

The DamSite model was run using 85% gridded annual exceedance runoff datasets generated by the Assessment for the study area (see companion technical report on river model calibration (Hughes et al., 2023)), and net evaporative losses were calculated by multiplying the reservoir surface area at 0.7 capacity by the median net evaporation between March and August (inclusive) for the Roper catchment.

Seepage losses were estimated to be 2 mm/day over the reservoir surface area at 0.7 capacity.

Every SRTM grid cell location with a catchment area greater than 1 km^2 and less than 40 km^2 was assessed for its potential as a farm-scale dam by constructing earth embankment structures at 1 m height intervals between 5 and 20 m in height, including freeboard. Dam wall heights of less than 5 m were not examined in this analysis because the uncertainty in the DEM-H elevations were deemed to be too large relative to the height of the dam and capacity of the reservoir.

Dam walls were constructed assuming a 3:1 (horizontal to vertical) ratio on the upstream face and a 2.5:1 ratio on the downstream face with a crest width of the square root of the height +1.

The results are reported in terms of GL per 1000 m^3 of earth moved. The dry freeboard was a function of the reservoir surface area plus 0.5 m wet freeboard.

These values are broadly in line with the recommendations in the farm water supplies design manual (QWRC, 1984).

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Part II Large instream and offstream dams

3 Opportunity analysis of potential dam sites

The opportunity analysis of potential dam sites in the Roper catchment involved a three-tier process to select the short-listed sites.

3.1 DamSite modelling

To ensure that no options had been overlooked, the DamSite model (see Section 2.1.2) was used to undertake a preliminary assessment of over 50 million potential dam sites in the Roper catchment. A desktop geological suitability assessment of the results of the DamSite model was undertaken by overlaying the dam locations on 1:250,000 geology data (see Section 2.1.3). The DamSite model results were then ranked using different criteria, and the locations compared likely arable land.

3.1.1 Large dams for irrigation and water supply in the Roper catchment

Large offstream storages in the Roper catchment

Figure 3-1 displays the most promising sites across the Roper catchment in terms of storage volume (GL) per million dollars of construction cost. Only locations with a ratio of storage to cost less than $5000/ML are shown. This provides a simple way of displaying locations in the Roper catchment with the most favourable topography for a large reservoir relative to the size (i.e. cost) of the dam wall necessary to create the reservoir. This figure is particularly useful for identifying more-promising sites for 'offstream' storage (i.e. where some or all of the water is pumped into the reservoir from an adjacent drainage line). The threshold value of $5000/ML is nominal and is used to minimise the amount of data displayed. Note that this analysis does not consider evaporation or hydrology.

Figure 3-1 shows that the parts of the Roper catchment with the most favourable topography for storing water are along the Wilton and lower Roper rivers and major tributaries either side of the Roper River and Waterhouse River in the headwaters of the Roper catchment.

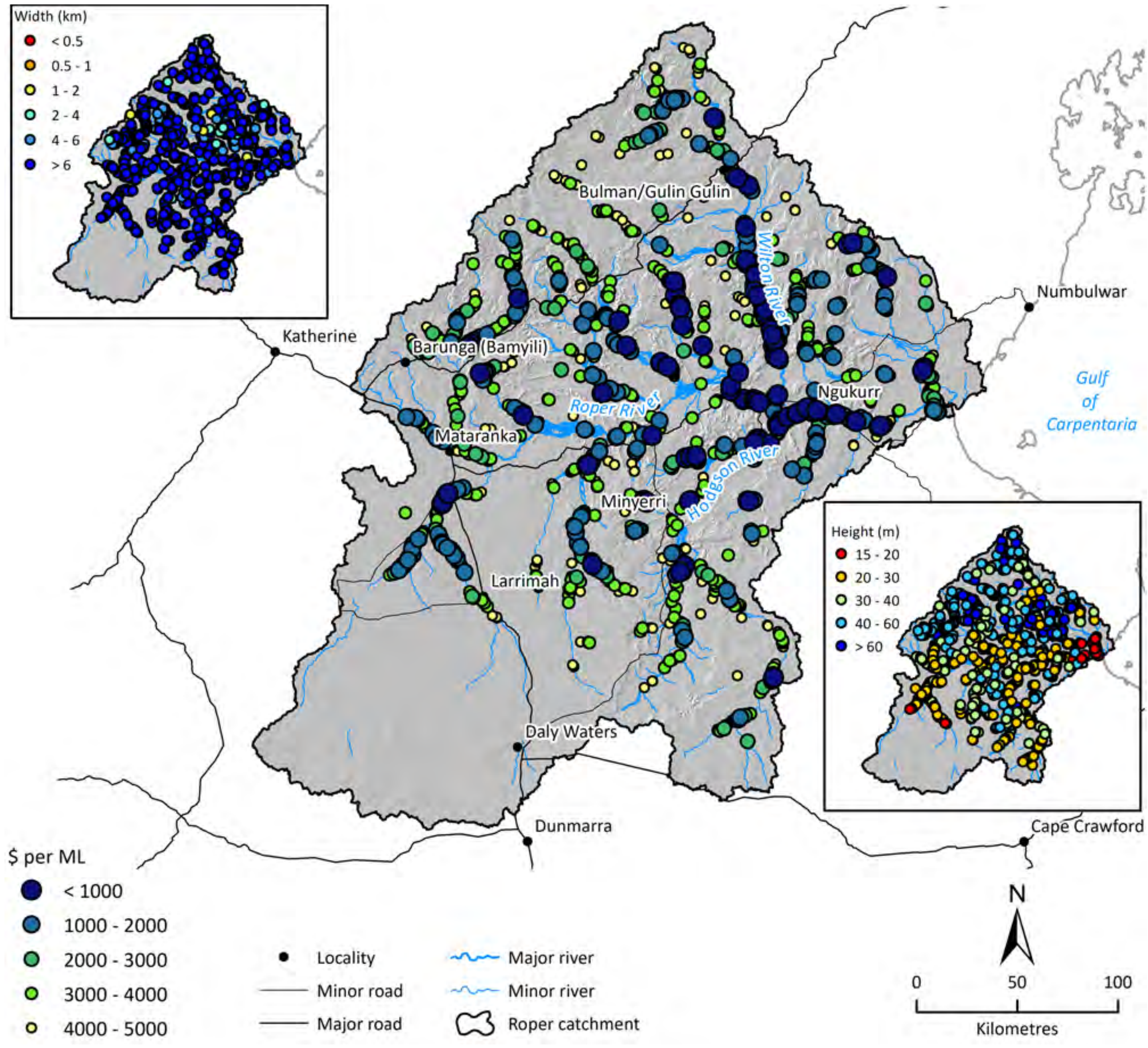

Figure 3-1 Potential storage sites in the Roper catchment based on minimum cost per ML storage capacity

This figure can be used to identify locations where topography is suitable for large offstream storages. At each location the minimum cost per ML storage capacity is displayed. The smaller the minimum cost per ML storage capacity ($/ML) the more suitable the site for a large offstream storage. Analysis does not take into consideration geological considerations, hydrology or proximity to water. Only sites with a minimum cost to storage volume ratio of less than $5000/ML are shown. $1000/ML is equivalent to 1 GL per million dollars. Costs are based on unit rates and quantity of material and site establishment for a roller compacted concrete (RCC) dam. Data are underlain by a shaded relief map. Inset displays height of full supply level (FSL) at the minimum cost per ML storage capacity.

Large instream storages in the Roper catchment

In addition to suitable topography (and geology), instream dams require sufficient inflows to meet a potential demand. Potential dams that command smaller catchments with lower runoff have smaller yields. Results relating to this criterion can be summarised and conveniently presented in terms of cost of constructing the dam per ML of yield. This is very similar to the cost of constructing a dam per ML of storage volume described above. The DamSite model was initially run using a preliminary storage-yield-reliability calculation method, the GDG method (see Section 2.1.2), which is very rapid to apply. Only the top 10,000 sites for the Roper catchment ranked in terms of the cost per ML GDG yield was the yield recalculated using the more numerically intensive behaviour analysis. Figure 3-2 only shows those sites with a cost of $5000/ML. The DamSite modelling indicates that the most cost-effective potential dam sites are on the Wilton River and lower Roper and Hodgson rivers.

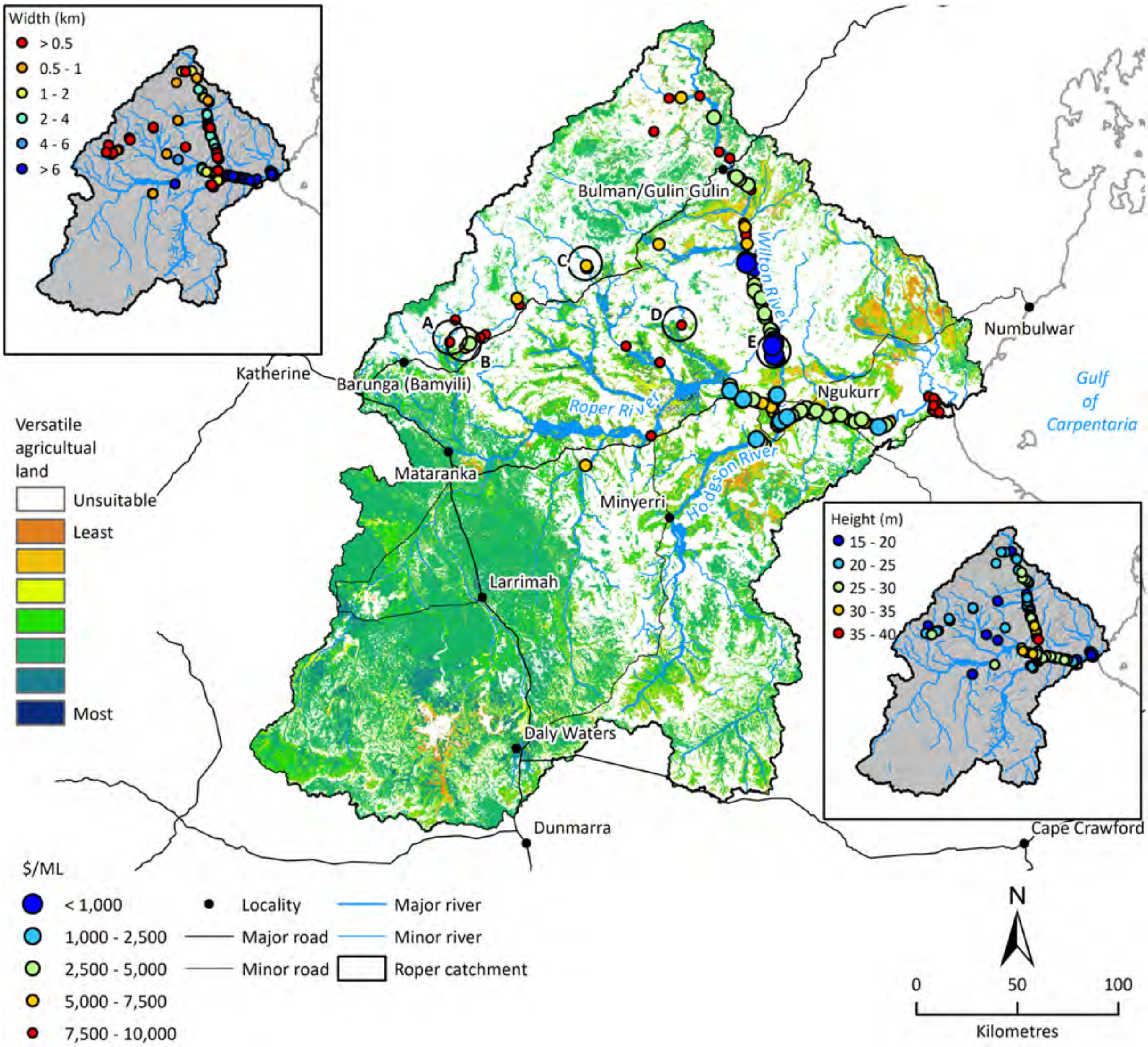

Figure 3-2 Potential storage sites in the Roper catchment based on minimum cost per ML yield at the dam wall

This figure indicates those sites more suitable for major dams in terms of cost per ML yield at the dam wall in 85% of years overlain on versatile land surface (see companion technical report on land suitability, Thomas et al., 2022). At each location the minimum cost per ML storage capacity is displayed. The smaller the cost per ML yield ($/ML) the more favourable the site for a large instream dam. Only sites with a minimum cost to yield ratio less than $10,000/ML are shown. Costs are based on unit rates and quantity of material required for a roller compacted concrete (RCC) dam with a flood design of 1 in 10,000. Right inset displays height of full supply level (FSL) at the minimum cost per ML yield and left inset displays width of FSL at the minimum cost per ML yield. Letters indicate location of potential dams A – Waterhouse River west branch; B – Waterhouse River; C – upper Flying Fox Creek; D – Jalboi River; E – Wilton River.

3.1.2 Large dams for hydro-electric power generation potential

The potential for major instream dams to generate hydro-electric power is presented in Figure 3-3, following a reconnaissance assessment of more than 50 million sites in the Roper catchment. This figure provides indicative estimates of hydro-electric power generation potential but does not consider the existence of supporting infrastructure.

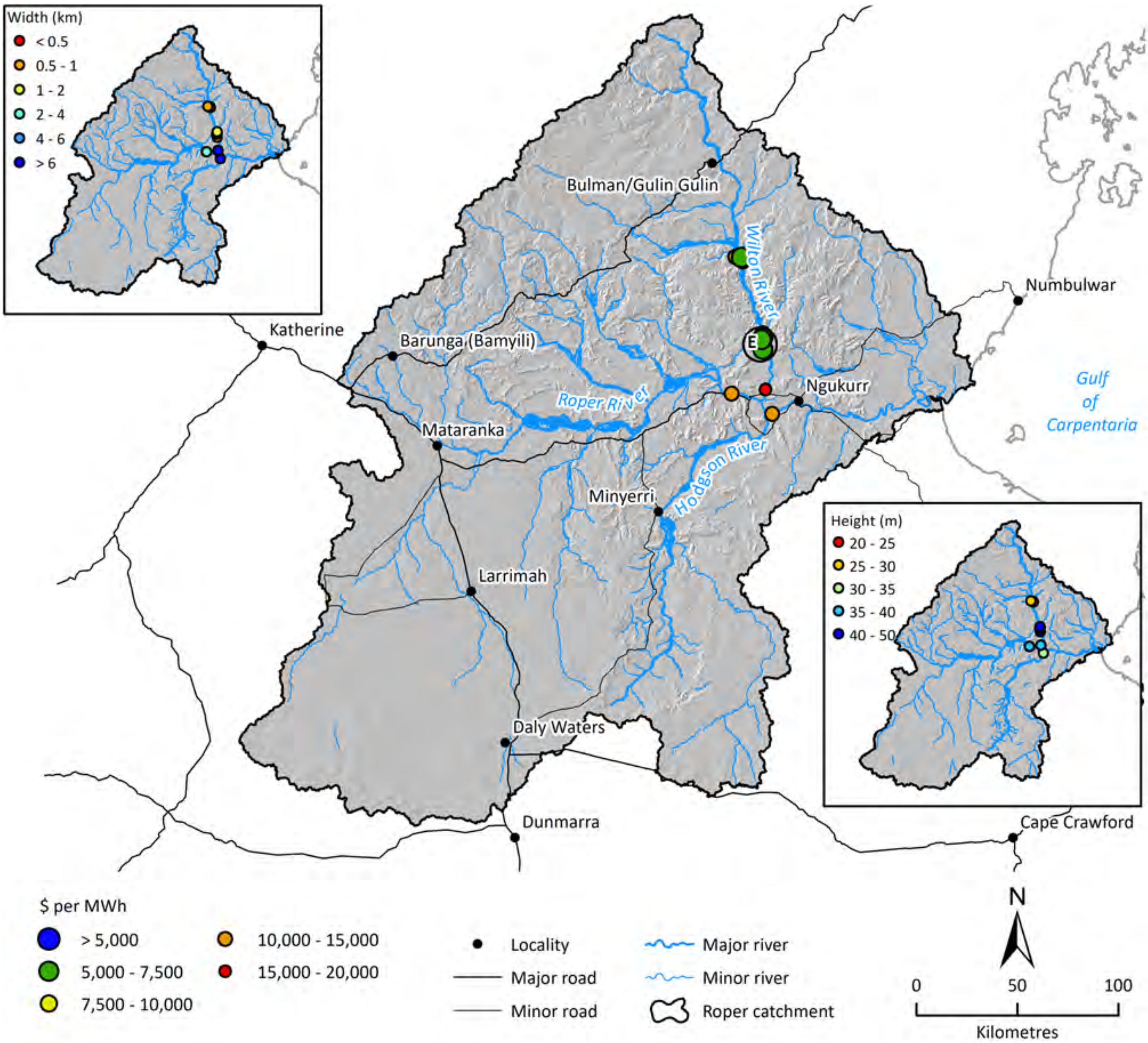

Figure 3-3 Roper catchment hydro-electric power generation opportunity map

Costs are based on unit rates and quantity of material required for a RCC dam with a flood design of 1 year in 10,000. Cost includes site establishment, fish lifts/traps (high dams) or ladders (low dams) and land resumption for the area of land impounded by a flood event of AEP 1%. Data are underlain by a shaded relief map.

3.2 Long-list of potential dam sites

Potential dam sites with the higher DamSite modelled water yield per unit cost in different geographic parts of the Roper catchment were selected for a rapid desktop geological evaluation. The long-listed sites are shown in Figure 3-4 overlaid on a geological map.

Geology of the Roper catchment with relevance to surface water storage

The landscape of the Roper catchment is relatively featureless with a topography that is generally flat to undulating. The landscape drains into the Gulf of Carpentaria and is characterised by broad alluvial plains associated with the Roper River and its tributaries, and low rubbly hills or strike ridges of various resistant strata. Local relief ranges between 20 and 120 m. Vegetation cover is dominated by open woodland with denser stands of trees along major watercourses and soil plains supporting grasses and low shrubs.

The oldest rocks in the area are of Proterozoic age (2500 to 540 million years old) and consist of repeated thick sequences of sediments and volcanics that include numerous prominent beds of sandstone. They were deposited in a series of basins extending across the area and then folded, faulted and intruded by igneous rocks to form mountain chains. Towards the end of the Proterozoic the mountain chains had been eroded down to a level not far above that of the current topography.

During the Cambrian period (540 to 485 million years ago) there was widespread extrusion of basalt lava, which was followed by deposition of limestones and dolomites. The Cambrian strata only occur south-west of the Roper River where the limestones and dolomites are affected by karst (solution effects producing underground cave systems) and provide an important regional groundwater source.

Erosion recommenced after the Cambrian and continued to the mid-Cretaceous period (about 100 million years ago) when subsidence and high global sea levels resulted in deposition of a thin succession of Cretaceous shallow marine sandstone, conglomerate and mudstone across the Roper catchment.

The present landscape has been produced by warping and dissection of a series of erosion surfaces formed during several cycles of erosion that started in the Late Cretaceous about 70 million years ago and ended in the mid-Cenozoic era about 25 million years ago. During this time, stable crustal conditions and subaerial exposure led to patchy erosion of the Cretaceous rocks and prolonged subaerial weathering of the remaining Cretaceous and Proterozoic rocks and resulted in the formation of deep weathering profiles and associated iron-cemented capping.

Between the mid-Cenozoic and the present day, there has been gentle uplift and warping of the various surfaces and their weathered capping. Continued erosion led to the emergence of the present-day landscape, which involved the removal of Cretaceous strata from most of the region and the etching out of structures in the underlying Proterozoic rocks (mainly Roper Group). Extensive floodplains and coastal deposits were built up on the margins of modern drainage systems and the coastline, respectively, in the region.

Potentially feasible dam sites occur where resistant ridges of Proterozoic sandstone beds that have been incised by the river systems outcrop on both sides of river valleys. The sandstones are generally weathered to varying degrees, and the depth of weathering and the amount of sandstone outcrop on the valley slopes is a fundamental control on the suitability of the potential dam sites. Where the sandstones are relatively unweathered and outcrop on the abutments of the dam site less, stripping will be required to achieve a satisfactory founding level for the dam. The other fundamental control on the suitability of the dam site is the extent and depth of Quaternary alluvial sands and gravels in the floor of the valley, as these materials will have to be removed to achieve a satisfactory founding level for the dam.

In general, where stripping removes the more weathered rock, it is anticipated that the Proterozoic sandstones will form a reasonably watertight dam foundation requiring conventional grout curtains and foundation preparation.

Where potentially soluble dolomites occur within the Proterozoic sequences (soluble over a geological timescale) then it is possible that potentially leaky dam abutments and reservoir rims may be present, which will require specialised and costly foundation treatment such as extensive grouting. Where this condition is possible based on review of the 250,000 geological map sheets, it has been noted.

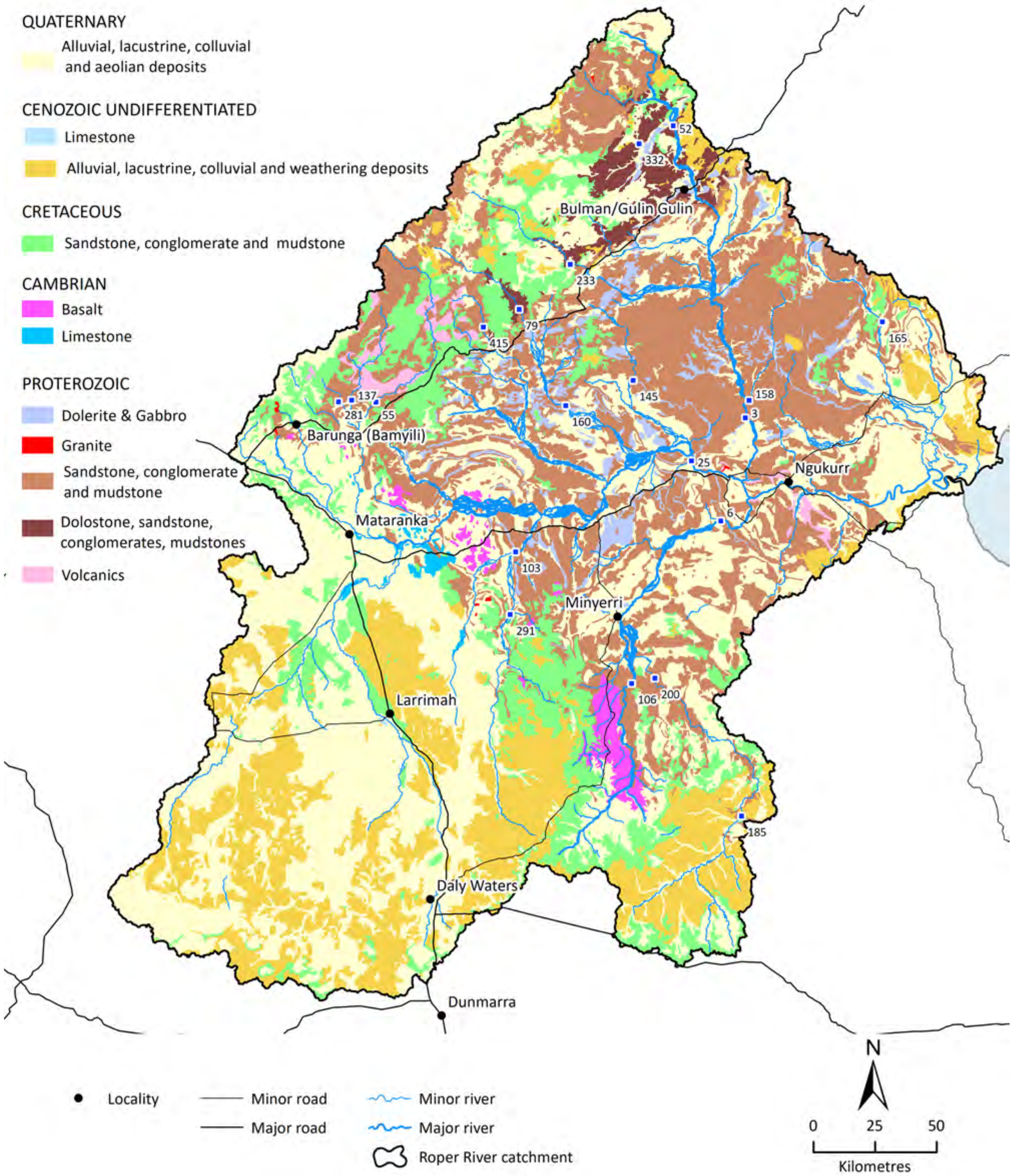

Figure 3-4 Long-listed potential dam sites and the main geological units of the Roper catchment

Table 3-1 Rapid desktop evaluation of long-listed potential dam sites in Roper catchment

Note: Grade 1 is best grade 5 is worst – holistic assessment based on whether bedrock is exposed at site, likely depth of weathering/stripping on abutments, likely depth of cut-off and presence of deep alluvium and overall height to width assessment.

DAM ID	GEOLOGY	LITHOLOGY	ALLUVIAL TRACT	GEOMORPHOLOGY	COMMENT	GRADE
3	Wide Qa/Prr	Sandstone and mudstone	Wide Qa	Incised bedrock surface, rock exposed, deep channel	Good dam site	1
6	Prh, Prom	Thickly bedded sandstone		Incised bedrock surface, rock exposed, deep channel	Good dam site	1
25	Ridge Prh, regional fault	Thickly bedded sandstone, regional fault		Nick point, Incised bedrock surface, no rock exposed	Good dam site	1
30	Wide Qa/Poo some Pri, Cz	Dolomite, siltstone, sandstone some sandstone, older alluvium, some calcrete	Wide Qa	Incised palaeosurface, deep river channel, downstream fan		4
52	Wide Qa/Poo	Dolomite, siltstone, sandstone	Wide Qa	Incised palaeosurface, braided alluvium		4
55	Phs	Coarse sandstone		Incised bedrock ridge, rock exposed,	Good dam site	1
79	Pooj	Sandstone, breccia, chert, dolostone		Older palaeosurface removed, incised channel		3
103	Wide Qa, Prh	Thickly bedded sandstone	Wide Qa	Incised palaeosurface, braided alluvium		4
106	Wide Qa Elb	Cross-bedded sandstone with minor shale	Wide Qa	Incised palaeosurface, braided alluvium, calcrete		4
137	Phw Pon	Sandstones minor volcanics, sandstones		Older palaeosurface removed, incised channel		3
145	Prom over Prh	Over thickly bedded sandstone		Incised palaeosurface, alluvial infill		3
158	Prr	Sandstone, siltstone, greywacke		Deeply incised palaeosurface, mainly bedrock ?nick point?,		3
160	Prv over Pdd	Siltstone and mudstone over dolerite		Incised palaeosurface, alluvial infill?		3
165	Wide Qa, Pri	Sandstone and siltstone	Wide Qa	Older palaeosurface removed, incised channel, some bedrock shapes		4
185	Prx	Cross-bedded sandstone		Older palaeosurface, incised, calcrete?, some bedrock structure		3
200	Wide Qa, Prm	Sandstone and siltstone	Wide Qa	Incised palaeosurface, braided alluvium, calcrete		4
233	Poo	Dolomite, siltstone, sandstone		Older palaeosurface removed, incised channel		3
281	Pom	Conglomerates and sandstone		Incised palaeosurface, some rock exposed	Fair dam site	2

DAM ID	GEOLOGY	LITHOLOGY	ALLUVIAL TRACT	GEOMORPHOLOGY	COMMENT	GRADE
291	Wide Qa, Prl, Kl	Sandstone, conglomerate; sandstone claystone, conglomerate	Wide Qa	Palaeosurface, broad meandering alluvial tract	Poor dam site	5
325	Prc	Flaggy sandstone and sitststone		Incised bedrock surface, rock exposed?	Fair dam site	2
332	Wide Qa/Poo	Dolomite, siltstone, sandstone	Wide Qa	Incised palaeosurface, very broad alluvial tract	Poor dam site	5
415	Phg	Cross-bedded sandstone, minor volcanics		Incised palaeosurface, calcrete?		3

4 Sites short-listed

Five potential dam sites listed in Table 3-1 were selected for pre-feasibility analysis and two short-listed for a more detailed costing. Details of the two short-listed sites are documented in sections 4.1 and 4.2. The three remaining sites selected for pre-feasibility analysis are documented in Appendix B.

4.1 Waterhouse River dam site on the Waterhouse River; ATMD 70.5 km

See Table 3-1 and Figure 3-4

PARAMETER	DESCRIPTION
Previous investigations	No previous investigations of this site have been located. The site was identified from CSIRO DamSite modelling.
References	No references to investigation of this site have been located.
Description of potential dam	This description is for a potential dam with FSL 200 mEGM96 (i.e. 21 m above (ALOS) bed level) and storage capacity of 219 GL. A storage at this site could provide supply water for irrigation to moderately suitable soils downstream of the storage. Under this hypothetical conceptual arrangement releases would be made from the storage to the stream for diversion by irrigators. The location of the potential site is shown in Figure 4-1 and Figure 4-2. Figure 4-3 shows the known water-dependent ecological assets in the vicinity of the potential dam site.
Regional geology	The Roper catchment landscape is flat to undulating and consists of a series of erosion surfaces developed over the last 70 million years which are characterised by deep weathering profiles and associated iron-cemented capping. The continued erosion has led to the emergence of the present-day landscape and involved the removal of Cretaceous strata from most of the region and the etching out of structures in the underlying Proterozoic rocks. The resulting landscape is characterised by broad alluvial plains associated with the Roper River and its tributaries, and low rubbly hills or strike ridges formed by folded and faulted resistant thick Proterozoic sandstone formations.
Site geology	**Based on geological mapping (high-level fly-over only)** The dam site is located on Proterozoic rocks of the Katherine River Group (Phs), which consist of medium to coarse and pebbly, trough cross-bedded quartz sandstone and dip to the north-west at 5°. The deeply weathered erosion surface characteristic of the region appeared to have been locally removed by erosion at the dam site. On the dam abutments, blocky weathered sandstone bedrock is exposed and open joints were observed, suggesting erosion of weathered material from between the blocks; assume a mean depth of stripping of 4 m. The river channel has rock bars and a mobile unvegetated tract of alluvium (sand and gravel). The depth of alluvium is anticipated to be 2 to 3 m locally. The geology of the site is shown in Figure 4-4.
Reservoir rim stability and leakage potential	There is no evidence of instability or leakage potential around the reservoir rim.
Potential structural arrangement	The site appears to be suitable for a roller compacted concrete type dam with a central uncontrolled spillway with crest length of 75 m. Outlet works and a fish lift facility would be located on the left bank of the dam.

<table>
<tr><th>PARAMETER</th><th>DESCRIPTION</th></tr>
<tr><td></td><td>Access to the left bank of the site could be via 15 km of new road branching from the Central Arnhem Highway a short distance east of the Beswick settlement. The total distance from Katherine via the Stuart and Central Arnhem highways would be some 127 km.</td></tr>
<tr><td>Availability of construction materials</td><td>A quarry in the Proterozoic sandstone with suitable aggregate for a RCC dam might be found within 5 km of the dam site. For estimating purposes a ratio of useful rock excavated to total volume excavated of 0.5 could be assumed. Hard rock quarries for higher quality aggregate to construct an outer layer of RCC for the dam could probably be sourced from Katherine.</td></tr>
<tr><td>Catchment area</td><td>1477 km^2</td></tr>
<tr><td>Modelled annual inflow data</td><td>
<table>
<tr><th>Parameter</th><th>Scenario A
GL/yr</th><th>Scenario Cdry
GL/yr</th><th>Scenario Cmid
GL/yr</th><th>Scenario Cwet
GL/yr</th></tr>
<tr><td>Max</td><td>764</td><td>579</td><td>681</td><td>986</td></tr>
<tr><td>Mean</td><td>192</td><td>148</td><td>170</td><td>264</td></tr>
<tr><td>Median</td><td>158</td><td>118</td><td>132</td><td>219</td></tr>
<tr><td>Min</td><td>3</td><td>3</td><td>3</td><td>3</td></tr>
</table>
</td></tr>
<tr><td>Reservoir characteristics</td><td>Reservoir characteristics are shown in Figure 4-5. Reservoirs with FSLs of different heights are tabulated below.
<table>
<tr><th>FSL (mEGM96)</th><th>Surface area (ha)</th><th>Capacity (GL)</th></tr>
<tr><td>198</td><td>2838</td><td>155</td></tr>
<tr><td>200</td><td>3540</td><td>219</td></tr>
<tr><td>202</td><td>4368</td><td>298</td></tr>
</table>
</td></tr>
<tr><td>Reservoir yield assessment at dam wall</td><td>
<table>
<tr><td>FSL 198 mEGM96</td><td>Estimated yield at 85% annual time reliability</td><td>80 GL</td></tr>
<tr><td>FSL 200 mEGM96</td><td>Estimated yield at 85% annual time reliability</td><td>89 GL</td></tr>
<tr><td>FSL 202 mEGM96</td><td>Estimated yield at 85% annual time reliability</td><td>92 GL</td></tr>
</table>
Reservoir yields under projected future climates shown in Figure 4-7.</td></tr>
<tr><td>Estimated rates of reservoir sedimentation at FSL 200 (mEGM96)</td><td>
<table>
<tr><th></th><th>Best case</th><th>Expected</th><th>Worst case</th></tr>
<tr><td>30 years (%)</td><td>0.8</td><td>1.1</td><td>1.3</td></tr>
<tr><td>100 years (%)</td><td>2.5</td><td>3.8</td><td>4.2</td></tr>
<tr><td>Years to fill</td><td>3946</td><td>2631</td><td>2368</td></tr>
</table>
</td></tr>
<tr><td>Potential use of supply</td><td>The area below the junction of the upper Waterhouse River and Waterhouse River West Branch is dominated by dissected tablelands of the Sturt Plateau in the upper catchment, alluvial plains adjacent to the river, and sandplains in the lower sections.

The tablelands and associated scarps have well-drained, predominantly moderately deep to shallow sandy-surfaced red Kandosols (SGG 4.1) with abundant ironstone gravels throughout the soil profile, and abundant rock on and adjacent to the scarps (SGG 7). The deeper soils with less gravels are suitable for a diverse range of spray- and trickle-irrigated crops, predominantly horticultural crops. However, these areas are heavily fragmented by shallow or rocky areas resulting in small usable areas, mainly for trickle-irrigated horticulture.</td></tr>
</table>

PARAMETER	DESCRIPTION
	The alluvial plains in the upper catchment are dominated by very deep sandy-surfaced brown Dermosols (SGG 2) with moderately permeable, moderately well-drained to imperfectly drained, mottled structured clay subsoils. Sandy-surfaced Kandosols with brown and yellow massive loamy subsoils (SGG 4.2) and red subsoils (SGG 4.1) are intermixed. Small areas of gilgaied grey cracking clays (SGG 9) occur on the alluvial back-plains in the Beswick area. The brown and grey soils are subject to seasonal wetness (wet season) and may be subject to flooding. Soils are suited to a diverse range of dry-season spray-irrigated grain, pulse and forage crops; horticultural small crops; wetness-tolerant horticultural tree crops, sugarcane and cotton. Wet-season crops are restricted to crops with a moderate tolerance to wetness such as spray-irrigated forage crops, sunflower, sesame and rice. Fragmentation of the area by creeks and soil distribution may limit the usable areas for various uses. The red, brown and yellow massive loamy soils with sandy surfaces (Kandosols SGG 4.1) occur on the gently undulating elevated sandplains and level plains on recent alluvium adjacent to the lower reaches of the Waterhouse River. Moderately deep to very deep (0.5 to >1 m), well-drained to imperfectly drained, red (SGG 4.1) and mottled brown or yellow (SGG 4.2), sandy-surfaced massive soils occur as a mosaic over the landscape, probably reflecting the depth to the underlying rock with red soils on the deeper areas. These moderately permeable soils have moderate to high (100 to 140 mm to 1 m) soil water storage and are highly suited to a broad range of spray- or trickle-irrigated crops. However, fragmentation of the area by creeks and soil distribution may limit the usable areas for various uses.
Storage impacts	As well as the dam storage area at FSL, an additional flood surcharge area above FSL would need to be acquired. This area would affect the Beswick Aboriginal Land Trust area.
Environmental considerations	**Barrier to movement of aquatic species** Records of fish at this site were limited, resulting in no records of fish at this site. Fish whose movement may be impeded by a dam include the mouth almighty (*Glossamia aprion*), giant gudgeon (*Oxyeleotris selheimi*), spangled grunter (*Leiopotherapon unicolor*), barramundi (*Lates calcarifer*), Hyrtl's catfish (*Neosilurus hyrtlii*), as well as the northern snapping turtle (*Elseya dentata*) as they all occur in the neighbouring streams. **Ecological implications of inundation** The vegetation at this potential dam site is ‘Arnhem Plateau Sandstone Shrubland Complex’ listed as Endangered Ecological Community (EPBC Act). The potential inundated area at FSL for this site (200 mEMG96) may impact this ecological community. Freshwater mangrove (*Barringtonia acutangular*) has been recorded downstream of the potential site. The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Stratford et al., 2023).
Indigenous land tenure, native title and cultural heritage considerations	There is a high likelihood of unrecorded sites in the inundation area.
Estimated cost	A manual cost estimate undertaken as part of the Assessment for a RCC dam on the Waterhouse River Creek site at FSL 200 mEGM96 found the dam would cost approximately $253 million. Details of this cost estimate are provided in Appendix A. To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO’s generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below. FSL 198 mEGM96 $230 million FSL 200 mEGM96 $259 million FSL 202 mEGM96 $303 million

PARAMETER	DESCRIPTION
Estimated cost / ML of supply	Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows: FSL 198 mEGM96 $2875/ML FSL 200 mEGM96 $2910/ML FSL 202 mEGM96 $3293/ML Based on the manual cost estimate, the cost/ML of supply at FSL of 200 mEGM96 is $2842/ML.
Summary comment	The Waterhouse River potential dam site has one of the highest yield-to-cost ratios in the upper parts of the Roper catchment. It is also upstream of large areas of sandy loam soils moderately suitable for irrigated agriculture. The site is situated on Aboriginal land scheduled under the Commonwealth *Aboriginal Land Rights (Northern Territory) Act 1976* and is near the community of Beswick and is classified under 'inalienable freehold title', which means that it cannot be bought, acquired or mortgaged. Although data from the NT cultural heritage sites register were not made available to the Assessment, it is likely that the site and parts of the potential inundation area would contain cultural heritage sites of significance.

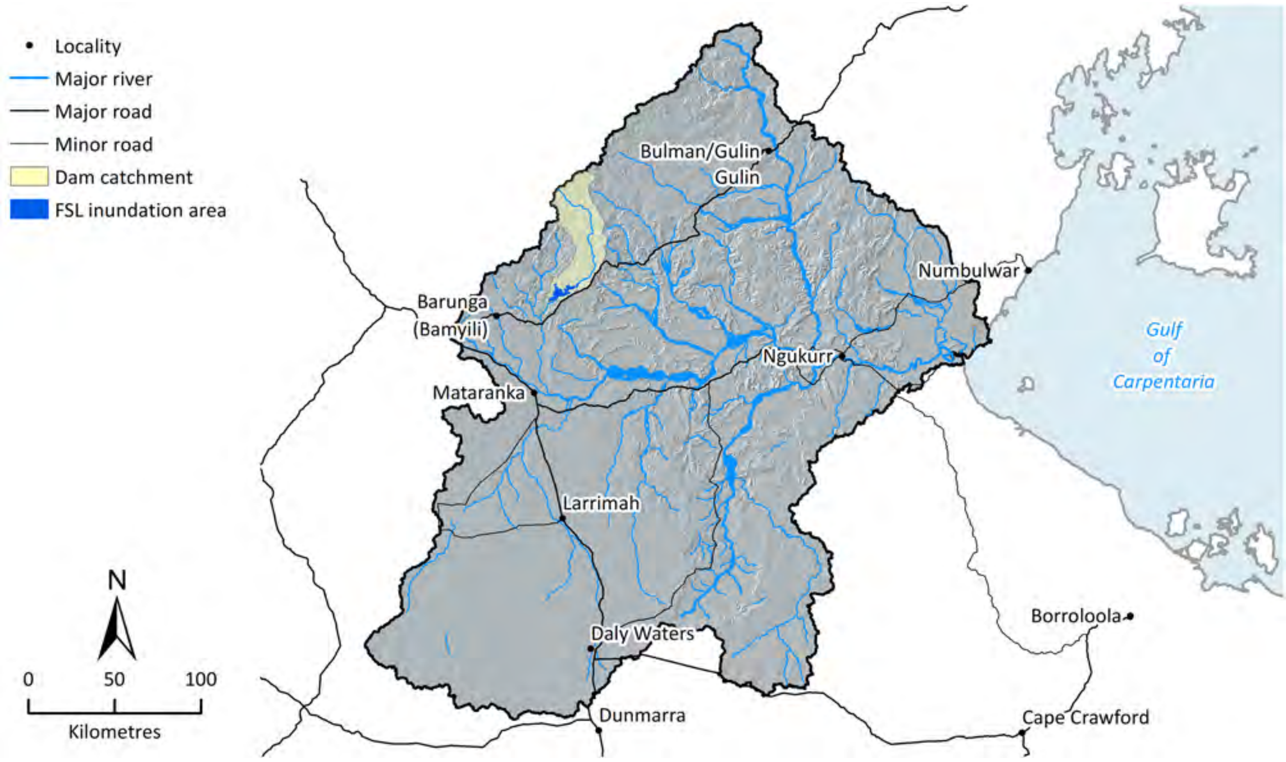

Figure 4-1 Location map of potential Waterhouse River dam site, reservoir extent and catchment area

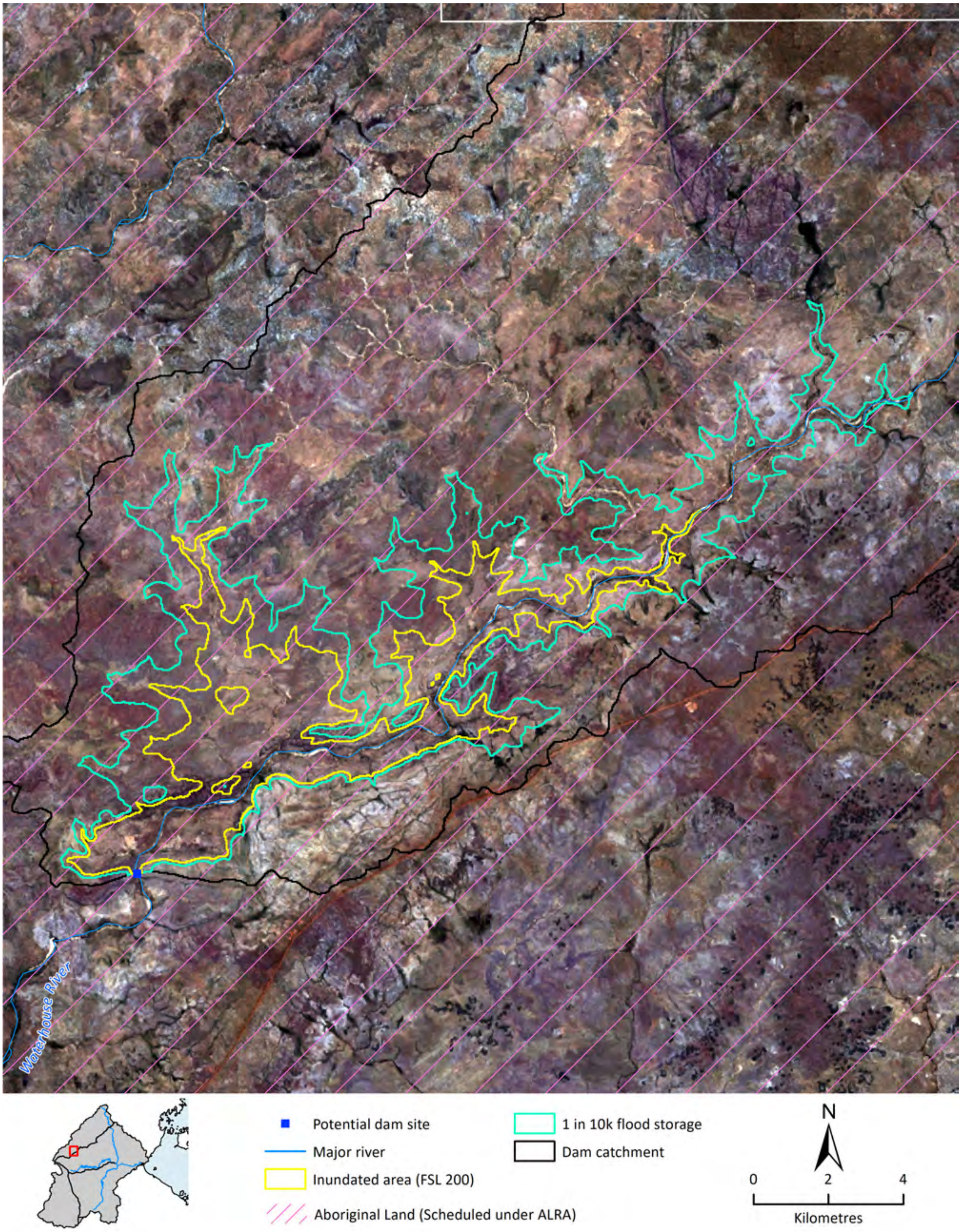

Figure 4-2 Potential Waterhouse River dam reservoir and property boundaries

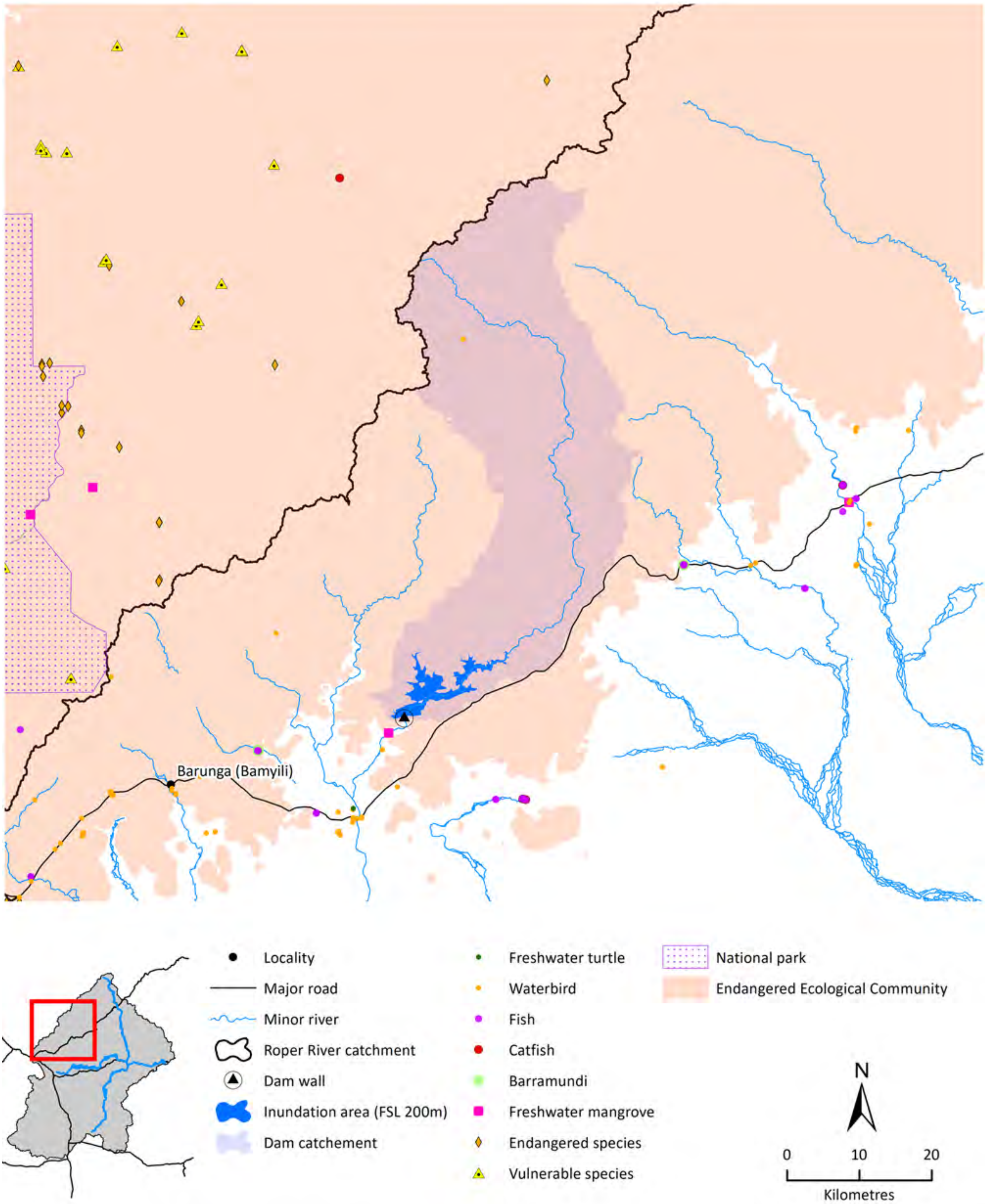

Figure 4-3 Known water-dependent ecological assets in the vicinity of the potential Waterhouse River dam site and reservoir

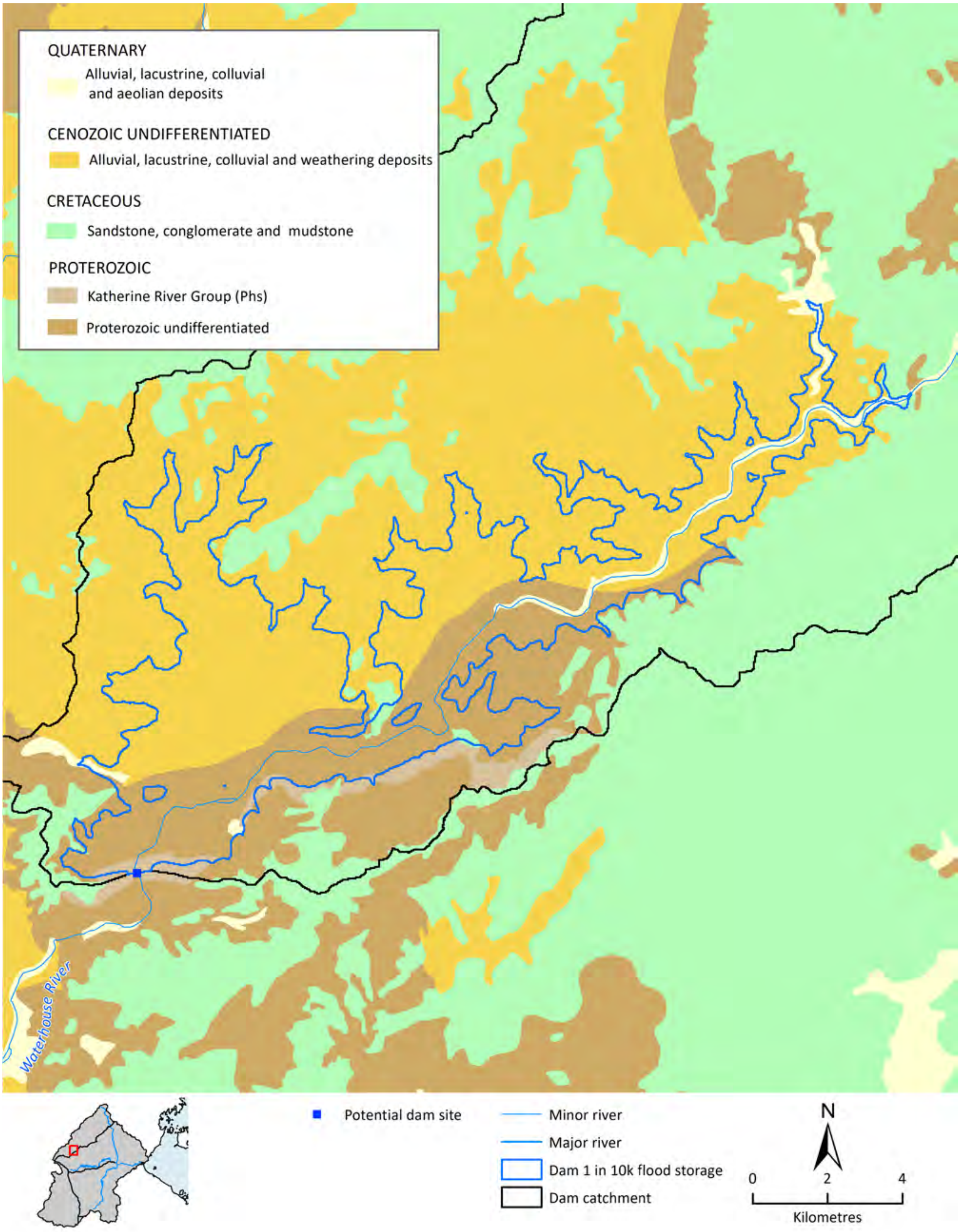

Figure 4-4 Geology underlying the potential Waterhouse River dam site and reservoir

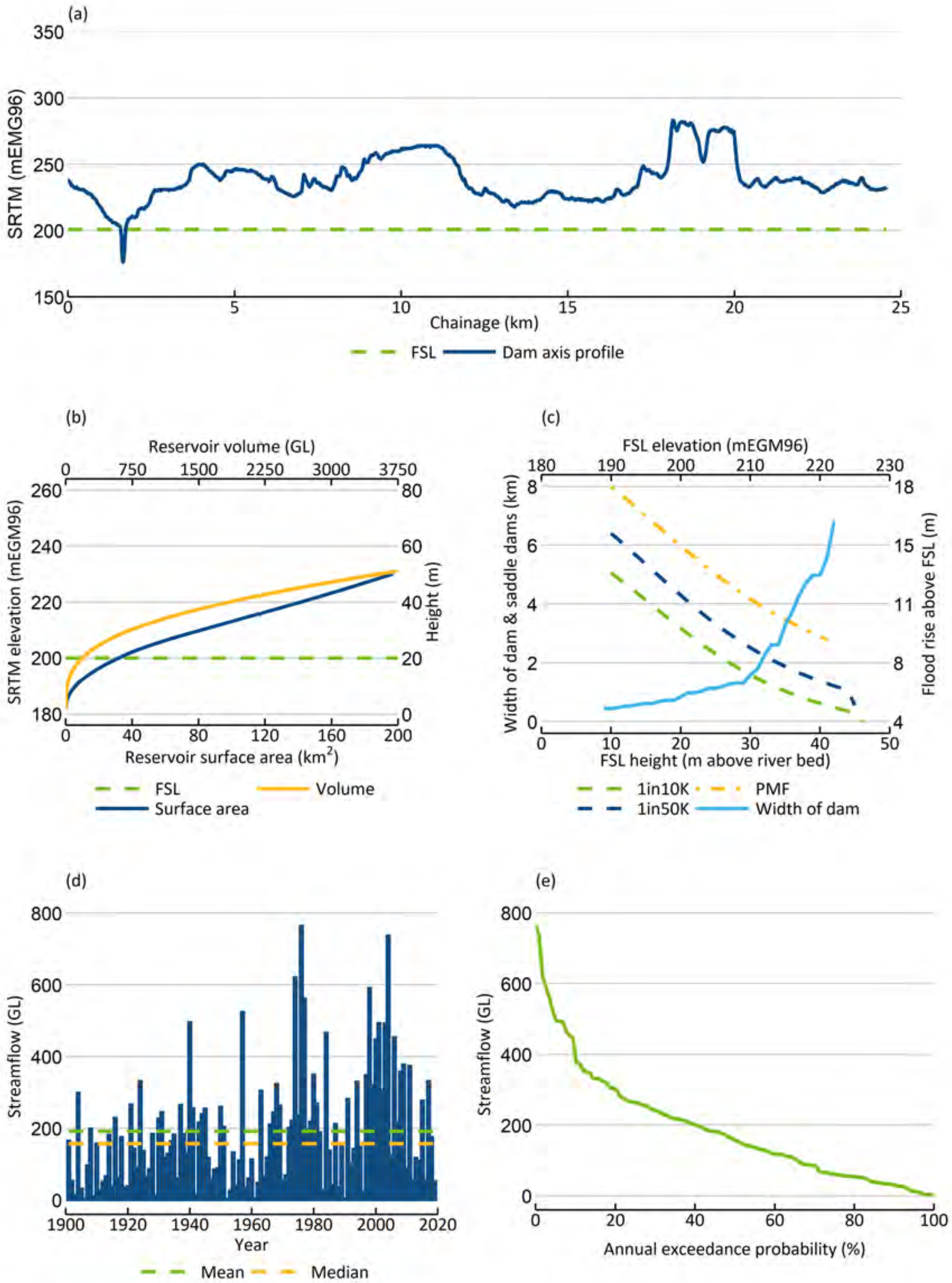

Figure 4-5 Waterhouse River potential dam site topographic dimensions and inflow hydrology

(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and probable maximum flood (PMF) events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance.

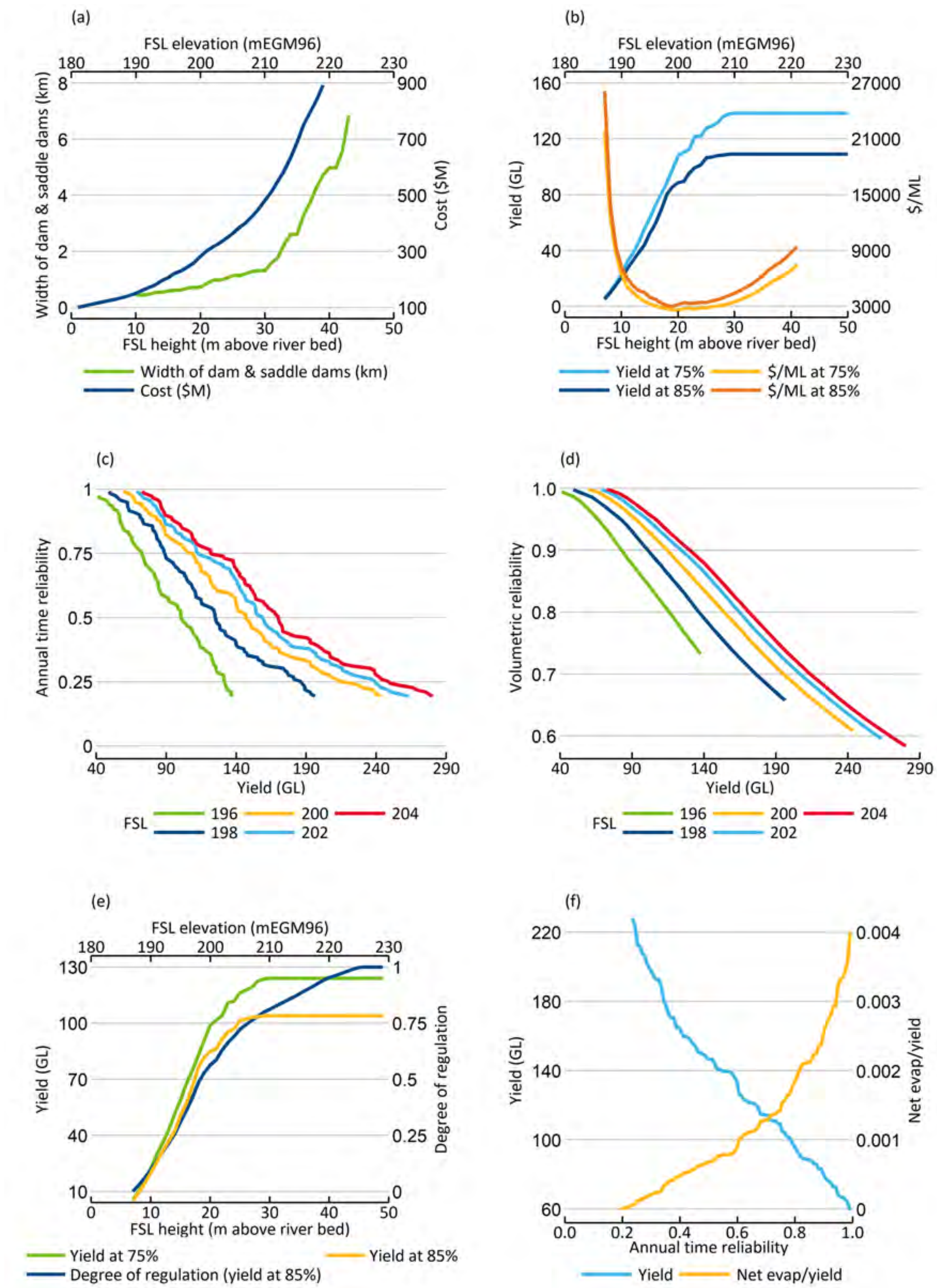

Figure 4-6 Waterhouse River potential dam site cost, water yield at the dam wall and evaporation

(a) Dam length and dam cost versus full supply level (FSL); (b) dam yield at 75% and 85% annual time reliability and yield per million dollars at 75% and 85% annual time reliability; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 75% and 85% annual time reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f) yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.

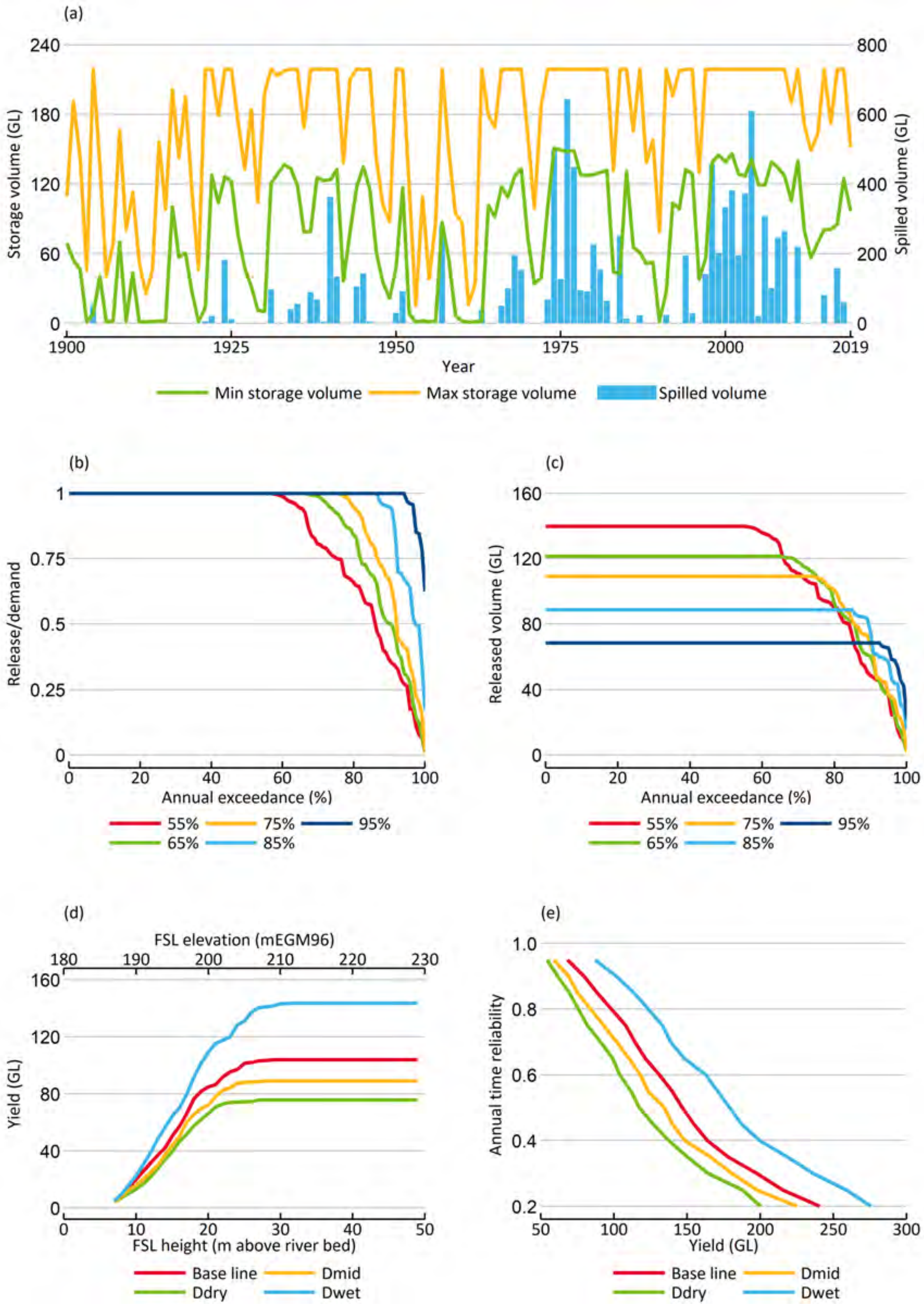

Figure 4-7 Waterhouse River potential dam site and storage levels and water yield

(a) Maximum and minimum annual storage trace at the selected FSL (200 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (d) annual yield at 85% annual time reliability plotted against FSL under Scenario A (baseline) and Scenario D; (e) annual time reliability vs yield for FSL 200 mEMG96 under Scenario A (baseline) and Scenario D.

4.2 Flying Fox Creek dam site on Flying Fox Creek; ATMD 105 km

See Table 3-1 and Figure 3-4

PARAMETER	DESCRIPTION
Previous investigations	No previous investigations of this site have been located. The site was identified from CSIRO DamSite modelling.
References	No references to investigations of this site have been located.
Description of potential dam	This is a potential dam with FSL 173 mEGM96 (22 m above (ALOS) bed level) and capacity of 133 GL. A storage at this site could release 99 GL of water in 85% of years for irrigation of moderately suitable soils downstream of the storage. Under this hypothetical conceptual arrangement, releases would be made from the storage downstream to a regulating weir for diversion by irrigators. Figure 4-8 shows the potential dam site looking upstream. The location of the potential site is shown in Figure 4-9 and Figure 4-10. Figure 4-11 shows the known water-dependent ecological assets in the vicinity of the potential dam site.
Regional geology	The Roper catchment landscape is flat to undulating and consists of a series of erosion surfaces developed over the last 70 million years, which are characterised by deep weathering profiles and associated iron-cemented capping. The continued erosion has led to the emergence of the present-day landscape and involved the removal of Cretaceous strata from most of the region and the etching out of structures in the underlying Proterozoic rocks. The resulting landscape is characterised by broad alluvial plains associated with the Roper River and its tributaries, and low rubbly hills or strike ridges formed by folded and faulted resistant thick Proterozoic sandstone formations.
Site geology	**Site visit** The dam site is located on Proterozoic rocks of the Mount Rigg Group (Pooj), which consist of medium- to very thick-bedded quartz sandstone; chert and sandstone clast pebble to cobble conglomerate; minor dolomitic siltstone with a sub-horizontal dip. The deeply weathered erosion surface characteristic of the region appeared to have been partially removed by erosion at the dam site. On the dam abutments, weathered sandstone bedrock is partially exposed with some talus (blocky slope deposits) on the surface. Possibly 1 to 3 m stripping would be required so assume a mean depth of stripping of 2 m. The river channel consists of a tract of vegetated alluvium (sand and gravel) and the depth of alluvium is anticipated to be 3 to 5 m locally, with some additional alluvial terraces 2 m deep. The geology of the site is shown in Figure 4-12.
Reservoir rim stability and leakage potential	There is no evidence of instability or leakage potential around the reservoir rim.
Potential structural arrangement	The site appears to be suitable for a roller compacted concrete type dam with a central uncontrolled spillway 150 m wide. Outlet works and a fish lift facility would be located on the right bank. No saddle dams are required at this level of development. Access to the right bank of the site would be via a 10 km new road from the Central Arnhem Highway branching before the creek crossing. The total distance via the Stuart and Central Arnhem highways from Katherine would be some 207 km.
Availability of construction materials	A quarry in the Proterozoic sandstone with suitable aggregate for a RCC dam might be found within 10 km of the dam site. For estimating purposes a ratio of useful rock excavated to total volume excavated of 0.5 could be assumed. Hard rock quarries for higher quality aggregate to construct an outer layer of RCC for the dam could probably be sourced from Katherine.
Catchment area	1173 km^2

PARAMETER	DESCRIPTION

Modelled annual inflow data

Parameter	Scenario A GL/yr	Scenario Cdry GL/yr	Scenario Cmid GL/yr	Scenario Cwet GL/yr
Max	656	500	599	834
Mean	151	118	140	211
Median	131	102	124	178
Min	2	2	2	2

Reservoir characteristics

Reservoir characteristics are shown in Figure 4-13. Reservoirs with FSL of different heights are tabulated below.

FSL (mEGM96)	Surface area (ha)	Capacity (GL)
171	1603	97
173	1924	133
175	2260	174

Reservoir yield assessment at dam wall

FSL 171 mEGM96	Estimated yield at 85% annual time reliability	59 GL
FSL 173 mEGM96	Estimated yield at 85% annual time reliability	68 GL
FSL 175 mEGM96	Estimated yield at 85% annual time reliability	71 GL

Reservoir yields under projected future climates shown in **Figure 4-15**.

Estimated rates of reservoir sedimentation at FSL 173 mEGM96

	Best case	Expected	Worst case
30 years (%)	1.0	1.5	1.7
100 years (%)	3.3	5.0	5.6
Years to fill	2990	1993	1794

Potential use of supply

The area below the potential dam site on the upper Flying Fox Creek is dominated by hills and undulating rises dissected by a narrow alluvial plain along the creek, then a relatively large area of alluvial plains of Flying Fox Creek around the Central Arnhem Road, and broad alluvial plains associated with the lower Flying Fox Creek approximately 45 km downstream of the Central Arnhem Road.

The hills and rises have shallow and/or rocky soils (SGG 7) that are unsuitable for irrigation development.

The alluvial plains in the upper catchment are dominated by very deep sandy-surfaced brown Dermosols (SGG 2) with moderately permeable, moderately well-drained to imperfectly drained, mottled structured clay subsoils. These soils are subject to seasonal wetness (wet season) and may be subject to flooding. Soils are suited to a diverse range of dry-season spray-irrigated grain, pulse and forage crops; spray- or trickle-irrigated horticultural small crops; wetness-tolerant horticultural tree crops; and spray-irrigated sugarcane and cotton. Wet-season crops are restricted to crops with a moderate tolerance to wetness such as spray-irrigated forage crops, sunflower, sesame and rice. Fragmentation of the area by creeks and soil distribution may limit the usable areas for various uses, particularly on the alluvial plains with numerous braided channels approximately 10 km downstream of the Central Arnhem Road.

The broad alluvial plains approximately 45 km downstream of the Central Arnhem Road are dominated by very deep, moderately well-drained to imperfectly drained, slowly permeable brown to grey cracking clay soils (SGG 9) with strongly sodic subsoils, and soft self-mulching or hard-setting structured clay surfaces. Soils have high to very high water-holding capacity (>140 mm to 1 m) but may have a restricted rooting depth due to very high salt levels in the subsoil. The self-mulching and structured brown and grey cracking clay soils are suited to a variety of dry-season flood- or spray-irrigated grain, forage and pulse crops, sugarcane and cotton. Much of the clay plains are subject to regular flooding and frequently have small (<0.3 m) gilgai depressions and numerous flood channels. However, the plains with braided channels are frequently in narrow, ribbon form, which limit opportunities for agricultural development.

PARAMETER	DESCRIPTION
Impacts	In addition to the storage area, a flood margin area would also need to be acquired.
Environmental impacts	**Barrier to movement of aquatic species** At this site there were no records of any species. **Ecological implications of inundation** The 'Arnhem Plateau Sandstone Shrubland Complex' listed as Endangered Ecological Community (EPBC Act) surrounds the potential inundated area at FSL for this site (173 mEMG96). The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Stratford et al., 2022).
Indigenous land tenure, native title and cultural heritage considerations	There is a high likelihood of unrecorded sites in the inundation area.
Estimated cost	A manual cost estimate undertaken as part of the Assessment for a RCC dam on the upper Flying Fox Creek potential dam site at FSL 173 mEGM96 found the dam would cost approximately $318 million. Details of this cost estimate are provided in Appendix A. To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO's generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below. FSL 171 mEGM96 $288 million FSL 173 mEGM96 $312 million FSL 175 mEGM96 $339 million
Estimated cost / ML of supply	Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows: FSL 171 mEGM96 $4881/ML FSL 173 mEGM96 $4588/ML FSL 175 mEGM96 $4775/ML Based on the manual cost estimate, the cost/ML of supply at FSL of 235 mEGM96 is $4676/ML.
Summary comment	The upper Flying Fox Creek potential dam site is one of the sites with the highest yield-to-cost ratio on non-Indigenous land, with potentially favourable geology and upstream of large areas of sandy loam soils moderately suitable for irrigated agriculture.

Figure 4-8 Flying Fox Creek potential dam site AMTD 105 km looking upstream

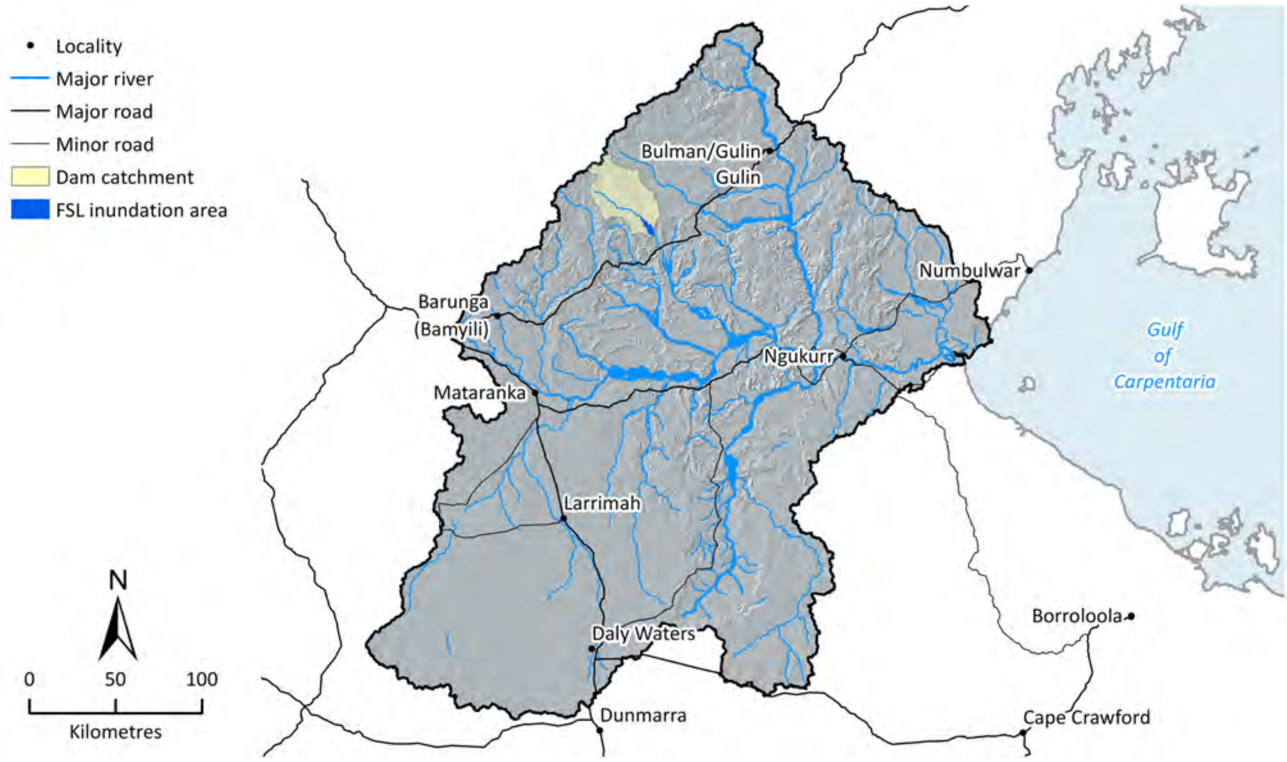

Figure 4-9 Location map of potential Flying Fox Creek dam site, reservoir extent and catchment area

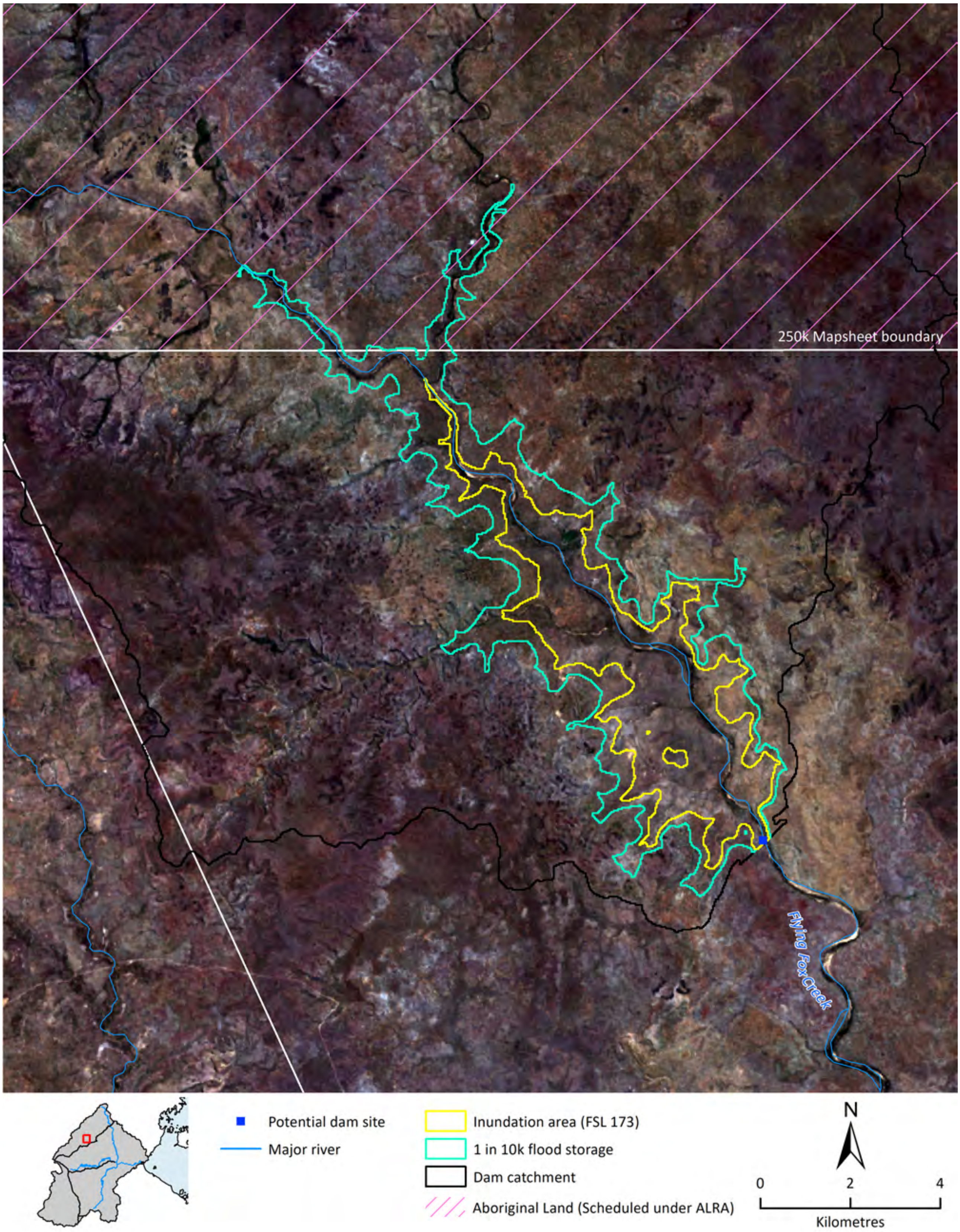

Figure 4-10 Potential Flying Fox Creek dam reservoir and property boundaries

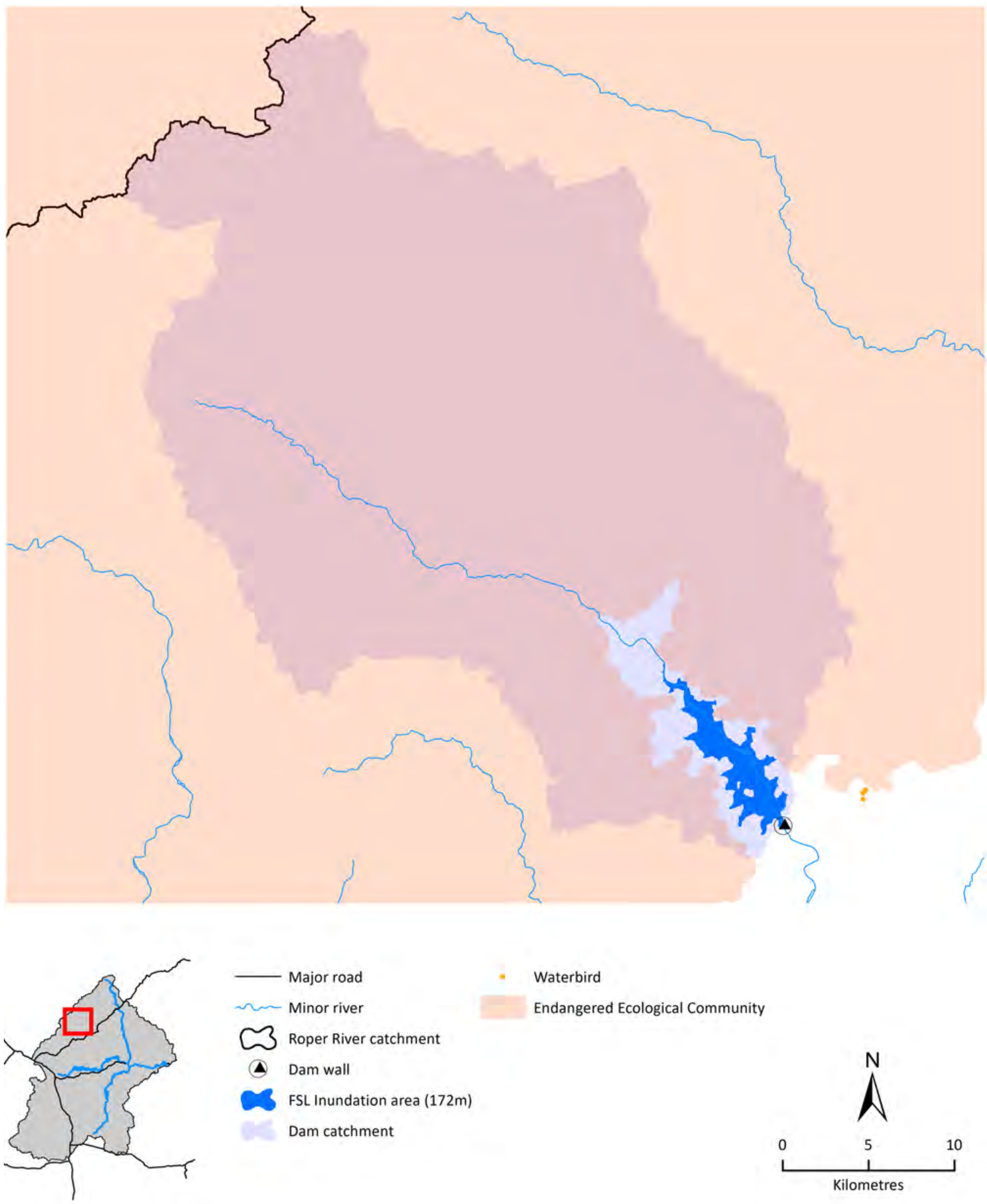

Figure 4-11 Known water-dependent ecological assets in the vicinity of the potential Flying Fox Creek dam site and potential reservoir extent

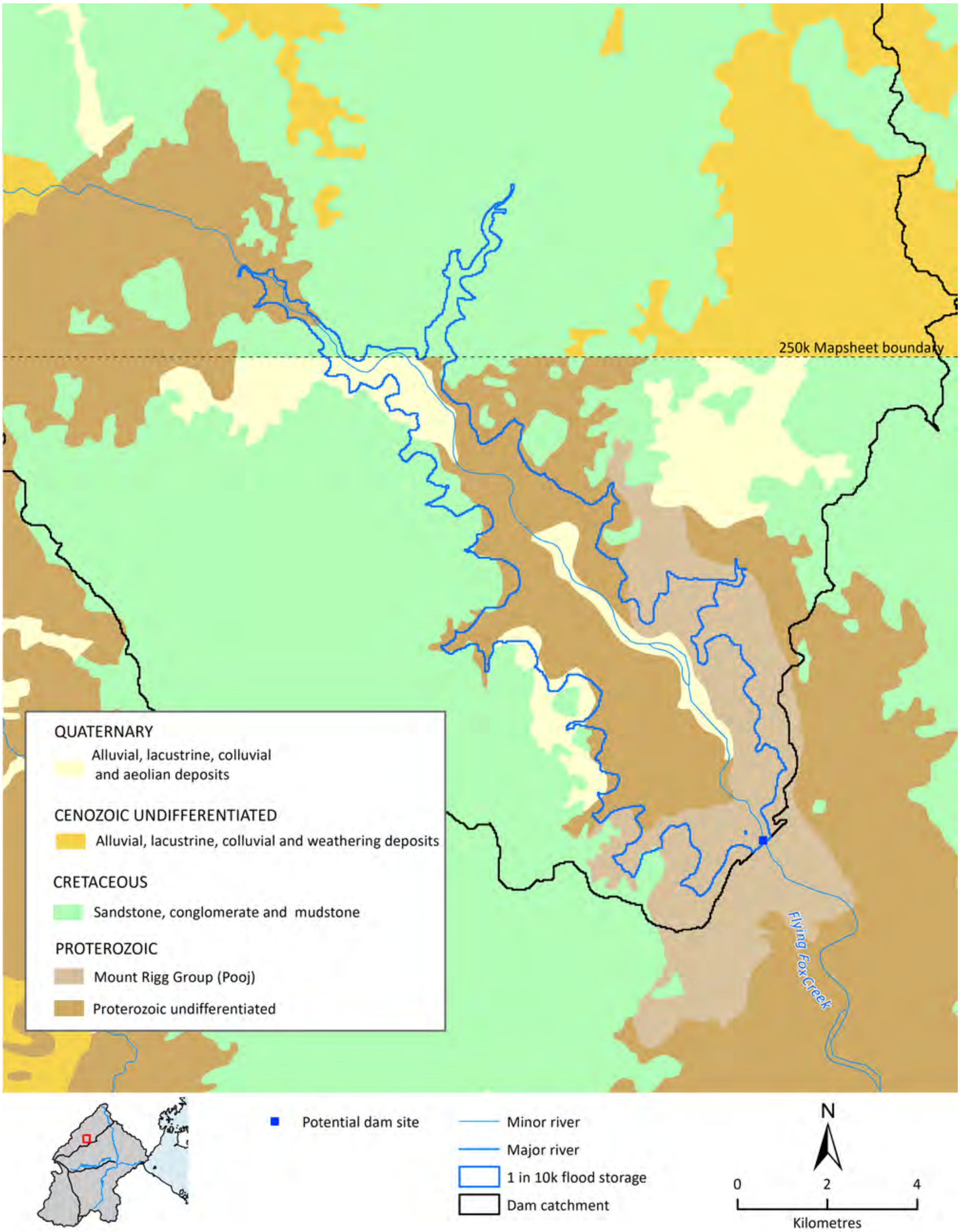

Figure 4-12 Geology underlying the potential Flying Fox Creek dam site and reservoir

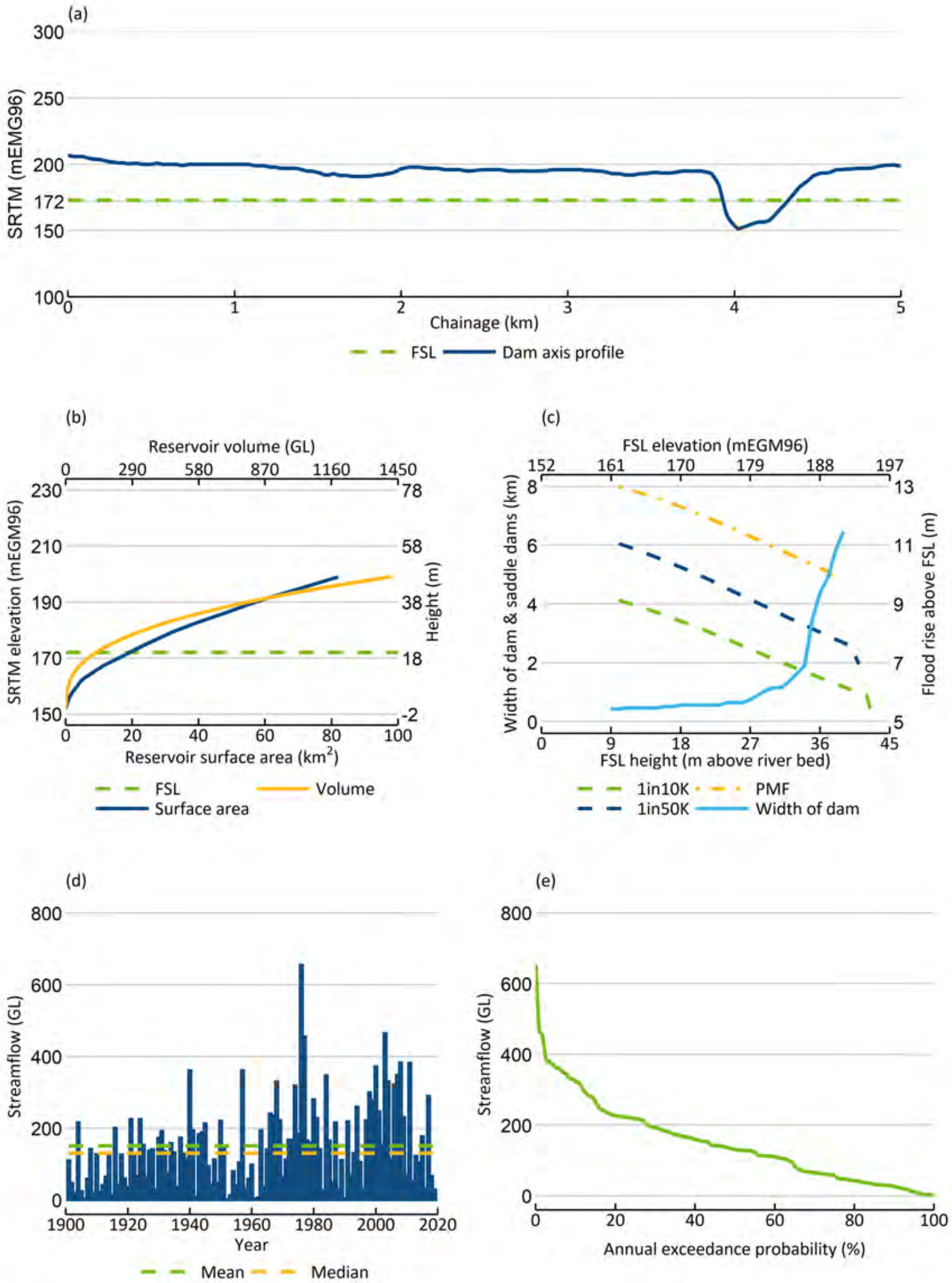

Figure 4-13 Flying Fox Creek potential dam site topographic dimensions and inflow hydrology

(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and probable maximum flood (PMF) events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance

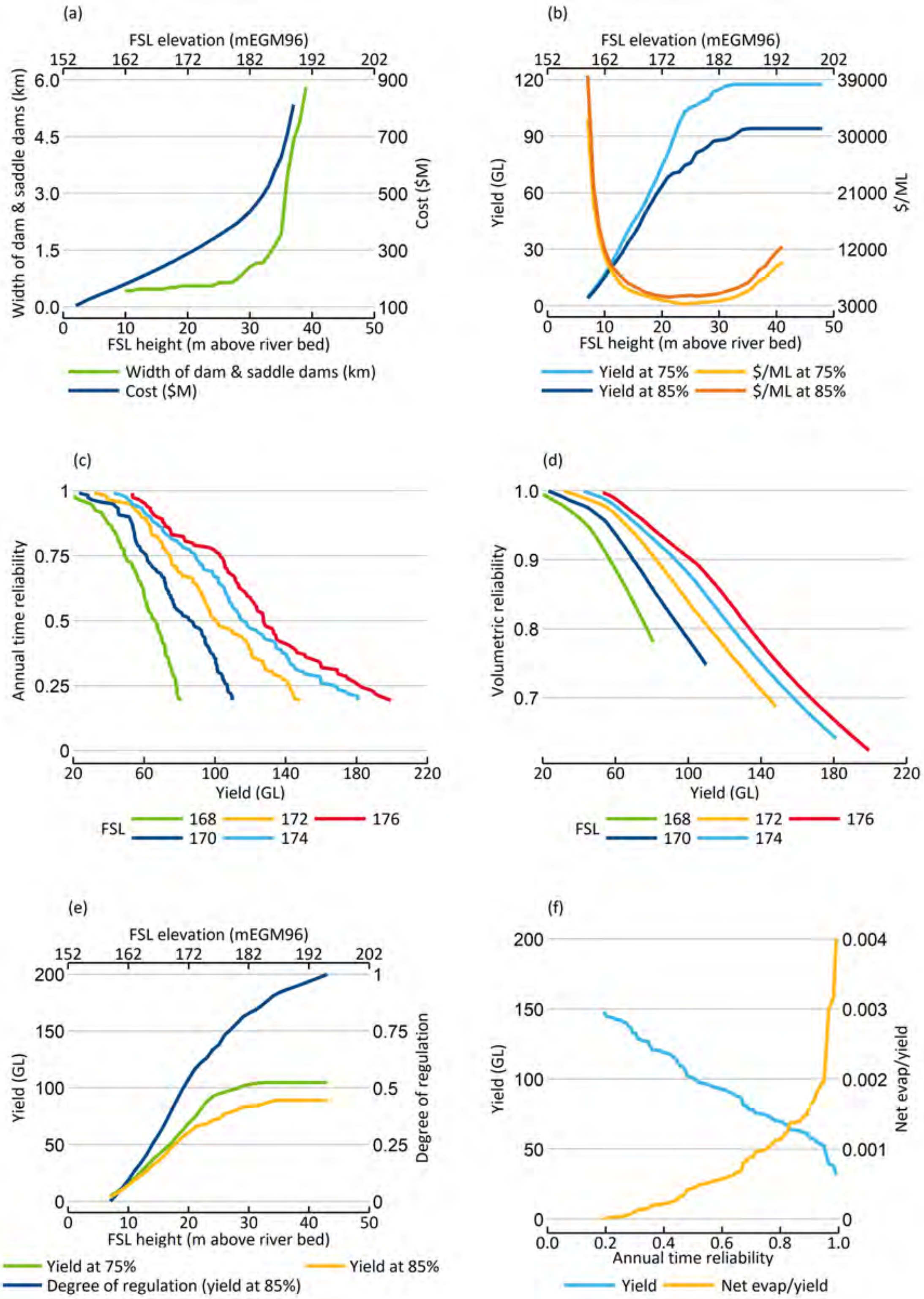

Figure 4-14 Flying Fox Creek potential dam site cost, water yield at the dam wall and evaporation

(a) Dam length and dam cost versus full supply level (FSL); (b) dam yield at 75% and 85% annual time reliability and yield per million dollars at 75% and 85% annual time reliability; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 75% and 85% annual time reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f) yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.

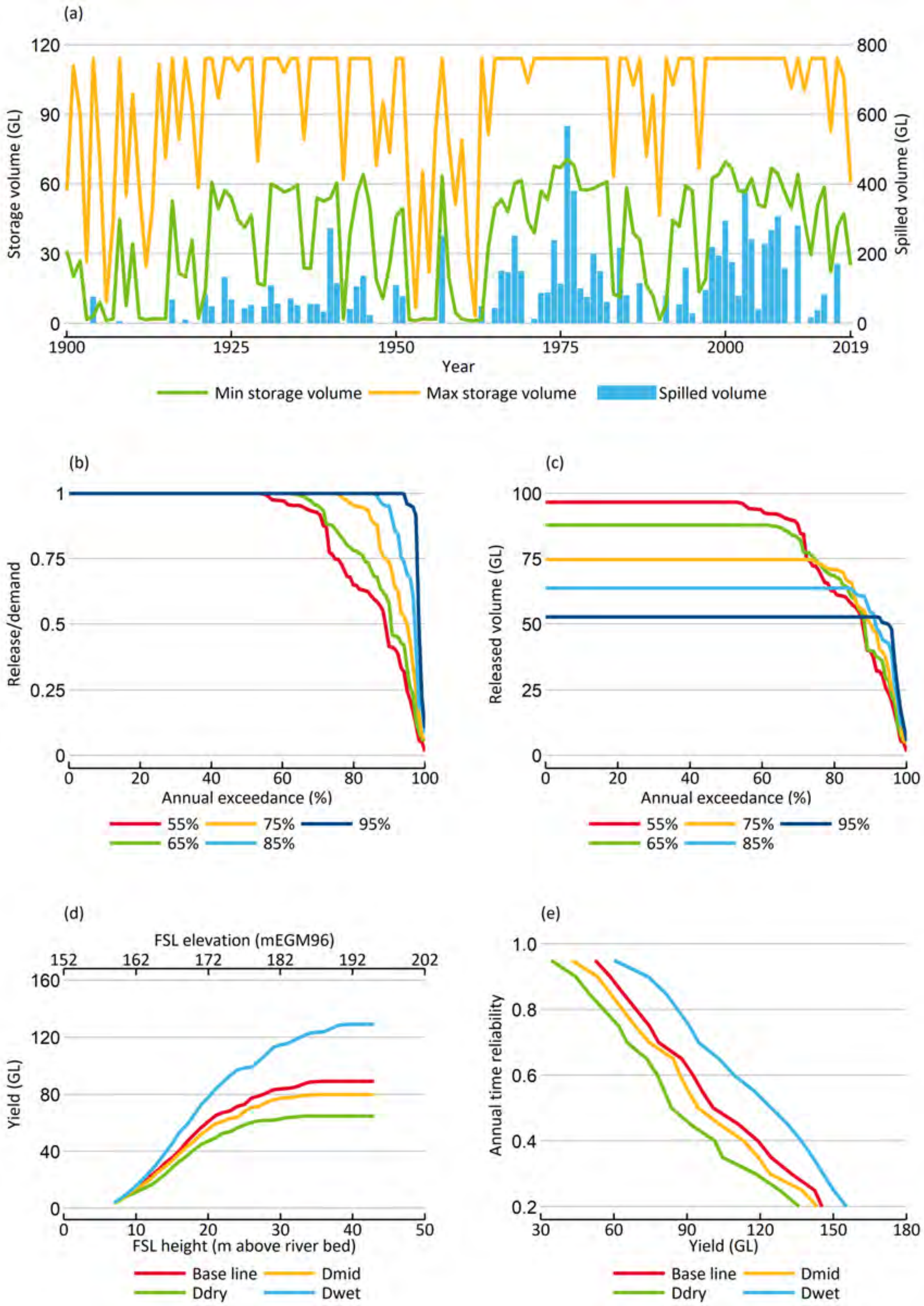

Figure 4-15 Flying Fox Creek potential dam site and storage levels and water yield

(a) Maximum and minimum annual storage trace at the selected FSL (172 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (d) annual yield at 85% annual time reliability plotted against FSL under Scenario A (baseline) and Scenario D; (e) annual time reliability vs yield for FSL 172 mEMG96 under Scenario A (baseline) and Scenario D.

5 Re-regulating structures

Re-regulating structures, such as weirs, are typically located downstream of large dams. They allow for more efficient releases from the storages and for some additional water yield from the weir storage itself, thereby reducing the transmission losses normally involved in supplemented river systems.

As a rule of thumb, however, weirs are constructed to one-half to two-thirds the river bank height. This height lets the weirs achieve maximum capacity while ensuring that the change in downstream hydraulic conditions does not result in excessive erosion of the toe of the structure and also that large flow events can still be passed without causing excessive flooding upstream.

Broadly speaking, there are two types of weir structure: concrete gravity weirs and sheet piling weirs. These are discussed below. Both weir types often use rock-filled mattresses on the stream banks extending downstream of the weir to protect erodible areas from flood erosion. Sand dams are also briefly discussed.

Note that weirs, sand dams and diversion structures obstruct the movement of fish in a similar way to dams during the dry season.

5.1 Sheet piling weirs

Where rock foundations are not available, stepped steel sheet piling weirs have been successfully used in many locations across Queensland. These weirs consist of parallel rows of steel sheet piling, generally about 6 m apart with a step of about 1.5 to 1.8 m high between each row. Reinforced concrete slabs placed between each row of piling absorb much of the energy as flood flows cascade over each step. The upstream row of piling is the longest, driven to a sufficient depth to cut off the flow of water through the most permeable material (Figure 5-1). Indicative costs are provided in Table 5-1.

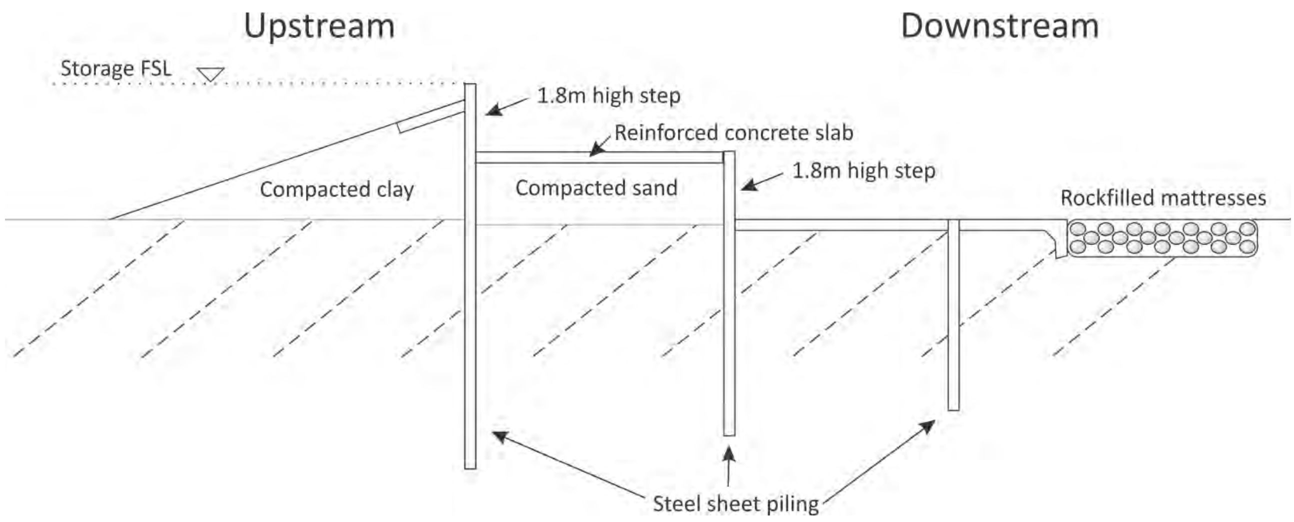

Figure 5-1 Schematic cross-section diagram of sheet piling weir

Source: Petheram et al. (2013a)

Table 5-1 Estimated generic construction cost of 3-m high sheet piling weir

WEIR CREST LENGTH (M)	ESTIMATED CAPITAL COST ($ MILLION)
100	28
150	36
200	43

5.1.1 Stepped steel sheet piling weir on Flying Fox Creek AMTD 36 km

A potential weir site was investigated on Flying Fox Creek AMTD 36 km, which could be used to regulate releases from an upstream dam on Flying Fox Creek AMTD 105 km reducing transmission losses. The weir storage would also increase system yield based on storing inflows (mean annual inflow from residual catchment was modelled to be 101.5 GL) from that part of the catchment downstream of the potential dam site.

The potential weir site is on a broad vegetated wide alluvial tract with patchy unvegetated areas suggesting alluvial sands and gravels locally mobilised under current flow regime. The bedload is likely to be mobile during large flood events. The alluvial tract is estimated to be about 400 m wide and 5 to 10 m deep. No rock exposed on either abutment suggesting deeply weathered siltstones and mudstones over dolerite. Although unsuitable for a concrete gravity storage structure the ground conditions are well suited to a steel sheet piling weir.

A nominal conceptual layout would entail a stepped steel sheet piling weir approximately 500 m in length with a central sloping low flow section and reinforced concrete slab protection between the piling rows. Four rows of piling would be required. Outlet works and a vertical slot type fish ladder would be located on the right abutment. It has been assumed that dry season flows would be diverted through a 1,800 mm diameter RC pipe which would also provide for environmental releases from the weir storage to the stream. Access to the right bank of the site would be via a 38 km new road from the Central Arnhem Highway branching before the creek crossing. The total distance via the Stuart and Central Arnhem highways from Katherine would be some 229 km. The access road would also provide access to a pump station servicing a potential irrigation area.

A weir with a FSL 4 m above the bed level would have a capacity of about 10 GL and with no environmental flow releases the system yield of the weir and a potential dam on Flying Fox Creek AMTD 105 km FSL 173 mEMG96 would be 87 GL in 85% of years (compared to 68 GL in 85% of years released from a with FLS 173 mEMG96 at Flying Fox Creek ATMD 105 km).

It is estimated that the weir would cost $89 million to construct.

5.2 Concrete gravity type weirs

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

Figure 5-2 shows an example of a concrete gravity weir on the Katherine River (NT).

Figure 5-2 Donkey Camp Weir on the Katherine River (Daly River catchment, Northern Territory)

An example of a reinforced concrete weir structure in the Northern Territory. Water from Donkey Camp Weir is treated and supplied to Katherine.

Photo: CSIRO

5.3 Sand dams

As many of the large rivers in northern Australia are very wide (e.g. >300 m), weirs are likely to be impractical and expensive at many locations. An alternative structure is sand dams, which are low embankments built of sand constructed at the start of each dry season during periods of low or no flow when heavy earth-moving machinery can access the bed of the river. They are constructed to form a pool of sufficient depth to enable pumping (i.e. typically greater than 4 m depth) and are widely used in the Burdekin River near Ayr, where the river is too wide to construct a weir.

Typically, sand dams take three to four large excavators about 2 to 3 weeks to construct, and no further maintenance is required until they need to be reconstructed again after the wet season. Bulldozers can construct a sand dam more quickly than can a team of excavators, but they have greater access difficulties. Because sand dams only need to form a pool of sufficient size and depth from which to pump water, they usually only partially span a river and are typically constructed immediately downstream of large, naturally formed waterholes.

The cost of 12 weeks of hire for a 20 t excavator and float (i.e. for transportation) is approximately $85,000. Although sand dams are cheap to construct relative to a concrete or sheet piling weir, they require annual rebuilding and have much larger seepage losses beneath and through the dam wall. No studies are known to have quantified losses from sand dams.

6 Farm-scale storages

The primary aim of this section is to provide a broad-scale assessment of the suitability of farm-scale water storage locations in the Roper catchment. It also provides a summary of farm-scale dam construction and operation and maintenance costs detailed in the Northern Australia Water Resource Assessment report on farm-scale dam costs (Benjamin, 2018) indexed to 2021. Note, however, in assessing regional-scale economics of water harvesting schemes, local variations in scale and site-specific nuances (e.g. length of supply channel, amount of diesel required for pumping, removal of sediment deposited in diversion channels, replacement of worn and damaged equipment, availability of materials, remoteness) result in considerably different construction and operational costs from one site to the next. Hence, operationally, each site would require its own specifically tailored engineering design. Many landholders will have observed the way water moves across their land and will have given considerable thought to their most suitable water harvesting configurations. This report does not attempt to produce engineering water harvesting infrastructure designs for individual producers. Nor does this report seek to provide instruction on the design and construction of offstream water storages. Numerous other texts and online tools provide detailed information on nearly all facets of offstream water storage. For instructional information the reader is directed in the first instance to QWRC (1984), Lewis (2002) and IAA (2007).

This section describes a desktop analysis of two types of farm-scale dams. Section 6.1 examines offstream storages, such as ringtanks, into which water is pumped from an adjacent drainage line, and Section 6.2 examines gully and hillside dams, which intercept and store runoff generated directly from the dam's catchment.

6.1 Offstream farm-scale storages (ringtanks)

This section presents the results of a desktop land suitability assessment for farm-scale offstream storages in the Roper catchment. This assessment is based on the soils data in the top 1.5 m of the soil profile generated as part of the Assessment (see companion technical report on digital soil mapping (Thomas et al., 2022)). Because of a lack of data on soils below a depth of 1.5 m, this analysis does not consider the suitability of subsurface material below this depth.

Farm-scale offstream water storages require consideration at a scale finer than is possible to assess in a regional-scale resource assessment. Hence, the results presented here are only indicative of potential suitable locations. Design and construction of offstream water storages should only be undertaken following a site investigation by a suitability qualified professional.

Land suitability requirements for ringtanks include impermeable soils, slopes less than 5%, clay content greater than 20%, no rock and deep soils.

Suitability criteria include:

- slowly permeable to very slowly permeable soils (<50 mm/day) to reduce unnecessary water losses from deep drainage and avoid rising watertables or potential secondary salinisation in the vicinity of the tanks
- level to gentle slopes to enable construction of a 'large storage' and reduce unnecessary excavation into hillslopes
- soils texture greater than 20% clay to the depth of excavation to allow machinery to compact the tank floor and walls to reduce deep drainage. Clay textures (>35% clay) are preferred
- non-rocky soils to enable ease of construction and uniform compaction
- deep soils, preferably greater than 1 m deep, to allow excavation of tanks with sufficient storage depth and wall height.

Most of the catchment is unsuitable for offstream storages (Figure 6-1), predominantly due to excessive slope, shallow soils, rockiness and permeable soils.

Several land types are likely to be suitable for ringtanks. These include the poorly drained coastal marine clay plains, the cracking clay soils on the alluvial plains of the Roper River and major tributaries, and the Cenozoic clay plains on the Sturt Plateau.

The low-lying, very deep (>1.5 m), very poorly drained, strongly mottled grey saline clay soils with potential acid sulfate deposits in the profile on the coastal marine plains are likely to be suitable for ringtanks but are subject to tidal inundation and storm surge from cyclones.

Other areas likely to be suitable are the slowly permeable cracking clay soils on the alluvial plains of the Roper River and other major rivers, which have very deep (>1.5 m), moderately well to imperfectly drained, slowly permeable brown to grey cracking clays that are usually strongly sodic at depth. The clay plains of the Roper River are subject to regular flooding and frequently have small (<0.3 m) gilgai depressions and numerous flood channels. These soils on the alluvial plains grade to seasonally wet soils in the catchment below Ngukurr. The Cenozoic clay plains of the Sturt Plateau with very deep (>1.5 m), impermeable, imperfectly drained grey cracking clay soils often have large deep gilgai (>0.3 to 0.8 m). This relict alluvium occurs in drainage depressions, enabling collection and storage of overland flows.

The non-cracking clay soils associated with the Cenozoic clay plains on the Sturt Plateau may be suitable for ringtanks. These very deep (>1.5 m), gilgaied non-cracking soils with moderately permeable clay loam to clay surfaces up to 1 m deep overly impermeable, mottled, structured, brown vertic (relating to shrink–swell properties) clay subsoils. Other soils that may be suitable are the gently undulating plains with deep (1 to 1.5 m), non-rocky, non-cracking clay soils developed on mudstones in the upper Hodgson River catchment. These soils frequently occur in association with shallow or rocky soils on slopes that are dissected by numerous creeks.

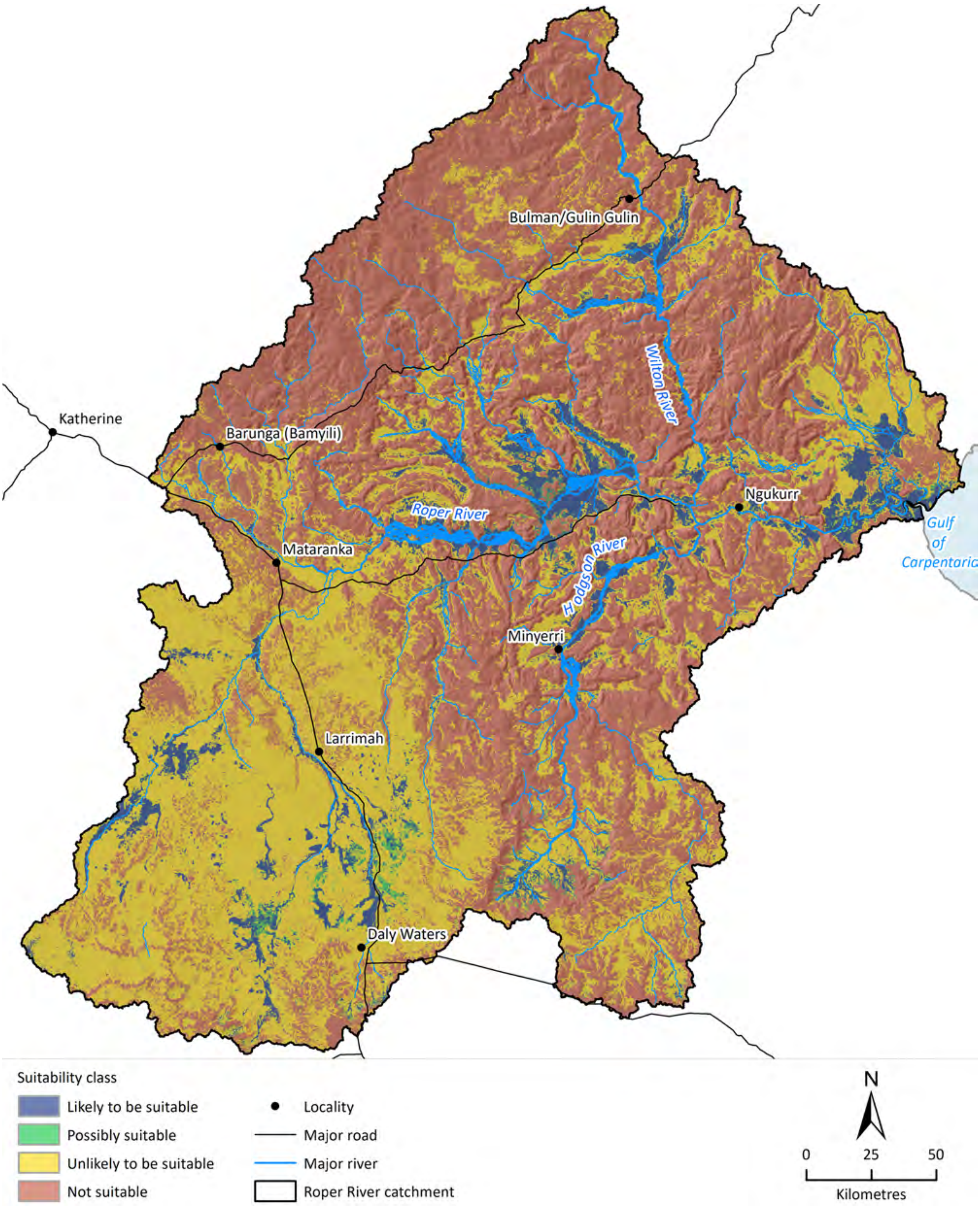

Figure 6-1 Suitability of farm-scale offstream water storage (ringtanks) in the Roper catchment

Soil and subsurface data were only available to a depth of 1.5 m, so this Assessment does not consider the suitability of subsurface material below this depth. This figure does not take into consideration flood risk or the availability of water. Data are underlain by a shaded relief map.

6.1.1 River flow exceeded in 80% of years

To enable a first-pass assessment of the potential for water harvesting in different parts of the Roper catchments, information on annual streamflow exceeded in 80% of years is presented in Figure 6-3. However, note that physical pumping constraints, environmental flow considerations and existing downstream usage mean the actual amount of water available for extraction may be considerably less than shown.

Figure 6-3 displays the 80% exceedance of annual streamflow in the Roper catchment under the historical climate (Scenario A). It shows that, with the exception of the Wilton and Hodgson rivers, the tributaries joining the Roper River have relatively low 80% exceedance of annual streamflow. This is significant in terms of both offstream storage and gully dams, as it indicates that most of the tributaries of the Roper River will only be able to support limited farm-scale water storage developments. Although the 80% exceedance of annual streamflow in the Roper River downstream of the junction with the Wilton River is large, there are limited areas adjacent to the river that are suitable for cropping.

Figure 6-2 Turkey nest offstream storage in the Roper catchment

Photo: CSIRO

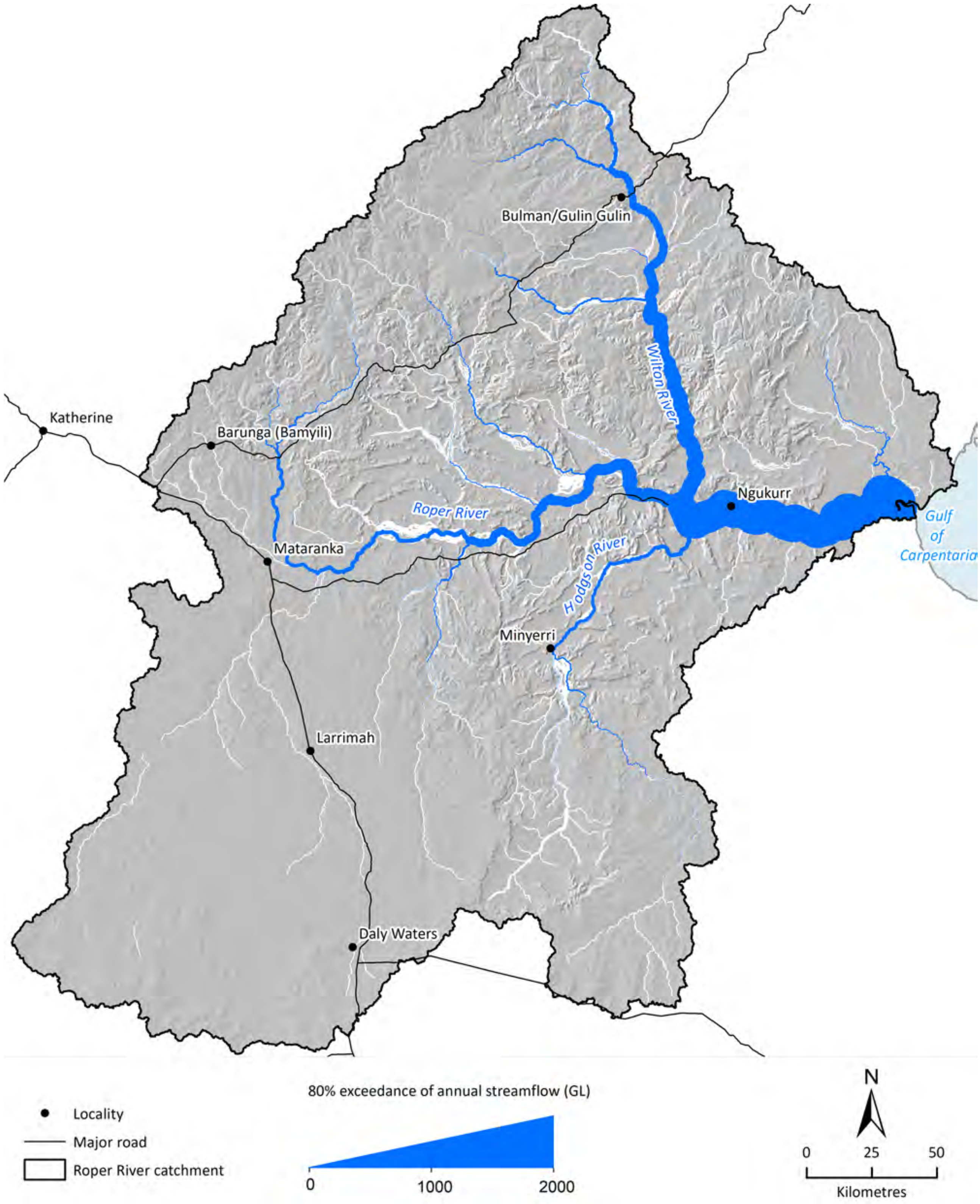

Figure 6-3 80% exceedance of annual streamflow in the Roper catchment under Scenario A

6.1.2 Evaporative and seepage losses

Losses from the reservoir of a farm-scale dam occur through evaporation and seepage. When calculating evaporative losses from a storage, it is important to calculate net evaporation (i.e. evaporation minus rainfall) rather than just evaporation. Strategies to minimise evaporation include liquid and solid barriers, but these are typically expensive per unit of inundated area (e.g.

\$12 to \$40 per m^2. In non-laboratory settings, liquid barriers such as oils are susceptible to being dispersed by wind and have not been shown to reduce evaporation from a water body (Barnes, 2008). Solid barriers can be effective in reducing evaporation but are expensive. For example, covering the reservoir surface (110 ha) of the 4000 ML hypothetical ringtank detailed below (Table 6-1 to Table 6-4) with an impermeable barrier to prevent evaporation at a cost of \$25/m^2 would increase the capital cost of the storage from \$2 million to \$30 million, more than a factor of ten. Evaporation losses from a ringtank can also be reduced slightly by subdividing the storage into multiple cells and extracting water from each cell in turn to minimise the total surface water area. However, constructing a ringtank with multiple cells requires more earthworks and incurs higher construction costs than outlined in this section.

A study of 138 farm dams ranging in capacity from 75 ML to 14,000 ML from southern NSW to central Queensland by the Cotton Catchment Communities CRC (2011) found mean seepage and evaporation rates of 2.3 and 4.2 mm/day, respectively. Of the 138 dams examined, 88% had seepage values of less than 4 mm/day and 64% had seepage values less than 2 mm/day. These results largely concur with IAA (2007), which states that reservoirs constructed on suitable soils will have seepage losses equal to or less than 1 to 2 mm/day and seepage losses will be greater than 5 mm/day if sited on less suitable (i.e. permeable) soils.

Ringtanks with greater mean water depth lose a lower percentage of their total storage capacity to evaporation and seepage losses; however, they have a smaller storage capacity-to-excavation ratio. In Table 6-1 effective volume refers to the actual volume of water that could be used for consumptive purposes after losses due to evaporation and seepage. For example, if water is stored in a ringtank in the Roper catchment (near the junction of the Roper and Jalboi rivers) with mean water depth of 3.5 m until October and the mean seepage loss is 2 mm/day, about 45% of the stored volume would be lost to evaporation and seepage. The examples provided in Table 6-1 are for 4000 ML ringtanks in the Roper catchment, but the effective volume expressed as a percentage of the ringtank capacity is applicable to any storage (e.g. ringtanks or gully dams) of any capacity for mean water depths of 3.5, 6 and 8.5 m.

In the Roper catchment, most moderate to large streamflow events occur before the end of March. Assuming the storage is full at this time, one strategy is to sow suitable crops during the early dry season to minimise evaporative and seepage losses and enable crops to use existing soil water. In the Roper catchment, however, the alluvial clay soils are not likely to be trafficable before May in many years. Hence the configurations in the following tables provide general information on construction costs and effective volumes in the Roper catchment for three seepage rates (1 mm/day, 2 mm/day and 5 mm/day) and for three storage durations (5 months, 7 months and 10 months), assuming the ringtank is full at the end of March. Sorghum planted for hay is an example of a crop where water may be required for irrigation for a 4-month period (i.e. May to August), sorghum planted for grazing is an example of a crop where water may be required for irrigation for a 6-month period (May to October) and Rhodes grass is an example of a perennial crop or a crop for which water is needed throughout the dry season (i.e. water may be required over a 10-month period).

Table 6-1 Effective volume after net evaporation and seepage for ringtanks of three average water depths and under three seepage rates near junction of Jalboi River and Roper River in the Roper catchment

Effective volume refers to the actual volume of water that could be used for consumptive purposes as a result of losses due to net evaporation and seepage, assuming a storage capacity is 4000 ML. For storages of 4000-ML capacity and average water depths of 3.5, 6 and 8.5 m, reservoir surface areas are 110, 65 and 45 ha, respectively. S:E ratio is the storage capacity to excavation ratio. Effective volumes calculated based on the 20% exceedance net evaporation.

AVERAGE WATER DEPTH† (M)	S:E RATIO	SEEPAGE LOSS (MM/DAY)	EFFECTIVE VOLUME (ML)	EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY (%)	EFFECTIVE VOLUME (ML)	EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY (%)	EFFECTIVE VOLUME (ML)	EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY (%)
				5 months (April to August)		7 months (April to October)		10 months (April to January)
3.5	14:1	1	2970	74	2447	61	2002	50
	14:1	2	2803	70	2213	55	1666	42
	14:1	5	2301	58	1510	38	660	16
6	7.5:1	1	3388	85	3077	77	2811	70
	7.5:1	2	3289	82	2938	73	2613	65
	7.5:1	5	2993	75	2523	63	2018	50
8.5	5:1	1	3574	89	3358	84	3173	79
	5:1	2	3506	88	3262	82	3036	76
	5:1	5	3301	83	2975	74	2624	66

6.1.3 Indicative capital, operation and maintenance costs of offstream storages

In this analysis the cost of a farm-scale offstream storage scheme includes the cost of the water storage, pumping infrastructure, limited length of supply channel/piping, levee banks, and operation and maintenance of the scheme.

For a given storage capacity, the construction costs (and opportunity cost of land used in the construction) vary considerably, depending on the way the storage is built. For example, circular storages have a better storage volume to cost ratio than rectangular or square storages. It is also considerably more expensive to double the height of an embankment wall than double its length.

Table 6-2 provides a high-level breakdown of the capital and operation and maintenance (O&M) costs of a large farm-scale ringtank, including the cost of the water storage, pumping infrastructure and up to 100 m of pipes, and operation and maintenance of the scheme. The costs and analyses presented in Table 6-3 and Table 6-4 are based on costs of $5/m^3 for earthfill and topsoil and $6.50/ m^3 for compacted clay (Benjamin 2018), indexed to 2021; it was assumed this includes the cost of compaction and that all earth can be obtained within close vicinity of the site. In this example it is assumed that the ringtank is within 100 m of the river and pumping infrastructure. It should be noted that the cost of pumping infrastructure and conveying water from the river to the storage is particularly site-specific. For more detailed breakdown of ringtank costs see the Northern Australia Water Resource Assessment technical report on large farm-scale dams (Benjamin, 2018).

In flood-prone areas where flood waters move at moderate to high velocities, riprap protection may be required, and this may increase the construction costs presented in Table 6 4 and Table 6 5 by 10 to 20% depending upon volume of rock required and proximity to a quarry with suitable rock.

Table 6-2 Indicative costs for a 4000-ML ringtank

Assumes a 4.25-m wall height, 0.75-m freeboard, 3:1 ratio on upstream slope, 3:1 ratio on downstream slope and crest width of 3.1 m, approximately 60% of material can be excavated from within storage, and cost of earthfill and compacted clay is $5.4/m^3$ and $7/m^3$, respectively. Earthwork costs include vegetation clearing, mobilisation/demobilisation of machinery and contractor accommodation. For more detail on costs see Northern Australia Water Resource Assessment technical report on large farm-scale dams (Benjamin, 2018). Pump station costs from companion technical report on pump stations in northern Australia (Devlin, 2023). Costs indexed to 2021. Pump station O&M costs assume cost of diesel of $1.49/L.

SITE DESCRIPTION/ CONFIGURATION	EARTHWORKS ($)	GOVERNMENT PERMITS AND FEES ($)	INVESTIGATION AND DESIGN FEES ($)	PUMP STATION ($)	TOTAL CAPITAL COST ($)	O&M OF RINGTANK ($/Y)	O&M OF PUMP STATION ($/Y)	TOTAL O&M ($/Y)
4000-ML ringtank	1,725,000	38,200	81,800	1,100,000	2,945,000	18,300	107,000	125,300

The capital costs can be expressed over the service life of the infrastructure (assuming a 7% discount rate, see Chapter 6) and combined with O&M costs to give an equivalent annual cost for construction and operation. This enables infrastructure with differing capital and O&M costs and service lives to be compared. The total equivalent annual costs for the construction and operation of a 1000-ML ringtank with 4.25-m high embankments and 55 ML/day pumping infrastructure is about $149,000 (Table 6-3). For a 4000-ML ringtank with 4.25-m high embankments and 160 ML/day pumping infrastructure, the total equivalent annual cost is about $374,400. For a 4000-ML ringtank with 6.75-m high embankments and 160 ML/day pumping infrastructure, the total equivalent annual cost is about $510,900.

Table 6-3 Annualised cost for the construction and operation of three ringtank configurations

Assumes freeboard of 0.75 m, pumping infrastructure can fill ringtank in 25 days and assumes a 7% discount rate. Costs based on those provided for 4000 ML provided in companion technical report on large farm-scale dams (Benjamin, 2018). Costs indexed to 2021. Pump station O&M costs assume cost of diesel of $1.49/L.

CAPACITY AND EMBANKMENT HEIGHT	ITEM	CAPITAL COST ($)	LIFESPAN (Y)	ANNUALISED CAPITAL COST ($)	ANNUAL O&M COST ($)
1000 ML and 4.25 m	Ringtank	925,000	40	69,400	9,250
	Pumping infrastructure†	380,000	15	41,700	7,600
	Pumping cost (diesel)	na	na	na	21,000
4000 ML and 4.25 m	Ringtank	1,725,000	40	129,400	17,250
	Pumping infrastructure†	1,100,000	15	120,800	22,000
	Pumping cost (diesel)	na	na	ns	85,000
4000 ML and 6.75 m	Ringtank	3,330,000	40	249,800	33,300
	Pumping infrastructure†	1,100,000	15	120,800	22,000
	Pumping cost (diesel)	ns	ns	ns	85,000

na = not applicable.
†Costs include rising-main, large-diameter concrete or multiple strings of high density polypipe, control valves and fittings, concrete thrust-blocks and head-walls, dissipater, civil works and installation.
‡Value assumes water is piped between river pumping infrastructure and ringtank.

Although ringtanks with an average water depth of 3.5 m (embankment height of 4.25 m) lose a higher percentage of their capacity to evaporative and seepage losses than ringtanks of equivalent capacity with average water depth of 6 m (embankment height of 6.75 m) (Table 6-1), their levelized cost (i.e. annualised cost divided by water supplied) are lower (Table 6-4) due to the considerably lower cost of constructing embankments with lower walls.

In Table 6-4 the equivalent annual cost of the water supplied from the ringtank takes into consideration net evaporation and seepage from the storage, which increase with the length of time water is stored (i.e. crops with longer growing seasons will require water to be stored longer). In these tables, the results are presented for the equivalent annual cost of water yield from a ringtank of different seepage rates and lengths of time for storing water.

Table 6-4 Equivalent annual cost per ML for two different capacity ringtanks under three seepage rates near Jalboi River in the Roper catchment

Assumes a 0.75-m freeboard, 3:1 ratio on upstream slope, 3:1 ratio on downstream slope. Crest widths are 3.1 m and 3.6 m for embankments with heights of 4.25 m and 6.75 m respectively and assumes earthfill and compacted clay costs $5/m3 and $6.50/m3 respectively. Earthwork costs include vegetation clearing, mobilisation/demobilisation of machinery and contractor accommodation. 1000-ML ringtank reservoir has surface area of 28 ha and storage volume to excavation ratio of about 7:1. 4000-ML ringtank and 4.25 m embankment height reservoir has surface area of 114 ha and storage volume to excavation ratio of about 14:1. 4000-ML ringtank with 6.75 m embankment height reservoir has surface area of 64 ha and storage volume to excavation ratio of about 7.5:1.

CAPACITY AND EMBANKMENT HEIGHT	ANNUAL-ISED COST* ($)	SEEPAGE LOSS (MM/DAY)	UNIT COST ($/ML)	EQUIVALENT ANNUAL UNIT COST ($/Y PER ML/Y)	UNIT COST ($/ML)	EQUIVALENT ANNUAL UNIT COST ($/Y PER ML/Y)	UNIT COST ($/ML)	EQUIVALENT ANNUAL UNIT COST ($/Y PER ML/Y)
				5 months (April to August)		**7 months (April to October)**		**10 months (April to January)**
1000 ML and 4.25 m	148,955	1	1769	202	2158	246	2656	303
	148,955	2	1877	214	2394	273	3214	367
	148,955	5	2299	262	3564	407	8712	994
4000 ML and 4.25 m	374,415	1	965	128	1187	157	1475	196
	374,415	2	1026	136	1321	175	1803	239
	374,415	5	1265	168	2004	266	5391	714
4000 ML and 6.75 m	510,855	1	1312	151	1448	167	1590	183
	510,855	2	1352	156	1518	175	1713	198
	510,855	5	1489	172	1775	205	2235	258

Taking into consideration the cost of constructing ringtanks and net evaporation and seepage losses, the optimal embankment height will vary depending upon the capacity of the storage and the time required to store water.

6.2 Farm-scale gully and hillside dams

Large farm-scale gully dams are generally constructed of earth or earth and rockfill embankments with compacted clay cores, and usually to a maximum height of about 20 m. Dams with a crest height of over 10 or 12 m typically require some form of downstream batter drainage incorporated in embankments. Large farm-scale gully dams typically have a maximum catchment area of about 30 km^2 due to the challenges in passing peak floods from large catchments (large farm-scale gully dams are generally designed to pass an event with an AEP of 1%), unless a site has an exceptionally good spillway option.

Like ringtanks, large farm-scale gully dams are a compromise between best-practice engineering and affordability. Designers need to follow accepted engineering principles relating to important aspects of materials classification, compaction of the clay core and selection of appropriate embankment cross-section. However, costs are often minimised where possible, for example, by employing earth bywashes and grass protection for erosion control rather than the more expensive concrete spillways and rock protection found on major dams. This can compromise the integrity of the structure during extreme events and its longevity as well as increase the ongoing maintenance costs but can considerably reduce the upfront capital costs.

In this section the following assessments are reported:

- suitability of the landscape for large farm-scale gully dams
- indicative capital, operating and maintenance costs of large farm-scale gully dams.

Net evaporation and seepage losses also occur from large farm-scale gully dams.

6.2.1 DamSite model results

The DamSite model (Petheram et al., 2017b) was used to assess every location in the Roper catchment for their potential as a farm-scale earth embankment gully or hillside dam. As discussed in Section 2.1.2, the model was used to assess dams of between 5 m and 20 m in height.

Figure 6-4 shows locations where it may be relatively economical to construct large farm-scale gully dams in the Roper catchment and the likely density of options. This analysis considers sites likely to have relatively favourable topography. It does not explicitly consider whether sites are underlain by soil that is suitable for the construction of the embankment and that will minimise seepage from the reservoir base. Soil suitability is shown in Figure 6-5. Dams can be constructed on eroded or skeletal soils provided there is access to a clay borrow pit nearby for the cut-off trench and core zone. However, those sites are likely to be less economically viable.

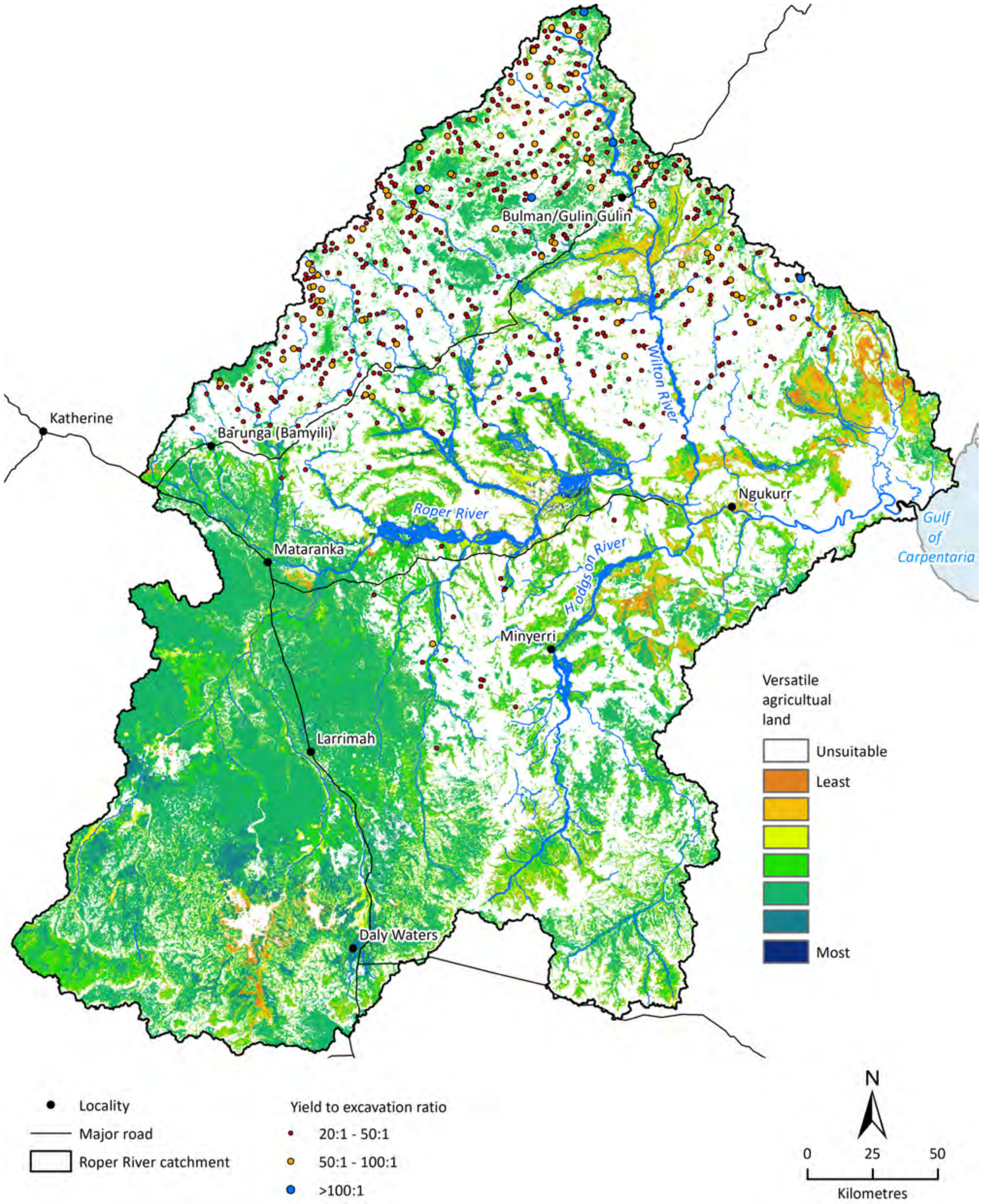

Figure 6-4 Most economically suitable locations for large farm-scale gully dams in the Roper catchment overlaid on map of versatile agricultural land

Gully dam data overlaid on agricultural versatility data. Versatile data sourced from companion technical report on digital soil mapping (Thomas et al., 2022). Agricultural versatility data show the parts of the catchment that are more or less versatile for irrigated agriculture. This Assessment does not consider the suitability of subsurface material. Sites with catchment areas greater than 40 km^2 or yield-to-excavation ratios less than 20:1 are not displayed.

In the Roper catchment, 1542 locations were modelled as having a maximum water yield of 20 ML per 1000 m^3 of excavation or greater. However, note that in many of these locations the soils are unsuitable for constructing embankment dams because the soil is too shallow to provide sufficient material for construction (Figure 6-5). This means dam walls would have to be constructed using rockfill, cement and imported clay soils. The maximum yield per 1000 m^3 of excavation was observed to be independent of catchment area. Data on farm-scale gully and hillside dams showing those locations with the highest yield-to-cost ratios are available through the Northern Australia Water Resource Assessment Explorer (https://nawra-explorer.csiro.au/).

It should be noted that the results presented in Figure 6-4 are modelled and consequently only indicative of the general locations where siting a gully dam may be most economically suitable. This analysis may be subject to errors in the underlying digital elevation model, such as effects due to the vegetation removal process. An important factor not considered in this analysis was the availability of a natural spillway. Site-specific investigations by a suitably qualified professional should always be undertaken prior to the construction of a gully dam.

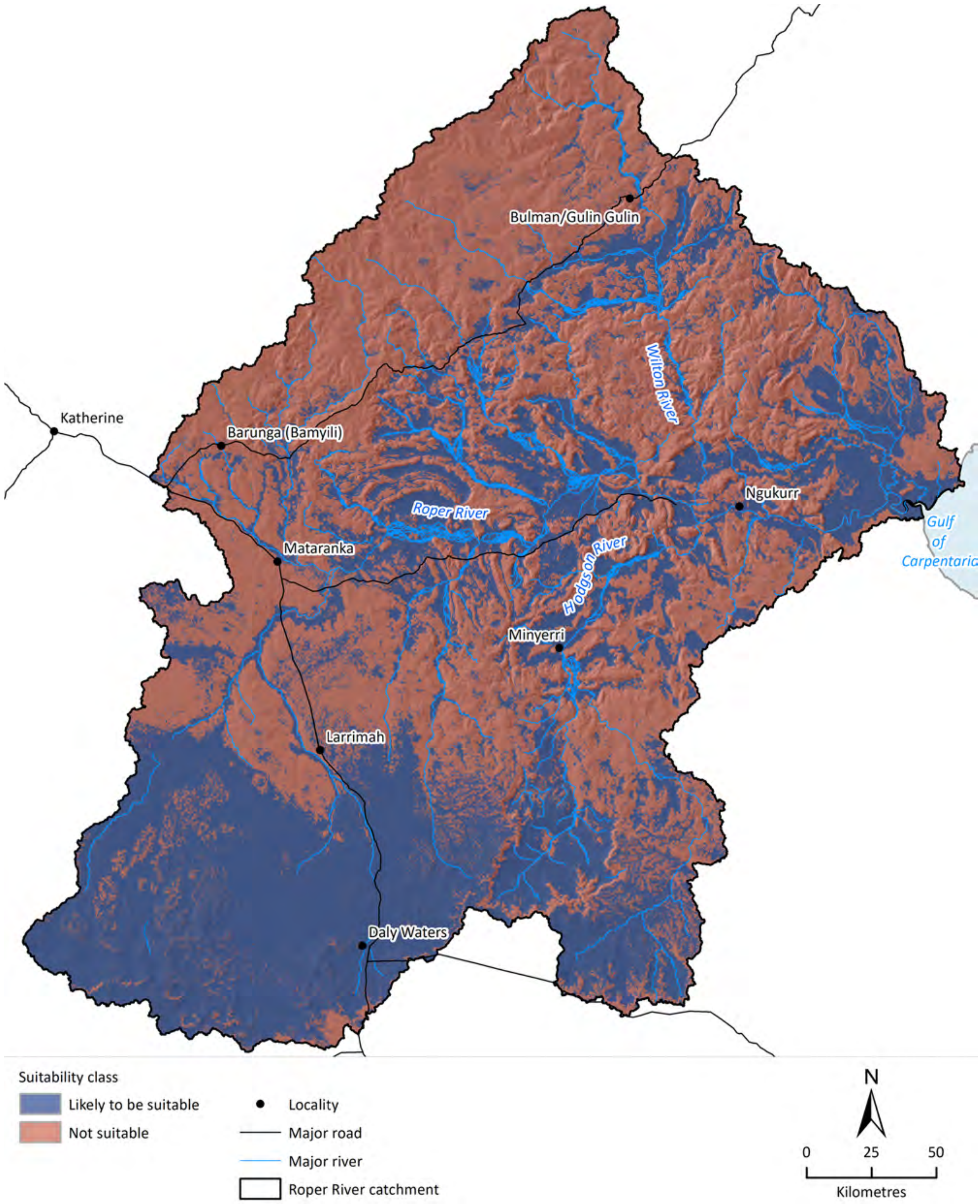

Figure 6-5 Suitability of soils for construction of gully dams

6.2.2 Indicative capital, operation and maintenance costs of farm-scale gully and hillside dams

The cost of a large farm-scale gully dam will vary depending upon a range of factors including the suitability of the topography of the site, the size of the catchment area, quantity of runoff, proximity of site to good-quality clay, availability of durable rock in the upper bank for a spillway and the size of the embankment. The height of the embankment, in particular, has a strong influence on cost. An earth dam to a height of 8 m is about 3.3 times more expensive to construct than a 4 m high dam. A dam to a height of 16 m will require 3.6 times more material than the 8 m high version, but the cost may be more than five times greater, depending on design and construction complexity (Benjamin, 2018).

Performance and cost of three hypothetical farm-scale gully dams in northern Australia

Table 6-5 summarises the key parameters for three hypothetical farm-scale gully dam configurations of with a capacity of 4 GL, and Table 6-6 provides a high-level breakdown of the major components of the capital costs for each configuration. Detailed costs for the three sites are provided in the companion technical report on large farm-scale dams (Benjamin, 2018).

Table 6-5 Cost of three hypothetical farm-scale gully dams of 4 GL capacity

Costs include government permits and fees, investigation and design, and fish passage. For a complete list of costs and assumptions, see the companion technical report on farm-scale dams (Benjamin, 2018). Costs are indexed to 2021.

SITE DESCRIPTION/ CONFIGURATION	CATCHMENT AREA (KM^2)	EMBANK -MENT HEIGHT (M)	EMBANK -MENT LENGTH (M)	S:E RATIO	MEAN DEPTH (M)	RESERVOIR SURFACE AREA (HA)	TOTAL CAPITAL COST ($)	O&M COST ($)
Favourable site with large catchment, suitable topography and simple spillway (e.g. natural saddle)	30	9.5	1100	29:1	5.0	80	1,380,000	60,000
Unfavourable site with small catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)	15	14	750	21:1	6.3	63	1,590,000	38,000
Unfavourable site with moderate catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)	20	14	750	21:1	6.3	63	1,670,000	43,000

Table 6-6 High-level breakdown of capital costs for three hypothetical farm-scale gully dams of 4 GL capacity

Earthworks include vegetation clearing, mobilisation and demobilisation of equipment, and contractor accommodation. Investigation and design fees include design and investigation of fish passage device and failure impact assessment (i.e. investigation of possible existence of fish population at risk downstream of site). Costs are based on experience in north Queensland – costs associated with government permits and fees in NT may differ. For a complete list of costs and assumptions, see the companion technical report on farm-scale dams (Benjamin, 2018). Costs are indexed to 2021.

SITE DESCRIPTION/CONFIGURATION	EARTHWORKS ($)	GOVERNMENT PERMITS AND FEES ($)	INVESTIGATION AND DESIGN FEES ($)	TOTAL CAPITAL COST ($)
Favourable site with large catchment, suitable topography and simple spillway (e.g. natural saddle)	1,247,000	40,000	93,000	1,380,000
Unfavourable site with small catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)	1,446,000	43,000	101,000	1,590,000
Unfavourable site with moderate catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)	1,526,000	43,000	101,000	1,670,000

Table 6-7 presents calculations of the effective volume for three configurations of 4-GL capacity gully dams (varying mean water depth/embankment height) for combinations of three seepage losses and water storage over three time periods in the Roper catchment.

Table 6-7 Effective volumes and cost per ML for three 4 GL storages with different mean depths and seepage loss rates near the Waterhouse River in the Roper catchment

Evaporation and seepage losses assumed to occur over 70% of the reservoir surface area.

AVERAGE DEPTH AND RESERVOIR SURFACE AREA	CON-STRUCTION COST ($)	COST ($/ML)	SEEPAGE LOSS (MM/D)	EFFECTIVE VOLUME (ML)	EFFECTIVE VOLUME AS PERCENT-AGE OF CAPACITY (%)	EFFECTIVE VOLUME (ML)	EFFECTIVE VOLUME AS PERCENT-AGE OF CAPACITY (%)	EFFECTIVE VOLUME (ML)	EFFECTIVE VOLUME AS PERCENT-AGE OF CAPACITY (%)
					5 months (April to August)		7 months (April to October)		10 months (April to January)
3 m and 133 ha	1,067,000	250	1	3131	78	2693	67	2394	60
	1,067,000	250	2	2990	75	2495	62	2111	53
	1,067,000	250	5	2566	64	1901	48	1260	31
6 m and 66 ha	1,614,000	375	1	3567	89	3348	84	3198	80
	1,614,000	375	2	3497	87	3250	81	3058	76
	1,614,000	375	5	3287	82	2956	74	2637	66
9 m and 44 ha	2,152,000	500	1	3707	93	3559	89	3457	86
	2,152,000	500	2	3660	91	3493	87	3362	84
	2,152,000	500	5	3518	88	3295	82	3078	77

Table 6-8 presents cost information for three hypothetical farm-scale gully dams and Table 6-9 explores the sensitivity of equivalent annual unit cost of three hypothetical farm-scale gully dams to changes in seepage rate and time of water storage.

Table 6-8 Cost of construction and operation of three hypothetical farm-scale gully dams of 4 GL capacity

Assumes operation and maintenance (O&M) cost of 3% of capital cost and a 7% discount rate. Figures have been rounded.

AVERAGE DEPTH AND RESERVOIR SURFACE AREA	ITEM	CAPITAL COST ($)	ANNUALISED CAPITAL COST ($)	ANNUAL O&M COST ($)	EQUIVALENT ANNUAL COST ($/Y)
3 m and 133 ha	Low embankment wide gully dam	1,076,000	92,300	30,000	124,600
6 m and 66 ha	Moderate embankment gully dam	1,614,000	138,500	45,000	186,900
9 m and 44 ha	High embankment narrow gully dam	2,152,000	184,700	60,000	249,200

Table 6-9 Equivalent annualised cost and effective volume for three hypothetical farm-scale gully dams of 4 GL capacity near the Waterhouse River in the Roper catchment

Dam details are in Table 6-8. Annual cost assumes a 7% discount rate.

AVERAGE DEPTH AND RESERVOIR SURFACE AREA	EQUIVALENT ANNUAL COST ($/Y)	SEEPAGE LOSS (MM/D)	UNIT COST ($/ML)	EQUIVALENT ANNUAL UNIT COST ($/Y PER ML/Y)	UNIT COST ($/ML)	EQUIVALENT ANNUAL UNIT COST ($/Y PER ML/Y)	UNIT COST ($/ML)	EQUIVALENT ANNUAL UNIT COST ($/Y PER ML/Y)
				5 months (April to August)		**7 months (April to October)**		**10 months (April to January)**
3 m and 133 ha	124,600	1	344	40	400	46	449	52
	124,600	2	360	42	431	50	510	59
	124,600	5	419	49	566	66	854	99
6 m and 66 ha	186,900	1	453	52	482	56	505	58
	186,900	2	462	53	497	58	528	61
	186,900	5	491	57	546	63	612	71
9 m and 44 ha	249,200	1	581	67	605	70	623	72
	249,200	2	588	68	616	71	640	74
	249,200	5	612	71	653	76	699	81

Where the topography is suitable for large farm-scale gully dams and a natural spillway is present, large farm-scale gully dams are typically cheaper to construct than ringtanks.

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Part III Scheme-scale reticulation infrastructure

7 Potential reticulated infrastructure and irrigation development

This chapter examines the scope for broad-scale irrigation developments serviced by the two short-listed dam sites described in sections 4.1 and 4.2. The digital soil modelling and land suitability analysis (Thomas et al., 2022) indicates that relatively limited soils are serviced directly by either storage site, so selection of the area served has been undertaken using the following principles:

- Aggregation of suitable soils. The focus has been on areas with aggregations of suitable soils rather than isolated patches of suitable soils. The main target of potential development will be the alluvium adjacent to the streams being impounded, downstream of the storage site.
- Proximity to source. The two short-listed storages are relatively modest in size. Proximity is important for two main reasons: (i) it limits the capital cost of transfer infrastructure to get the water from the source impoundment, whether by connector pipeline or channel, or downstream regulating structure and re-lift, and (ii) it limits losses in transferring the water from source to point of use in all cases other than the fully piped option.
- Compatibility to topography. Both short-listed storages are in sections of the river where the stream is relatively incised, and hence distribution of water by realising it downstream or by channel conveyance will only potentially serve areas further down the catchment. Distribution of water from the storages by pipeline has the potential to reach adjacent catchments, but at the expense of additional re-lift pumping.
- Compatibility with a range of crop types. Preference will be given to soils suitable for a range of crop types rather than soils suitable for a limited suite of crops.

The inescapable conclusion for both short-listed dam sites is that the potential for irrigation development in the immediate proximity to the dam sites is limited. Therefore, the means of conveyance of water from the storage to the development site will be the most crucial consideration in both cases.

7.1 Learnings from other northern Australian Irrigation Developments relevant to potential Gulf developments

A number of larger-scale irrigation developments in northern Australia in recent decades hold potential lessons for any potential irrigation development in the Roper catchment or elsewhere across the north. The following discussion draws on such lessons from four schemes:

- Emerald Irrigation Scheme, Central Queensland – both in-situ derived basaltic soils and associated alluvial deposits along the Nogoa River
- Burdekin Irrigation Scheme, north Queensland – a range of soil types on the Burdekin and Haughton River floodplain, and associated upslope areas
- Ord Stage 2, Kimberley region of WA – mostly clay alluvium deposits on the Weaber Plain

- Cane supplementation schemes, in particular Pioneer Valley Water Board and Proserpine Water Board – pumping from rivers and piped reticulation.

Pumping pools are important for any river re-lift pumps to ensure adequate submergence and avoid complications from flood siltation. Since the total river flow for a good proportion of the year will only comprise the irrigation releases – and is likely to only average some 900 ML/day at the dam and be decreasing downstream – providing adequate submergence will normally mean either a flow constriction or a constructed re-regulating weir. As some options could potentially be served by each parcel having its own pump site, this submergence requirement will be a major limitation.

Infrastructure must be aligned to cater for flood flows in internal and adjacent catchments. This is more of an issue for schemes involving open flow reticulation, rather than piped and pumped schemes, but will apply to some degree to all schemes.

Farm units are best shaped by existing topography and soils distribution. This is especially the case for spray systems, as spray system design can cater for reasonably irregular layouts.

Hydrogeology is critical to long-term sustainability. That is, any irrigation system must have a mechanism to cater for the increased accessions to groundwater that are an unavoidable part of irrigation. This is mainly because accessions from rainfall are greater in the areas under irrigation than in dryland, due to the higher mean antecedent moisture profile in the soil. In this situation, riparian lands, above but adjacent to a river system are normally better for irrigated agriculture than isolated lands without drainage incisions. Natural country slope also plays a part in this requirement.

Water use efficiency needs to be designed at the start. For example open reticulation system should be designed with control structures, overflows and be implemented with Total Channel Control technology etc. Long systems involving substantial travel time can be inefficient and waste valuable water in operational overflows if the above components are not included.

7.2 Areas serviced by the potential dam site on the Waterhouse River ATMD 70.5 km

This site has the potential to serve up to 10,150 ha, based on the following assumptions:

- dam yield at 85% annual reliability: ~90 GL/year
- crop demand assuming dry-season field crops or perennial trees under spray: 8 ML/ha
- irrigation efficiency for spray application: 85%
- irrigation efficiency for trickle application: 90%
- distribution efficiency for open-channel distribution: 80%
- distribution efficiency for piped reticulation: 98%
- river reticulation efficiency: 80%
- percentage of gross area irrigated: 95%.

Targeted gross areas are therefore between 7,800 ha and 10,141 ha, depending on crop type, irrigation method and reticulation arrangement.

The soils downstream of the potential Waterhouse River dam site can be characterised as follows:

- Soils suitable for a broad range of cropping options are limited in the immediate vicinity of the dam site. The closest large contiguous areas of suitable soils are immediately to the north and east of Mataranka, some 55 km from the potential dam site.
- Areas closer to the dam site exist in two main configurations: some areas adjacent to the river are in reasonably contiguous parcels, and a significant block of land along the Waterhouse River West Branch is geographically close to the dam but in an adjacent catchment.
- Soils targeted for development are mapped by the digital soils mapping as predominantly SGG4.1 red loamy soils and SGG 2 friable non-cracking clay or clay loam soils. These are rated as suitability class 2 or 3 for a broad range of dry-season crops under spray, with less suitability to wet-season cropping or furrow application. The soils are particularly suited to perennial tree crops, dry-season cultivation of intensive horticulture and root crops under trickle and to a lesser extent spray, grain and fibre crops under spray, small-seeded crops, pulse crops, and forage crops under spray.

Three development themes are possible for use of the water from this potential dam site, namely:

- riparian development of suitable soils, extending as far as required to achieve the targeted gross areas described above
- development of the area along Waterhouse River West Branch as well as sufficient lands adjacent to the main Waterhouse River downstream of the dam to achieve the targeted gross areas described above
- release of water into the Waterhouse River with a re-regulating structure at a major re-lift point near Mataranka to allow development of the major contiguous areas of suitable soils.

Each option has some advantages and disadvantages, as summarised in Table 7-1.

Table 7-1 Advantages and disadvantages of the three development options

DEVELOPMENT THEMES	ADVANTAGES	DISADVANTAGES
Theme 1: Riparian development on Waterhouse River	Some of the target areas are relatively close to the dam.	Majority of target areas are a long way downstream, meaning expensive reticulation, or significant losses if reticulation is not piped. Soil types are a mixture of red loamy soils and friable non-cracking clays or clay loamy soils, so will require more management than the more uniform area downstream.
Theme 2: Waterhouse River West Branch lands plus Theme 1 areas	Gives access to large contiguous areas in relative proximity to the dam.	Has the same soil complexity as the Theme 1 areas. The larger area to the west of the Waterhouse West Branch will require some form of re-lift pumping, and a very extensive pipe network.
Theme 3: Re-regulating structure near Mataranka	Has access to more uniform areas of red loamy soils. This option will have better existing road connections than the other two themes do.	Will require a significant structure in the river, and multiple pump stations. The first suitable areas close to the river are upstream of the Waterhouse River – Roper River junction east of Mataranka town. Below this area, while significant areas of suitable soils exist, they are not near the river.

Another factor to consider in evaluating the development themes will be the mechanism for transferal of water from the potential Waterhouse River dam site to the demand areas.

Theme 1 would allow either a piped reticulation, or a combined channel and pipe system, where pipes are used to cross the river from a channel system on the west bank of the Waterhouse River. The overall river gradient from the dam site to the head of the last block served is approximately 1 m/km, making a piped system potentially economically viable compared to an equivalent capacity open channel system, which would have to be membrane lined in these soil types. Other factors against an open channel solution are the number of cross-drainage facilities required and the large number of control and drop structures required to cater for that slope.

Theme 2 would potentially have to be mostly fully piped, and the section on the Waterhouse West Branch would require a lateral pipeline of about 13 km overall length, with in-line boosting to reach the elevations required. However the main reticulation on the east bank would have to extend to at least point L in Figure 7-1 to serve an area equivalent to that of Theme 1.

Theme 3 would require a re-regulating weir at the head of the best aggregation of suitable soils. There are two main options for this.

The first is a site some 43.5 km downstream of the potential dam, where there is a single section of stream after a braided reach and suitable soils on either bank. However, the area serviced from this re-regulation point would be segmented, and strung out along the river, in much the same manner as Theme 1 above. There are no major inflows to this reach, so all river releases would be subject to instream losses, with no opportunity for water yield increases due to storages operating in conjunction.

The second option is much further downstream, just after the junction of the Roper River and Elsey Creek. This option opens up the opportunity of serving the largest area of contiguous Class 2 soils, but all will require re-lifting from the Roper River. Depending on the area served, this re-lift would have to be to 10 km long and have a static lift of up to 30 m. While this pump site is 88 km from the dam, and subject to significant losses in transmission, the system does have the advantage that system yield could be increased due to the inflows from the Elsey Creek and Roper River systems. This option is not covered by the present analysis.

Given the above, the development theme chosen for further investigation is Theme 1, Riparian development on Waterhouse River via pipe reticulation.

7.2.1 Piped reticulation layout

Design of the pipe reticulation will be based on the following assumptions.

Gross area targeted will be based on:

- fully piped reticulation, based on 98% efficiency, to allow for initial filling and some minor system losses
- spray irrigation, with assumed efficiency of 85%
- net land usage of 95%, to allow for on farm infrastructure etc. It has been assumed that more detailed soils surveys may change the configuration of the suitable soils, but not the overall availability

- annual crop demand of 8 ML/ha allowing for a range of cropping options as outlined above. For the dam yield of ~90 GL/year, a net area of 9,580 ha will be targeted. This corresponds to a gross area of 10, 100 ha, made up of areas 1 to 11 in Figure 7-1.

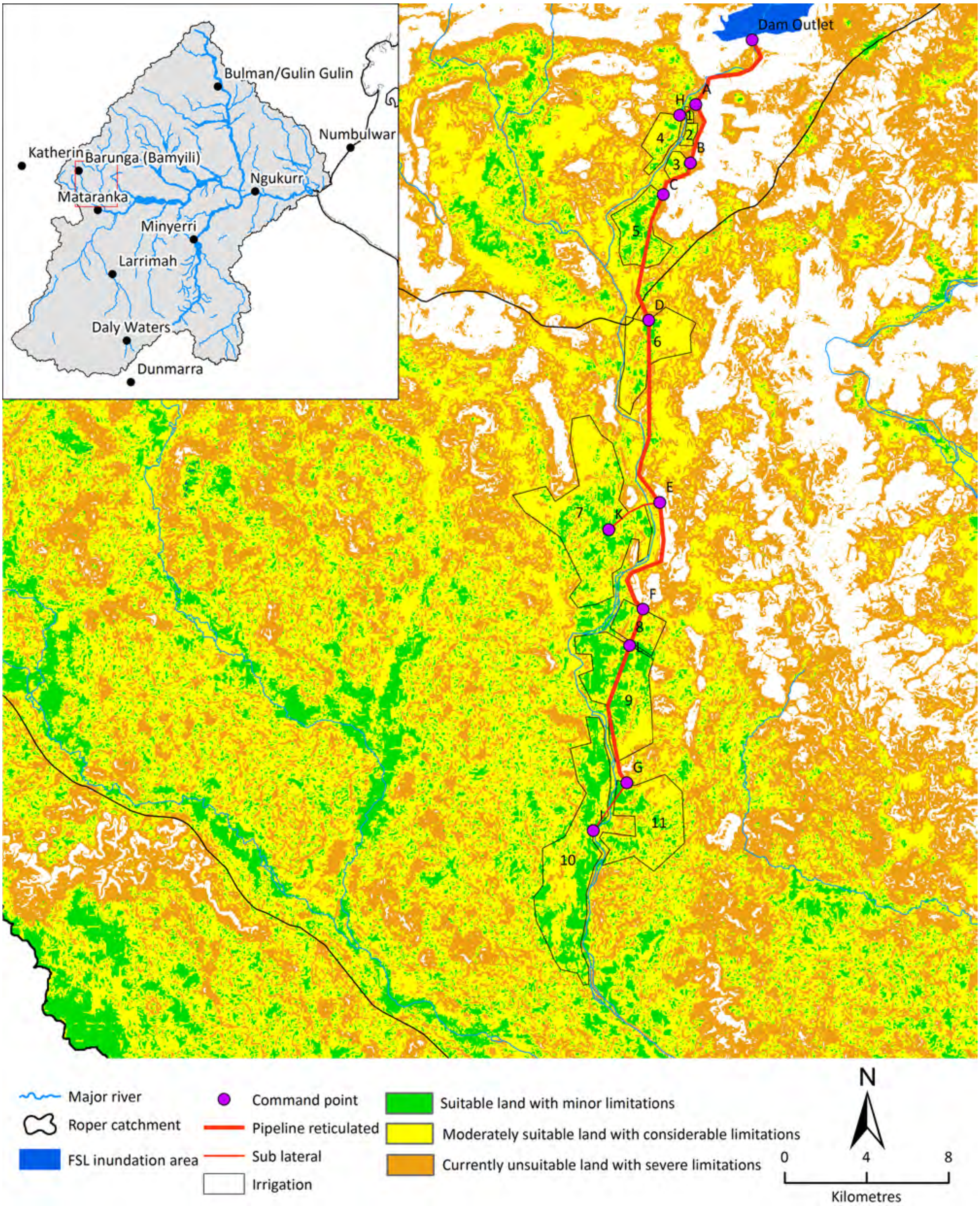


Figure 7-1 Potential piped reticulated layout

Additional assumptions are as follows:

- Daily crop demand is based on Et=p*f1*0.8*E0, where p is climate factor, assumed as 0.7, f1 is crop factor assumed as 1.0, and E0 is assumed at 11.9 mm/day, based on SILO values for Mataranka. Et is therefore 6.66 mm/day.
- Irrigation demand is 7.8 mm/day/ha, assuming spray allocation.
- No diversity factor is applied, as the total area is small and soil types reasonably uniform.
- Flowrate at the head of the system is therefore 8.71 m^3/s, with flow decreasing progressively downstream as areas are serviced.

The adopted design involves selecting pipe sizes to meet the following criteria:

- Indicative alignment as shown in Figure 7-1. This allows for command of the high point in each parcel of served land and avoids intermediate high points. Some of the parcels served are large and will presumably require further pipelines within the parcel. However, they will also require re-pressurisation at some point, which would make most sense at the top of the area. The subsequent pipelines can therefore be considered as part of the on-farm works rather than the backbone reticulation infrastructure. The exception to this is the service to parcels 7 and 10 on the west bank, where the parcels are large, and re-pressurisation would realistically be a little further down towards the centroid of the area served. In these cases, the main reticulation lines have been extended further down-slope.
- Offtake from the dam at a maximum drawdown of 5 m above bed level.
- A minimum residual head of 2 m at each of the offtake points for the 11 served areas.
- The use of glass reinforced plastic (GRP) pipe throughout, mainly driven by the large diameters required. An effective roughness of k=0.06 mm is assumed, representing an achievable long-term value. Head loss is calculated using the Colebrook–White equation.
- The design for the gravity option is summarised in Table 7-2 .

Table 7-2 Reach parameters for nominal conceptual layout of reticulation scheme

REACH	LENGTH (M)	FLOW RATE (L/SEC)	PIPE REQUIREMENTS
Dam-A	5,272	7,640	DN3000 PN10 GRP
A-B	3,102	7,340	DN2000 PN10 GRP
B-C	2,261	7,250	DN2000 PN10 GRP
C-D	6,421	6,750	DN2000 PN10 GRP
D-E	5,716	6,030	DN1900 PN10 GRP
E-F	10,076	4,000	DN2000 PN10 GRP
F-L	1,899	3,690	DN1600 PN10 GRP
L-G	7,012	2,930	DN1600 PN10 GRP
Lat A-H	952	230	DN373 DICL
Lat E-K	2,916	2,030	DN1200 PN10 GRP
Lat G-I	2,841	1,620	DN1200 PN10 GRP

Pipe reticulation costing

Preliminary costs for the above design (Table 7-3) come to $15,025.27/ha for the 9,560 ha of irrigated area.

Table 7-3 Preliminary costs for nominal conceptual layout

ITEM	COST ($)
Pipes supply and installation	105,958,000
Structures	2,259,500
Contractors overheads	5,333,000
Design and construction overheads	11,355,000
Contingency	18,736,000
Total	$143,641,500

Boosted scheme

The above scheme represents a conservative design, since the pipeline system will have excess capacity at all times when the storage is above the minimum 5 m above bed level. Another approach that makes a less conservative assumption is to assume that the storage operates by gravity at higher storage levels but is boosted by pumping at the dam outlet for lower levels. There is a practical limit to the extent this approach can be used, as the pipeline velocities get higher for higher levels of pressure boost, and consequent water hammer issues will become difficult to resolve. A 10 m boost was found to result in pipeline velocities below 2.5 m/sec, where the surge issues will be controllable.

The arrangement adopted is for a pipeline alignment identical to that adopted above, but with a booster pump arrangement at the dam outlet. This would operate so that it is only activated when pipeline pressures at the outlets fell below their prescribed value of 2 m residual head. A variable frequency drive (VFD) would allow tuning of the pump boost to the minimum required, subject to limits of the VFD's operation. The pump would feature a non-return valve in the bypass, allowing gravity operation at all other times.

Parameters for the reaches of the boosted scheme are detailed in Table 7-4. That scheme allows the use of smaller pipe diameters than are used in the gravity case above.

Table 7-4 Reach parameters for nominal conceptual layout of boosted scheme

REACH	LENGTH (M)	FLOW RATE (L/SEC)	PIPE REQUIREMENTS
Dam-A	5,272	7,640	DN2000 PN10 GRP
A-B	3,102	7,340	DN2000 PN10 GRP
B-C	2,261	7,250	DN2000 PN10 GRP
C-D	6,421	6,750	DN2000 PN10 GRP
D-E	5,716	6,030	DN2000 PN10 GRP
E-F	10,076	4,000	DN2000 PN10 GRP
F-L	1,899	3,690	DN1500 PN10 GRP
L-G	7,012	2,930	DN1500 PN10 GRP

REACH	LENGTH (M)	FLOW RATE (L/SEC)	PIPE REQUIREMENTS
Lat A-H	952	230	DN373 DICL
Lat E-K	2,916	2,030	DN1100 PN10 GRP
Lat G-I	2,841	1,620	DN1100 PN10 GRP

Boosted pipe reticulation costing

Preliminary costs for the above design (Table 7-5) come to $13,223.13 /ha for the 9,560 ha of irrigated area.

Table 7-5 Preliminary costs for nominal conceptual layout

ITEM	COST ($)
Pipes supply and installation	91,195,500
Structures	3,705,500
Contractors overheads	5,030,000
Design and construction overheads	9,993,000
Contingency	16,488,500
Total	126,412,500

Option evaluation

The only difference in the ongoing cost of the two reticulated options described above is the operation of the pump station. There is about $17 million difference in the capital cost of the two schemes. Since the proportion of the dam releases that need boosting cannot easily be predicted at this time, an upper limit of these costs can be calculated by assuming that all flow has to be boosted. This indicates an NPV of below $7, meaning the boosted scheme is likely to be the more cost effective option.

7.3 Area serviced by the potential dam site on upper Flying Fox Creek ATMD 105 km

This potential dam site, on Flying Fox Creek ATMD 10 km or about 11 km north of the Central Arnhem Highway, is smaller than the potential dam site on the Waterhouse River and has a smaller water yield. Using similar criteria to that developed for the site on the Waterhouse River, it has the potential to serve up to 6,800 ha, depending on the transmission and irrigation method chosen. The major difference is that the target areas are likely to feature clay soils, and hence the soils are less versatile in terms of the range of irrigated crops compared to the sandy loamy soils downstream of the potential Waterhouse River dam site.

Calculations are based on the following assumptions:

- dam yield at 85% annual reliability: 68 GL/year
- crop demand assuming dry-season field crops: 8 ML/ha
- irrigation efficiency for spray application: 85%
- irrigation efficiency for trickle application: 90%

- irrigation efficiency for furrow irrigation: 80%
- distribution efficiency for open-channel distribution: 90%
- distribution efficiency for piped reticulation: 98%
- river reticulation efficiency: 80%
- percentage of gross area irrigated: 95%

Targeted gross areas are therefore between 5,448 ha and 6,811 ha, depending on crop type, irrigation method and reticulation arrangement.

The soils downstream of the potential upper Flying Fox Creek dam site can be characterised as follows:

- A limited area of suitable soils exists some 10 km south of the Central Arnhem Highway. However, this is a section where the river is braided into at least six channels, and most of the suitable area is within the braided sections, limiting the usefulness due to flooding risk.
- The largest aggregation of suitable soils is much further downstream, some 42 km south of the Arnhem Highway, where the creek runs to the northern side of a large area of clay soils.
- Soils targeted for development are mapped by the digital soil modelling (Thomas et al., 2022) as predominantly SGG 2 friable non-cracking clay or clay loam soils and SGG 9 cracking clay soils. These are rated as suitability Class 3 for a broad range of dry-season crops under spray and furrow, with less suitability to wet-season cropping. They are particularly suited to dry-season cultivation of intensive horticulture under trickle and to a lesser extent spray, grain and fibre crops under spray and furrow, small-seeded crops, pulse crops, and forage crops under spray. Some of the soils are also rated as suitable for wet-season cultivation of rice and industrial crops.

The major challenge in serving this area of soils is the fact that the suitable soils are some 53 km below the potential dam site. Distribution of water this far, without substantial demand on the way, will not be economical. This only leaves river distribution with a re-regulating structure as the likely mode of development. While this will result in significant losses in transmission, there is the potential to pick up additional yield from inflow from the intervening catchment, in particular that form Derim Derim Creek and Maori Creek.

The potential re-regulating structure is assumed to be located on Flying Fox Creek ATMD 36 km and is descripted in Section 5.1.1.

Other elements of the potential scheme for service of this area are:

- a pump station at the re-regulating structure able to meet the full demand of the channel distribution network
- an associated rising main, of sufficient length to (i) reach an elevation where the required area can be served by a gravity channel system, and (ii) extend far enough that the cross slope, which is very steep near the river, is flat enough to allow practical construction of an open-channel system. In practical terms, this indicates a cross slope below about one in six
- an open-channel distribution system along the western edge of the serviced area. A significant feature of this channel system will be allowance for cross drainage from the upslope catchments. This will be by way of both cross-drainage culverts and drainage overpasses

featuring inverted siphons. The former will allow the gradeline to be maintained, whereas the latter will involve a reduction in gradeline due to the head loss associated with the piped section of the inverted siphon under the overpass. Since the main limitation to this area will be wetness related to river flooding, there will be incentive to maintain the gradeline as high as possible.

Areas were chosen for development based on the following:

- suitability for a broad range of crop types; however, the base case chosen for the selection was Crop Type 7 under dry-season spray
- allowance for the drainage network that will be required to get flows from above the channel through the developed area
- a preference for regular-shaped areas that may be suited to both spray and furrow irrigation. Note that this implies the inclusion of some minor areas of Class 4 soils.

The area able to be irrigated is calculated as 5,200 ha, based on the following assumptions:

- Available water yield is assumed as 80% of 68 GL. Note that this assumes the contribution from the intervening catchments is minor, with the majority of flows released for environmental flow purposes.
- Crop demand is assumed as 8 ML/ha.
- Irrigation efficiency is assumed as 85% for spray.
- Channel distribution efficiency is assumed as 90%. Note that this reflects the relatively short system and assumes some supervisory control system, such as Total Channel Control, is implemented.

This corresponds to a gross area of some 5,485 ha, using the same 95% land usage factor as above.

The location of the serviced areas and the alignment of the channel serving these areas are shown in Figure 7-2.

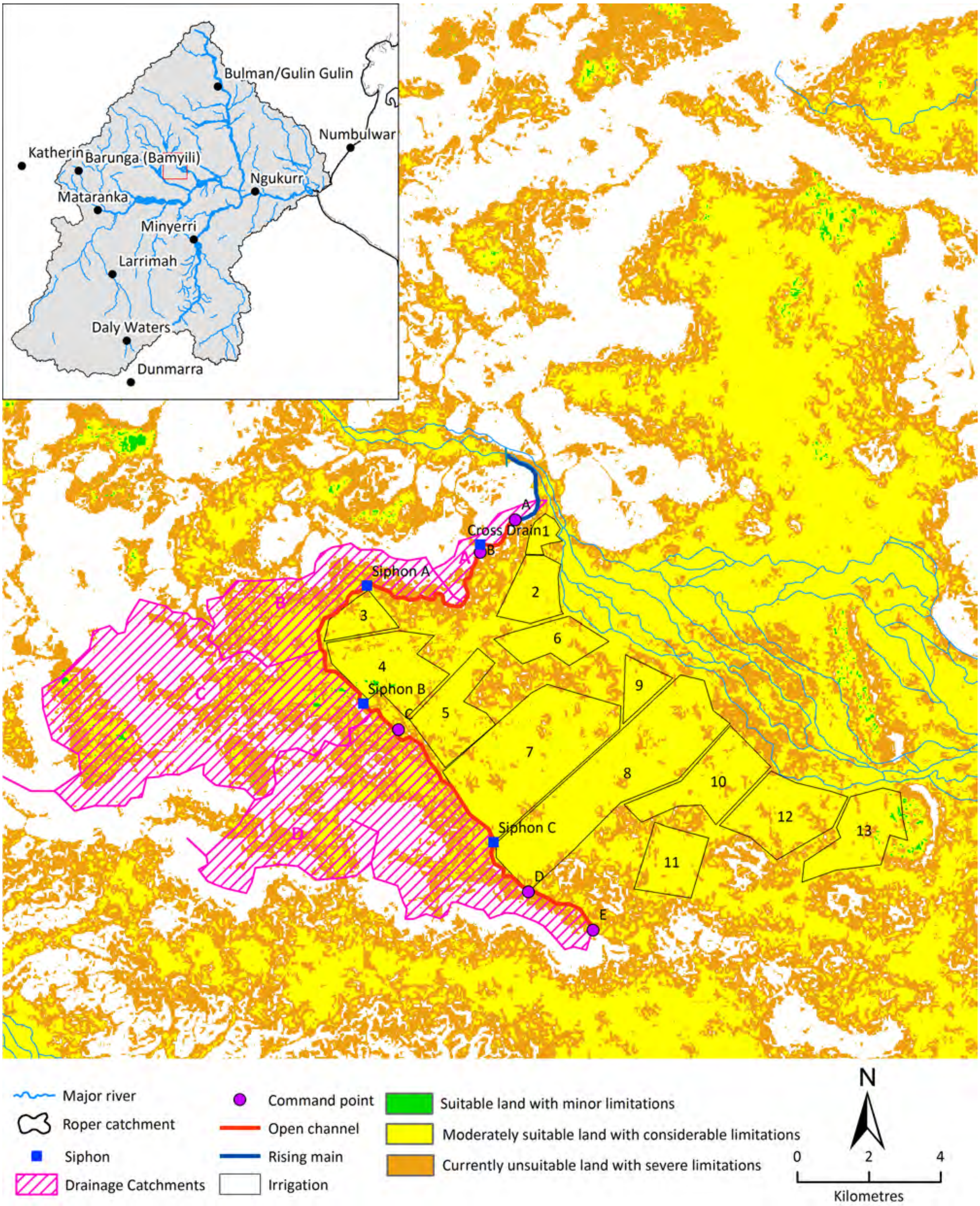


Figure 7-2 Nominal conceptual layout of potential irrigation area on Flying Fox Creek

The irrigation demand is assessed as 7.8 mm/ha/day. The capacities of the main reaches are shown in Table 7-6.

Table 7-6 Pipe parameters for nominal conceptual layout of scheme servicing soils downstream of potential dam on upper Flying Fox Creek

REACH	CHAINAGE (KM)		LENGTH (M)	AREA COMMANDED (HA)	FLOWRATE (CUMEC)
	From	To			
Rising Main	0	1.15	1,150		5.13
A-B	0	1.625	1,625	550	5.13
B-C	1.625	12.481	10,856	997	4.63
C-D	12.481	18.915	6,434	2,511	3.73
D-E	18.915	21.157	2,242	1,597	1.45
Total				5,655	

The total area shown in Table 7-6 is slightly above the gross area calculated above, but will be used for this preliminary design, to ensure the design is conservative.

Adopted channel parameters are provided in Table 7-7 based on:

- all channels being earth lined from material borrowed from adjacent sections. Some sections are in shallow, lighter-textured soils, and are assumed to be over-excavated . Given the soils distribution, this is a realistic assumption
- Manning's equation, using n = 0.04
- a bank width of 4 m, one side gravelled
- a 1:10,000 slope to maintain command over the suitable soil areas
- channel commencement at an elevation of 80 mEMG96, where the majority of the suitable soils identified can be served, and where cross falls are below one in six.

Table 7-7 Channel parameters for nominal conceptual layout of scheme servicing soils downstream of potential dam on upper Flying Fox Creek

REACH	DESIGN FLOWRATE (CUMEC)	BED WIDTH (M)	WATER DEPTH (M)	FREEBOARD (M)	SLOPE (M/KM)	VELOCITY (M/SEC)
A-B	5.13	4	2.15	0.5	0.1	0.3
B-C	4.63	4	2.0	0.5	0.1	0.29
C-D	3.73	4	1.8	0.5	0.1	0.27
D-E	1.45	3	1.5	0.4	0.1	0.24

Cross drainage will be a major consideration for this channel system, since it is essentially aligned to accrue water draining into the river system. The channel will also require a number of control points to allow the water level to be maintained at a minimum level in the channel at all times of operation, to minimise both erosion potential during increases in flow and weed growth.

Contributing catchments that need to be safely passed across the channel alignment and align with downstream drainage lines are shown in Figure 7-2. Details are provided in Table 7-8.

Table 7-8 Details of contributing catchments adjacent to main channel

CATCHMENT	AREA (SQ KM)	Q50 (M^3/S)	ADOPTED	DETAILS
A	1.925	43	Cross drain	6*DN1500
B	10.692	116	Siphon	2*DN1800
C	31.6	218	Siphon	2*DN1800
D	26.8	190	Siphon	2*DN1800

Flows for the contributing catchments are derived via the Regional Flood Frequency Estimation Model and are for a 1 in 50 AEP.

Each siphon identified above is also used as a regulation point to maintain minimum flow depths in the channel and allow for adequate flow control. Rubicon Flow Gates would be used for regulation and would be remotely controlled using the Total Channel Control technology.

The longitudinal profile adopted and the resulting hydraulic gradeline is shown in Figure 7-3. The chainages in this instance commence at the re-regulating weir.

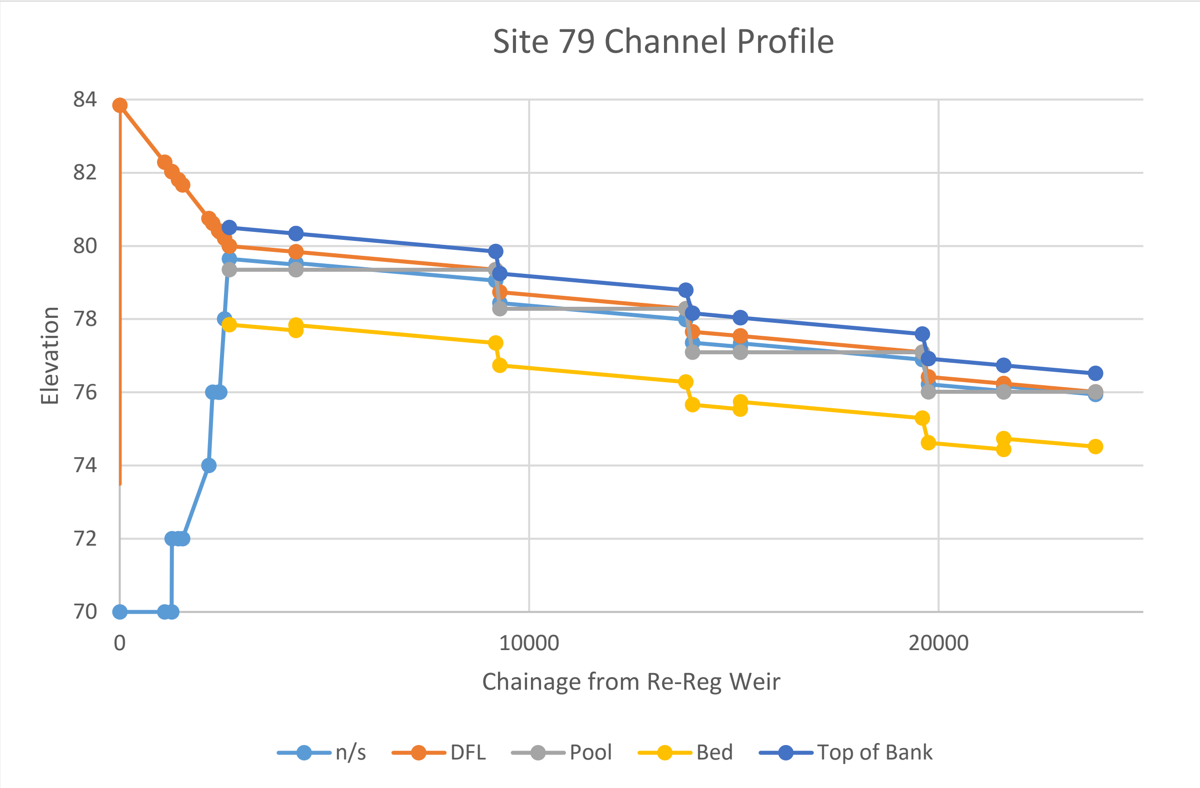


Figure 7-3 Elevation profile of channel

7.3.1 Cost estimate

Costing of the channel and associated structures is based on the following assumptions for different soil generic groups:

- Channels in SGG 7 are assumed to be fully over-excavated and lined, with rock excavation below 1 m depth.
- Channels in SGG 4 are assumed to be fully over-excavated and lined.

- Channels in SGG2 are assumed to not require lining.
- Channels in SGG9 are assumed to not require lining.
- All channels are designed for roughly balanced cut and fill, taking into account the use of excavated material in the various zones in the channel. This should be attainable by lateral movement of the channel alignment.

Costs are summarised in Table 7-9.

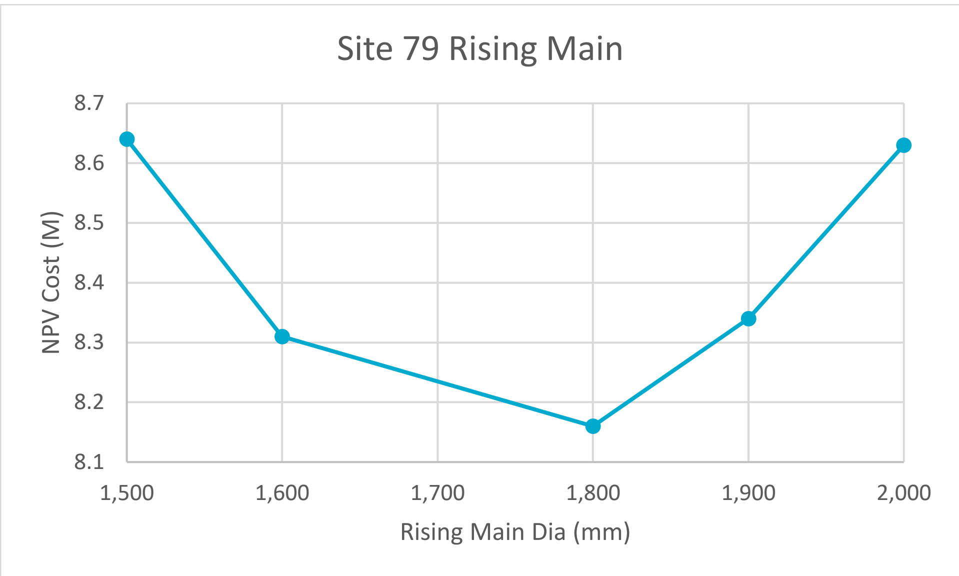
Table 7-9 Cost summary

COMPONENT	COST ($)
Channel earthworks	8,903,671
Structures	2,355,637
Contractors overheads	$,814,826
Design and construction overheads	1,407,413
Contingency	2,322,232
Total	17,803,780

7.3.2 Pump station and rising main

Rising main

As outlined above, the rising main would run from the re-regulating weir to a section on the ridge adjacent to the right bank where slopes meet the criteria above. This results in a length of rising main of 2.67 km. The rising main has been sized using a net present value approach, where the capital cost of the rising main and associated pumps is added to the amortised value of the power cost. The result is that a DN1800 PN10 GRP pipe is selected as the optimum choice. Note that due to the relatively short rising main length, the cost curves are flat and the final choice is likely to be driven by the relative tax treatment of capital and recurrent expenses by the constructing authority.



Pump station

The above analysis indicates that the pump station will require an installed capacity with:

- a flow rate of 5.13 m^3/s
- installed power of 650 kW.

The arrangement would feature two submersible units in a pump well capable of closing the inlet during major flooding events. As little information is available on the site, the costing (Table 7-10) has been based on cost functions derived from similar installations in north Queensland.

Table 7-10 Costs for the pump station and rising main

COMPONENT	COST ($)
Pipeline	5,034,206
Structures incl pump station	2,640,542
Contractors overheads	886,675
Design and construction overheads	856,142
Contingency	2,696,848
Total	12,114,413

The combined cost of both the earthworks components and the rising main and pump station is therefore some $29.9 million, equivalent to some $5,700/ha of the 5,200 ha of serviced land.

Part IV Summary comments

8 Summary comments

The relatively undeveloped state of the water resources across northern Australia represents a globally unique opportunity for governments and communities to take a long-term view to water resource development and undertake a considered evaluation of different potential development pathways, including ‘do nothing’. This report documents the results of a catchment-scale pre-feasibility assessment of surface water storage options in the Roper catchment. Larger sites were a major focus of this study as the design and construction of smaller farm-scale dams is highly site specific.

Overall the landscape of the Roper catchment is relatively subdued and as a result sites topographically suitable for dam construction are relatively uncommon. The best potential dam sites in terms of yield per unit cost are along the lower Roper River, lower Hodgson River, Wilton River and Waterhouse River, the latter two areas scheduled as Aboriginal Land under ALRA. Sites along the lower Roper River and Wilton River, while relatively high yielding by virtue of having large catchment areas, there are limited areas of contiguous soil suitable for irrigated agriculture downstream of these locations. Potential dam sites in the Roper catchment occur where resistant ridges of Proterozoic sandstone beds have been incised by the river systems and outcrop on both sides of river valleys. To the north of the Roper River the majority of the potential dam sites are located in the headwater of tributaries of the Roper River. Many of these sites and their potential irrigated areas would be difficult to access during the wet season without the construction of substantial bridge and road infrastructure. To the south of the Roper River there are few locations suitable for large dams as the topography is particularly subdued, and the better locations tend to be closer to the Roper River. The Sturt Plateau has no sites suitable for large dams. A major limitation to the use of large dams for irrigated agriculture in the Roper catchment is the disaggregated nature of soils suitable for irrigated agriculture. Few locations have moderately large contiguous areas of soils suitable for irrigation. Five potential dam sites were examined as part of a pre-feasibility analysis, four for the purpose of supplying water for irrigation and the fifth (on the Wilton River) for the purpose of hydro-electric power generation. These sites are summarised in Table 8-1.

Table 8-1 Summary comments for potential dams in the Roper catchment

NAME	SUMMARY COMMENT
Waterhouse River West Branch ATMD 70.5 km	A low yielding site on the Waterhouse River West Branch. Upstream of large areas of sandy loam soils moderately suitable for irrigated agriculture. The site is situated also on Aboriginal land scheduled under ALRA and is classified under ‘inalienable freehold title’, which means that it cannot be bought, acquired or mortgaged. Although data from the NT cultural heritage sites register were not made available to the Assessment, it is likely that the site and parts of the potential inundation area would contain cultural heritage sites of significance.
Waterhouse River ATMD 70.5 km	The Waterhouse River potential dam site has one of the highest yield to cost ratios in the upper parts of the Roper catchment. The site appears to be suitable for a roller compacted concrete type dam with a central uncontrolled spillway The potential dam site is upstream of large areas of sandy loam soils moderately suitable for irrigated agriculture. The site is situated also on Aboriginal land scheduled under ALRA and is classified under ‘inalienable freehold title’, which means that it cannot be bought, acquired or mortgaged. Although data from the NT cultural heritage sites register were not made available to the Assessment, it is likely that the site and parts of the potential inundation area would contain cultural heritage sites of significance.

NAME	SUMMARY COMMENT
Upper Flying Fox Creek ATMD 105 km	A moderately high yielding site relative to other sites in the Roper catchment that appears to be suitable for a roller compacted concrete type dam with a central uncontrolled spillway 150 m wide. There is potential for a regulating weir downstream from the storage that would enable additional inflows to be captured and allow for the more efficient use of water released from the storage. conceptual arrangement releases would be made from the storage downstream to a regulating weir for diversion by irrigators. There is a high likelihood of unrecorded cultural heritage sites in the inundation area.
Jalboi River ATMD 53 km	A low yielding site on the Jalboi River that appears to be suitable for a roller compacted concrete type dam with a central uncontrolled spillway. The potential dam site a lower yield to cost ratio that other sites selected for pre-feasibility analysis; however, it is relatively close to large areas of alluvial soils moderately suitable for irrigated agriculture. Being north of the Roper River accessing the dam site and potential irrigation areas during the wet season would be challenging without major road and bridge infrastructure. The affected area would primarily affect the Lonesome Dove pastoral lease area. There is a high likelihood of unrecorded cultural heritage sites in the inundation area.
Wilton River ATMD 33 km	A very high yield potential dam site. However, there are limited areas of land that would be suitable for irrigated agriculture downstream of the site. The site has the most suitable characteristics for a dam supplying water for hydro-electric power in the Roper catchment, however, the site is remote and there is no electricity transmission infrastructure. The site is situated also on Aboriginal land scheduled under ALRA and is classified under 'inalienable freehold title', which means that it cannot be bought, acquired or mortgaged. Although data from the NT cultural heritage sites register were not made available to the Assessment, it is highly likely that the site and parts of the potential inundation area would contain cultural heritage sites of significance.

In the Roper catchment land suitable for siting farm-scale offstream storages is limited in extent and geographically constrained to the alluvial soils adjacent to the Roper River and its major tributaries. In many of the better locations broad-scale flooding may be a concern, which may make access and wet season cropping challenging. In the Roper catchment the largest contiguous areas likely to be suitable for siting offstream storages were along the recent alluvium of the Roper River.

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Part V Appendices

Appendix A Detailed costings for short-listed dam sites in the Roper catchment

A.1 Potential dam site on the Waterhouse River ATMD 70.5 km

Apx Table A-1 Potential dam site on the Waterhouse River ATMD 70.5 km - direct construction costs

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
General				
Environmental management	Lump sum			2,000,000
Cultural heritage management	Lump sum			600,000
Community consultation	Lump sum			200,000
Mobilisation and demobilisation				
Establishment of workforce accommodation	Lump sum			6.000,000
Establishment of survey control	Lump sum			500,000
Establish construction power supply (temporary)	Lump sum			2,500,000
Establish communications	Lump sum			250,000
Mobilisation of major plant	Lump sum			3,500,000
Demobilisation of major plant	Lump sum			875,000
Demobilisation of workforce accommodation	Lump sum			1,800,000
Clear site and 50% of storage area	ha	1,720	2,800	4,816,000
Mobilize/demobilise site laboratory	Lump sum			400,000
Access				
Access road to site from Central Arnhem Highway	km	15	1,150,000	17,250,000
Establish site access roads	Lump sum			2,000,000
Rehabilitation of roads on construction completion	Lump sum			1,500,000
Construction				
Material sources				
Remove quarry overburden	Lump sum			300,000
Develop quarry	Lump sum			450,000
Access road to quarry	km	2	700,000	1,400,000
Access road to sand gravel sources	km	5	700,000	3,500,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Diversion and care of river				
Excavate LB diversion channel (rock)	cu m	17,500	60	1,050,000
Excavation for coffer dams	cu m	4,760	20	95,000
Place material for coffer dams	cu m	17,750	30	532,000
Dewatering	Lump sum			350,000
Divert river	Lump sum			400,000
Removal of coffer dams	cu m	17,750	25	444,000
Foundations cross river section				
Excavate sand from river bed	cu m	8,890	15	133,000
Excavate rock from abutments and bed	cu m	57,645	50	2,882,000
Detailed excavation	cu m	1,000	250	250,000
Detailed clean up	sq m	11,020	130	1,433,000
Dental concrete	cu m	1,000	800	800,000
Foundation grouting cross river section				
Concrete to grouting plinth	cu m	1,072	800	858,000
Reinforcement to grout plinth	tonne	43	5,500	235,000
Drill grout holes	m	5,220	100	522,000
Supply and install standpipes	no	480	200	96,000
Hook ups and pressure tests	no	564	200	113,000
Pressure grouting	bags	10,440	50	522,000
RCC dam river section				
Mobilise RCC placement plant	Lump sum			3,500,000
De mobilise RCC placement plant	Lump sum			1,050,000
Trial mixes	Lump sum			400,000
Diversion channel plug	cu m	2,640	700	1,848,000
Conventional concrete to faces	cu m	9,680	800	7,744,000
RCC concrete to dam wall	cu m	68,775	535	36,795,000
Gallery floor units and precast slabs	m	146	4,000	584,000
Conventional concrete to spillway crest	cu m	900	1,800	1,620,000
Reinforcement to spillway crest	tonne	36	7,000	252,000
Conventional concrete to spillway crest	cu m	1,200	800	960,000
Reinforcement to spillway apron	tonne	48	6,000	288,000
Conventional concrete to end sill	cu m	253	1,500	380,000
Reinforcement to end sill	tonne	15	7,000	105,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Drill holes for apron anchors	m	1,680	150	252,000
Supply and install apron anchors	tonnes	11	7,000	77,000
Conventional concrete to training walls	cu m	1,234	1,700	2,098,000
Reinforcement to training walls	m	74	7,500	555,000
Drill drainage holes	m	384	150	58,000
Water stops - supply and install	m	370	200	740,000
Backfill on abutments	cu m	3,580	50	179,000
Instrumentation HW/TW recorders etc	Lump sum			200,000
Miscellaneous metalwork	Lump sum			100,000
Outlet works				
Intake tower concrete	cu m	262	2,000	524,000
Intake tower reinforcement	tonne	15	8,000	120,000
Intake tower guides and seals	Lump sum			300,000
Trashracks	item	12	40,000	480,000
Selective withdrawal baulks	item	12	30,000	360,000
Bulkhead gate	Lump sum			160,000
Hoist crane, install and commission	Lump sum			200,000
Ladders and platforms	Lump sum			200,000
Supply and install 1,200 mm dia outlet conduits	tonne	70	14,000	980,000
Outlet conduits concrete encasement	cu m	168	2,000	336,000
Outlet conduits concrete reinforcement	tonne	7	8,000	56,000
Valve house concrete	cu m	140	2,000	280,000
Valve house reinforcement	tonne	5.6	8,000	45,000
Outlet works pipework	Lump sum			350,000
Butterfly valves and actuators	no	2	200,000	400,000
Fixed cone regulating valves	no	2	250,000	500,000
Outlet works hoist crane	Lump sum			150,000
Electrical hydraulic installations	Lump sum			300,000
Fish transfer facility				
Concrete to intake channels, hopper chamber and valve pit	cu m	500	2,000	1,000,000
Reinforcement to intake channels, hopper chamber and valve pit	tonne	25	8,000	200,000
Fish attraction pipework, valves and diffusers	Lump sum			500,000
Fish traps	Lump sum			250,000
Fish lift hopper	no			250,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Hopper tracks	Lump sum			300,000
Overhead crane at crest	Lump sum			350,000
Monitoring equipment	Lump sum			300,000
Electrical and mechanical installations	Lump sum			300,000
Fish lift commissioning	Lump sum			400,000
Permanent downstream access crossing	Lump sum			2,500,000
Total direct construction costs (TDC)				126,432,000

Apx Table A-2 Potential dam site on the Waterhouse River ATMD 70.5 km – on site costs

ON SITE COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Project and field staff	Lump sum	3% of TDC		3,792,960
Staff recruitment and training	Lump sum	0.6% of TDC		758,592
Camp operations	Lump sum	3.5% of TDC		4,425,120
Site office expenses	Lump sum	0.6% of TDC		758,592
Site water services	Lump sum	0.06% of TDC		75,859
Operating cost temporary power supply	Lump sum			2,250,000
Site communication, IT expenses	Lump sum	0.45% of TDC		568,944
Site cleaning, rubbish removal	Lump sum	0.04% of TDC		50,573
Project control testing	Lump sum			650,000
Misc. travel expenses	Lump sum	0.2% of TDC		252,864
Insurances, public liability	Lump sum	3.4% OF TDC		4,298,688
Total on site overheads (OSO)				17,882,192
Total direct and on site overhead costs				144,314,192
Profit and off site overheads 10% of TDC and OSO				14,431,419
Total Out Turn Costs (TOC)				158,745,611

Apx Table A-3 Potential dam site on the Waterhouse River ATMD 70.5 km – owner costs

OWNERS COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Investigation and design				
Preliminary design	Lump sum	0.5% of TDC		632,160
Geotechnical and materials	Lump sum	2.0% of TDC		2,528,640
Hydraulic model study	Lump sum			750,000
Detailed design and documentation	Lump sum	2.5%of TDC		3,160,800
Acquisition and Approvals				
Environmental assessment and approvals	Lump sum			4,000,000
Cultural heritage	Lump sum			3,000,000
Native title	Lump sum			500,000
Storage area acquisition	ha	5,400	750	4,050,000
Storage area access relocations	Lump sum			500,000
Surveys and legals	Lump sum			500,000
Permanent onsite buildings and services	Lump sum			500,000
Principal's insurances (1.1% of TOC)	Lump sum			1,746,202
Owners management and supervision (0.15% of TOC)	Lump sum			238,118
Total owners costs				22,105,920

A.2 Potential dam site on the Flying Fox Creek ATMD 105 km

Apx Table A-4 Potential dam site on the Flying Fox Creek ATMD 105 km – direct construction costs

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
General				
Environmental management	Lump sum			2,000,000
Cultural heritage management	Lump sum			400,000
Community consultation	Lump sum			200,000
Mobilisation and demobilisation				
Establishment of workforce accommodation	Lump sum			6,500,000
Establishment of survey control	Lump sum			300,000
Establish construction power supply (temporary)	Lump sum			2,500,000
Establish communications	Lump sum			500,000
Mobilisation of major plant	Lump sum			4,000,000
Demobilisation of major plant	Lump sum			875,000
Demobilisation of workforce accommodation	Lump sum			1,800,000
Clear site and 50% of storage area	ha	885	3,000	2,655,000
Mobilise/demobilise site laboratory	Lump sum			400,000
Access				
Access to site from Central Arnhem Highway	km	10	1,150,000	11,500,000
Establish site access roads	Lump sum			2.000.000
Rehabilitation of roads on construction completion	Lump sum			1.500.000
Construction				
Material sources				
Remove quarry overburden	Lump sum			350,000
Develop quarry	Lump sum			500,000
Access road to quarry	km	2	700,000	1,400,000
Access road to sand gravel sources	km	5	700,000	3,500,000
Diversion and care of river				
Excavate LB diversion channel (rock)	cu m	18,240	60	1.094.000
Excavation for coffer dams	cu m	15,770	17.5	276,000
Place material for coffer dams	cu m	49,700	30	1,491,000
Dewatering	Lump sum			450,000
Divert river	Lump sum			400,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Removal of coffer dams	cu m	49,700	20	994,000
Foundation excavation and treatment				
Excavate sand from river bed	cu m	18,000	15	270,000
Excavate rock from bed and abutments	cu m	55,460	50	2,773,000
Detailed excavation	cu m	1,000	250	250,000
Detailed clean up	sq m	9,320	130	1,212,000
Dental concrete	cu m	1,000	800	800,000
Foundation grouting cross river section				
Concrete to grouting plinth	cu m	788	800	630,000
Reinforcement to grout plinth	tonne	32	6,000	192,000
Drill grout holes	m	5,290	100	529,000
Supply and install standpipes	no	350	200	70,000
Hook ups and pressure tests	no	690	200	138,000
Pressure grouting	bags	10,580	50	529,000
RCC dam river section				
Mobilise RCC placement plant	Lump sum			4,000,000
De mobilise RCC placement plant	Lump sum			1,200,000
Trial mixes	Lump sum			400,000
Diversion channel plug	cu m	2,640	700	1,848,000
Conventional concrete to faces	cu m	19,465	775	15,085,000
RCC concrete to dam wall	cu m	130,275	500	65,138,000
Gallery floor units and precast slabs	m	350	3,500	1,225,000
Conventional concrete to spillway crest	cu m	1,800	1,750	3,150,000
Reinforcement to spillway crest	tonne	72	7,000	504,000
Conventional concrete to spillway apron	cu m	2,400	800	1,920,000
Reinforcement to spillway apron	tonne	96	6,000	576,000
Conventional concrete to end sill	cu m	506	1,400	708,000
Reinforcement to end sill	tonne	30	7,000	210,000
Drill holes for apron anchors	m	2,880	150	432,000
Supply and install apron anchors	tonnes	21	7,000	147,000
Conventional concrete to training walls	cu m	1,234	1,700	2,098,000
Reinforcement to training walls	tonne	74	7,500	555,000
Drill drainage holes	m	975	150	145,000
Water stops - supply and install	m	645	200	129,000
Backfill on abutments	cu m	3,220	50	161,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Instrumentation HW/TW recorders etc	Lump sum			250,000
Miscellaneous metalwork	Lump sum			150,000
Outlet works				
Intake tower concrete	cu m	262	2,000	524,000
Intake tower reinforcement	tonne	15	8,000	120,000
Intake tower guides and seals	Lump sum			300,000
Trashracks	item	12	40,000	480,000
Selective withdrawal baulks	item	12	30,000	360,000
Bulkhead gate	Lump sum			160,000
Hoist crane, supply, install and commission	Lump sum			200,000
Ladders and platforms	Lump sum			200,000
Supply and install 1200 mm dia outlet conduits	tonnes	70	14,000	980,000
Place concrete surround	cu m	168	2,000	336,000
Reinforcement to concrete surround	tonnes	7	8,000	56,000
Supply and install 1200 mm dia butterfly guard valves	Item	2	200,000	400,000
Supply and install 900 mm dia regulating valves	Item	2	250,000	500,000
Valve house pipework	Lump sum			350,000
Valve house concrete	cu m	140	2,000	280,000
Reinforcement to valve house	tonne	5.6	8,000	45,000
Electrical mechanical installations	Lump sum			100,000
Hoist crane, supply, install and commission	Lump sum			150,000
Fish transfer facility				
Concrete to intake channels, hopper chamber and valve pit	cu m	500	2,000	1,000,000
Reinforcement to intake channels, hopper chamber and valve pit	tonne	25	8,000	200,000
Fish attraction pipework, valves and diffusers	Lump sum			500,000
Fish traps	Lump sum			250,000
Fish lift hopper	Lump sum			250,000
Hopper tracks	Lump sum			300,000
Overhead crane at crest	Lump sum			350,000
Monitoring equipment	Lump sum			300,000
Electrical and mechanical installations	Lump sum			300,000
Fish lift commissioning	Lump sum			400,000
Permanent downstream crossing	Lump sum			4,000,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Total direct construction costs (TDC)				163,806,000

Apx Table A-5 Potential dam site on the Flying Fox Creek ATMD 105 km – on site overheads

ON SITE OVERHEAD	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
ON SITE OVERHEADS				
Project and field staff	Lump sum	3% of TDC		4,914,180
Staff recruitment and training	Lump sum	0.6% of TDC		982,836
Camp operations	Lump sum	3.5% of TDC		5,733,210
Site office expenses	Lump sum	0.6% of TDC		982,836
Site water services	Lump sum	0.06% of TDC		98,284
Operating cost temporary power supply	Lump sum			2,500,000
Site communication, IT expenses	Lump sum	0.45% of TDC		737,127
Site cleaning, rubbish removal	Lump sum	0.04% of TDC		65,522
Project control testing	Lump sum			750,000
Misc. travel expenses	Lump sum	0.2% of TDC		327,612
Insurances, public liability	Lump sum	3.4% OF TDC		5,569,404
Total on site overheads (OSO)				22,661,011
Total direct and on site overhead costs				186,467,011
Profit and off site overheads 10% of TDC and OSO				18,646,701
Total Out Turn Costs (TOC)				205,113,712

Apx Table A-6 Potential dam site on the Flying Fox Creek ATMD 105 km – owner costs

OWNERS COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Investigation and design				
Preliminary design	Lump sum	0.5% of TDC		819,030
Geotechnical and materials	Lump sum	2.0% of TDC		3,276,120
Hydraulic model study	Lump sum			750,000
Detailed design and documentation	Lump sum	2.5% of TDC		4,095,150
Acquisition and Approvals				

OWNERS COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Environmental assessment and approvals	Lump sum			4,000,000
Cultural heritage	Lump sum			3,000,000
Native title	Lump sum			500,000
Storage area acquisition	ha	2600	700	1,820,000
Storage area access relocations	Lump sum			500,000
Surveys and legals	Lump sum			500,000
Permanent onsite buildings and services				500,000
Principal's insurances	Lump sum1.1% of TOC			2256251
Owners management and supervision	Lump sum	0.015% of TOC		307,671
Total owners costs				22,324,221
TOTAL PROJECT COSTS (TPC)				227,437,934
Risk adjustment				90,975,173
TOTAL CAPITAL COST				318,413,107

A.3 Potential weir site on the Flying Fox Creek ATMD 36 km

Apx Table A-7 Potential weir site on the Flying Fox Creek ATMD 36 km – direct construction costs

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
General				
Environmental management	Lump sum			150,000
Cultural heritage management	Lump sum			150,000
Community consultation	Lump sum			50,000
Mobilisation and demobilisation				
Establishment of workforce accommodation	Lump sum			3,000,000
Establishment of survey control	Lump sum			100,000
Establish construction power supply (temporary)	Lump sum			750,000
Establish communications	Lump sum			200,000
Mobilisation of major plant	Lump sum			1,500,000
Demobilisation of major plant	Lump sum			500,000
Demobilisation of workforce accommodation	Lump sum			1,000,000
Clear site and 50% of storage area	ha	265	5,000	1,325,000
Site laboratory	Lump sum			200,000
Access				
Access road to site	km	38	500,000	19,000,000
Establish site access roads	Lump sum			500,000
Rehabilitation of roads on construction completion	Lump sum			200,000
Supply sheet piling to site	tonnes	1,892	2,500	4,730,000
CONSTRUCTION				
Material sources				
Develop sources for clay and sand materials	Lump sum			100,000
Establish source of rock spalls	Lump sum			150,000
Diversion and care of river				
Excavate diversion channel	cu m	13,440	20	269,000
Excavation for coffer dams	cu m	3,840	15	58,000
Place material for coffer dams	cu m	22,100	30	663,000
Dewatering	Lump sum			400,000
Divert river	Lump sum			200,000
Removal of coffer dams	cu m	22,100	15	332,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Foundations				
Excavate OTR from river bed and abutments	cu m	26,760	15	401,000
Over flow section				
Drive row 4 piling	sq m	3,120	420	1,310,000
Drive row 3 piling	sq m	3,360	430	1,445,000
Drive row 2 piling	sq m	4,080	440	1,795,000
Drive row 1 piling	sq m	4,560	450	2,052,000
Downstream protective apron slabs	cu m	3,270	600	1,962,000
Reinforcement to slabs	tonne	131	6,000	786,000
Upstream concrete slab	cu m	654	600	392,000
Reinforcement to upstream slab	tonne	26	6,000	156,000
Concrete low flow channel	cu m	456	650	296,000
Reinforcement to low flow channel	tonne	18	6,000	108,000
Waterstops	m	960	200	192,000
Drains through piling rows 2,3 and 4	no	140	300	42,000
Filter fabric under mattresses	sq m	6,540	5	33,000
Rockfilled mattresses	sq m	6,540	150	981,000
Compacted sand	cu m	10,000	25	250,000
Compacted clay	cu m	7,350	40	294,000
Left and right abutment sections				
Drive rows 1-4	sq m	972	420	408,000
Concrete protection slabs	cu m	216	800	173,000
Reinforcement to slabs	tonne	9	6,000	54,000
Filter fabric under matresses	sq m	1,566	10	16,000
Rockfilled mattresses	sq m	1,566	160	251,000
Outlet works				
Inlet box concrete	cu m	40	2,000	80,000
Inlet box reinforcement	tonne	2	8,000	16,000
Trashscreens	Lump sum			10,000
Outlet pipe supply and install	m	100	2,000	200,000
Backfill around outlet pipe	cu m	8,950	50	447,000
Outlet box	Lump sum	27	2,000	54,000
Outlet box reinforcement	tonne	1	8,000	88,000
Outlet box pipework	Lump sum			25,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Regulating valve	Lump sum			50,000
Guard valve	Lump sum			35,000
Miscellaneous items	Lump sum			50,000
Vertical slot fish ladder				
Concrete to floor and walls of ladder	cu m	60	2,000	120,000
Reinforcement	tonne	2.4	8,000	19,000
Install baffles for slots	no	50	750	37,000
Cover gratings	Lump sum			15,000
Total Direct Construction Costs (TDC)				50,170,000

Apx Table A-8 Potential weir site on the Flying Fox Creek ATMD 36 km – on site overheads

ON SITE OVERHEADS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Project and field staff	Lump sum	3% of TDC		1505100
Staff recruitment and training	Lump sum	0.6% of TDC		301020
Camp operations	Lump sum	3.5% of TDC		1755950
Site office expenses	Lump sum	0.6% of TDC		301020
Site water and power expenses	Lump sum	0.1% of TDC		50170
Site communication, IT expenses	Lump sum	0.45% of TDC		225765
Site cleaning, rubbish removal	Lump sum	0.04% of TDC		20068
Project control testing	Lump sum			
Misc. travel expenses	Lump sum	0.2% of TDC		100340
Insurances, public liability	Lump sum	3.4% OF TDC		1705780
Total On Site Overheads				5965213
TDC and OSO costs				56,135,213
Profit and off site overheads (10% of TDC and OSO)				5,613,521
Total Out Turn Costs (TOC)				61,748,734

Apx Table A-9 Potential weir site on the Flying Fox Creek ATMD 36 km – owner costs

OWNER COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Investigation and design				
Preliminary design	Lump sum	0.5% of TDC		250850
Geotechnical and materials	Lump sum	2.0% of TDC		1003400
Detailed design and documentation	Lump sum	2.5%of TDC		1254250
Acquisition and Approvals				
Environmental assessment and approvals	Lump sum			400,000
Cultural heritage	Lump sum			200,000
Native title	Lump sum			75,000
Site acquisitions	Lump sum			200,000
Surveys and legals	Lump sum			150,000
Principal's insurances	Lump sum	1.1% of TDC		551,870
Owners management and supervision	Lump sum	0.4% of TDC		200,680
Total owners costs				4,286,050
TOTAL PROJECT COSTS				66,034,784
Risk adjustment				23,112,175
TOTAL CAPITAL COST				89,146,959

Appendix B Potential dam site summary tables

B.1 Waterhouse River West Branch dam site on Waterhouse River West Branch; ATMD 70.5 km

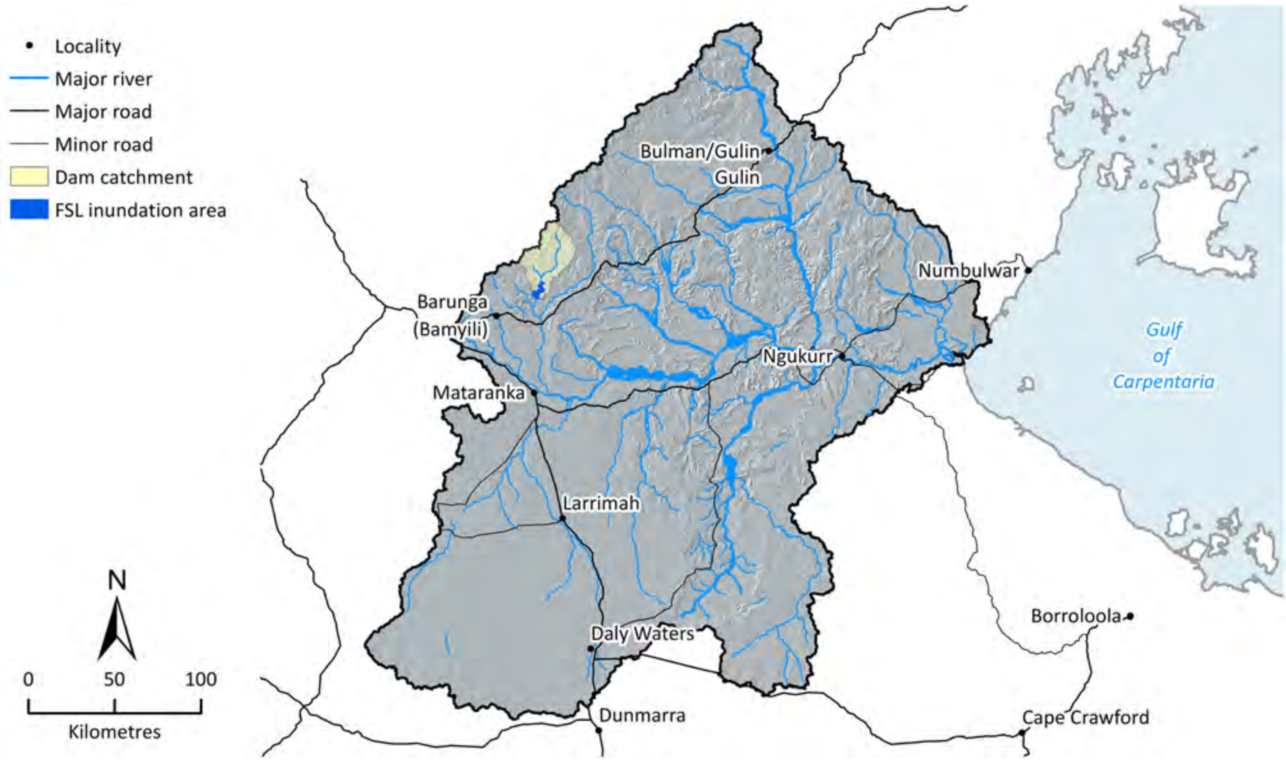
PARAMETER	DESCRIPTION
Previous investigations	No previous investigations of this site have been located. The site was identified from CSIRO DamSite modelling.
References	No references to any investigation of this site have been located.
Description of potential dam	This is a potential dam with FSL 23 m (elevation 188 mEMG96) above bed level and a storage capacity of 128 GL. A storage at this site could provide supply for irrigation of suitable lands downstream of the storage. Releases would be made from the storage to the stream for diversion by irrigators. The location of the potential site is shown in Apx Figure **B-1** and Apx Figure **B-2**. Apx Figure **B-3** shows the known water-dependent ecological assets in the vicinity of the potential dam site.
Regional geology	The Roper catchment landscape is flat to undulating and consists of a series of erosion surfaces developed over the last 70 million years which are characterised by deep weathering profiles and associated iron-cemented capping. The continued erosion has led to the emergence of the present-day landscape and involved the removal of Cretaceous strata from most of the region and the etching out of structures in the underlying Proterozoic rocks. The resulting landscape is characterised by broad alluvial plains associated with the Roper River and its tributaries, and low rubbly hills or strike ridges formed by folded and faulted resistant thick Proterozoic sandstone formations.
Site geology	**Based on geological mapping (high-level fly-over only)** The potential dam site is located on Proterozoic rocks of the Mount Rigg Group (Pon) which consist of quartz sandstone, commonly cross-bedded and which overlie rocks of the Katherine River Group (Phw) which consist of basalt: massive and vesicular and dolerite and dip to the north at about 10°. The deeply weathered erosion surface characteristic of the region appeared to have been removed by erosion at the dam site. On the dam abutments weathered sandstone bedrock outcrops as cliff lines with some talus (blocky slope deposits) on the surface; possibly 2 to 5 m stripping would be required. The river channel consists of a tract of mobile unvegetated alluvium (sand and gravel) and the depth of alluvium is anticipated to be 3 to 5 m locally. The geology of the site is shown in Apx Figure **B-4**.
Reservoir rim stability and leakage potential	There is no evidence of instability or leakage potential around the reservoir rim.
Potential structural arrangement	The site appears suitable for a roller compacted concrete type dam with a central uncontrolled spillway with crest length of 75 m. Outlet works and a fish lift facility would be located on the right abutment. A saddle dam some 2 km long will be required on the western side of the storage to contain the storage and flood rises. Access to the right bank of the site would be via 19 km of new road branching from the Central Arnhem Highway. The total distance from Katherine would be 128 km. A crossing over a tributary of Beswick Creek would be required to reach the site.

<table>
<tr><th>PARAMETER</th><th>DESCRIPTION</th></tr>
<tr><td>Availability of construction materials</td><td>A quarry in the Proterozoic sandstone with suitable aggregate for an RCC dam might be found within 5 km of the dam site. Fine aggregate might be won from the river bed. For estimating purposes a ratio of useful rock excavated to total volume excavated of 0.5 could be assumed. Hard rock quarries for higher quality aggregate to construct an outer layer of RCC for the dam could probably be sourced from the Katherine area.</td></tr>
<tr><td>Catchment area</td><td>795 km^2</td></tr>
<tr><td>Modelled annual inflow data</td><td>
<table>
<tr><th>Parameter</th><th>Scenario A (GL/yr)</th><th>Scenario Cdry (GL/yr)</th><th>Scenario Cmid (GL/yr)</th><th>Scenario Cwet (GL/yr)</th></tr>
<tr><td>Max</td><td>412</td><td>312</td><td>367</td><td>531</td></tr>
<tr><td>Mean</td><td>103</td><td>80</td><td>92</td><td>142</td></tr>
<tr><td>Median</td><td>85</td><td>63</td><td>71</td><td>118</td></tr>
<tr><td>Min</td><td>2</td><td>1</td><td>2</td><td>2</td></tr>
</table>
</td></tr>
<tr><td>Reservoir characteristics</td><td>Reservoir characteristics are shown in Apx Figure B-5. Reservoirs with FSLs of different heights are tabulated below.
<table>
<tr><th>FSL (mEGM96)</th><th>Surface area (ha)</th><th>Capacity (GL)</th></tr>
<tr><td>186</td><td>1628</td><td>91</td></tr>
<tr><td>188</td><td>2067</td><td>128</td></tr>
<tr><td>190</td><td>2564</td><td>174</td></tr>
</table>
</td></tr>
<tr><td>Reservoir yield assessment at dam wall</td><td>FSL 186 mEGM96 Estimated yield at 85% annual time reliability 45 GL
FSL 188 mEGM96 Estimated yield at 85% annual time reliability 48 GL
FSL 190 mEGM96 Estimated yield at 85% annual time reliability 52 GL
Reservoir yields under projected future climates shown in Apx Figure B-7.</td></tr>
<tr><td>Estimated rates of reservoir sedimentation at FSL 188 mEGM96</td><td>
<table>
<tr><th></th><th>Best case</th><th>Expected</th><th>Worst case</th></tr>
<tr><td>30 years (%)</td><td>0.7</td><td>1.1</td><td>1.2</td></tr>
<tr><td>100 years (%)</td><td>2.4</td><td>3.6</td><td>4.0</td></tr>
<tr><td>Years to fill</td><td>4201</td><td>2801</td><td>2521</td></tr>
</table>
</td></tr>
<tr><td>Potential use of supply</td><td>The area below the junction of the upper Waterhouse River and Waterhouse River West Branch is dominated by dissected tablelands of the Sturt Plateau in the upper catchment, alluvial plains adjacent to the river, and sandplains in the lower sections.

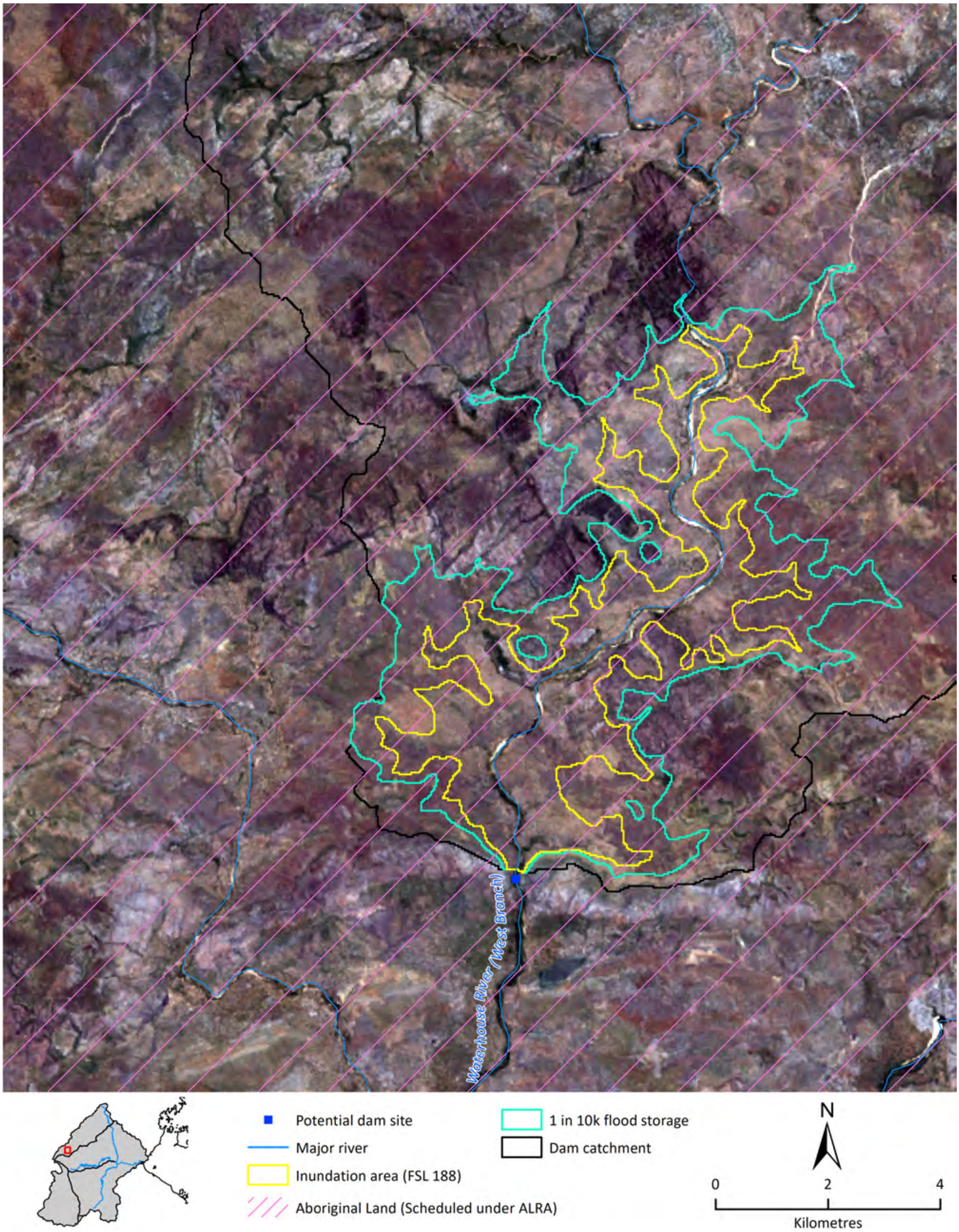
The tablelands and associated scarps have well-drained, predominantly moderately deep to shallow sandy-surfaced red Kandosols (SGG 4.1) with abundant ironstone gravels throughout the soil profile, and abundant rock on and adjacent to the scarps (SGG 7). The deeper soils with less gravels are suitable for a diverse range of spray- and trickle-irrigated crops, predominantly horticultural crops. However, these areas are heavily fragmented by shallow or rocky areas resulting in small usable areas, mainly for trickle-irrigated horticulture.

The alluvial plains in the upper catchment are dominated by very deep sandy-surfaced brown Dermosols (SGG 2) with moderately permeable, moderately well-drained to imperfectly drained, mottled structured clay subsoils. Sandy-surfaced Kandosols with brown and yellow massive loamy subsoils (SGG 4.2) and red subsoils (SGG 4.1) are intermixed. Small areas of gilgaied grey cracking clays (SGG 9) occur on the alluvial back-plains in the Beswick area. The brown and grey soils are subject to seasonal wetness (wet season) and may be subject to flooding. Soils are suited to a diverse range of dry-season spray-irrigated grain, pulse and forage crops; horticultural small crops; wetness-tolerant horticultural tree crops, sugarcane and cotton. Wet-season crops are restricted to crops with a moderate tolerance to wetness such as spray-irrigated forage crops, sunflower, sesame and rice. Fragmentation of the area by creeks and soil distribution may limit the usable areas for various uses.</td></tr>
</table>

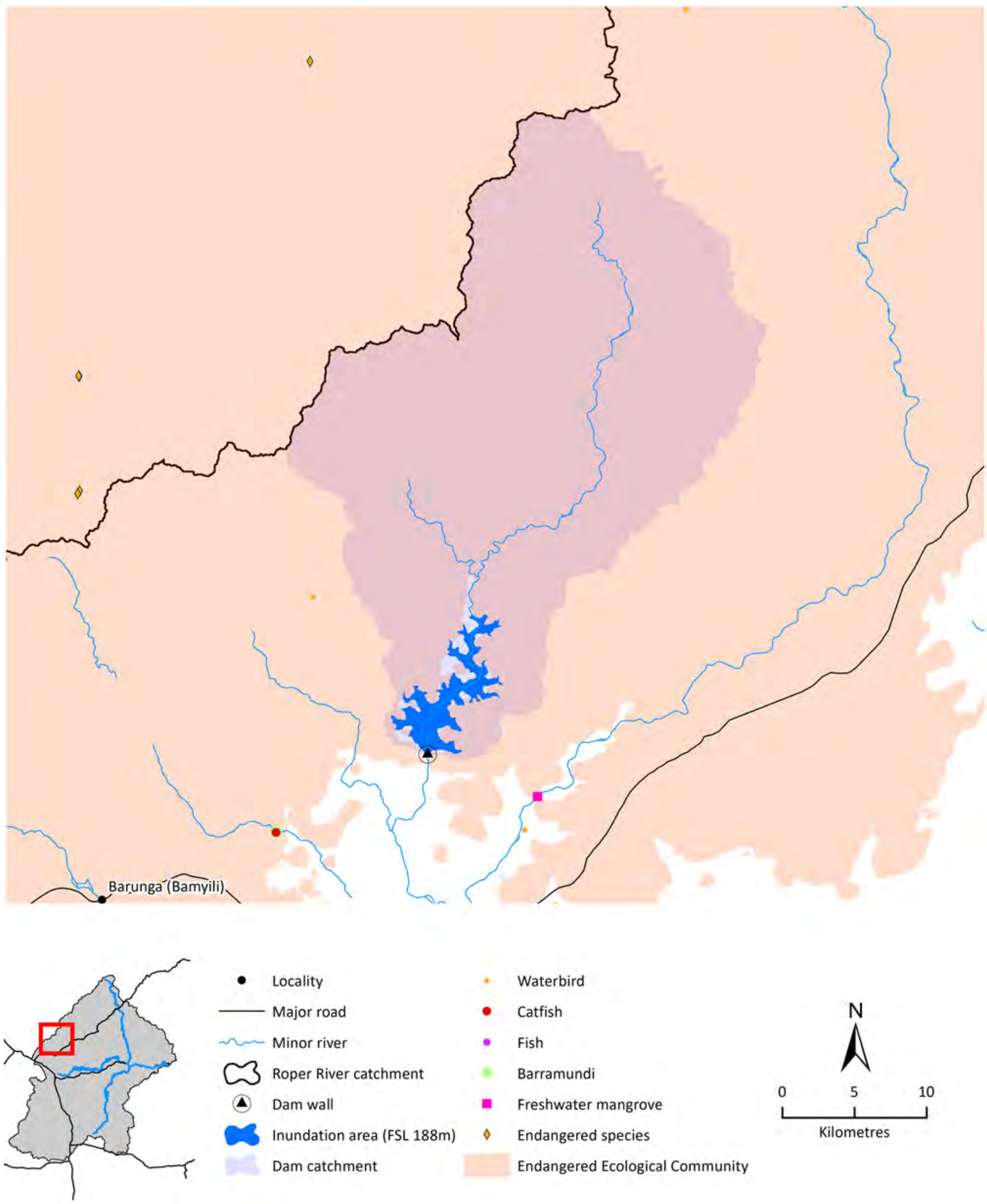
PARAMETER	DESCRIPTION
	The red, brown and yellow massive loamy soils with sandy surfaces (Kandosols SGG 4.1) occur on the gently undulating elevated sandplains and level plains on recent alluvium adjacent to the lower reaches of the Waterhouse River. Moderately deep to very deep (0.5 to >1 m), well-drained to imperfectly drained, red (SGG 4.1) and mottled brown or yellow (SGG 4.2), sandy-surfaced massive soils occur as a mosaic over the landscape, probably reflecting the depth to the underlying rock with red soils on the deeper areas. These moderately permeable soils have moderate to high (100 to 140 mm to 1 m) soil water storage and are highly suited to a broad range of spray- or trickle-irrigated crops. However, fragmentation of the area by creeks and soil distribution may limit the usable areas for various uses.
Impacts	In addition to an area of 2067 ha at FSL 188 mEMG96, a flood margin area would also need to be acquired. This area would primarily affect the Beswick Aboriginal Land Trust area.
Environmental impacts	**Barrier to movement of aquatic species** At this site there were no records of any species. However, in nearby streams there are records of catfish (*Porochilus rendahli*) and barramundi (*Lates calcarifer*) and their movement may be impeded by a dam. **Ecological implications of inundation** The 'Arnhem Plateau Sandstone Shrubland Complex' listed as Endangered Ecological Community (EPBC Act) surrounds the potential inundated area at FSL for this site (188 mEMG96). The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Stratford et al., 2023).
Indigenous land tenure, native title and cultural heritage considerations	There is a high likelihood of unrecorded sites in the inundation area.
Estimated cost	To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO's generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below. FSL 186 mEGM96 $361 million FSL 188 mEGM96 $415 million FSL 190 mEGM96 $478 million.
Estimated cost / ML of supply	Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows: FSL 186 mEGM96 $8022/ML FSL 188 mEGM96 $8646/ML FSL 190 mEGM96 $9192/ML
Summary comment	A low yielding site on the Waterhouse River West Branch. Upstream of large areas of sandy loam soils moderately suitable for irrigated agriculture. The site is situated also on Aboriginal land scheduled under ALRA and is classified under 'inalienable freehold title', which means that it cannot be bought, acquired or mortgaged. Although data from the NT cultural heritage sites register were not made available to the Assessment, it is likely that the site and parts of the potential inundation area would contain cultural heritage sites of significance.



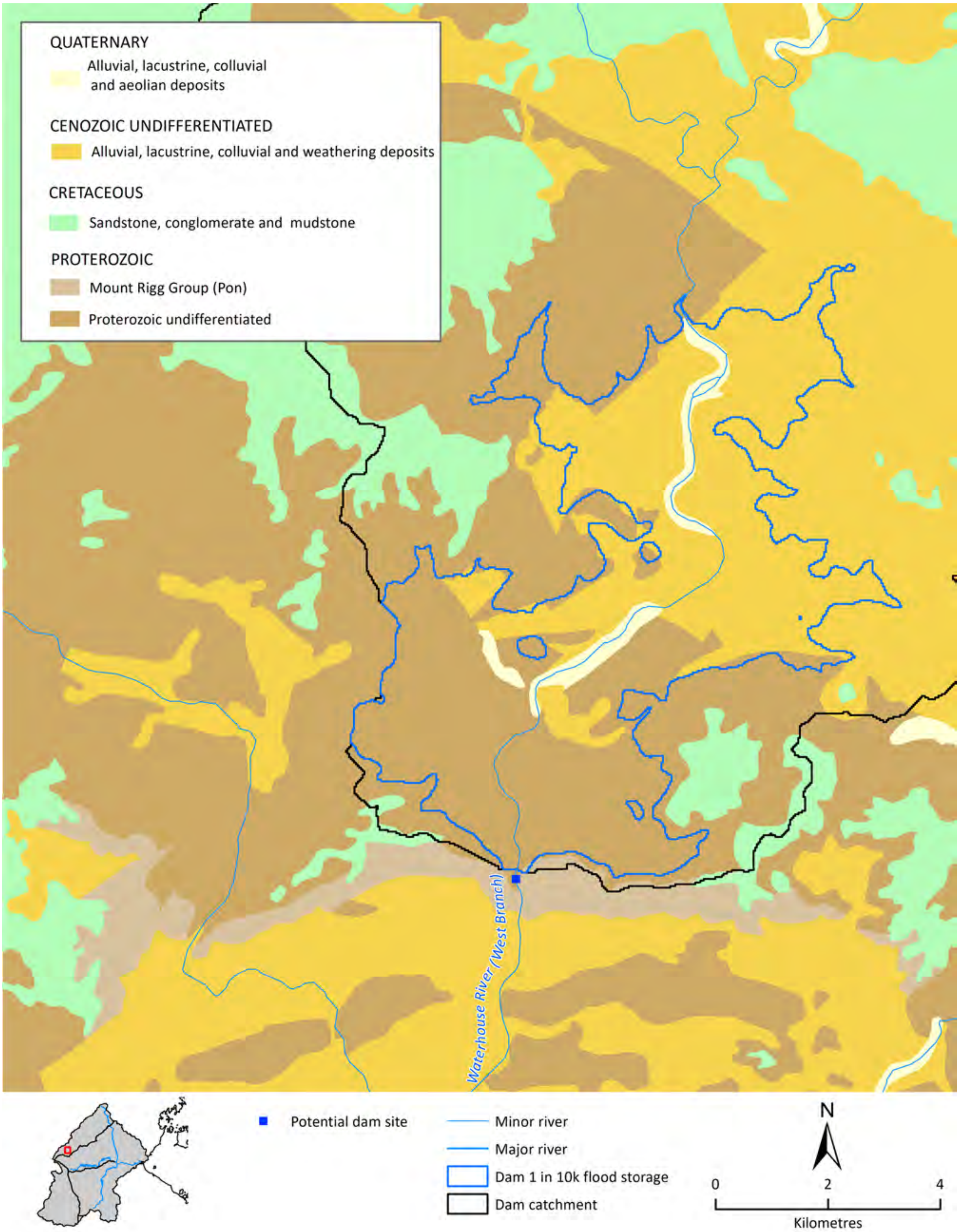
Apx Figure B-1 Location map of potential Waterhouse River West Branch dam site, reservoir extent and catchment area



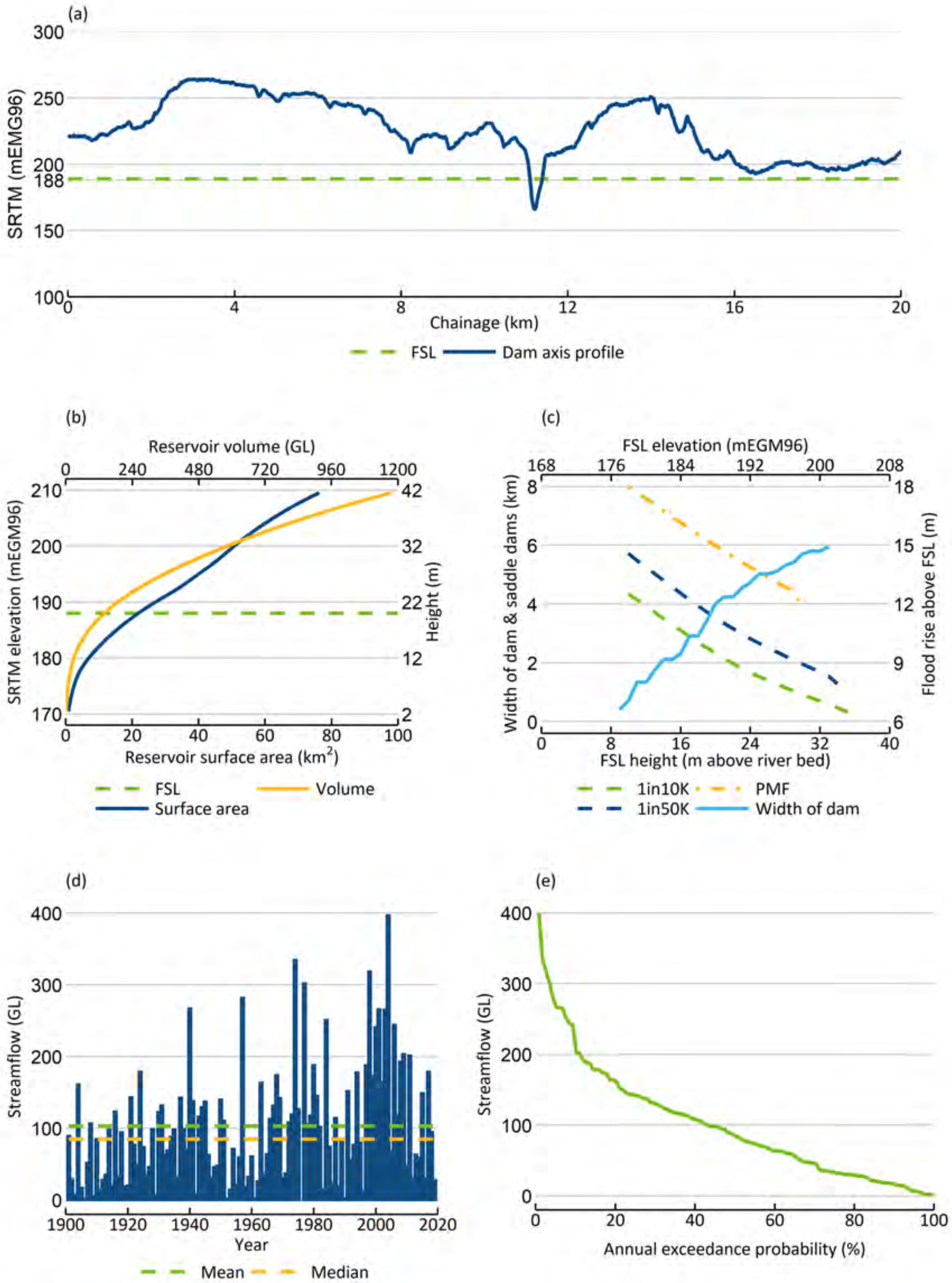
Apx Figure B-2 Potential Waterhouse River West Branch dam reservoir and property boundaries



Apx Figure B-3 Known water-dependent ecological assets in the vicinity of the potential Waterhouse River West Branch dam site and depth of reservoir as full capacity

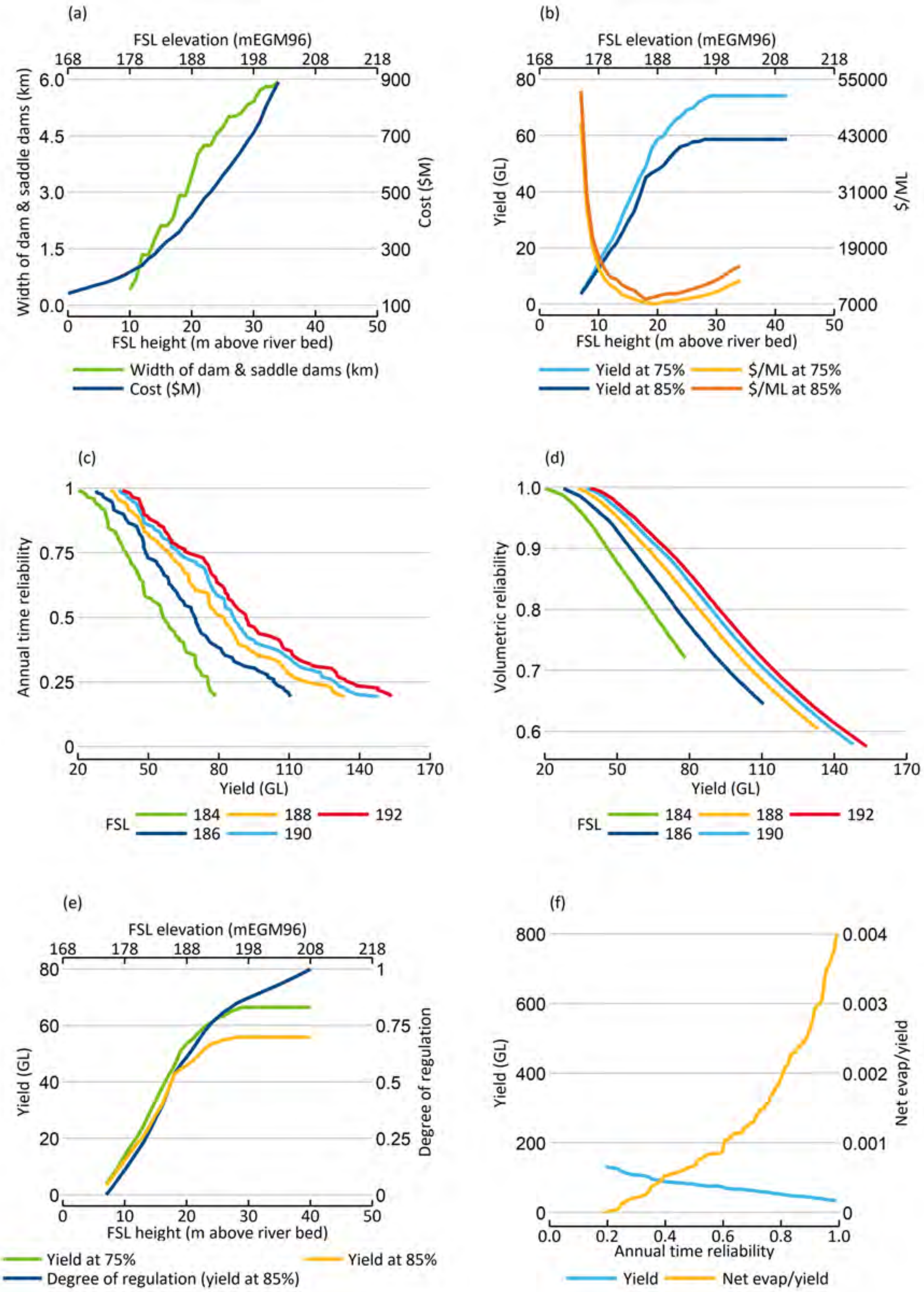


Apx Figure B-4 Geology underlying the potential Waterhouse River West Branch dam site and reservoir



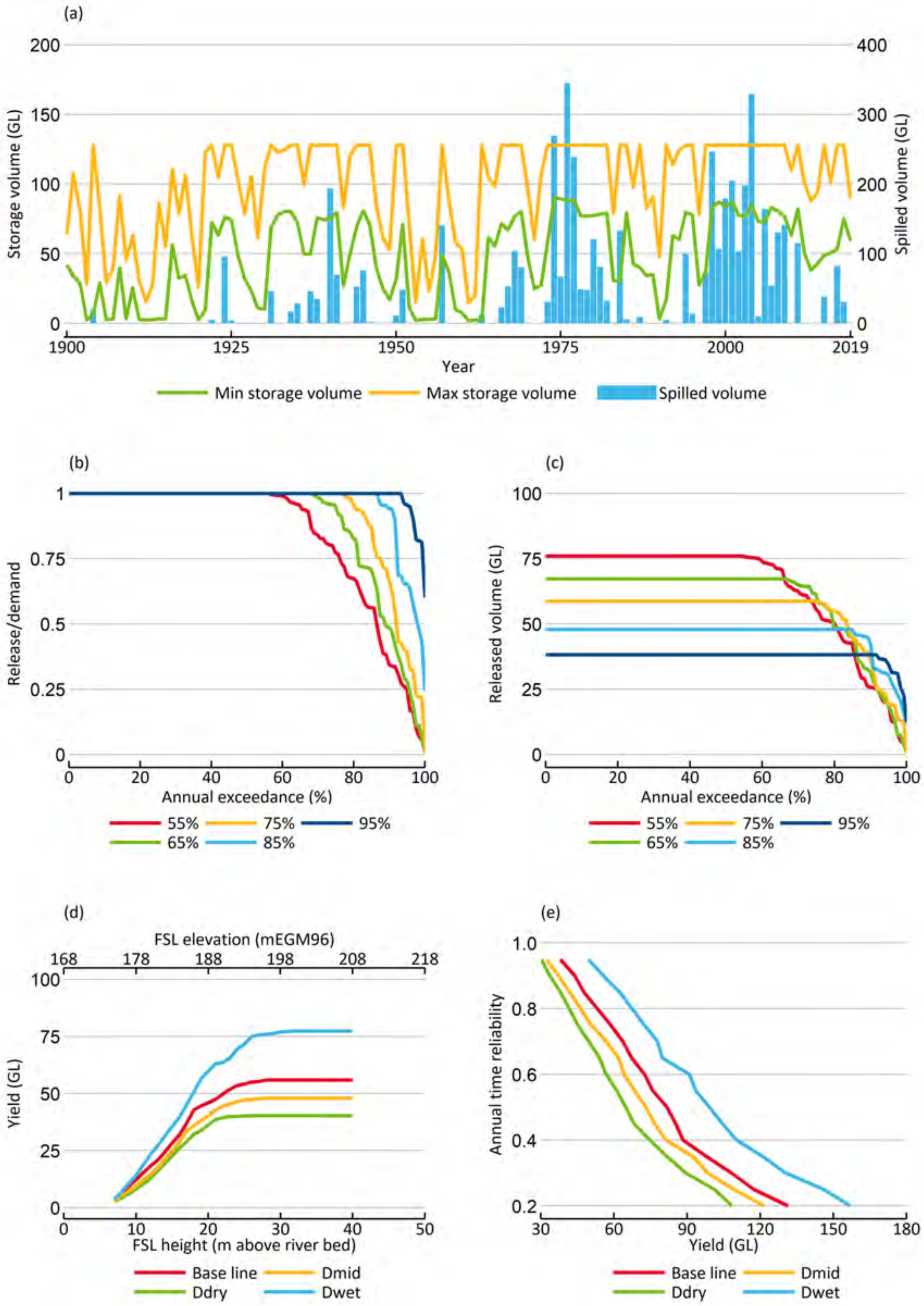
Apx Figure B-5 Waterhouse River West Branch potential dam site topographic dimensions and inflow hydrology

(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and probable maximum flood (PMF) events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance



Apx Figure B-6 Waterhouse River West Branch potential dam site cost, yield at the dam wall and evaporation

(a) Dam length and dam cost versus full supply level (FSL); (b) dam yield at 75% and 85% annual time reliability and yield per million dollars at 75% and 85% annual time reliability; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 75% and 85% annual time reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f) yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.



Apx Figure B-7 Waterhouse River West Branch potential dam site and storage levels and water yield

(a) Maximum and minimum annual storage trace at the selected FSL (188 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (d) annual yield at 85% annual time reliability plotted against FSL under Scenario A (baseline) and Scenario D; (e) annual time reliability vs yield for FSL 188 mEMG96 under Scenario A (baseline) and Scenario D.

B.2 Jalboi River dam site on the Jalboi River; ATMD 53 km

PARAMETER	DESCRIPTION
Previous investigations	No previous investigations of this proposal have been located. The site has been identified from CSIRO DamSite modelling.
References	No references to investigation of this site have been located.
Description of potential dam	This table details a potential dam with FSL 25 m (elevation 73 mEMG96) above bed level and a storage capacity of 189 GL. A storage at this site could provide supply for irrigation of suitable lands downstream of the storage. Releases would be made from the storage to the stream for diversion by irrigators. The location of the potential site is shown in Apx Figure **B-9** and Apx Figure **B-10**. Apx Figure **B-11** shows the known water-dependent ecological assets in the vicinity of the potential dam site.
Regional geology	The Roper catchment landscape is flat to undulating and consists of a series of erosion surfaces developed over the last 70 million years which are characterised by deep weathering profiles and associated iron-cemented capping. The continued erosion has led to the emergence of the present-day landscape and involved the removal of Cretaceous strata from most of the region and the etching out of structures in the underlying Proterozoic rocks. The resulting landscape is characterised by broad alluvial plains associated with the Roper River and its tributaries, and low rubbly hills or strike ridges formed by folded and faulted resistant thick Proterozoic sandstone formations.
Site geology	**Site visit** The dam site is located on Proterozoic rocks of the Roper Group (Prom, Prh & Prj), which consist of blocky and flaggy quartz sandstone and ferruginous medium to very coarse sandstone and dip to the south-west at 10°. The deeply weathered erosion surface characteristic of the region appeared to have been partially removed by erosion at the dam site. On the dam abutments weathered sandstone bedrock is partially exposed with some talus (blocky slope deposits) on the surface; possibly 1 to 3 m stripping would be required. The river channel consists of a tract of vegetated alluvium (sand and gravel) and the depth of alluvium is anticipated to be 4 to 8 m locally. The geology of the site is shown in Apx Figure **B-12**.
Reservoir rim stability and leakage potential	There is no evidence of instability or leakage potential around the reservoir rim.
Potential structural arrangement	The site appears to be suitable for a roller compacted concrete type dam with a central uncontrolled spillway with crest length of 75 m. Outlet works and a fish lock facility would be located on the right abutment. Access to the right bank of the site would be via 38 km of new road branching from the Central Arnhem Highway. The total distance from Katherine via the Stuart and Central Arnhem highways would be some 255 km.
Availability of construction materials	~~A~~ quarry in the Proterozoic sandstone with suitable aggregate for an RCC dam might be found within 10 km of the dam site. For estimating purposes a ratio of useful rock excavated to total volume excavated of 0.5 could be assumed. Hard rock quarries for higher quality aggregate to construct an outer layer of RCC for the dam could probably be sourced from the Katherine area.
Catchment area	828 km^2
Modelled annual inflow data	

Parameter	**Scenario A (GL/yr)**	**Scenario Cdry (GL/yr**	**Scenario Cmid (GL/yr)**	**Scenario Cwet (GL/yr**
Max	300	237	285	454
Mean	84	63	78	126
Median	66	47	56	99

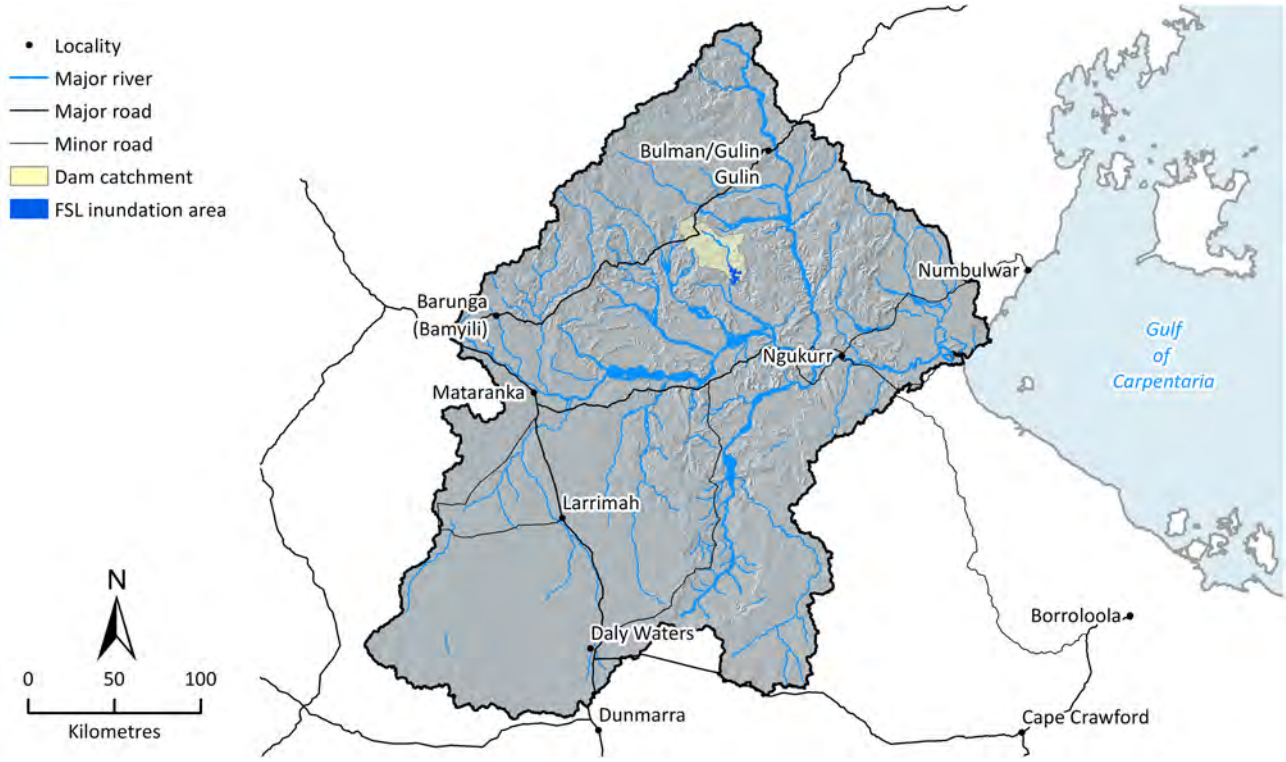
<table>
<tr><th>PARAMETER</th><th>DESCRIPTION</th></tr>
<tr><td></td><td><table><tr><td>Min</td><td>1</td><td>1</td><td>1</td><td>1</td></tr></table></td></tr>
<tr><td>Reservoir characteristics</td><td>Storage characteristics are shown in Apx Figure B-13. Storages with FSLs of different heights are tabulated below.<table><tr><th>FSL</th><th>Surface area (ha)</th><th>Capacity (GL)</th></tr><tr><td>71</td><td>1742</td><td>137</td></tr><tr><td>73</td><td>1960</td><td>174</td></tr><tr><td>75</td><td>2285</td><td>216</td></tr></table></td></tr>
<tr><td>Reservoir yield assessment at dam wall</td><td>FSL 71 mEGM96 Estimated yield at 85% annual time reliability 36 GL
FSL 73 mEGM96 Estimated yield at 85% annual time reliability 40 GL
FSL 75 mEGM96 Estimated yield at 85% annual time reliability 42 GL
Reservoir yields under projected future climates shown in Apx Figure B-15.</td></tr>
<tr><td>Estimated rates of reservoir sedimentation at FSL 73 mEGM96</td><td><table><tr><th></th><th>Best case</th><th>Expected</th><th>Worst case</th></tr><tr><td>30 years (%)</td><td>0.5</td><td>0.8</td><td>0.9</td></tr><tr><td>100 years (%)</td><td>1.8</td><td>2.7</td><td>3.0</td></tr><tr><td>Years to fill</td><td>5502</td><td>3668</td><td>3301</td></tr></table></td></tr>
<tr><td>Potential use of supply</td><td>The area below the potential Jalboi River dam is dominated by a broad alluvial plain with abundant braided channels. Broad level plains with no channels also exist. The areas adjacent to the plains are dominated by undulating to steep hills and rises on Proterozoic sediments and dolerites.
The broad alluvial plains are dominated by very deep, moderately well to imperfectly drained, slowly permeable brown to grey cracking clay soils (SGG 9) with strongly sodic subsoils, and soft self-mulching or hard-setting structured clay surfaces. Soils have high to very high water-holding capacity (>140 mm to 1 m) but may have a restricted rooting depth due to very high salt levels in the subsoil. These cracking clay soils are suited to a variety of dry-season flood or spray-irrigated grain, forage and pulse crops, sugarcane and cotton. Much of the clay plains are subject to regular flooding and frequently have small (<0.3 m) gilgai depressions and numerous flood channels. However, the plains with braided channels are frequently in narrow, ribbon form which limit opportunities for agricultural development. Intermixed with the clay soils on the braided plains are very deep, well-drained, sandy-surfaced red Kandosols (SGG 4.1), adding to the soil complexity and further limiting agricultural opportunities.
Minor areas of moderately deep to deep (0.5 to 1.5 m), well-drained, red friable clay soils (Red Ferrosols SGG 2) with few stones or boulders occur on gentle plains. Soils are developed on dolerite. These soils are suitable for horticultural tree crops, but the small areas limit agricultural opportunities.</td></tr>
<tr><td>Impacts</td><td>In addition to the storage area of 1,958 ha, a flood margin area would also need to be acquired. The affected area would primarily affect the Lonesome Dove pastoral lease area.</td></tr>
<tr><td>Environmental impacts</td><td>Barrier to movement of aquatic species
Fish whose movement may be impeded by a dam at this site include the sooty grunter (Hephaestus fuliginosus), mouth almighty (Glossamia aprion) and sleepy cod (Oxyeleotris lineolata).

Ecological implications of inundation
The potential inundated area at FSL for this site (73 mEMG96). Part of this potential site is within the Wongalara Private Nature Reserve.

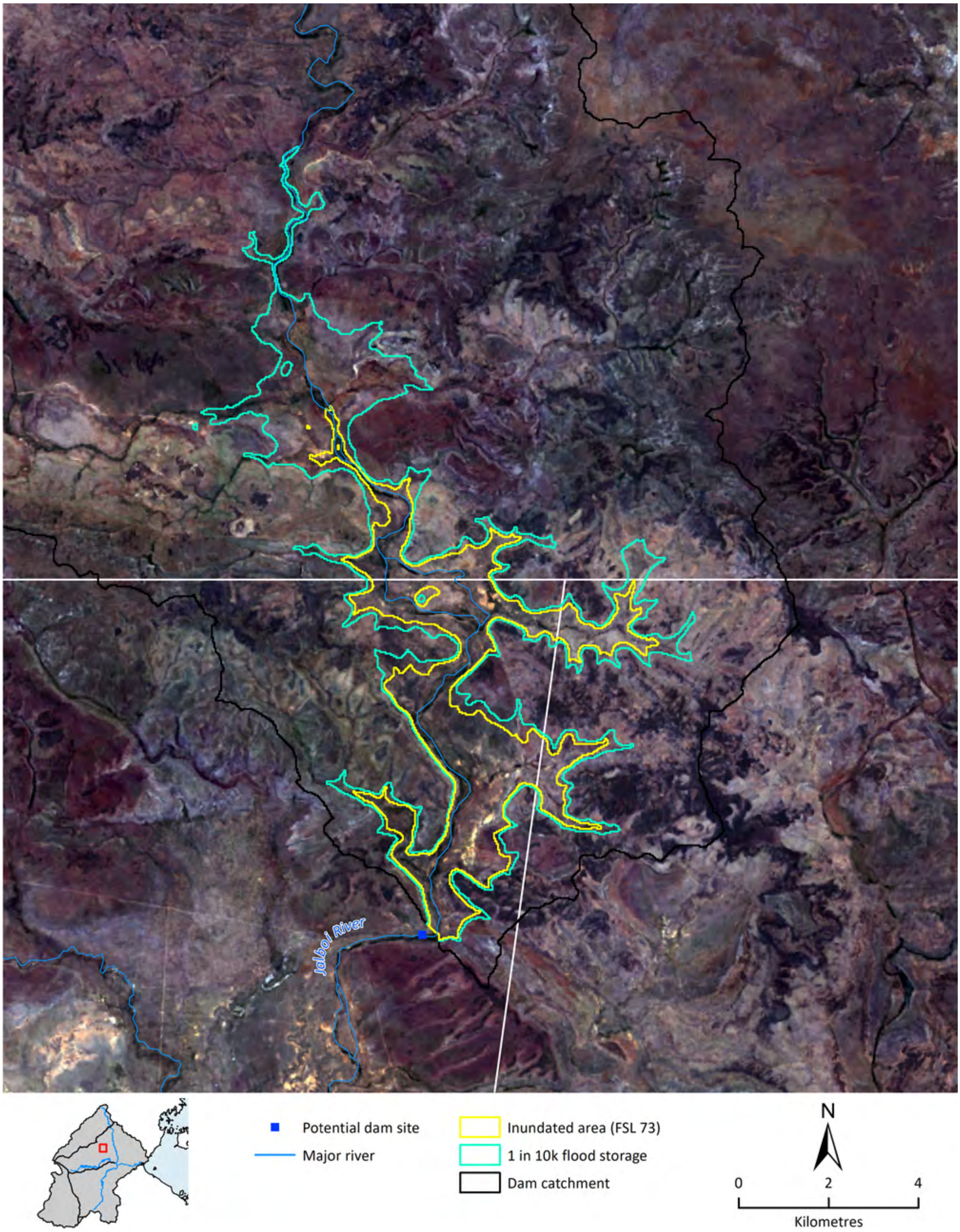
The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Stratford et al., 2023).</td></tr>
</table>

PARAMETER	DESCRIPTION
Indigenous land tenure, native title and cultural heritage considerations	There is a high likelihood of unrecorded sites in the inundation area.
Estimated cost	To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO's generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below. FSL 71 mEGM96 $437 million FSL 73 mEGM96 $463 million FSL 75 mEGM96 $491 million.
Estimated cost / ML of supply	Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows: FSL 171 mEGM96 $12,139/ML FSL 173 mEGM96 $11,575/ML FSL 175 mEGM96 $11,690/ML
Summary comment	A low yielding site on the Jalboi River that appears to be suitable for a roller compacted concrete type dam with a central uncontrolled spillway. The potential dam site a lower yield to cost ratio that other sites selected for pre-feasibility analysis; however, it is relatively close to large areas of alluvial soils moderately suitable for irrigated agriculture. Being north of the Roper River accessing the dam site and potential irrigation areas during the wet season would be challenging without major road and bridge infrastructure. The affected area would primarily affect the Lonesome Dove pastoral lease area. There is a high likelihood of unrecorded sites in the inundation area.

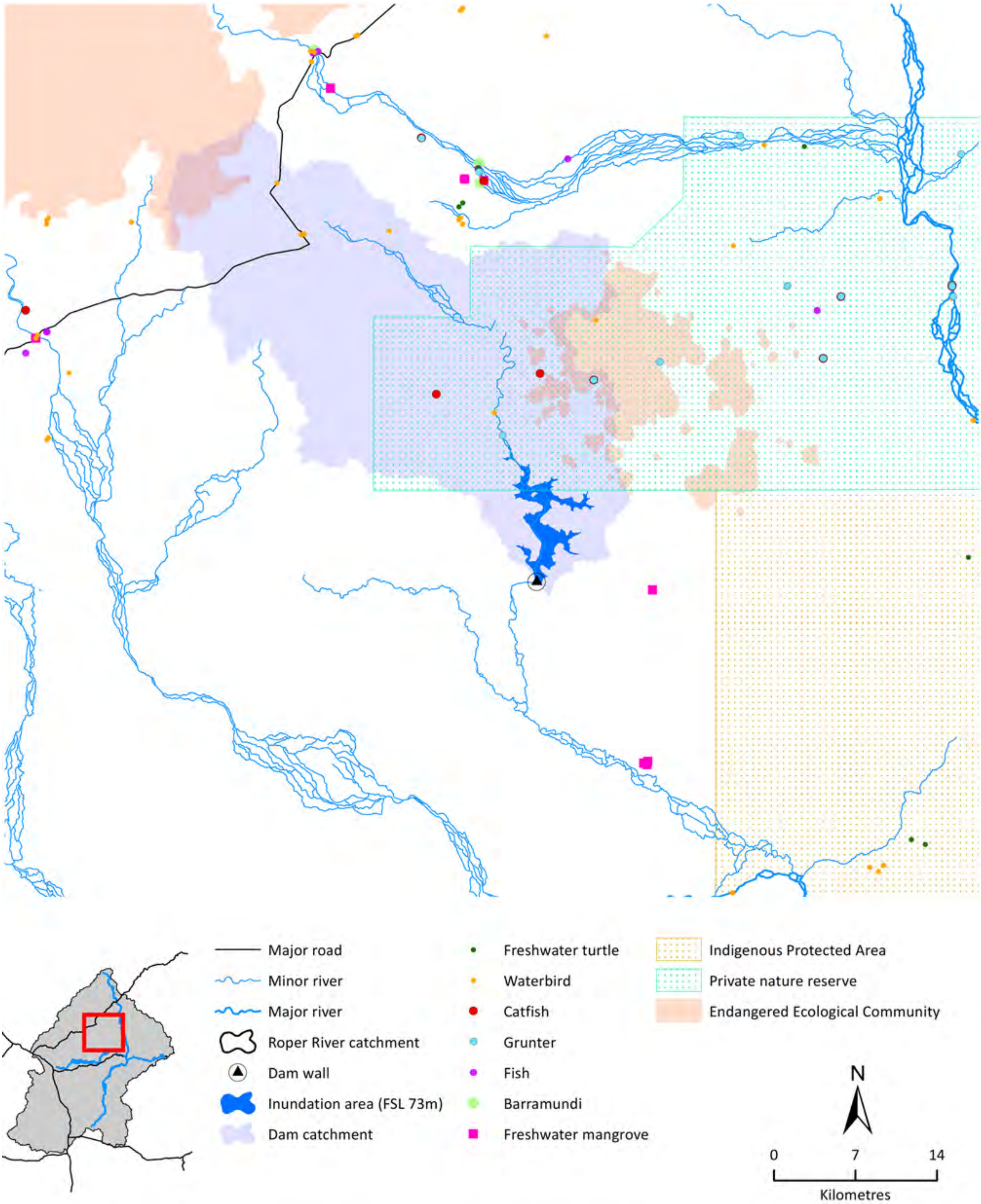
Apx Figure B-8 Jalboi River potential dam site AMTD 53 km looking upstream



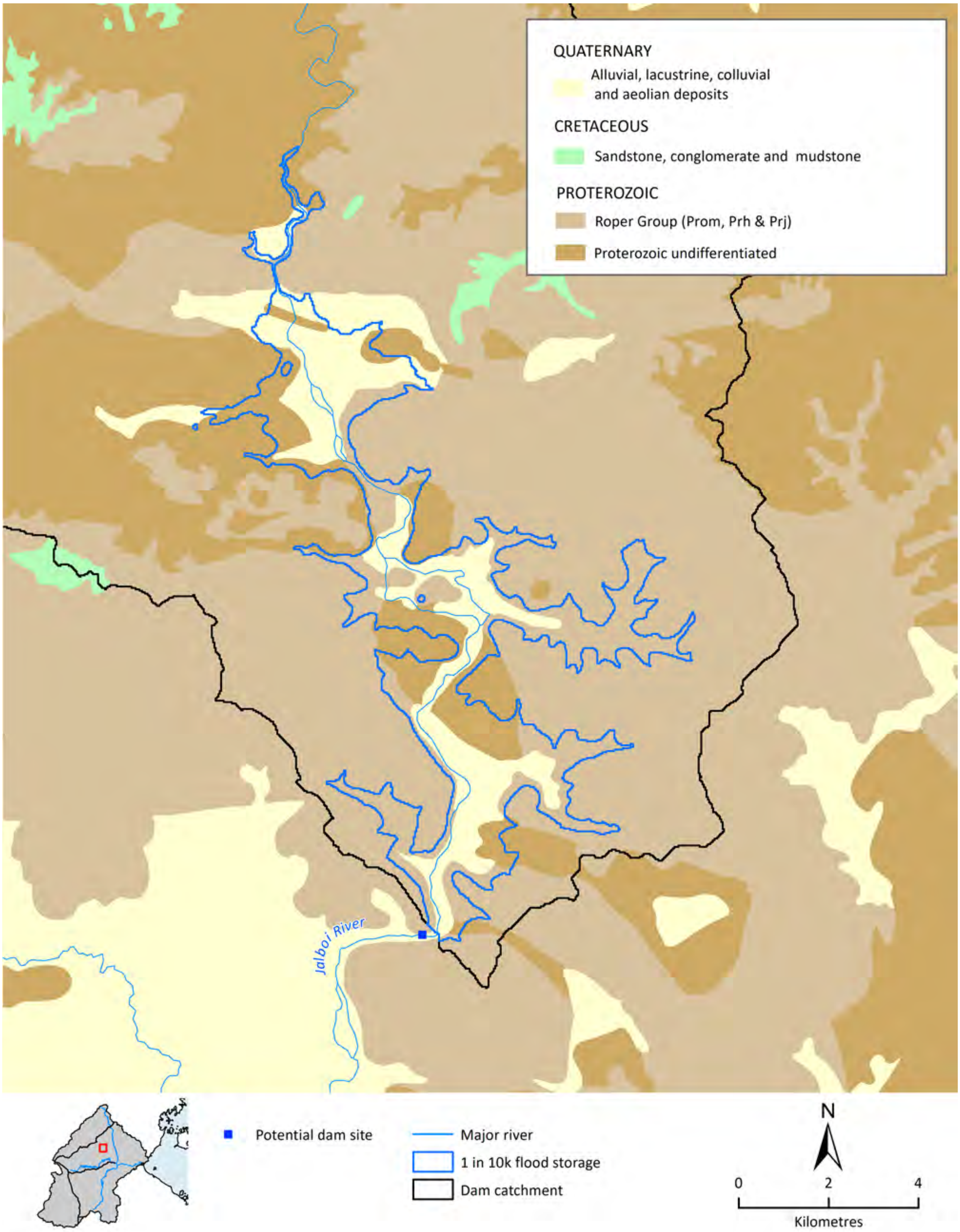
Apx Figure B-9 Location map of potential Jalboi River dam site, reservoir extent and catchment area



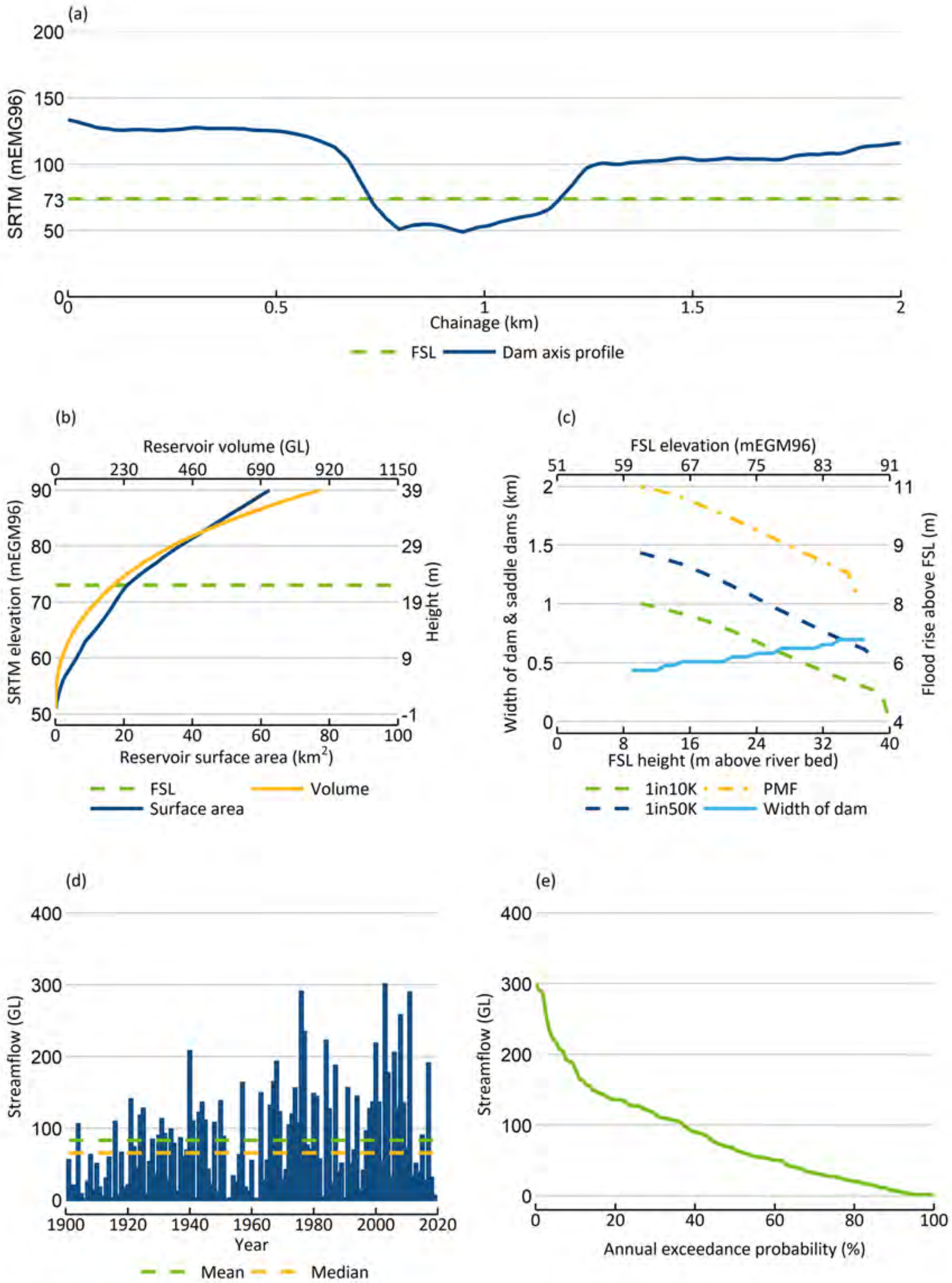
Apx Figure B-10 Potential Jalboi River dam reservoir and property boundaries



Apx Figure B-11 Known water-dependent ecological assets in the vicinity of the potential Jalboi River dam site and depth of reservoir as full capacity

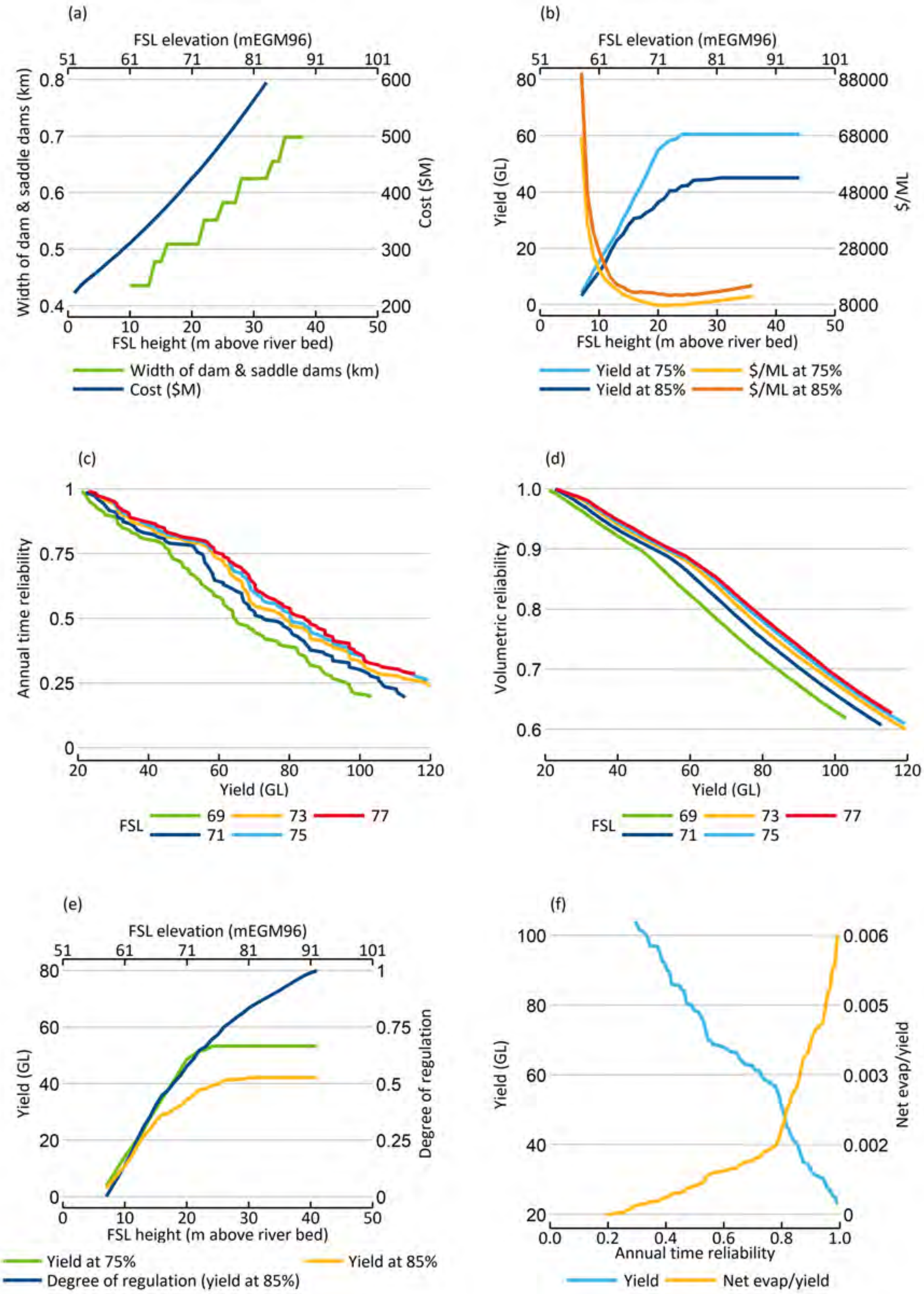


Apx Figure B-12 Geology underlying the potential Jalboi River dam site and reservoir



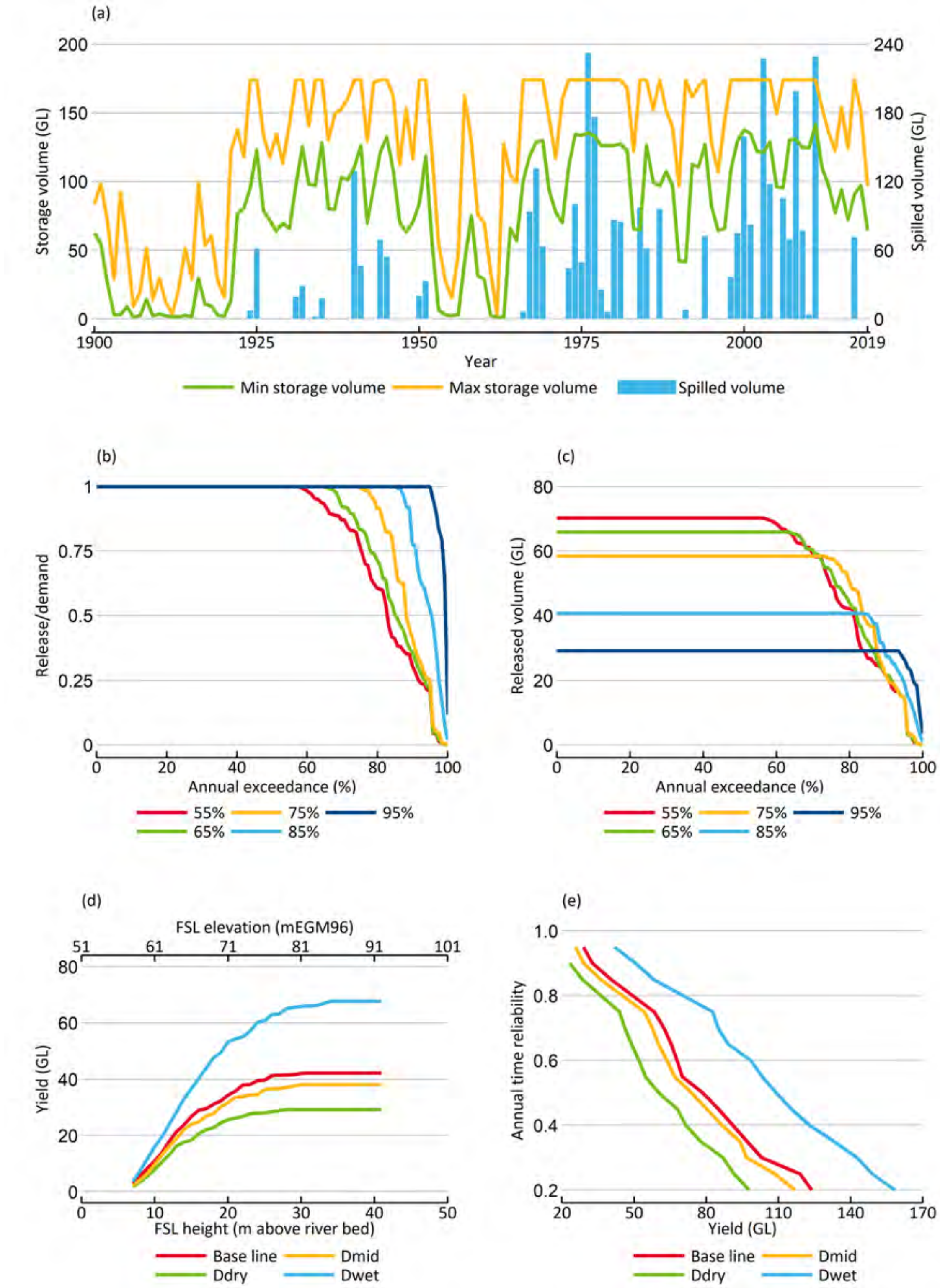
Apx Figure B-13 Jalboi River potential dam site topographic dimensions and inflow hydrology

(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and probable maximum flood (PMF) events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance



Apx Figure B-14 Jalboi River potential dam site cost, water yield at the dam wall and evaporation

(a) Dam length and dam cost versus full supply level (FSL); (b) dam yield at 75% and 85% annual time reliability and yield per million dollars at 75% and 85% annual time reliability; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 75% and 85% annual time reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f) yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.



Apx Figure B-15 Jalboi River potential dam site and storage levels and water yield

(a) Maximum and minimum annual storage trace at the selected FSL (73 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (d) annual yield at 85% annual time reliability plotted against FSL under Scenario A (baseline) and Scenario D; (e) annual time reliability vs yield for FSL 73 mEMG96 under Scenario A (baseline) and Scenario D.

B.3 Wilton River dam site on the Wilton River; ATMD 33 km

PARAMETER	DESCRIPTION
Previous investigations	No previous investigations of this site have been located. The site was identified from CSIRO DamSite modelling.
References	No references to investigation of this site have been located.
Description of potential dam	This table details a potential dam with FSL 39 m (elevation 62 mEMG96) above bed level and a storage capacity of 2253 GL. A storage at this site would have the largest hydro-electric power generation capacity in the Roper catchment. Water released from the storage could also provide for irrigation of limited areas of suitable lands downstream. The location of the potential site is shown in Apx Figure **B-16** and Apx Figure **B-17**. Apx Figure **B-18** shows the known water-dependent ecological assets in the vicinity of the potential dam site.
Regional geology	The Roper catchment landscape is flat to undulating and consists of a series of erosion surfaces developed over the last 70 million years which are characterised by deep weathering profiles and associated iron-cemented capping. The continued erosion has led to the emergence of the present-day landscape and involved the removal of Cretaceous strata from most of the region and the etching out of structures in the underlying Proterozoic rocks. The resulting landscape is characterised by broad alluvial plains associated with the Roper River and its tributaries, and low rubbly hills or strike ridges formed by folded and faulted resistant thick Proterozoic sandstone formations.
Site geology	**Geological mapping (no inspection)** The dam site is located on Proterozoic rocks of the Roper Group (Prr) which consist of flaggy micaceous and feldspathic sandstone with glauconite and dip gently to the north-west at about 7°. The deeply weathered erosion surface characteristic of the region appears to be present at the dam site and there is no rock exposed on the abutments so assume a mean depth of stripping of 10 m. The Wilton River channel is about 70 to 100 m wide at the dam site and appears to be still water. However, there appear to be rock bars downstream of the dam site, so the channel is unlikely to be over-deepened. Assume founding of the dam structure level 8 m below river level. The geology of the site is shown in Apx Figure **B-19**.
Reservoir rim stability and leakage potential	There is no evidence of instability or leakage potential around the reservoir rim.
Potential structural arrangement	The site may be suitable for a roller compacted concrete type dam with a central uncontrolled spillway 300 m wide. Outlet works and a fish lift facility would be located on the right abutment side. Access to the right abutment at the site would be by 30 km of new road branching from the Roper Highway a short distance downstream of the Roper Bar crossing. The total distance from Katherine to the site would be 310 km.
Availability of construction materials	A quarry in the Proterozoic sandstone with suitable aggregate for an RCC dam could be found within 20 kms of the potential damsite. For estimating purposes the ratio of useful rock excavated to total volume excavated of 0.5 could be assumed. Hard rock quarries for higher quality aggregate to construct an outer layer of RCC for the dam could probably be sourced from Katherine.
Catchment area	12,073 km^2
Modelled annual inflow data	

Parameter	Scenario A (GL/yr)	Scenario Cdry (GL/yr)	Scenario Cmid (GL/yr	Scenario Cwet (GL/yr)
Max	5965	4030	5573	7745
Mean	1495	1113	1412	1990

PARAMETER	DESCRIPTION				
	Median	1227	930	1120	1651
	Min	20	20	21	23

Reservoir characteristics

Reservoir characteristics are shown in Apx Figure **B-20**. Reservoirs with FSLs of different heights are tabulated below.

FSL (mEGM96)	Surface area (ha)	Capacity (GL)
60	34,372	3,809
62	39,055	4,541
64	47,703	5,405

Reservoir yield assessment at dam wall

FSL 60 mEGM96	Estimated yield at 85% annual time reliability	899 GL
FSL 62 mEGM96	Estimated yield at 85% annual time reliability	926 GL
FSL 64 mEGM96	Estimated yield at 85% annual time reliability	929 GL

Reservoir yields under projected future climates shown in **Apx Figure B-22**.

Estimated rates of reservoir sedimentation at FSL 62 mEGM96

	Best case	Expected	Worst case
30 years (%)	0.3	0.4	0.5
100 years (%)	0.9	1.4	1.6
Years to fill	10,687	7,125	6,412

Potential use of supply

There are limited areas of land suitable for irrigated agriculture downstream of this site on the Wilton River and the confluence of the Wilton River and the Roper River. This site was examined for its hydro-electric power generating potential, however, there is no transmission line infrastructure that would support this development.

Impacts

In addition to the inundated area of 22,290 ha at FSL, a flood margin area would also need to be acquired. The area required would primarily affect the Urapunga pastoral lease area.

Environmental impacts

Barrier to movement of aquatic species

Fish whose movement may be impeded by a dam at this site include the banded grunter (*Amniataba percoides*), spangled grunter (*Leiopotherapon unicolor*), sooty grunter (*Hephaestus fulginosus*), silver cobbler (*Neoarius midgleyi*), mouth almighty (*Glossamia aprion*), giant gudgeon (*Oxyeleotris selheimi*), shovelnose catfish (*Sciades paucus*), blue catfish (*Neoarius graeffei*), black catfish (*Neosilurus ater*), sleepy cod (*Oxyeleotris lineolata*), common archerfish (*Toxotes chatareus*), barramundi (Lates calcarifer), freshwater anchovy (*Thryssa scratchleyi*), bony bream *(Nematalosa erebi*), Rendahl's Tandan (*Porochilus rendahli*) and the freshwater sawfish (*Pristis pristis*), listed as vulnerable in the EPBC Act. Similarly, the movement of freshwater turtles, such as, the gulf snapping *turtle (Elseya lavarackorum*), northern snapping turtle (*Elseya dentata*), northern snake-necked turtle, oblong turtle (*Chelodina oblonga oblonga*), Cann's snake-necked turtle (*Chelodina canni*) and Worrell's turtle (*Emydura subglobosa worrelli*) could be affected.

Ecological implications of inundation

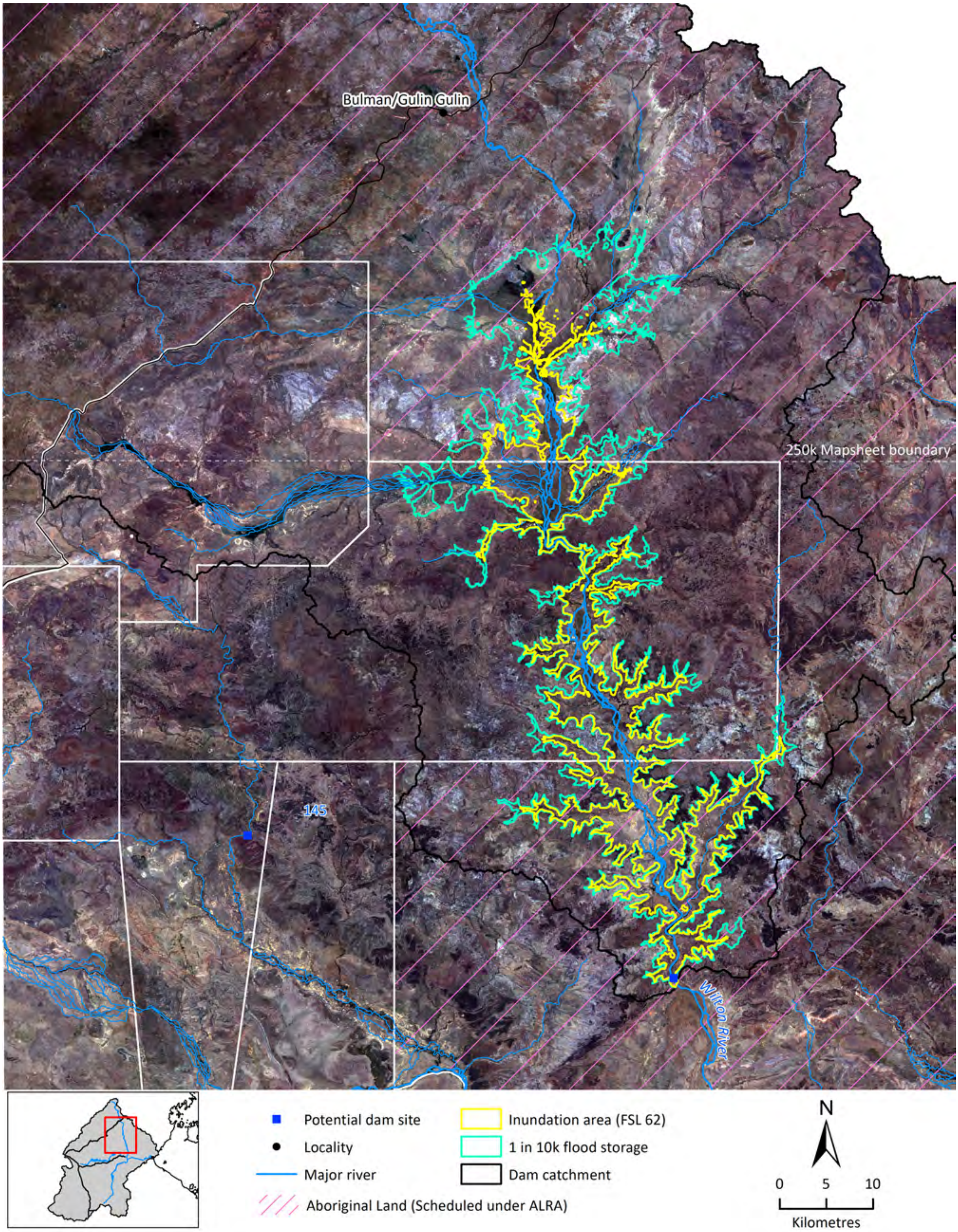
A dam development at this site would inundate a large area of the Wilton River floodplain, which contain important habitat for small river-floodplain specialist fish, including: *Anodontoglanis dahli*, flyspecked hardyhead (*Craterocephalus stercusmuscarum*), Gulf grunter (*Scortum ogilbyi*) and for waterbirds, such as, straw-necked ibis (*Threskiornis spinicollis*), white-faced heron (*Egretta novaehollandiae*), and Nankeen Night-Heron (*Nycticorax caledonicus*).

Freshwater mangrove (*Barringtonia acutangular*) has also been recorded in this potential site. The potential inundated area at FSL for this site (62 mEMG96) may affect these species by changing their habitat.

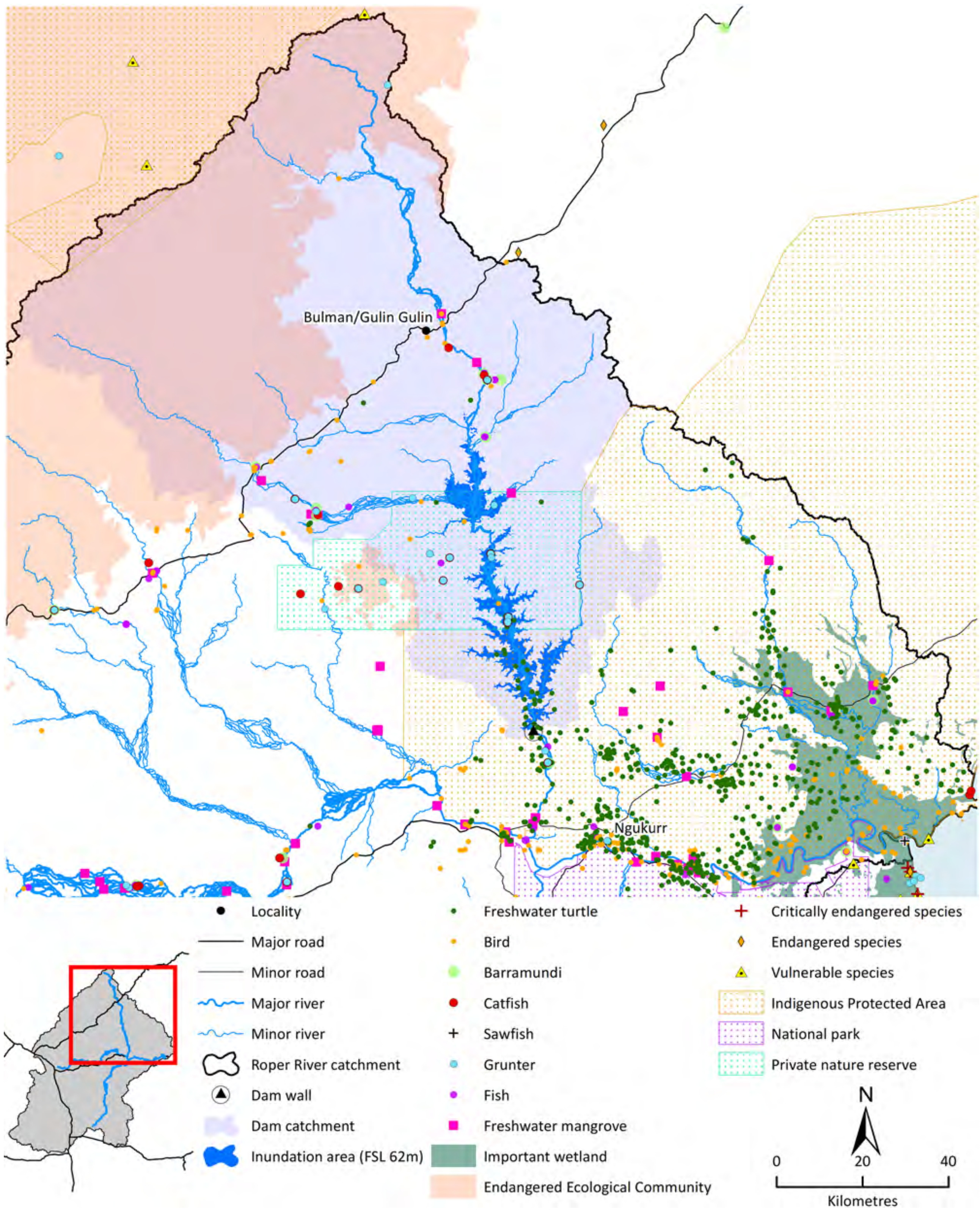
Most of the inundated area is within the South-East Arnhem Land Indigenous Protected Area or the Wongalara Private Nature Reserve.

PARAMETER	DESCRIPTION
	The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Stratford et al., 2023).
Indigenous land tenure, native title and cultural heritage considerations	There is a high likelihood of unrecorded sites in the inundation area.
Estimated cost	To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO's generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below. FSL 60 mEGM96 $814 million FSL 62 mEGM96 $849 million FSL 64 mEGM96 $889 million
Estimated cost / ML of supply	Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows: FSL 171 mEGM96 $905/ML FSL 173 mEGM96 $916/ML FSL 175 mEGM96 $957/ML
Summary comment	A very high yield potential dam site. However, there are limited areas of land that would be suitable for irrigated agriculture downstream of the site. The site has the most suitable characteristics for a dam supplying water for hydro-electric power in the Roper catchment, however, the site is remote and there is no electricity transmission infrastructure. The site is situated also on Aboriginal land scheduled under ALRA and is classified under 'inalienable freehold title', which means that it cannot be bought, acquired or mortgaged. Although data from the NT cultural heritage sites register were not made available to the Assessment, it is highly likely that the site and parts of the potential inundation area would contain cultural heritage sites of significance.

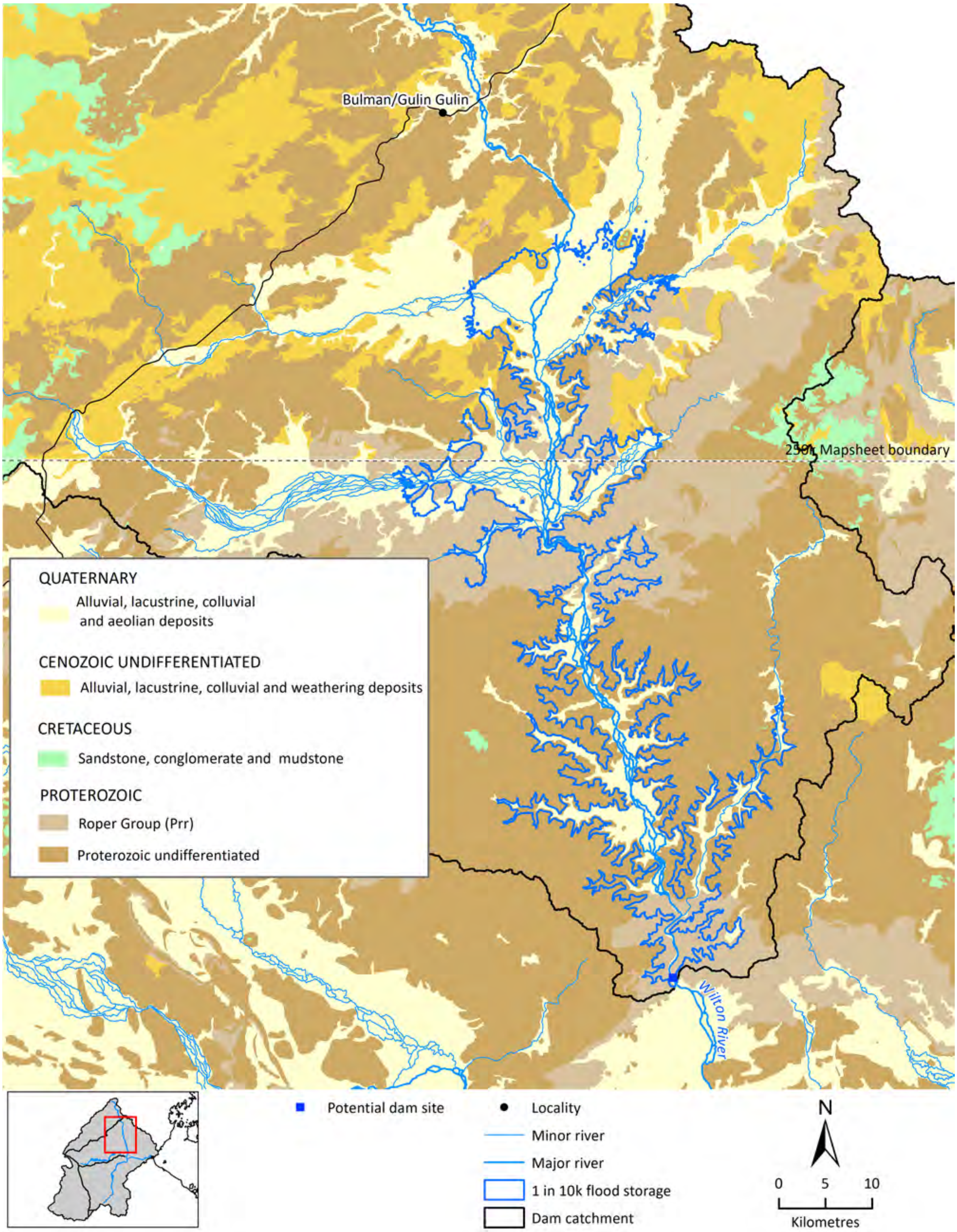
Apx Figure B-16 Location map of potential Wilton River dam site, reservoir extent and catchment area



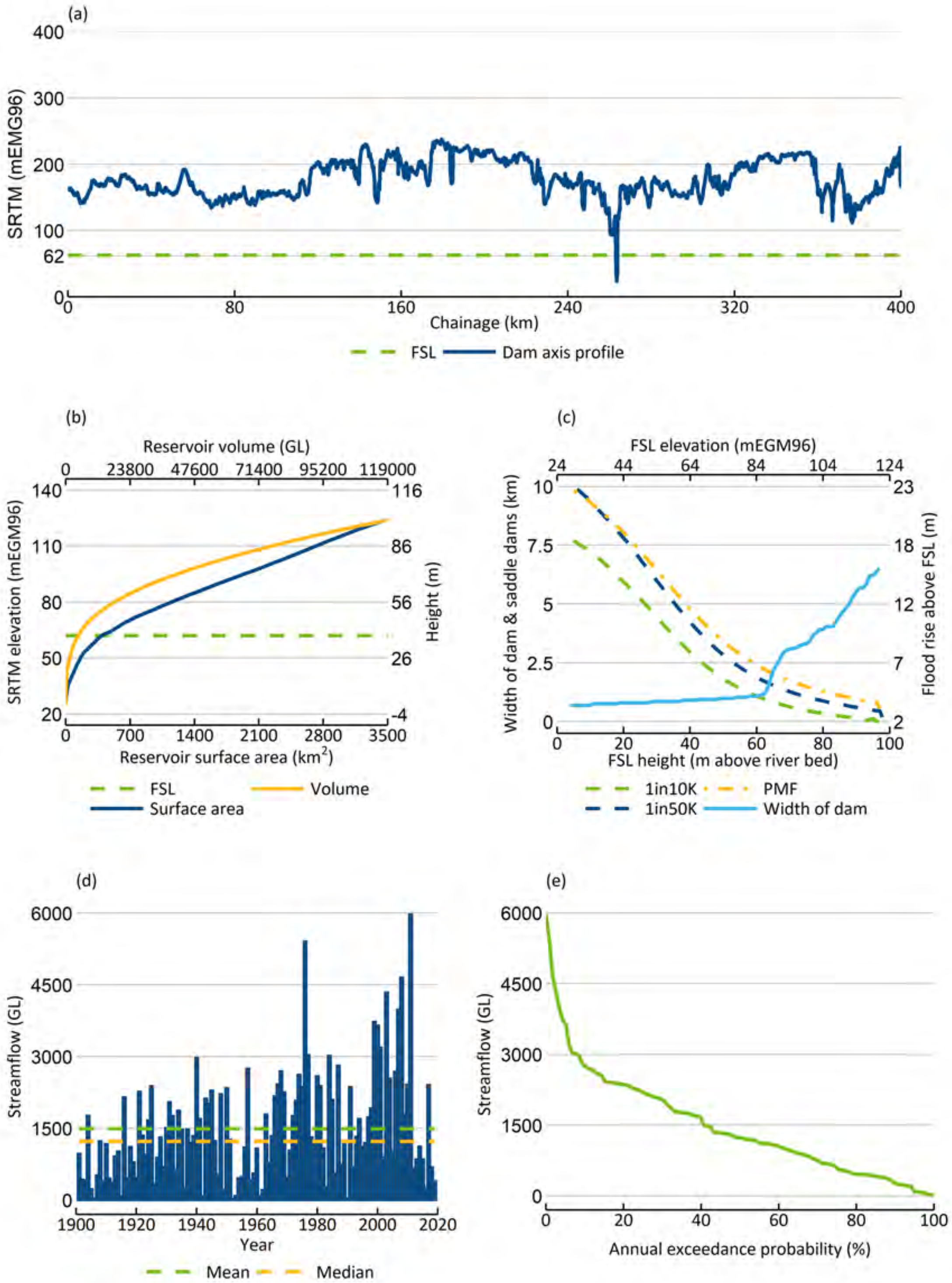
Apx Figure B-17 Potential Wilton River dam reservoir and property boundaries



Apx Figure B-18 Known water-dependent ecological assets in the vicinity of the potential Wilton River dam site and depth of reservoir as full capacity

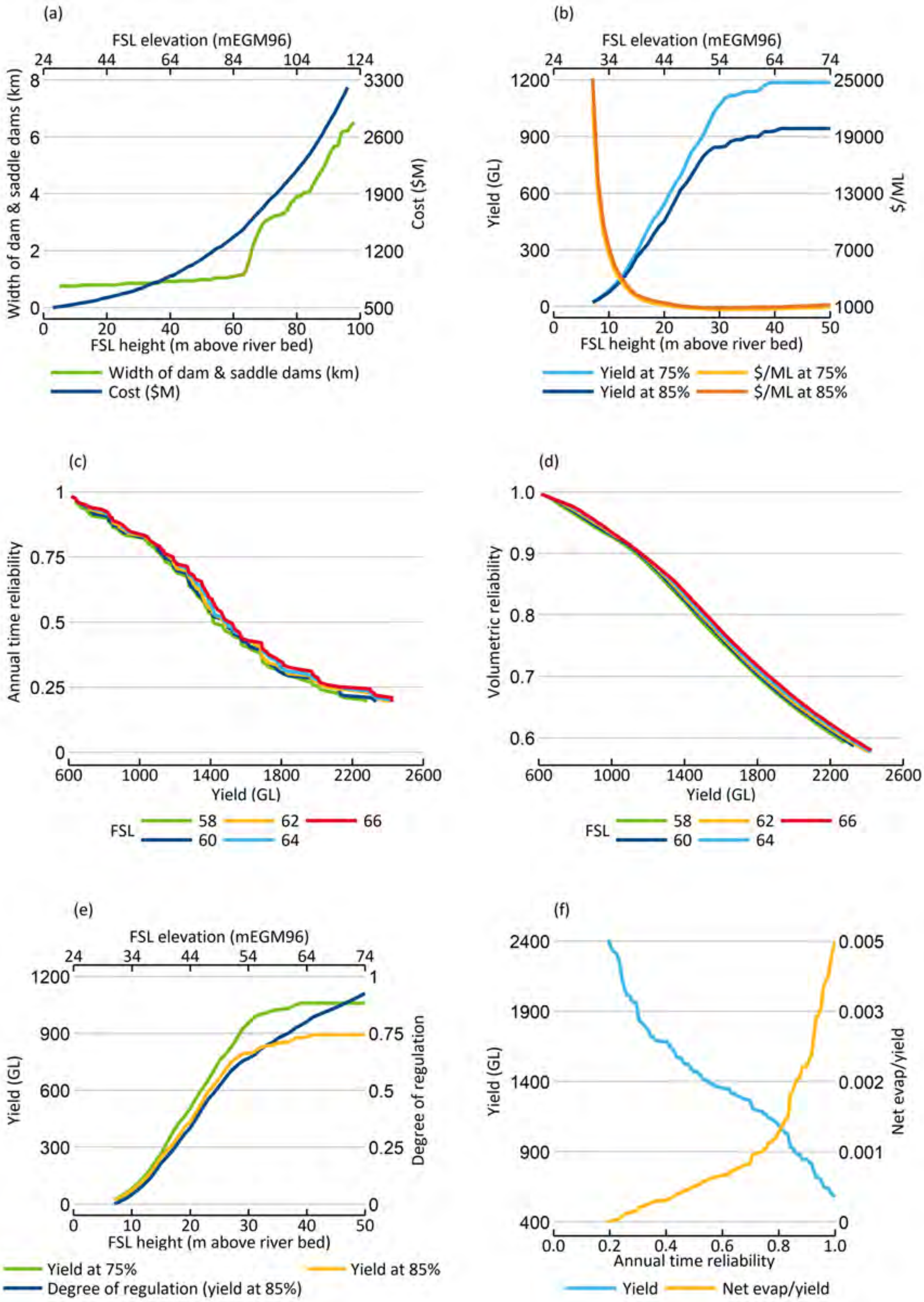


Apx Figure B-19 Geology underlying the potential Wilton River dam site and reservoir



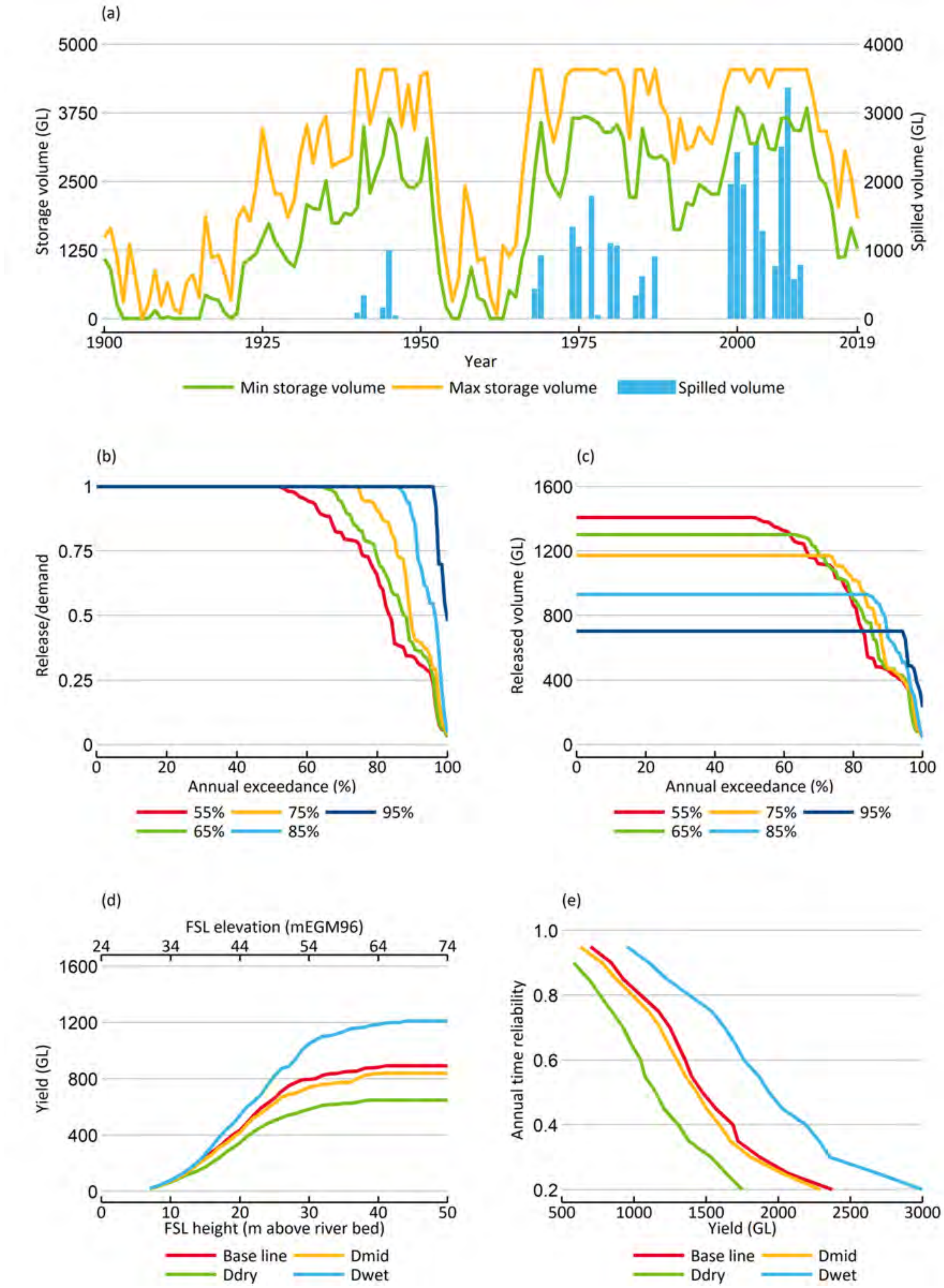
Apx Figure B-20 Wilton River potential dam site topographic dimensions and inflow hydrology

(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and probable maximum flood (PMF) events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance



Apx Figure B-21 Wilton River potential dam site cost, water yield at the dam wall and evaporation

(a) Dam length and dam cost versus full supply level (FSL); (b) dam yield at 75% and 85% annual time reliability and yield per million dollars at 75% and 85% annual time reliability; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 75% and 85% annual time reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f) yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.



Apx Figure B-22 Wilton River potential dam site and storage levels and water yield

(a) Maximum and minimum annual storage trace at the selected FSL (62 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55% to 95% of years at the selected FSL; (d) annual yield at 85% annual time reliability plotted against FSL under Scenario A (baseline) and Scenario D; (e) annual time reliability vs yield for FSL 62 mEMG96 under Scenario A (baseline) and Scenario D.

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Contact us

1300 363 400
+61 3 9545 2176
csiroenquiries@csiro.au
csiro.au

For further information

Environment
Dr Chris Chilcott
+61 8 8944 8422
chris.chilcott@csiro.au

Environment
Dr Cuan Petheram
+61 467 816 558
cuan.petheram@csiro.au

Agriculture and Food
Dr Ian Watson
+61 7 4753 8606
Ian.watson@csiro.au