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Assessment of surface water storage options in the Fitzroy, Darwin and Mitchell catchments

A technical report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments

Appendices to the Technical Report

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Important disclaimer

CSIRO Northern Australia Water Resource Assessment acknowledgements

This report was prepared for the Department of Infrastructure, Regional Development and Cities. The Northern Australia Water Resource Assessment is an initiative of the Australian Government's White Paper on Developing Northern Australia and the Agricultural Competitiveness White Paper, the government's plan for stronger farmers and a stronger economy. Aspects of the Assessment have been undertaken in conjunction with the Northern Territory Government, the Western Australian Government, and the Queensland Government.

The Assessment was guided by three committees:

(i) The Assessment's Governance Committee: Consolidated Pastoral Company, CSIRO, DAWR, DIIS, DoIRDC, Northern Australia Development Office, Northern Land Council, Office of Northern Australia, Queensland DNRME, Regional Development Australia - Far North Queensland and Torres Strait, Regional Development Australian Northern Alliance, WA DWER

(ii) The Assessment's Darwin Catchments Steering Committee: CSIRO, Northern Australia Development Office, Northern Land Council, NT DENR, NT DPIR, NT Farmers Association, Power and Water Corporation, Regional Development Australia (NT), NT Cattlemen's Association

(iii) The Assessment's Mitchell Catchment Steering Committee: AgForce, Carpentaria Shire, Cook Shire Council, CSIRO, DoIRDC, Kowanyama Shire, Mareeba Shire, Mitchell Watershed Management Group, Northern Gulf Resource Management Group, NPF Industry Pty Ltd, Office of Northern Australia, Queensland DAFF, Queensland DSD, Queensland DEWS, Queensland DNRME, Queensland DES, Regional Development Australia - Far North Queensland and Torres Strait

Note: Following consultation with the Western Australian Government, separate steering committee arrangements were not adopted for the Fitzroy catchment, but operational activities were guided by a wide range of contributors.

This report was reviewed by Dr Ian Watson

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Photo: Depiction of a dam at the potential Palmer River dam site on the Palmer River. Source: CSIRO

Director's foreword

Sustainable regional development is a priority for the Australian, Western Australian, Northern Territory and Queensland governments. In 2015 the Australian Government released the 'Our North, Our Future: White Paper on Developing Northern Australia' and the Agricultural Competitiveness White Paper, both of which highlighted the opportunity for northern Australia's land and water resources to enable regional development.

Sustainable regional development requires knowledge of the scale, nature, location and distribution of the likely environmental, social and economic opportunities and 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.

The Australian Government commissioned CSIRO to complete the Northern Australia Water Resource Assessment (the Assessment). In collaboration with the governments of Western Australia, Northern Territory and Queensland, they respectively identified three priority areas for investigation: the Fitzroy, Darwin and Mitchell catchments.

In response, CSIRO accessed expertise from across Australia to provide data and insight to support consideration of the use of land and water resources for development in each of these regions. While the Assessment focuses mainly on the potential for agriculture and aquaculture, 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 development and other interests.

Chris Chilcott

Project Director

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Shortened forms

SHORT FORM	FULL FORM
AAR	alkali–aggregate reaction
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 System 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
Cu	cubic
DEM	digital elevation model
DEM-H	national 1 second hydrological digital elevation model
DIWA	Directory of Important Wetlands in Australia
EB	Embankment
EPBC	Environmental Protection and Biodiversity Conservation act
FSL	full supply level
GAB	Great Artesian Basin
GCM	global climate model
GDG	Gould-Dincer-Gamma algorithm (or method)
IQQM	Integrated Quantity and Quality Model
MDIA	Mareeba–Dimbulah Irrigation Area (previous name of Mareeba–Dimbulah Water Supply Scheme)
MDWSS	Mareeba–Dimbulah Water Supply Scheme
mEGM96	Datum upon which SRTM and DEM-H are based
OSO	Total on-site overheads
NASY	Northern Australia Sustainable Yields Project
PMF	probable maximum flood
PMP	probable maximum precipitation
PWC	Northern Territory Power and Water Corporation
RCC	roller compacted concrete
REDD	Regional Ecosystem Description Database

SHORT FORM	FULL FORM
RORB	Runoff routing
SRTM	Shuttle Radar Topographic Mission
TDC	Total direct costs
TOC	Total out turn costs
TPC	Total project costs
VAST	Vegetation Assets, States and Transitions

Units

UNITS	DESCRIPTION
cu m	cubic metre
GL	gigalitre
ha	hectares
km	kilometre
m	metre
ML	megalitre
ML/year	megalitres per year (ML/y)
mm	millimetre
Mt	million tonnes
sq m	Square metre
y	year

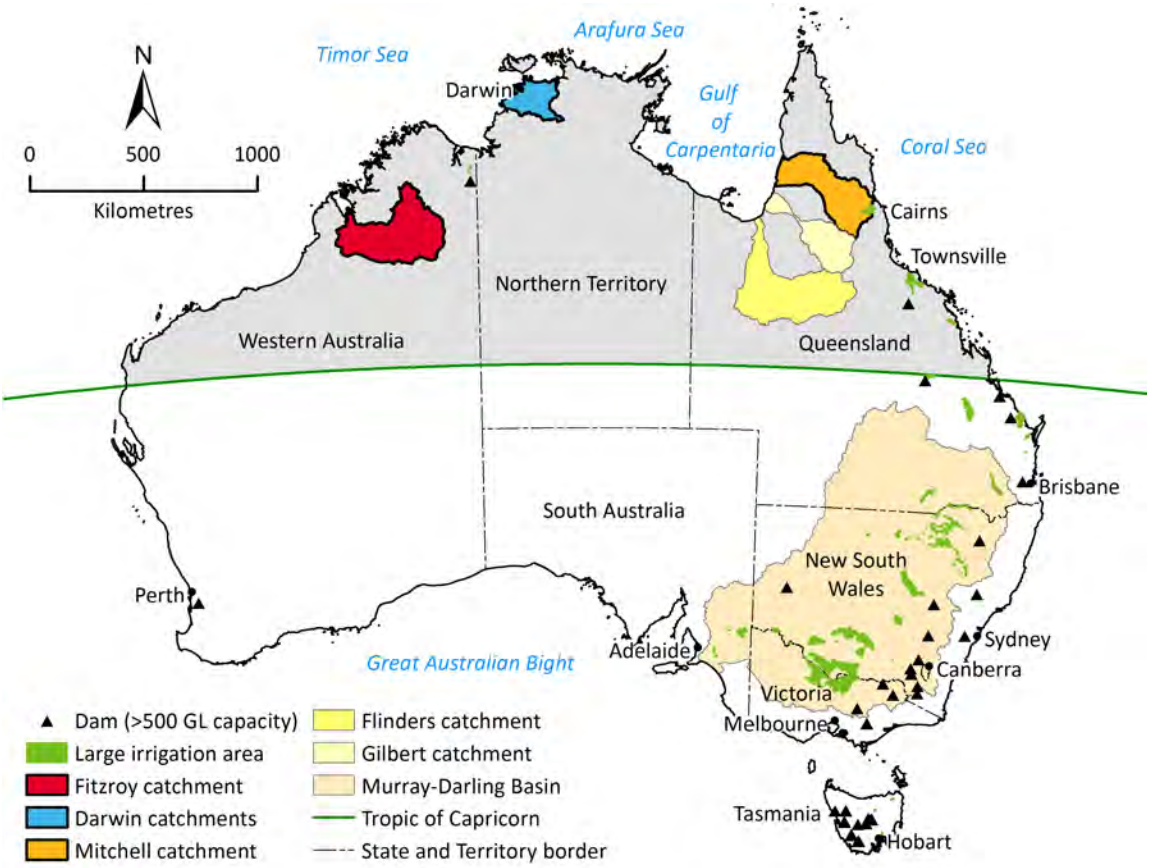
Preface

The Northern Australia Water Resource Assessment (the Assessment) provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water and agricultural development in three priority regions shown in Preface Figure 1:

- Fitzroy catchment in Western Australia
- Darwin catchments (Adelaide, Finniss, Mary and Wildman) in the Northern Territory
- Mitchell catchment in Queensland.

For each of the three regions, the Assessment:

- evaluates the soil and water resources
- identifies and evaluates water capture and storage options
- identifies and tests the commercial viability of irrigated agricultural and aquaculture opportunities
- assesses potential environmental, social and economic impacts and risks of water resource and irrigation development.



Preface Figure 1 Map of Australia showing three Assessment areas
Northern Australia defined as that part of Australia north of the Tropic of Capricorn. Murray Darling Basin and major irrigation areas and large dams (>500 GL capacity) in Australia shown for context.

While agricultural and aquacultural 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 did 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.

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 (e.g. impacts of irrigation development on terrestrial ecology) are discussed with reference to and in the context of the existing literature.

Assessment reporting structure

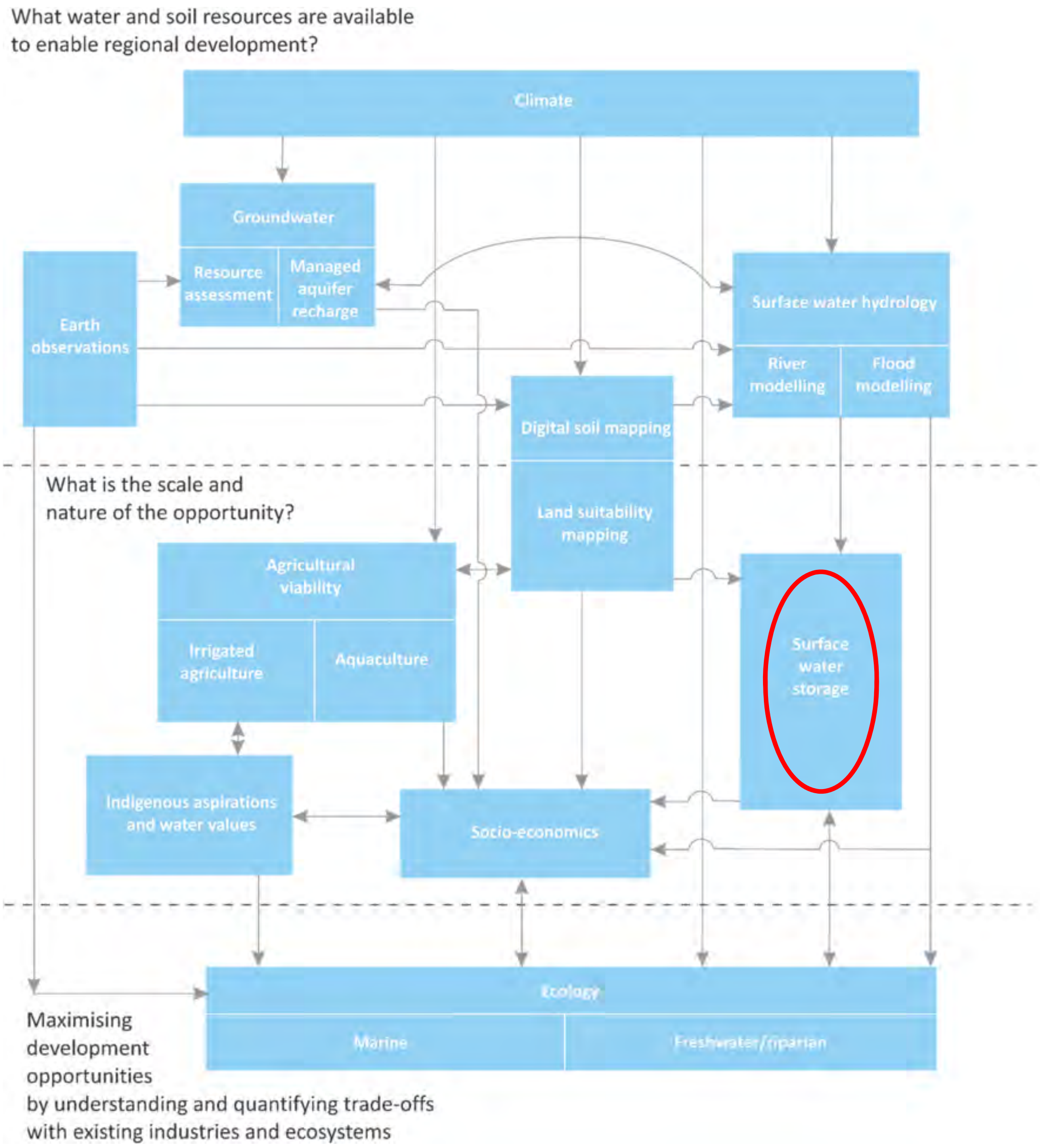
Development opportunities and their impacts are frequently highly interdependent and, consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports most reliably informs discussion and decision concerning regional development 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 ten activities (outlined below) has one or more corresponding technical reports.
- Catchment reports; that for each catchment synthesise 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.
- Summary reports; that for each catchment provide a summary and narrative for a general public audience in plain English.
- Factsheets; that for each catchment provide 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 http://www.csiro.au/NAWRA. 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.

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



Preface Figure 2 Schematic diagram illustrating high level linkages between the ten activities (blue boxes)
Activity boxes that contain multiple compartments indicate key sub-activities. This report is a technical report. The red oval in Preface Figure 2 indicates the primary activity (or activities) that contributed to this report.

Executive summary

Overview

Current allocations of water in the Fitzroy, Darwin and Mitchell catchments are low, relative to their median annual streamflow (<2%). The development of the surface water resources of these highly seasonal catchments 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.

There are a wide range of methods by which water can be stored, including large instream and offstream dams, farm-scale dams, weirs and other within-bank structures, natural water bodies and below the ground surface using managed aquifer recharge. However, decisions regarding river regulation and water storage are complex and the consequences of decisions can be inter-generational, where even relatively small inappropriate releases of water may preclude the development of other more appropriate (and possibly larger) developments in the future. Consequently, the benefits to government and communities of having a wide range of reliable information available prior to making decisions, including the manner of ways water can be stored, can have long-lasting benefits and facilitate an open and transparent debate. This report presents information on the broad-scale opportunities for storing surface water in the Fitzroy, Darwin and Mitchell catchments, though information on large dams is only presented for the Darwin and Mitchell catchments. A companion technical report presents information on the opportunities for managed aquifer recharge in these same catchments.

The construction of the more cost-effective large instream dams in the Darwin catchments is estimated to cost between $600/ML and $1200/ML of water supplied in 85% of years (excluding water distribution costs and losses). These dams have an equivalent annual unit cost per ML (including annual operation and maintenance costs of the dam) of water supplied at the dam wall in 85% of years of between $50 and $90, which is:

- one to two times the equivalent annual unit cost per ML/yr supplied in 85% of years by farm-scale gully dams (~$55) with a yield in 85% years to excavation.
- Half to one times the equivalent annual unit cost per ML/yr for large farm-scale ringtanks (i.e. ringtanks ~4 GL, $100) (after accounting for evaporation and seepage losses and including maintenance and operating costs).

The construction of the more cost-effective large instream dams in the Mitchell catchment is estimated to cost between $550/ML and $1300/ML of water supplied in 85% of years. These dams have an equivalent annual unit cost per ML/yr of water supplied in 85% of years of about $40 to $110, which is:

- one to two times the equivalent annual unit cost per ML/yr supplied in 85% of years by farm-scale gully dams (~$59) with a yield (in 85% years).
- half to one times the equivalent annual unit cost per ML/yr for large farm-scale ringtanks (~4 GL, ~$115) (after accounting for evaporation and seepage losses and including maintenance and operating costs).

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.

Large instream and offstream dams

This report documents the results of a pre-feasibility assessment of 15 potential dam locations, 7 in the Darwin catchments and 8 in the Mitchell catchment. Two and six of the potential dam locations in the Darwin and Mitchell catchments, respectively, had not previously been investigated. The remaining seven potential dam locations had been investigated and documented in some form prior to the Assessment. Prior investigations ranged from vague and isolated references to potential locations (e.g. Pinnacles on the Mitchell River) to feasibility level assessments (e.g. AROWS offstream storage in the Darwin catchments). A difficultly in comparing the outcomes of these studies was that they were undertaken by a wide range of organisations, at different times, using different methods and with varying degrees of rigour. Furthermore, many of the reports have not been officially published or remain confidential.

As part of the Assessment, all available published and unpublished literature on the previously identified potential dam locations were accessed from the Queensland State Government and SunWater archives, Northern Territory Government and Northern Territory Power and Water Corporation (PWC). These studies were reviewed and all dam site locations were reassessed using a consistent set of methods, and updated data where available. The majority of potential storage locations were visited by an experienced water infrastructure planner and/or engineering geologist as part of the Assessment, but no geotechnical investigations were undertaken. Geotechnical investigations are expensive and time consuming and were beyond the scope of this regional-scale Assessment.

To ensure that no potential dam options had been overlooked, the DamSite model was applied to the two catchments. This model is a series of algorithms that automatically determine favourable locations in the landscape as sites for intermediate to large instream and offstream dams. The DamSite model was used to assess over 20 million potential dam sites in each of the Darwin and Mitchell catchments. In the Darwin catchments the model confirmed the relative potential of previously identified dam sites. In the Mitchell catchment the model identified a number of new potential dam sites.

While a prospective dam site depends on a physiographic constriction of the river channel, it also requires favourable foundation geology. Favourable foundation conditions include a relatively shallow layer of unconsolidated materials such as alluvium, and rock that is relatively strong, non-erodible, has low permeability and is capable of being grouted. A preliminary desktop geological assessment of the DamSite results was undertaken using digital 1:250,000 geological maps. Only those new potential dam sites identified by the DamSite model that were revealed to be more favourable than known potential dam sites were investigated further. The most notable of these were in the Mitchell catchment, and included the Pinnacles site on the Mitchell River, a site on the Palmer River and two sites on the Walsh River.

To enable potential locations to be compared, the results are presented in this report using a consistent tabular format. Summaries of the results for the Darwin and Mitchell catchments are provided in Preface Table 1 and Preface Table 2, respectively. While the Assessment did investigate the suitability of soils for irrigation, that aspect is reported in the companion technical reports on digital soil mapping (Thomas et al., 2018a) and land suitability (Thomas et al., 2018b).

Potential dam sites in the Darwin catchments

One of the primary limitations to siting large dams in the Darwin catchments is that topographically suitable areas are limited to the relatively small headwater catchments. The best potential dam sites in the Darwin catchments are found where rivers have eroded through meta-sedimentary volcanic or igneous rocks in the Pine Creek Orogen, preferably where there is relatively shallow rock in the valley floor. Substantial excavation may be required to provide suitable foundations where alluvium is deep. Where the rivers are 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.

Seven potential dam sites in the Darwin catchments were reviewed. These are summarised in Preface Table 1. Two potential dam sites in the Darwin catchments were selected for further analysis on the basis that each was initially deemed to be the most promising in each of two distinct geographical areas. The selected sites were Mount Bennett and Upper Adelaide River.

The investigations of the two short-listed options sought to further assess the supply potential and to develop conceptual arrangements for each of the potential dams, as well as preliminary cost estimates based on current construction costs.

Preface Table 1 Potential dam sites in the Darwin catchments examined as part of the Assessment
All numbers have been rounded.

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)
Mount Bennett dam site on the Finniss River	RCC	20	343	1155	283	190 ◘	671	50
Upper Adelaide River dam site	RCC	23	298	616	153	182 ◘	1190	88
Acacia Gap dam site	EB	11	37	232	29	132 ☐	4452	337
AROWS	EB	18	91	34^	32^^	154 ☐	4873	342^^^
Marrakai dam site on the Adelaide River	EB	15	1520	4341	861	855 ☐&	992	73
McKinlay River dam site	EB	14	512	922	158	492 ☐	3114	231
Mary River dam site	RCC	30	1311	3063	492	756 ☐	1537	114

FSL = full supply level
* Embankment dam (EB), 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 +30% of 'true cost'. ☐ Indicates modelled preliminary cost estimate, which is likely to be –20% to +50% 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.
^ Catchment area of offstream storage only. Catchment area of Adelaide River at point of extraction is approximately 4500 km^2.
^^ Yield at the dam wall at 95% annual time reliability Based on a 26 m^3/s pump capacity at Adelaide River, 20:80 rule, 1 m^3/s pumping threshold and extraction only permitted during the falling limb of the hydrograph.
^^^ Includes cost of pumping water from Adelaide River into the reservoir.
& The original modelled cost ($657 million) was inflated by a nominal 30% to better reflect the likely additional costs of constructing a dam at a site with the poor foundation conditions, the additional costs involved for protecting the construction site from flooding (e.g. levees protecting the construction site) and the complex logistical challenges of constructing a large dam at this site.

Preface Table 1 shows that the Mount Bennett site has the lowest cost to yield ratio of all potential dam sites in the Darwin catchments. However, the quality of water inflowing to the potential Mount Bennett reservoir is unlikely to be suitable for urban water supplies given the location of the (closed) Rum Jungle uranium mine in the upper reaches of the catchment. Additionally, part of the Wagait Aboriginal Reserve would be inundated by a dam at this site. There are a number of registered and/or recorded sacred or cultural heritage sites known to exist in the area which would be potentially inundated. Substantial land in the area is subject to current or future native title claim.

The Upper Adelaide River dam site, also known as the Warrai site, is the most topographically favourable site for a dam in the Darwin catchments. It has the third-lowest cost to yield ratio of all the potential dam sites in the Darwin catchments. The yield from the dam could augment Darwin's future water demand via a supply pipeline as well as irrigating all of the land suitable for irrigated agriculture downstream of Adelaide River township and upstream of the Arnhem Highway. There are a number of registered and/or recorded sacred or cultural heritage sites known to exist in the area that would be potentially inundated. Substantial land in the area is subject to current or future native title claim.

Potential dam sites in the Mitchell catchment

The best potential dam sites in the Mitchell catchment are found where rivers have eroded through meta-sedimentary or volcanic rocks in the Mossman Orogen. Some of the potential dam sites in the area are where rivers have cut through ridges of strong sedimentary or metamorphic rock (such as arenite or chert) of the Hodgkinson Formation. Other potential dam sites occur where rivers have eroded through the younger volcanic rocks (ignimbrites and lavas) of Carboniferous to Permian age. The ignimbrites in this area are strong rocks formed by the welding of pyroclastic flows (hot mixtures of ash, and gas that flow rapidly from a volcano during an eruption). They have formed thick deposits covering large areas, which have been preserved because they have been deposited in subsidence areas (volcanic cauldrons). As ignimbrite is resistant to weathering and erosion, river valleys tend to be relatively narrow with relatively little alluvium.

Eight potential dam sites in the Mitchell catchment were examined as part of this pre-feasibility assessment. These are summarised in Preface Table 2. Two of these were previously identified, the Nullinga dam site on the Walsh River and the Pinnacles dam site on the Mitchell River, although the only reference to the latter was a location name and brief description. Four potential dam sites in the Mitchell catchment were selected for further analysis on the basis that each was initially deemed to be the most likely site to proceed in four distinct geographical areas. The selected sites were potential dams at Elizabeth Creek on Elizabeth Creek, Pinnacles dam site on the Mitchell River and two sites on the Walsh River.

The investigations of the four short-listed options sought to assess supply potential and to develop conceptual arrangements for each of the potential storage developments, as well as preliminary cost estimates based on current construction costs.

Preface Table 2 Potential dam sites in the Mitchell catchments examined as part of the Assessment
All numbers have been rounded.

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## ($/ML)	EQUIVALENT ANNUAL UNIT COST### ($/y per ML/y)
Lynd downstream dam site on the Lynd River	RCC	45	810	4554	507	731 ☐	1442	107
Lynd upstream dam site on the Lynd River	RCC	36	644	3983	412	750 ☐	1820	142
Palmer River dam site	RCC	56	1444	3801	553	690 ☐	1248	92
Elizabeth Creek dam site	RCC	36	149	580	55	189 ◘	3436	256
Pinnacles dam site on the Mitchell River	RCC	58	2316	7728	1248	755 ◘	605	45
Rookwood dam site on the Walsh River	RCC	61	1288	4855	575	655 ◘	1139	84
Chillagoe dam site on the Walsh River	RCC	50	600	3423	388	601 ◘	1549	115
Nullinga dam site on the Walsh River	RCC	31	145	327	65	349 ☐	5269	398

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 +30% of 'true cost'. ☐ Indicates modelled preliminary cost estimate, which is likely to be –25% to +50% 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.

Preface Table 2 shows that the potential Pinnacles dam site on the Mitchell River has the largest catchment area and highest yield of all sites examined in the Mitchell catchment. A storage at this site could support a large irrigation development at and downstream of Wrotham Park. At the level of development assessed, a very long saddle dam is required on the right bank. Nevertheless, the site has the lowest cost to yield ratio in the Mitchell catchment as a result of its high yield. Further assessment including geotechnical investigation of the saddle dam area would be required to determine the optimal level of development. Although a fish transfer facility would be constructed, the dam's potential impact on migration, movement and colonisation of key species, including the freshwater sawfish and barramundi, would need to be further considered.

The site with the second-lowest cost to yield ratio is the potential Rookwood dam site on the Walsh River. It is situated at the upstream end of a straight gorge section and is the most downstream site on the Walsh River suitable for a large dam. The site is easily accessed from the Bourke Development Road and is approximately 30 km from Chillagoe. It is about 60 km upstream of large contiguous areas of land suitable for irrigated agriculture near Wrotham Park. The potential Rookwood dam site commands a larger catchment area than the upstream Chillagoe dam site. Extensive saddle dams are required at the level of development assessed.

Total divertible yield

In the Darwin catchments it was found that the total divertible yield, before losses, from five of the more promising potential dam sites was about 1100 GL in 85% of years at the dam wall. With the addition of more potential dam sites, the construction cost per ML of yield increased from about $600/ML with the first potential dam site (i.e. Mount Bennett) to nearly $1600/ML for all five dams.

In the Mitchell catchment it was found that the total divertible yield, before losses, from four and six of the more promising potential dam sites was about 2800 GL and 3000 GL, respectively, in 85% of years at the dam wall. It was found that after the fourth dam there were marginal returns with the addition of each subsequent dam.

Farm-scale gully and hillside dams and offstream storages in the Fitzroy, Darwin and Mitchell catchments

This report provides a broad-scale assessment of the suitability of farm-scale gully and hillside dams and offstream water storage locations in the Fitzroy, Darwin and Mitchell 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 Fitzroy, Darwin and Mitchell catchments was undertaken based on soil parameter grids developed by the Assessment team. These data were sourced from the companion technical report on digital soil mapping (Thomas et al., 2018a). 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 Fitzroy catchment are along the recent alluvial soils adjacent to the Fitzroy River. This area is, however, susceptible to flooding. Elsewhere in the Fitzroy catchment the soils are too sandy or landscape too steep and rocky for farm-scale offstream storages. The most promising areas for farm-scale offstream storages are in the upper Adelaide and Mary rivers. Although the coastal plains, which extend up to 50 km inland, appear suitable for farm-scale offstream storages around Darwin, these areas have limited opportunity for cropping as they are generally too wet. The Mitchell catchment has the largest area of land suitable for farm-scale offstream storages, predominately located below the junction of the Mitchell and Palmer rivers. This area is susceptible to flooding so care would need to be taken when siting offstream storages.

Farm-scale gully and hillside dams were modelled using the DamSite model. A large number of storages with storage to excavation ratios greater than 20 were identified in all three study areas. The cumulative effect of farm-scale ringtanks is examined in the companion technical report on river system simulation (Hughes et al., 2018) and the companion technical report on ecology (Pollino et al., 2018a,b).

Natural water bodies

Natural surface water bodies such as large waterholes offer the cheapest source of surface water. However, the scale of irrigation and regional economic development they may enable is limited in extent and highly distributed. Furthermore, natural water bodies that persist throughout the dry season are considered to be key ecological refugia and can have cultural significance. Larger natural water bodies that could enable 1 to 10 ha of irrigation may be best placed for 'staging' an irrigation enterprise, where mistakes and lessons are made at a small scale before considerable sums of money have been invested.

Sedimentation considerations

Sedimentation within dams can be a major problem for water storage capacity since infilling progressively reduces the volume available for active water storage. Often deposition of coarser-grained sediments occurs in the backwater (upstream) areas of reservoirs, which can cause back-flooding beyond the flood limit originally determined for the reservoir. Downstream impacts can also occur, including sediment starvation, which can trigger channel-bed incision and bank erosion.

Potential dams in the Darwin catchments, which were examined as part of the Assessment, were estimated to have less than 3% sediment infilling after 30 years and less than 7% sediment infilling after 100 years. Potential dams in the Mitchell catchment, which were examined as part of the Assessment, were estimated to have about 1% or less sediment infilling after 30 years and less than 3% sediment infilling after 100 years.

The impacts of sediment trapping in triggering a sediment-starved response downstream of the dams were not considered, nor were the patterns of deposition within the potential reservoirs. Deposition within a reservoir can have an impact on the trap efficiency of the dam and the effective storage volume over time.

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.

Ecological considerations

A desktop assessment of potential environmental issues associated with large potential dam sites in the Darwin and Mitchell catchments was undertaken. Assessment of potential impacts was based on fish distribution and passage, for which reasonable information exists, inundation of vegetation communities (regional ecosystems), which have been mapped in reasonable detail by the Queensland Government across the Mitchell catchment, 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).

Large dams constructed on the mid-reaches of the Finniss, Adelaide and Mary rivers in the Darwin catchments and mid-reaches of the Palmer, Mitchell, Walsh and Lynn rivers may limit the migration, movement or colonisation of habitat by fish species. Potential dam sites in the headwaters of the Darwin and Mitchell catchments (e.g. Upper Adelaide River dam site in the Darwin catchments and Nullinga and Elizabeth Creek dam sites in the Mitchell catchment) 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.

The majority of potential dam sites in the Mitchell catchment contain some regional ecosystems considered to be either 'Endangered' or 'Of concern'. Complex changes in habitat resulting from inundation could create new habitat to benefit some of these species, while other species would be impacted by loss of habitat. If any potential dam site is considered for further investigation, the vegetation and fauna communities present would need to be investigated much more thoroughly as part of a feasibility analysis. The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018a,b).

Cultural heritage considerations

Insufficient information relating to the cultural heritage values of the short-listed sites was accessed to allow full understanding or quantification of the likely impacts of water storages. The Fitzroy, Darwin and Mitchell catchments are 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.

Contents

Figures

Tables

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Part V Appendices

This report contains the six appendices to the main technical report and must be read in conjunction to the main technical report.

Appendix A (page 202) provides summary tables for the non-short-listed potential dam sites in the Darwin catchments.

Appendix B (page 258) provides summary tables for the non-short-listed potential dam sites and existing dams in the Mitchell catchment.

Appendix C (page 304) provides detailed costings for the short-listed potential dam sites and existing dams in the Darwin catchments.

Appendix D (page 315) provides detailed costings for the short-listed potential dam sites in the Mitchell catchment.

Appendix E (page 338) contains the petrology report for rock samples taken at the six short-listed sites.

Appendix F (page 358) provides additional detail for the reservoir sediment infill assessment.

Appendix A Non-short-listed sites

A.1 Darwin catchments

Existing and potential dam sites are listed from west to east.

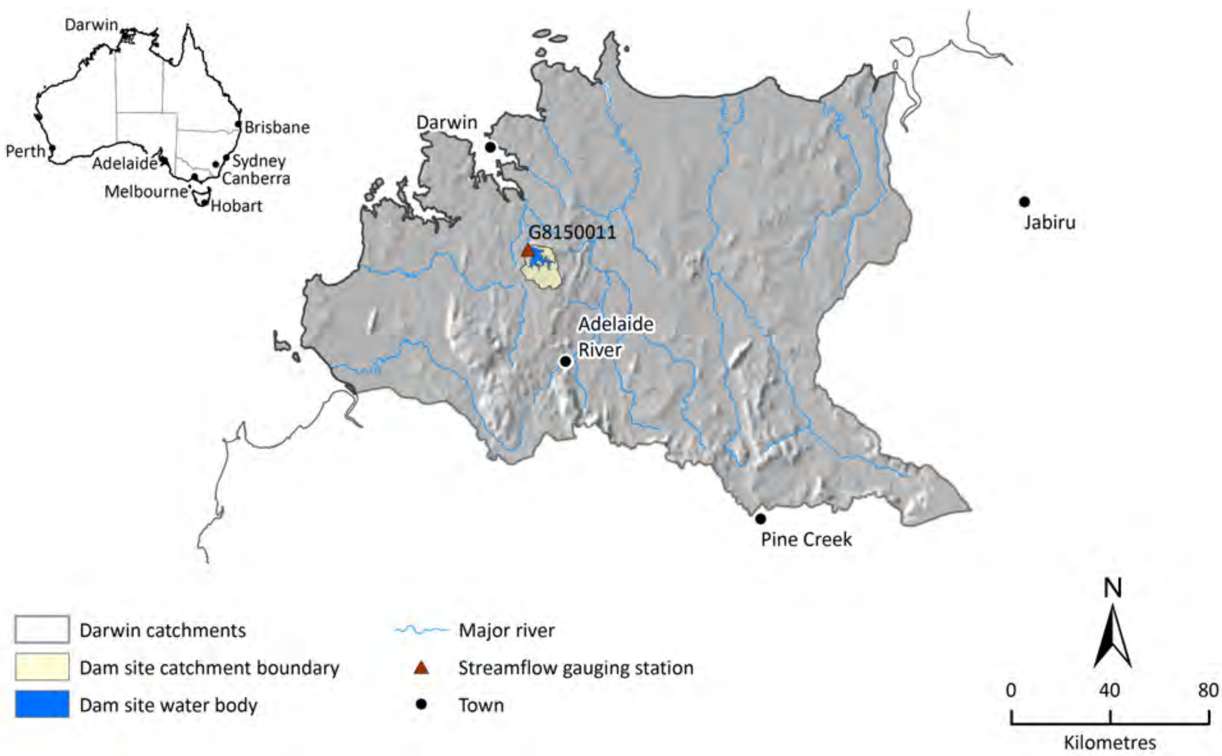
A.1.1 DARWIN RIVER DAM

PARAMETER	DESCRIPTION
Description of dam	The Darwin River Dam, owned and operated by the Northern Territory Power and Water Corporation (PWC), currently provides 85% of Darwin's water supply. The other 15% is sourced from the McMinns and Howard East borefields. The dam was completed in 1972 with a 35-m wide uncontrolled spillway on the left abutment. The spillway was widened in 2002 to 265 m to improve spillway capacity and in 2010 the embankment was upgraded and the spillway crest raised 1.3 m, increasing storage capacity and yield. Releases from the dam are made via a pipeline to a pump station downstream of the dam and then via pipeline to a reservoir and transfer station where the supply is blended with the bore water supply. Environmental flow releases are also made to the river. **The following figures accompany this description of the site** The Darwin River Dam is shown in Apx Figure A-1. Apx Figure A-2 provides a map showing its location in the Mitchell catchment, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Site topography and dam hydrology are shown in Apx Figure A-3 and Apx Figure A-4.
Regional geology	The dam site and reservoir area are located in a geological province known as the Pine Creek Orogen, which is an area underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The rocks in the area have been intruded by granite, folded, faulted and uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the older rocks in the area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on some of the slopes. The project and storage area consists of ridges and isolated hills of quartzite and sandstone striking north-east/south-west at and near the dam site and east-west north of the storage. Most of the flatter ground in the storage area is underlain by sandy and gravelly soils (alluvium and colluvium) of Tertiary age and alluvium of Quaternary age, which is likely to consist of gravel, sand and silt, and black clayey soils.
Site geology	The existing dam is on a west-northwest-trending section of the river where it cuts through a relatively narrow northeast/southwest-trending ridge of Acacia Gap Quartzite. The dam foundations and abutments are likely to be underlain by sandstone, quartzite and greywacke. According to the published geological map the rocks are likely to dip at 40° to 50° downstream (north-west). More information on the geology of the dam site may be available in investigation, design and construction reports for the existing dam.
Reservoir rim stability and leakage potential	No reservoir stability issues have been observed. Given the lack of soluble rocks in the storage area and the lack of narrow low steep-sided saddles, reservoir leakage is unlikely to be a significant issue.
Structural arrangement	The dam is a 28 m maximum height, 518-m long zoned earthfill embankment with riprap protection on the upstream face. The spillway, which is excavated through the left abutment, has a low ogee-shaped crest structure and a short concrete apron. The floor of the spillway chute downstream of the apron is unlined and appears to be erosion resistant.

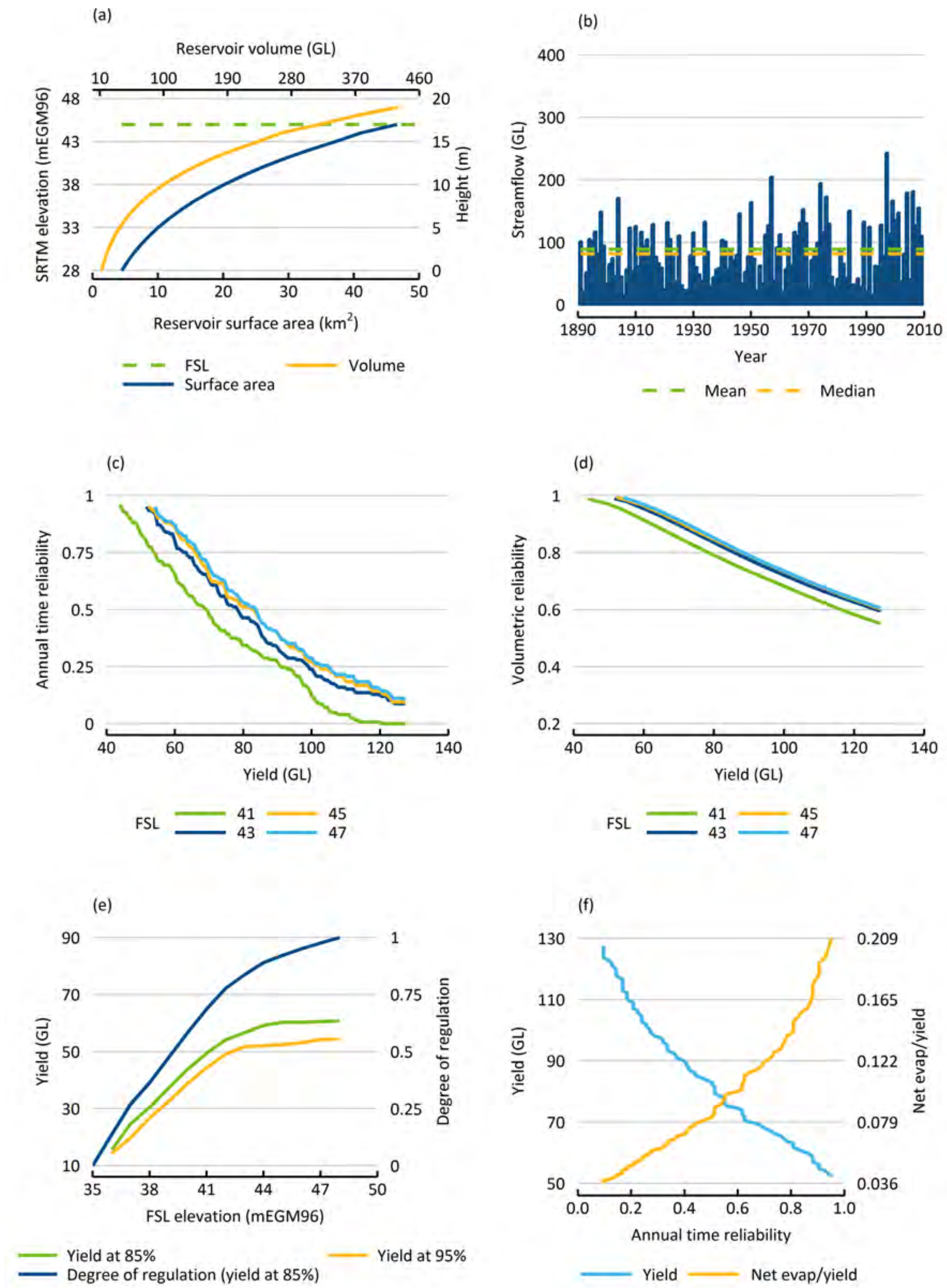
PARAMETER	DESCRIPTION
	An outlet conduit under the embankment located on the left abutment can make releases to the river to meet downstream requirements and delivers supply to a pump station located on the right bank of the river, which delivers supply to Darwin.
Availability of construction materials	Previous reports on other potential projects suggest that the quartzite, sandstone and greywacke from the Acacia Gap Quartzite may be suitable for rockfill, filter materials and concrete aggregate. Concrete aggregate and other products may also be available from existing quarries in granite and quartzite in the area. Clay, sand and gravel may be available in alluvium close to rivers, in flatter ground between the hills and ridges, and near the base of slopes.
Catchment area	The catchment area upstream of the dam site is estimated to be 205 km^2.
Storage capacity	The raised storage has a capacity of 265 GL.
Reservoir yield assessment at the dam wall	Although Power and Water is licensed to extract 49.1 GL from the dam, yield has recently been assessed as 36.78 GL after the latest 5-yearly review of yield. As part of the Assessment the yield from Darwin River Dam reservoir at 85% annual time reliability was assessed as being 37.4 GL. The yield at 95% annual time reliability was assessed as being 28.6 GL. Note for consistency with the other sites the yield values reported in the Assessment assume the Darwin River Dam reservoir is operated separately and not as part of a system and demand was not modified during periods that water restrictions may have been enforced.
Open water evaporation	At full supply level (FSL), surface area of the storage is about 4100 ha. If used to supply 37.4 GL of water in 85% of years the mean annual evaporation and mean annual net evaporation from the Darwin River Dam reservoir is 43.2 GL and 9.7 GL, respectively. The ratio of mean annual net evaporation to total water supplied is 0.274. If used to supply 28.6 GL of water in 95% of years the mean annual evaporation and mean annual net evaporation from the Darwin River Dam reservoir is 50.9 GL and 11.4 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.401.
Potential use of supply	The existing dam is fully committed to urban supply. **Agriculture** The landscape below the Darwin River Dam is dominated by lower foot-slopes and pediments (<5%) derived from sandstones and siltstones of the metasediments hills and rises grading to level to gently undulating plains and rises on deeply weathered Tertiary sediments to the north. The lower foot-slopes and pediments (<5%) usually have moderately deep (0.5–1 m), moderately well-drained to imperfectly drained, sandy to loamy surfaced, yellow and brown massive (Kandosols) or structured (Dermosols) soils frequently with rock fragments throughout the profile. Iron nodules in the profile also frequently occur, especially on lower slopes. These foot-slopes and pediments are often fragmented due to abundant drainage lines and 'short' slopes between rock outcrops, but relatively large areas (100 ha) may be usable for horticultural land uses and small-scale grain and forage cropping. Soils are unlikely to be suitable for ringtanks. The deeply weathered plains and rises have sandy to loamy surfaced well-drained red, brown and yellow soils on the upper slopes while sandy to loamy surfaced moderately well-drained to imperfectly drained yellow and grey soils occur on the plains and lower landscape positions. The depth to iron pans and the amount of iron nodules generally increases lower in the landscape. Generally, the intact level deeply weathered surface has deep red soils with small to moderate amounts of iron nodules throughout the profile grading to shallow soils with abundant iron nodules and iron pans on the eroded edges of the plains and upper slopes of rises. Exposed laterite is common. Moderately deep soils with abundant iron nodules and iron pans frequently occur on mid- to lower slopes. The red and yellow moderately deep to very deep soils are suitable for all agricultural uses except furrow or flood irrigation methods. Soils are unlikely to be suitable for ringtanks. See companion technical report on land suitability (Thomas et al., 2018).

PARAMETER	DESCRIPTION			
	Urban Darwin River Dam currently provides 85% of Darwin's water supply, with the other 15% sourced from the McMinns and Howard East borefields. Current annual demand for water in the Darwin region (between about 40 to 45 GL/y) is approaching the current water supply system yield. As a result, PWC is currently investigating short- and medium-term supply augmentation options. Future water demand to 2065 is projected to be between about 50 and 60 GL/y, depending upon assumptions regarding population growth and the success of demand-management programs (e.g. Living Water Smart).			
Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)	0.0	0.2	02
	100 years (%)	0.0	0.6	0.7
	Years to fill	200,122	16,393	14,409
Estimated cost	**Existing dam** The dam construction cost was $4.4 million in 1972 (written correspondence Ian Smith (Assistant Secretary Water Resources), 10 March 1977), which when adjusted by CPI to 2017 dollars is approximately $45 million. It would be more appropriate to use a local construction index to index the cost rather than CPI; however, construction indexes are not available back to 1972. This cost does not include any wall raising or spillway upgrades.			
Estimated cost/ML of supply	The Darwin River Dam is a low-cost source of water supply for the Darwin region, being a relatively low-cost structure providing a significant yield volume.			
Summary comment	Current annual demand for water in the Darwin region (i.e. between about 40 to 45 GL) is approaching the current water supply system yield. The Darwin River Dam supplies 85% of Darwin's water, the other 15% being sourced from the McMinns and Howard East borefields. PWC is currently investigating short- and medium-term supply augmentation options. The Darwin River Dam storage level was raised in 2010, as a short-term option at the time. Future annual water demand to 2065 is projected to be between about 50 and 60 GL depending upon assumptions regarding population growth and the success of demand-management programs (e.g. Living Water Smart).			

Apx Figure A-1 Darwin River Dam looking upstream

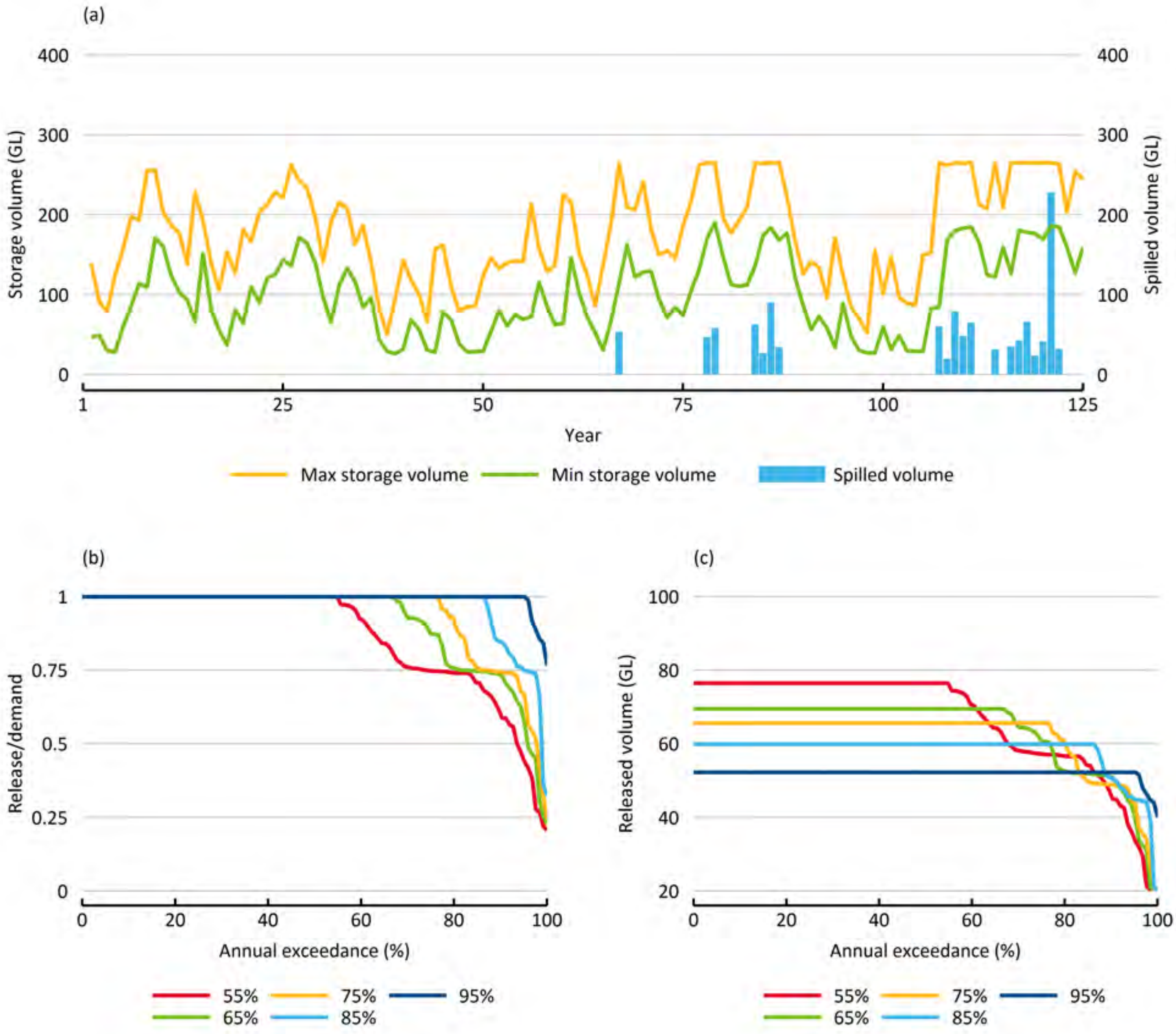


Apx Figure A-2 Location map of Darwin River Dam, reservoir extent and catchment area



Apx Figure A-3 Darwin River Dam topographic dimensions, inflow hydrology and yield

(a) Reservoir volume, surface area and height relationship; (b) annual streamflow; (c) annual time reliability plotted against yield for different full supply levels (FSL); (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% 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 A-4 Darwin River Dam site storage levels and yield

(a) Maximum and minimum annual storage trace at the selected FSL 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

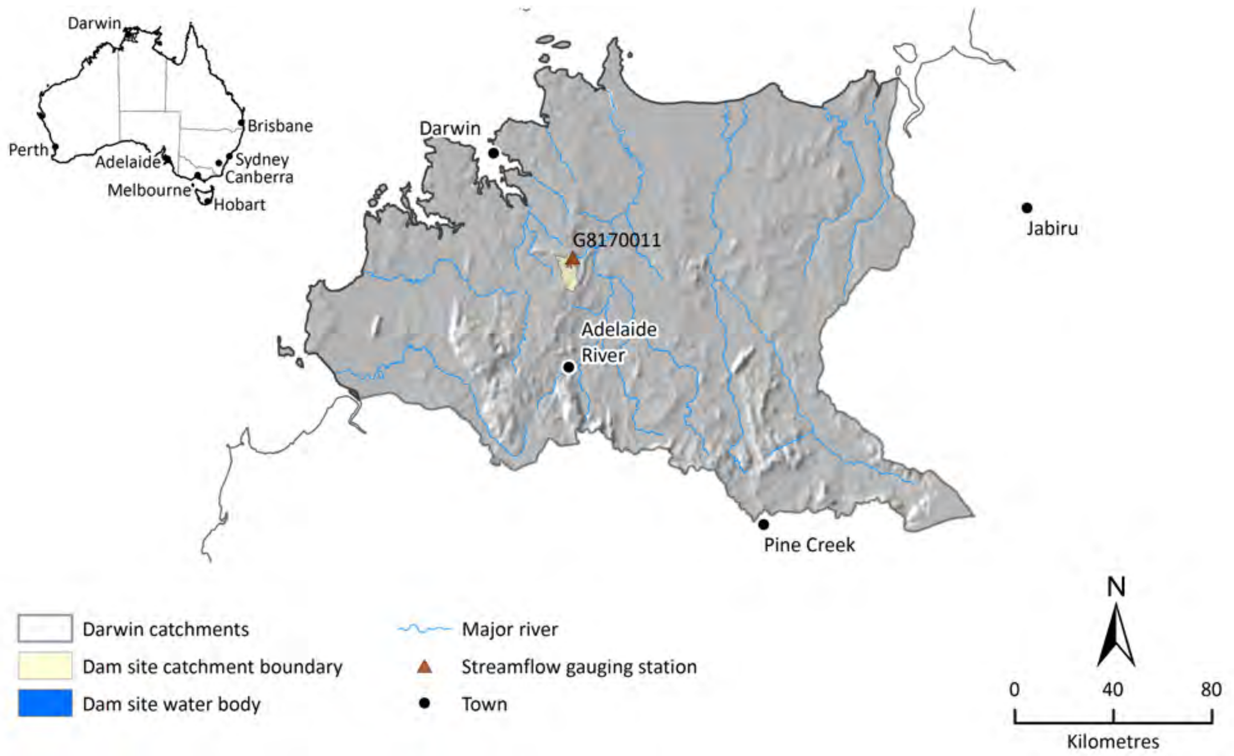
A.1.2 MANTON DAM

PARAMETER	DESCRIPTION
Previous investigations	Manton Dam was Darwin's first source of surface water supply. Construction was completed in 1942. Supply was conveyed to Darwin via a pump station downstream of the dam and two transmission pipelines (300 mm and 375 mm diameter). Since the completion of the Darwin River Dam in 1972, Manton Dam has not been used as part of the Darwin supply. Releases from the dam can be made to the river through a micro hydro power plant. The dam, which is managed by PWC, has over later years become a popular recreation facility for boating, water sports and fishing. The following reports are known to provide information on Manton Dam. Power Water (2013) Darwin region water supply strategy. SMEC (2012) Darwin yield assessment and multi objective decision support system volume 2 – Manton Dam return to service and upgrade options. Entura (2015) Darwin region water supply medium term water source options assessment, cost estimate report. Entura, June 2015.
Description of dam	PWC intend to return the dam to its water supply service function by about 2025 as a short-term measure to provide additional water supply to Darwin. The dam is described below under Structural arrangement. **The following figures accompany this description of the site** A photograph of Manton Dam is provided in Apx Figure A-5. Apx Figure A-6 provides a map showing its location in the Darwin catchments, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Site topography and dam hydrology are shown in Apx Figure A-7 to Apx Figure A-8.
Regional geology	The dam and reservoir area are located in a geological province known as the Pine Creek Orogen, which is an area underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The rocks in the area have been intruded by granite, folded, faulted and uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the older rocks in the project area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on some of the slopes. The project area consists of ridges and isolated hills of quartzite and sandstone striking north/south at and near the dam site and north-west/south-east in the storage area. There are also isolated hills of granite, gneiss and schist in the catchment area. Most of the flatter ground in the storage area is underlain by sandy and gravelly soils (alluvium and colluvium) of Tertiary age and alluvium of Quaternary age, which is likely to consist of gravel, sand and silt, and black clayey soils.
Site geology	The existing dam is on an east-trending section of the river where it cuts through a relatively narrow ridge north/south-trending ridge of Acacia Gap Quartzite. The dam foundations and abutments are likely to be underlain by sandstone, quartzite and greywacke. According to the published geological map the rocks are likely to dip at 60° to 80° downstream (east) or upstream (west). More information on the geology of the dam site may be available in investigation, design and construction reports for the existing dam.
Reservoir rim stability and leakage potential	No issue has been observed since the completion of the dam in 1942. Given the lack of soluble rocks in the storage area and the lack of narrow low steep-sided saddles, reservoir leakage is unlikely to be a significant issue.
Structural arrangement	The existing dam is a thin concrete arch dam 24 m high (Australian National Committee on Large Dams (ANCOLD) register) with a central overflow spillway section. An inlet tower, river outlet and pipeline to the pump station are located on the left bank side. Consideration has been given to developing a larger storage at the site by constructing a higher dam downstream of the existing structure, or alternatively, a higher dam further upstream in the catchment, maintaining the existing storage level in the existing dam. Consideration has also been given to a raising of the existing dam structure. These options would have major impacts on the existing recreation facilities and only provide a modest increase in the available supply.

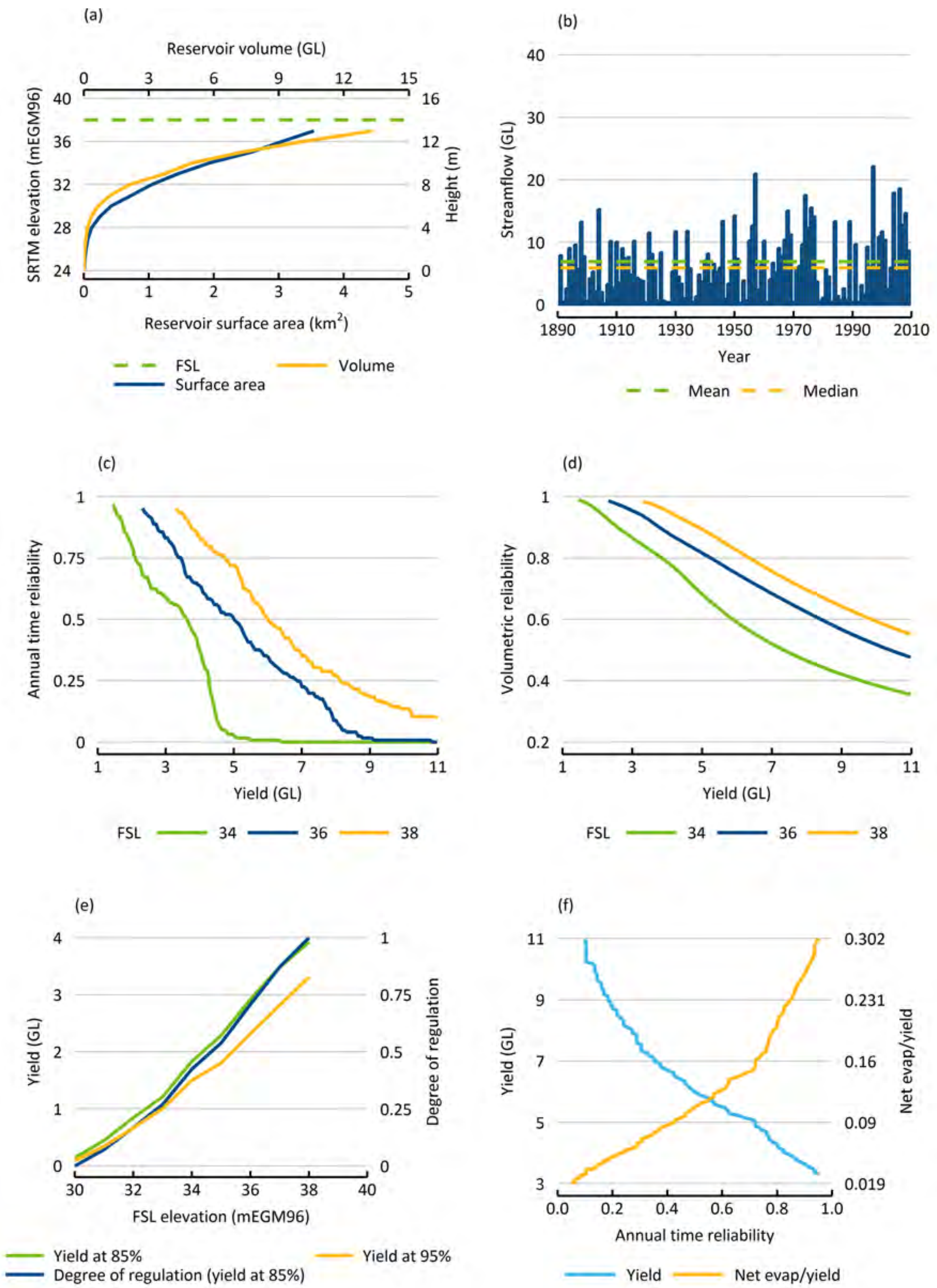
PARAMETER	DESCRIPTION
	The return to service proposal involves a new intake arrangement, new suction main, pump station and 21-km long 1050-mm diameter delivery main to a proposed new storage and treatment facility at Strauss south of Darwin.
Availability of construction materials	Previous reports on other potential projects suggest that the quartzite, sandstone and greywacke from the Acacia Gap Quartzite may be suitable for rockfill, filter materials and concrete aggregate. Concrete aggregate and other products may also be available from existing quarries in granite and quartzite in the area. Clay, sand and gravel may be available in alluvium close to rivers, in flatter ground between the hills and ridges and near the base of slopes.
Catchment area	The catchment area of Manton Dam is 83.9 km^2
Flow data	The only stream gauging station on the Manton River is G8170075, which is located upstream of the dam storage. The station, which was established in October 1963, has a catchment area of 28 km^2. Height data are available for the majority of years since establishment of the station but prepared outputs are not available.
Storage capacity	Storage capacity at the existing FSL of 38 mEMG96 is 13.3 GL.
Reservoir yield assessment	As part of the Assessment the yield from Manton Dam reservoir was assessed as being 3.9 GL at 85% annual time reliability. The yield at 95% annual time reliability was assessed as being 3.3 GL. Note the yield assessments reported here assume the reservoir operates separately and not as part of a system. PWC are licensed to extract 7.4 GL/y from the dam. However, net system yield is reported to be 6.2 GL/y.
Open water evaporation	Surface area of the storage at FSL is 354 ha. If used to supply 3.31 GL of water in 95% of years the mean annual evaporation and mean annual net evaporation from the Manton Dam reservoir is 4.3 GL and 1.0 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.31.
Potential use of supply	**Recreation** Manton Dam is a popular recreation facility for boating, water sports and fishing. **Agriculture** The alluvial plains of Manton River above the confluence with the Adelaide River has a narrow alluvial plain while the Adelaide River below the dam typically has a tidal main channel, a narrow levee, extensive level alluvial plains subject to occasional to regular flooding, and frequent drainage depressions and swamps. The alluvial plains are subject to annual flooding for extended periods. Soils on the level alluvial plains in the upper catchments are predominantly imperfectly drained to poorly drained, slowly permeable, structured gradational soils (Dermosols, Hydrosols) with hard-setting clay loam to silty clay loam surfaces over sodic, mottled, grey clay subsoils. Hard-setting poorly drained clay soils occur throughout the Adelaide River alluvial plains. Soils are generally unsuitable for irrigated cropping but may be suitable for dry-season rice and forage cropping. Soils are likely to be suitable for ringtanks. Very narrow levees of the Adelaide River with imperfectly drained, moderately permeable, mottled brown, massive, loamy soils (Kandosols) and friable loamy soils (Dermosols) are suitable for wetness tolerant horticultural crops. The generally long thin units associated with the levees may restrict irrigation layout and machinery use in most areas. Soils are unlikely to be suitable for ringtanks. The lower foot-slopes and pediments (<5%) derived from sandstones and siltstones of the metasediments hills and rises usually have moderately deep (0.5–1 m), moderately well-drained to imperfectly drained, sandy to loamy surfaced, yellow and brown massive (Kandosols) or structured (Dermosols) soils frequently with rock fragments throughout the profile. Iron nodules in the profile also frequently occur, especially on lower slopes. These foot-slopes and pediments are often fragmented due to abundant drainage lines and 'short' slopes between rock outcrops, but relatively large areas (100 ha) may be usable for horticultural land uses and small-scale grain and forage cropping. Soils are unlikely to be suitable for ringtanks. See companion technical report on land suitability (Thomas et al., 2018).

PARAMETER	DESCRIPTION			
	Urban Current annual demand for water in the Darwin region (i.e. between about 40 to 45 GL) is approaching the current water supply system yield. Darwin River Dam supplies 85% of Darwin's water, the other 15% sourced from the McMinns and Howard East borefields. PWC is currently investigating short- and medium-term supply augmentation options. Future annual water demand to 2065 is projected to be between about 50 and 60 GL depending upon assumptions regarding population growth and the success of demand-management programs (e.g. Living Water Smart). PWC intend to return the dam to its water supply service function by about 2025 as a short-term measure to provide additional water supply to Darwin.			
Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)		2.2	
	100 years (%)		7.4	
	Years to fill		1352	
Ecological and cultural considerations raised by previous studies	PWC intends that the future of recreational activities at the dam be reviewed as part of the return to service strategy.			
Water quality and stratification considerations	Water quality studies initiated by PWC in 2008 have identified that the storage experiences seasonal thermal stratification, has elevated levels of iron, manganese, colour and turbidity at times and is susceptible to periodic high levels of cyanobacteria (blue-green algae). Significant water treatment will be necessary to manage these challenges.			
Storage impacts	No additional storage impacts will result from the dam's return to service.			
Environmental considerations	No significant additional environmental impacts are expected as a result of the dam's return to service.			
Indigenous cultural heritage considerations	No significant additional cultural considerations are expected as a result of the dam's return to service.			
Estimated cost	Allowing for direct costs, on costs and contingencies, upgrade works at the dam are estimated to cost $5.2 million (Entura, 2015). The transmission main from the dam to the Strauss storage and treatment facility is estimated to cost $85.2 million (Entura, 2015).			
Estimated cost/ML of supply	Based on the estimated cost of upgrade works at the dam only and assuming a yield at 85% annual time reliability (for consistency with other sites) the cost/ML of supply at the dam wall is $1323. Including the transmission main required for the dam's return to service, delivery pump station and pipeline, and a yield at 95% annual time reliability the estimated cost ML of supply is $27,311. Note the yield values reported here assume the Manton Dam reservoir is operated separately and not as part of a system.			
Summary comment	Manton Dam is a small existing dam currently only used for recreational purposes. PWC have identified that their short-term water supply risks (to 2020) will be most effectively managed by the return to service of Manton Dam in combination with their Living Water Smart demand-management strategy. Water quality studies indicate that significant water treatment would be necessary for the water from Manton Dam to be potable.			

Apx Figure A-5 Manton Dam looking upstream

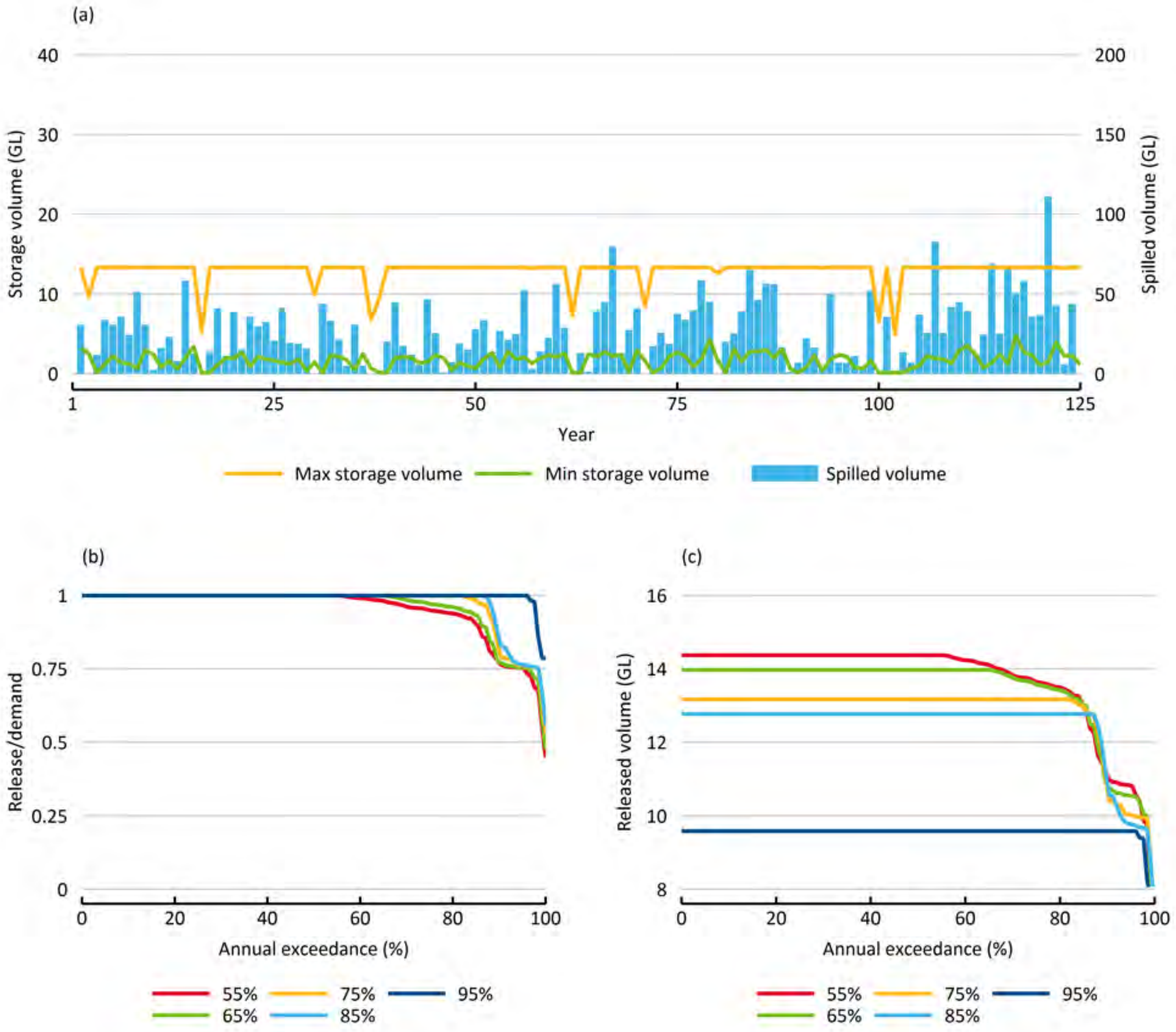


Apx Figure A-6 Location map of Manton Dam, reservoir extent and catchment area



Apx Figure A-7 Manton Dam topographic dimensions, inflow hydrology and yield

(a) Reservoir volume, surface area and height relationship; (b) annual streamflow; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% 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 A-8 Manton Dam storage levels and yield

(a) Maximum and minimum annual storage trace at the selected FSL 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

A.1.3 ADELAIDE RIVER OFFSTREAM WATER STORAGE (AROWS)

PARAMETER	DESCRIPTION
Previous investigations	Previous investigations of the AROWS scheme (Adelaide River Offstream Water Storage) include: PWC (2013a) Darwin region water supply strategy. Power and Water Corporation. SMEC (2016) Draft AROWS options development and assessment. SMEC, August 2016. Entura (2015) Darwin region water supply – medium term water source options assessment, cost estimate report. Entura, June 2015. The following SMEC references to previous investigations have not been reviewed by CSIRO but are referred to in SMEC (2016): PWC (2013b) Adelaide River offstream water storage – Stage 1 Investigations. Report for Power and water Corporation, June 2013. PWC (2014) Adelaide River offstream water storage – Stage 2a and 2b Investigations. Report for Power and water Corporation, June 2014. PWC (2014) Adelaide River offstream water storage – Stage 2c and Stage 3 Geotechnical and geological investigations. Report for Power and water Corporation, December 2014. Care has been taken not divulge information confidential to PWC, nor use information confidential to PWC in this analysis.
Description of potential dam configuration	The scheme involves the development of an offstream storage approximately 55 km south-east of Darwin, which would store water diverted from the Adelaide River during wet-season flood events. Supply from the storage would be delivered by pipeline to the proposed Strauss storage and water treatment facility. **The following figures accompany this description of the site** A photograph of the potential AROWS offstream water storage site is provided in Apx Figure A-9. Apx Figure A-10 provides a map showing its location in the Darwin catchments, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Apx Figure A-11. Apx Figure A-12 and Apx Figure A-13 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Apx Figure A-14 to Apx Figure A-15.
Regional geology	The potential dam site and reservoir area are located in a geological province known as the Pine Creek Orogen, which is an area underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The rocks in the area have been intruded by granite, folded, faulted and uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the older rocks in the area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on some of the slopes. The storage area is a natural pond structure surrounded by ridges of quartzite (the Acacia Gap Quartzite) formed by erosion of the core of the north-south-trending De Monchax Creek anticline. The valley floor consists of clayey alluvial soils to depths of 1 to 3 m overlying gravelly soils to depths of at least 5 m. There are colluvial soils (including cobbles and boulders) on the slopes of the quartzite ridges.
Site geology	The three proposed embankments on the eastern side of the storage are located in gaps or saddles on the eastern limb of the anticline. The proposed embankment is at the Central Gap narrow quartzite ridge. Previous investigations have shown that the quartzite is interbedded with siltstone and sandstone. The geological map indicates that there is an east-northeast-trending geological fault and SMEC (2016) found a number of faults and two dykes during earlier investigations. More information on the geology of the Central Gap dam site, the other dam sites and the storage area is given in SMEC (2016).
Reservoir rim stability and leakage potential	Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. Potential leakage through quartzite ridges will need to be investigated but significant leakage is not expected to be an issue.

PARAMETER	DESCRIPTION
Potential structural arrangement	The offstream storage area is largely formed by natural ridges with three embankments required on the eastern side to contain the storage. The embankments are proposed to be of earth and rockfill construction and are described as Northern Gap, Central Gap and Saddle Dam Number 1. The proposed diversion works involve a 13 m^3/s pump station on the Adelaide River and a buried rising main of 2800 mm diameter to the offstream storage at the Central Gap site. A number of spillway sites in the Saddle Dam 1 area have been considered. An uncontrolled spillway with crest width of up to 70 m has been considered. Lining of the downstream chute and an energy dissipater are likely to be necessary given the expected erodibility of the siltstones in the area. An outlet comprising a pump station with a selective withdrawal intake and 26-km long 1350-mm diameter delivery pipeline from the storage area is proposed to be located in the north-west corner of the storage area with either a tunnel through the ridge or open-cut excavation. A new bridge over the Manton River is proposed on which the pipeline would cross the river. Access to the eastern side of the storage would be via the Stuart Highway and the Marrakai track with 12 km of new roads leading to the two embankments, diversion pump station and the spillway site. Access would also be required to the proposed outlet works in the north-east corner of the storage area
Availability of construction materials	Limited geotechnical investigations indicate that suitable rockfill, filter and core materials may be available from the site area but further investigations will be necessary to confirm whether sufficient volumes are available. If needed, materials can be imported from a number of commercial operators in the area, although costs will be somewhat higher.
Catchment area	Catchment area of the offstream storage is estimated to be 34.4 km^2. Catchment area of the Adelaide River at the diversion site is approximately 4500 km^2.
Flow data	The nearest streamflow gauging station on the Adelaide River to the proposed diversion location is G8170020, Adelaide River at Dirty Lagoon, which has a catchment area of 4235 km^2. Data has been collected for the station from 1960 to date with summary data as follows: Maximum annual flow volume 4967 GL Mean annual flow volume 1276 GL Median annual flow volume 1167 GL Minimum annual flow volume 52 GL The quality of the data from the station is poor, particularly at low flows, because it is located within the tidal zone.
Storage capacity	Previous studies have considered storages with a capacity of up to 300 GL. PWC have purchased LiDAR data over the AROWS storage area and capacities were estimated by SMEC using a combination of ground survey and LiDAR data. These data are owned by PWC and are not reported here. However, with the exception of low potential dam wall heights, reservoir capacity and surface area calculated using the SRTM compare favourably with those calculated using LiDAR (Petheram et al., 2013). The following reservoir capacities were calculated using the SRTM-H: FSL 21 mEGM96 Estimated capacity 48 GL FSL 23 mEGM96 Estimated capacity 68 GL FSL 25 mEGM96 Estimated capacity 91 GL
Reservoir yield assessment	Reservoir yields were estimated assuming that diversions from the Adelaide River occurred under the full range of permutations possible under the following constraints: Extractions limited to 10, 20 and 40% of instantaneous flow in the river. With and without a constraint that water can only be taken during the falling limb of a flood hydrograph. Pumping capacity of 7, 13, 26, 39, m^3/s. Minimum flow thresholds of 1, 2, 4 and 144 m^3/s. The yield values undertaken by the Assessment and reported below are for the following set of conditions:

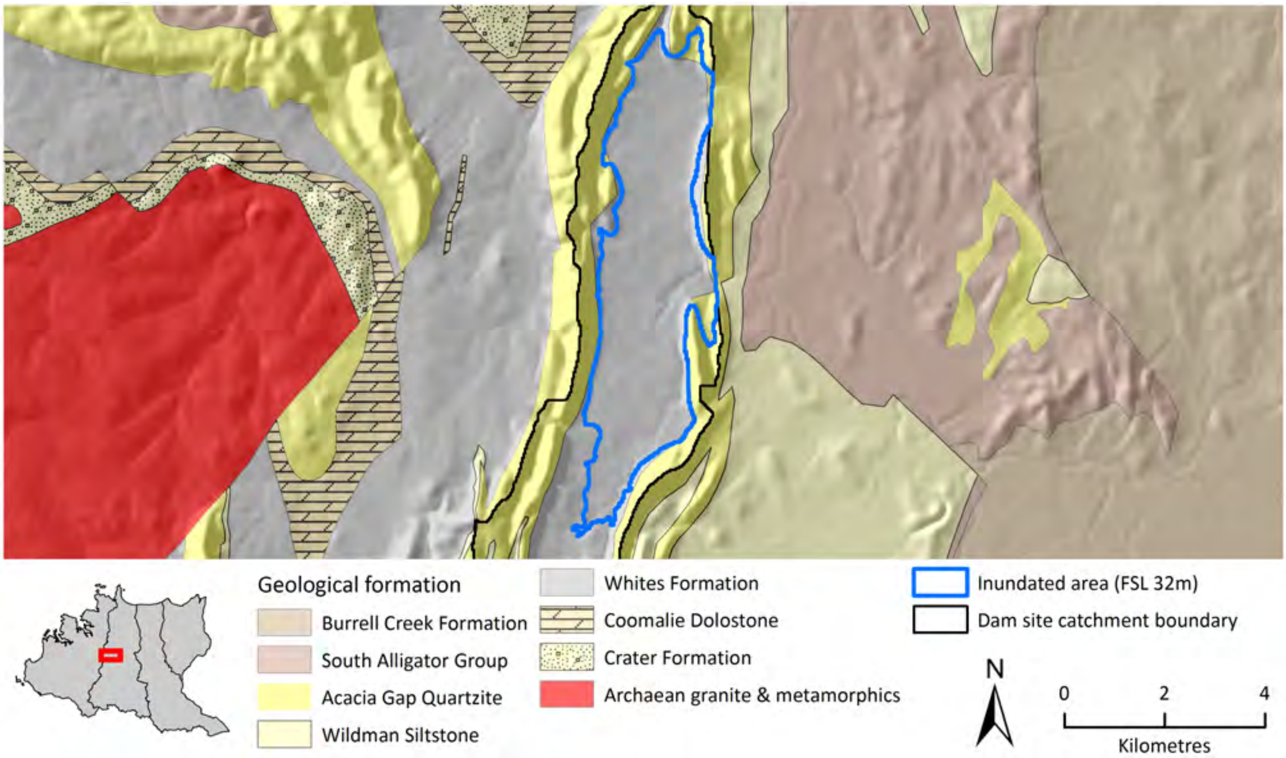
PARAMETER	DESCRIPTION
	Extractions were limited to 20% of instantaneous flow during falling limb of a flood hydrograph, a minimum flow threshold of 144 m^3/s and a pumping capacity of 26 m^3/s. A minimum flow threshold of 144 m^3/s was selected as this was the minimum upstream gauged flow (lower flows may potentially be impacted by tidal flows, this requires further investigation). Under these conditions the maximum yield per unit of annualised cost (i.e. considering dam and pumping infrastructure capital cost and annual operation and maintenance costs) occurred at an FSL of 25 mEMG96. Under these conditions the yield at FSL 25 mEMG96 (18 m above river bed) is 31.6 GL in 95% of years. PWC have commissioned detailed studies into the hydrology of the AROWS offstream storage. These studies are commercial-in-confidence and are not reported here.
Open water evaporation	At FSL, surface area of the storage is about 1208 ha. If used to supply 31.6 GL of water in 95% of years (at the dam wall) the mean annual net evaporation from the Darwin River Dam reservoir is 4.9 GL. The ratio of mean annual net evaporation to total water supplied is 0.16.
Potential use of supply	**Agriculture** The alluvial plains of the Adelaide River below the potential dam typically has a tidal main channel, a narrow levee, extensive level alluvial plains subject to occasional to regular flooding, and frequent drainage depressions and swamps. The alluvial plains are subject to annual flooding for extended periods. Soils on the level Adelaide River alluvial plains are dominated by hard-setting poorly drained clay soils. Soils are generally unsuitable for irrigated cropping but may be suitable for dry-season rice and forage cropping. Soils are likely to be suitable for ringtanks. Very narrow levees with imperfectly drained, moderately permeable, mottled brown, massive, loamy soils (Kandosols) and friable loamy soils (Dermosols) are suitable for wetness tolerant horticultural crops. The generally long thin units associated with the levees may restrict irrigation layout and machinery use in some areas. Soils are unlikely to be suitable for ringtanks. See companion technical report on land suitability (Thomas et al., 2018). **Urban** Current annual demand for water in the Darwin region (i.e. between about 40 to 45 GL) is approaching the current water supply system yield. Darwin River Dam supplies 85% of Darwin’s water, the other 15% sourced from the McMinns and Howard East borefields. PWC is currently investigating short- and medium-term supply augmentation options. Future annual water demand to 2065 is projected to be between about 50 and 60 GL depending upon assumptions regarding population growth and the success of demand-management programs (e.g. Living Water Smart). PWC intend to return the dam to its water supply service function by about 2025 as a short-term measure to provide additional water supply to Darwin. Subject to the outcomes of further studies, PWC consider that the AROWS scheme is the preferred medium- to long-term option to meet the Darwin region’s water supply needs.
Storage impacts	The area inundated for a range of FSL are reported below: FSL 25 mEGM96 1208 ha An additional area providing for flood rise would normally be acquired. The majority of the potential storage area is undeveloped grazing land. At the southern end of the basin there has been some rural subdivision and consideration has been given to a southern bund embankment to limit storage inundation in this area. A section of the Marrakai road would also be inundated. Relocation of the road around the upstream end of the storage is proposed.

PARAMETER	DESCRIPTION
Environmental considerations	**Barrier to movement of aquatic species** Only blackbanded rainbowfish (*Melanotaenia nigrans*), a stable flow spanner, has been recorded to occur within the potential inundated area. **Ecological implications of inundation** At this site there were no records of species of national significance or species listed under the *Territory Parks and Wildlife Conservation Act* (NT). The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).
Estimated cost	CSIRO generated preliminary estimates of cost based on a generalised costing algorithm, which takes into account major cost elements for embankment (EB) type dams. FSL 25 mEGM96 Modelled estimated cost $154 million This cost estimate includes direct construction costs, land resumption, contractor on-site overheads, contractors profit and off-site overheads, turn out costs, owners costs and risk adjustment (33%). It does not include cost of pumping infrastructure or pipeline to water treatment plant. PWC have commissioned detailed studies into the cost to construct and operate the AROWS offstream water storage (at a higher FSL than reported here) and for the pipe delivery works to the Strauss water treatment facility.
Estimated cost/ML of supply	$4873/ML at 95% annual time reliability, not including pumping infrastructure. Annualised cost (including capital costs of dam, pumping and operation and maintenance of dam and pumping infrastructure and energy costs) were estimated to be $342/ML at 95% annual time reliability.
Summary comment	The AROWS offstream storage proposal would see the storage filled by pumped diversions from the Adelaide River. This site has one of the higher cost to yield ratios of all of the potential sites in the Darwin catchments, and the highest annualised cost/ML of yield. It does, however, have various advantages over other sites as it is an offstream storage. It will not for example, impede the movement of migratory fish species. Subject to the outcomes of further studies, Northern Territory Power and Water consider that the AROWS scheme is the preferred medium- to long-term option to meet the Darwin region’s water supply needs.

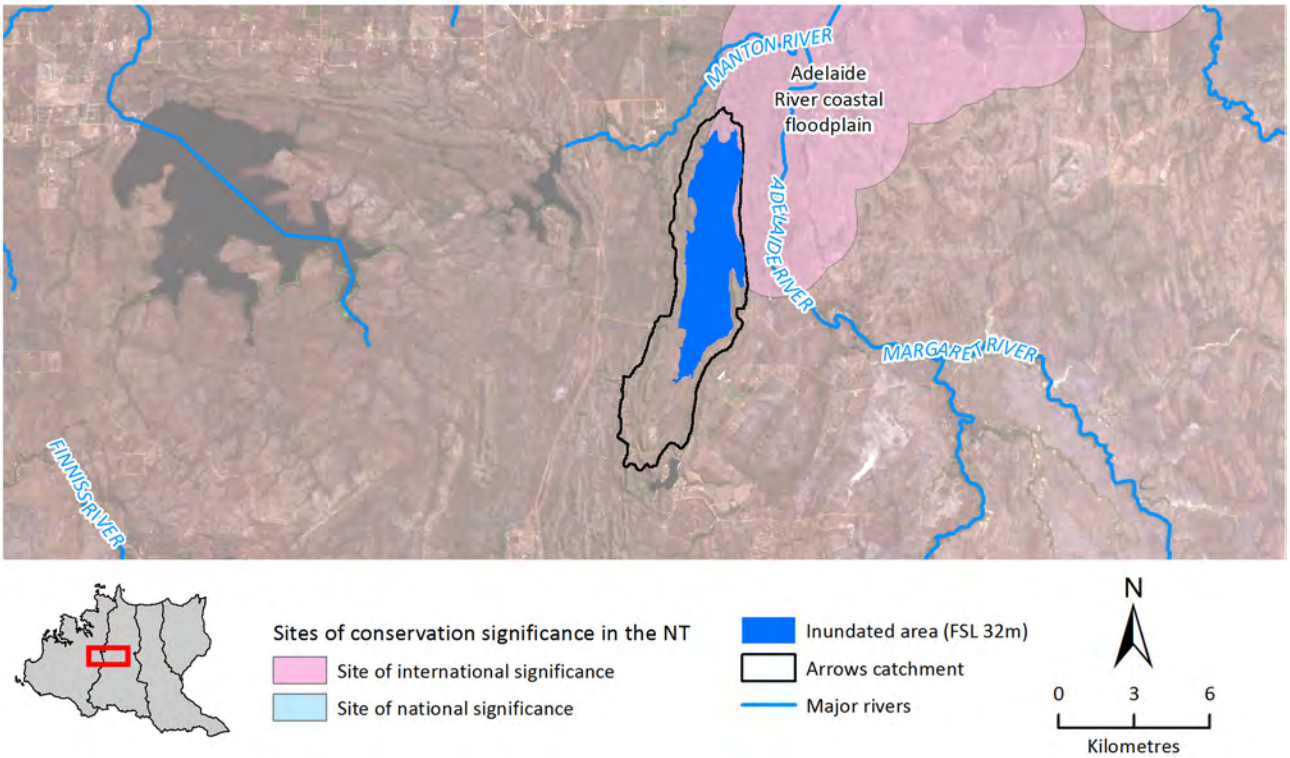
Apx Figure A-9 AROWS offstream storage looking upstream across the main axis

Apx Figure A-10 Location map of AROWS reservoir extent and catchment area

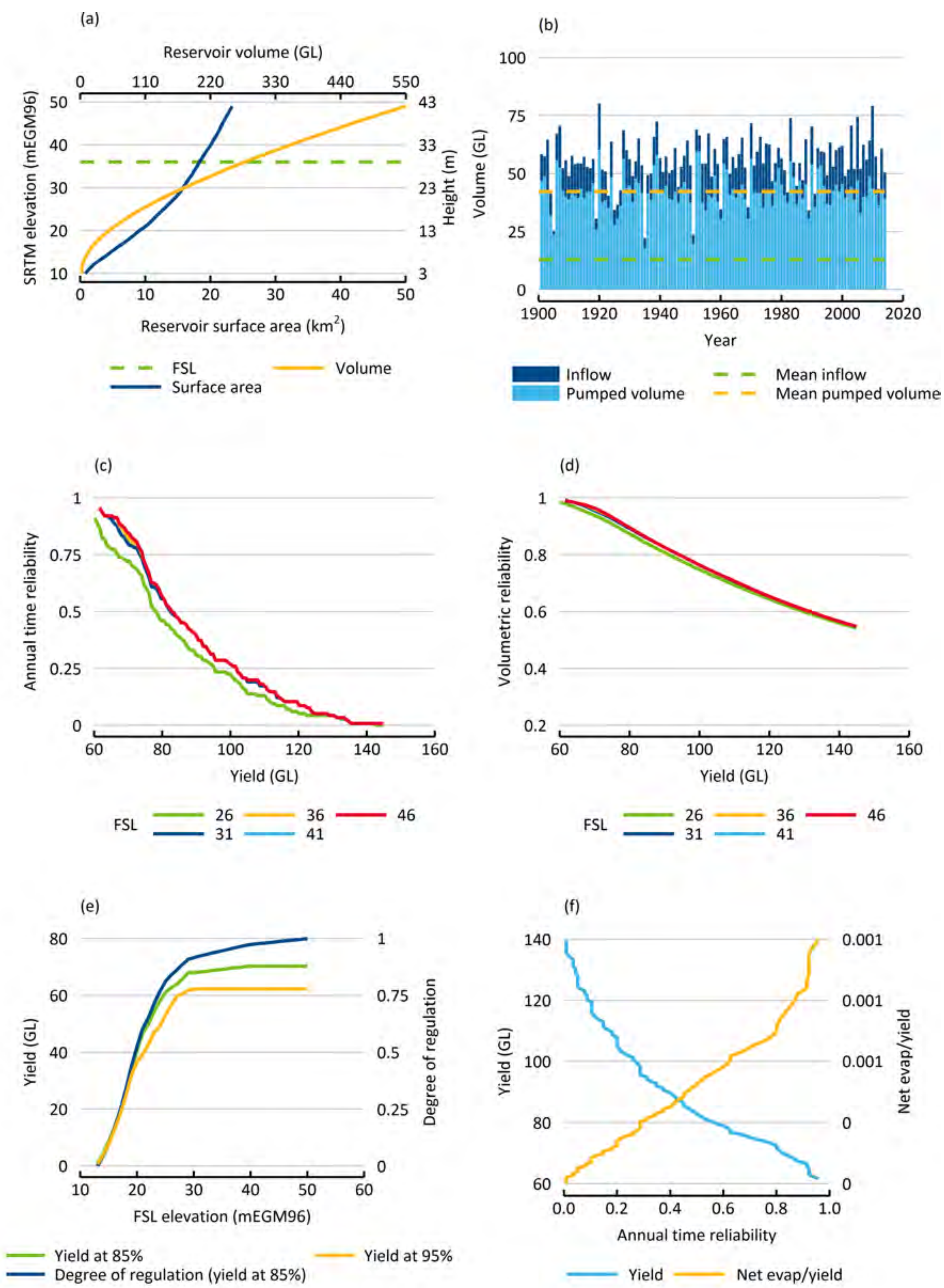
Apx Figure A-11 AROWS reservoir and property boundaries



Apx Figure A-12 Geology underlying the AROWS dam wall and reservoir

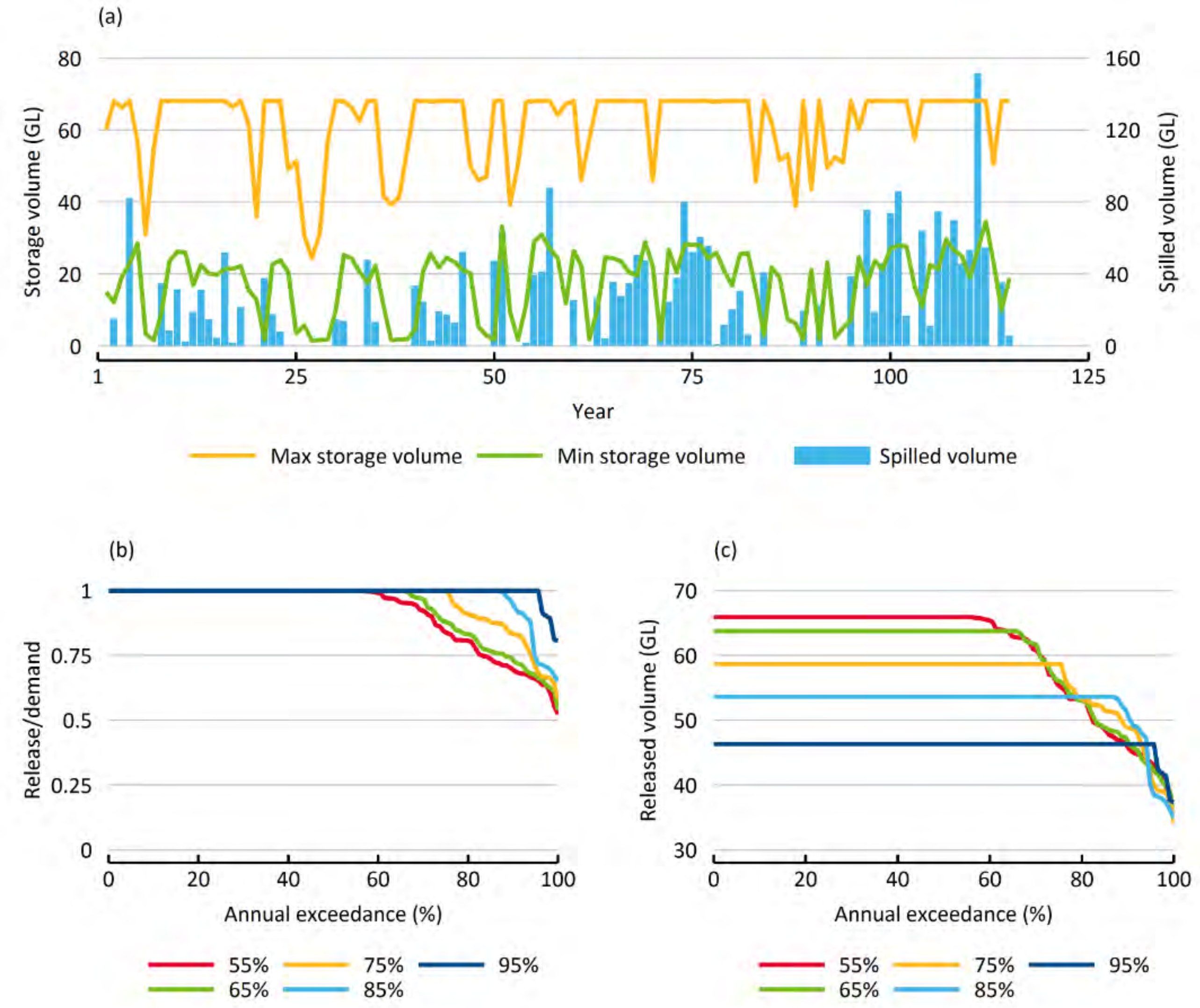


Apx Figure A-13 Known water-dependent ecological assets in the vicinity of the AROWS dam wall storage



Apx Figure A-14 AROWS offstream storage topographic dimensions, inflow hydrology and yield

(a) Reservoir volume, surface area and height relationship; (b) annual streamflow and annual pumped volume; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% 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. Plots based on a pumping configuration of 1 m^3/s minimum flow threshold, 20:80 rule and pumping capacity of 26 m^3/s.



Apx Figure A-15 AROWS offstream water storage storage levels and yield

(a) Maximum and minimum annual storage trace at the selected FSL (FSL, 23 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL. Plots based on a pumping configuration of 1 m^3/s minimum flow threshold, 20:80 rule and pumping capacity of 26 m^3/s.

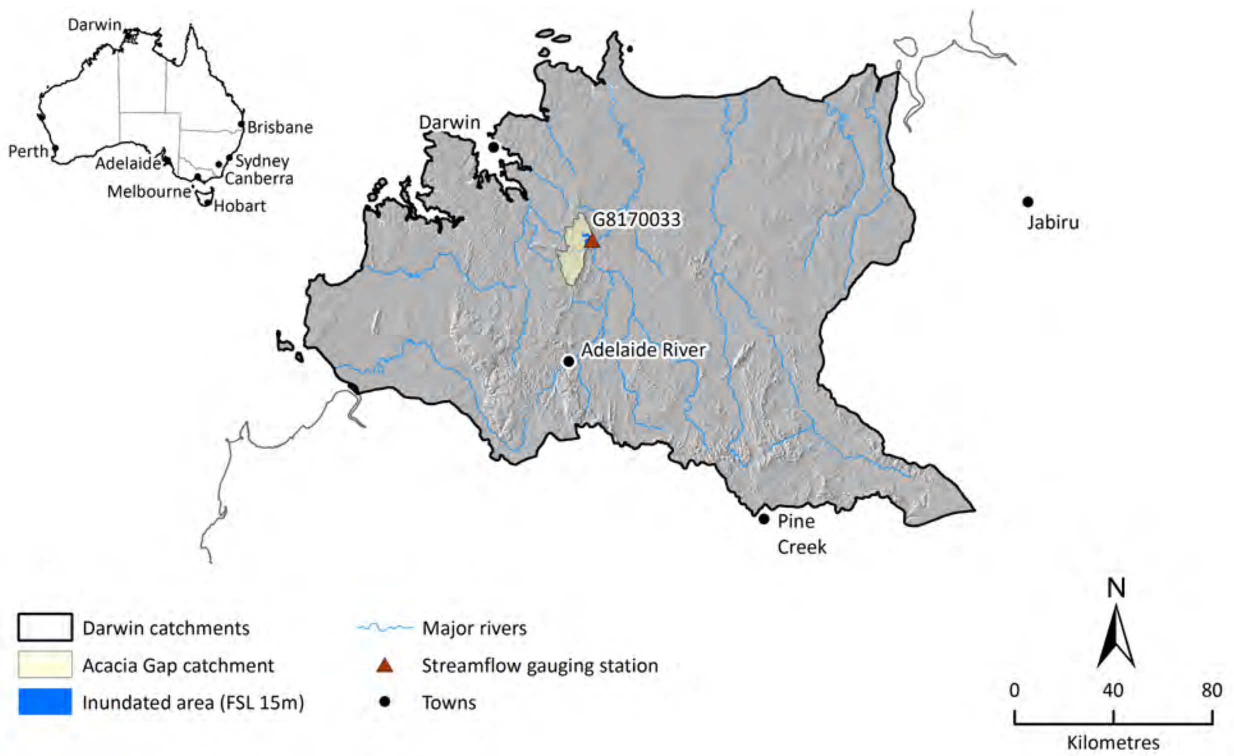
A.1.4 ACACIA GAP DAM SITE ON MANTON RIVER; AMTD 2.0 KM

PARAMETER	DESCRIPTION
Previous investigations	Previous investigations of the Acacia Gap dam site have included the following: SMEC (1979) Darwin water supply future source – appraisal study. Snowy Mountains Engineering Corporation, December 1979. GHD (1988) Estimated costs of potential dams in the Darwin region. Gutteridge Haskins & Davey Pty Ltd (now GHD), December 1988.
Description of potential dam configuration	The Acacia Gap dam site was originally identified as a possible development to increase the water supply available to Darwin and was investigated by SMEC (1979). GHD (1988) compared the Acacia Gap dam site to other options in the vicinity of Darwin. The site was not adopted by the Northern Territory Government at the time as one of its three preferred major dam options. **The following figures accompany this description of the site** The potential Acacia Gap dam site is shown in Apx Figure A-16. Apx Figure A-17 provides a map showing its location in the Darwin catchments, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Apx Figure A-18. Apx Figure A-19 and Apx Figure A-20 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Apx Figure A-21 to Apx Figure A-23.
Regional geology	The potential dam site and reservoir area are located in a geological province known as the Pine Creek Orogen, which is an area underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The rocks in the area have been intruded by granite, folded, faulted and uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the older rocks in the area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on some of the slopes. The storage area consists of ridges and isolated hills of quartzite and sandstone mainly striking north/south and dipping steeply east or west. Most of the flatter ground in the area is underlain by sandy and gravelly soils (alluvium and colluvium) of Tertiary age and alluvium of Quaternary age, which consists of gravel, sand and silt, and black clayey soils.
Site geology	The potential main dam is on an east-southeast-trending section of the river where it cuts through a relatively narrow ridge of Acacia Gap Quartzite. Sandstone, quartzite and greywacke crop out on both abutments. The quartzite is folded and steeply dipping. There is an alluvial terrace at the base of the right abutment. The depth of alluvium in the valley floor is unknown but was assumed to be about 7 m in earlier investigations. The valley floor is about 100 m wide at the dam axis and includes silty clay alluvium, sandy channel deposits, levee banks of fine sand and the river channel. There is a lagoon up to about 80 m wide downstream of the axis. Investigations have shown that the alluvium overlies weathered rock. Sandy colluvium with rock fragments occur on the lower slopes of the abutments.
Reservoir rim stability and leakage potential	Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. Potential leakage though dolomite in the storage area will need to be investigated further if this site were to be considered further.
Potential structural arrangement	SMEC (1979) considered alternative dam types including an earth and rockfill embankment dam, a concrete faced rockfill embankment dam and roller compacted concrete (RCC) dam across the river section. The concrete faced rockfill type was favoured at the time, in part, because of a reported shortage of suitable earthfill material at the site. A 75-m wide chute spillway was located on the right abutment with outlet works also located on the right abutment. Small saddle dams were required on the western side to contain the storage during flood rise. Given the major increase in the estimated magnitude of probable maximum floods (PMF) since the time of these studies, an RCC dam with a central overflow spillway is now favoured for the site. Outlet works with selective withdrawal capability would be located on the right abutment.

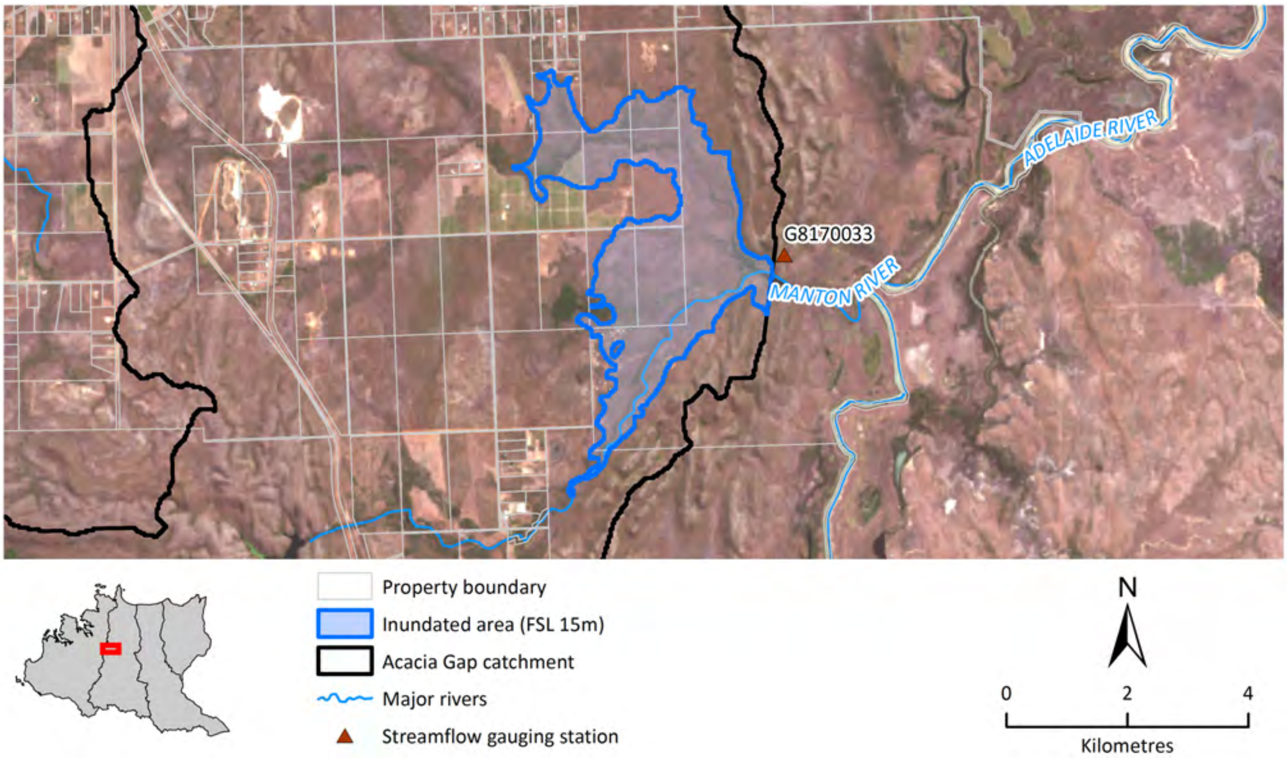
PARAMETER	DESCRIPTION
	Access to the site would be from the Stuart Highway south of the Manton Dam turnoff 62 km south of Darwin, eastwards for 2 km along an existing track, then northwards to the right bank of the site. Total length of the access road from the highway would be 16 km.
Availability of construction materials	Previous reports suggest that the quartzite, sandstone and greywacke may be suitable for rockfill, filter materials and concrete aggregate. The black soil alluvium is unlikely to be suitable for construction and local sands and gravels were reported to be scarce.
Catchment area	The catchment area upstream of the potential dam site was estimated to be 232 km^2.
Flow data	The only stream gauging station on the Manton River is G8170075, which is located upstream of the existing Manton Dam. The station, which was established in October 1963, has a catchment area of 28 km^2 compared with the catchment area at the Acacia Gap site of 232 km^2.
Storage capacity	Capacities estimated using the SRTM-H for FSL of 15, 18 and 21 mEGM96 are reported below (note the SRTM datum is different to that used in SMEC (1979) study at this location): FSL 15 mEGM96 Capacity 37 GL FSL 18 mEGM96 Capacity 79 GL FSL 21 m EGM96 Capacity 148 GL
Reservoir yield at dam wall	The Assessment estimated the yield at the following FSL: FSL 15 mEMG96 Estimated yield at 85% annual time reliability 29 GL FSL 18 mEMG96 Estimated yield at 85% annual time reliability 44 GL FSL 21 mEMG96 Estimated yield at 85% annual time reliability 50 GL The only yield assessment previously undertaken at this site appears to have been made by the Power and Water Corporation. Annual safe yield assessed using Goulds method (a preliminary reservoir-yield-reliability assessment method) was reported to be 32 GL/y for a dam at FSL 20 mAHD. It is likely that this estimate did not take account of downstream entitlements or environmental flow requirements.
Open water evaporation	At the following FSL, the surface area of the storage as estimated using the SRTM-H is: FSL 15 mEMG96 1048 ha FSL 18 mEMG96 1849 ha FSL 21 mEMG96 2719 ha Mean annual evaporation and mean annual net evaporation at FSL 15 mEMG96 at 85% annual reliability is 11.1 GL and 2.3 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.08.
Potential use of supply	**Agriculture** The alluvial plains of the Adelaide River below the potential dam typically has a tidal main channel, a narrow levee, extensive level alluvial plains subject to occasional to regular flooding, and frequent drainage depressions and swamps. The alluvial plains are subject to annual flooding for extended periods. Soils on the level Adelaide River alluvial plains are dominantly hard-setting poorly drained clay soils. Soils are generally unsuitable for irrigated cropping but may be suitable for dry-season rice and forage cropping. Soils are likely to be suitable for ringtanks. Very narrow levees with imperfectly drained, moderately permeable, mottled brown, massive, loamy soils (Kandosols) and friable loamy soils (Dermosols) are suitable for wetness tolerant horticultural crops. The generally long thin units associated with the levees may restrict irrigation layout and machinery use in some areas. Soils are unlikely to be suitable for ringtanks. See companion technical report on land suitability (Thomas et al., 2018). **Urban** Current annual demand for water in the Darwin region (between about 40 to 45 GL/y) is approaching the current water supply system yield. The proximity of the potential Acacia Gap dam site to Darwin means it could potentially be used to augment Darwin's water supply in the future. However, for reasons outlined below, it is not a preferred option.
	Best case Expected Worst case

PARAMETER	DESCRIPTION			
Estimated rates of reservoir sedimentation	30 years (%)	0.1	1.3	1.7
	100 years (%)	0.4	4.3	5.7
	Years to fill	24,420	2,080	1,760
Storage impacts	A storage at the Acacia Gap site would inundate a significant number of blocks developed for intensive horticulture production.			
Environmental considerations	**Barrier to movement of aquatic species** This potential dam site is within the range of the saltwater crocodile (*Crocodylus porosus*), a species of national significance. However, the catchment area of the potential Acacia Gap dam site is small compared to the larger Adelaide River catchment and crocodiles are known to successfully navigate large barriers (e.g. Darwin River Dam). **Ecological implications of inundation** Approximately 53 ha of important wetlands could be inundated if this dam was constructed at the selected FSL (15 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 (Pollino et al., 2018).			
Estimated cost	CSIRO generated preliminary estimates of cost based on a generalised costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways and cost items for embankment type saddle dams. The costs for a selection of FSL are reported below: FSL 15 mEMG96 $132 million FSL 18 mEMG96 $168 million FSL 21 mEMG96 $206 million These modelled costs estimates are likely to be within –20% and +50% of the true value. If geotechnical investigations found geological complications at the site dam costs may be substantially higher. No further cost estimates were made at this site as part of the Assessment.			
Estimated cost/ML of supply	Based on the yields estimated by the CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm estimated cost/ML of supply are reported at the following FSL: FSL 15 mEMG96 $4490/ML FSL 18 mEMG96 $3818/ML FSL 21 mEMG96 $4162/ML Although an FSL of 18 mEMG96 had a lower cost/ML of supply it would inundate considerably more infrastructure. For this reason, a dam with an FSL of 15 mEMG96 was selected for reporting other criteria on the basis that at this FSL the inundation of additional infrastructure would be considerably less the higher FSL options. GHD (1988) previously reported estimated costs as follows: FSL 17 mAHD $26.0 million (Oct. 1987 $) ($72 million March 2017 $) FSL 18 mAHD $26.8 million (Oct. 1987 $) ($74 million March 2017 $) FSL 20 mAHD $27.6 million (Oct. 1987 $) ($76 million March 2017 $) GHD (1988) costs were inflated by CPI between 1987 and 1988 and then Queensland Road and Bridge construction index between 1988 and March 2017. The estimated costs appear to be primarily construction costs not including the significant costs now involved in the construction of dams such as environmental and heritage management costs nor owner's costs. The contingency allowance of 15% also seems low given the preliminary nature of the investigations.			
Summary comment	The Acacia Gap site is downstream of the Manton Dam and is attractive because of its proximity to Darwin. However, it has the highest cost to yield ratio of all of the potential sites in the Darwin catchments. Furthermore, if a dam were constructed at the site it would have major impacts on horticulture producers in the area and the Acacia Indigenous Community.			

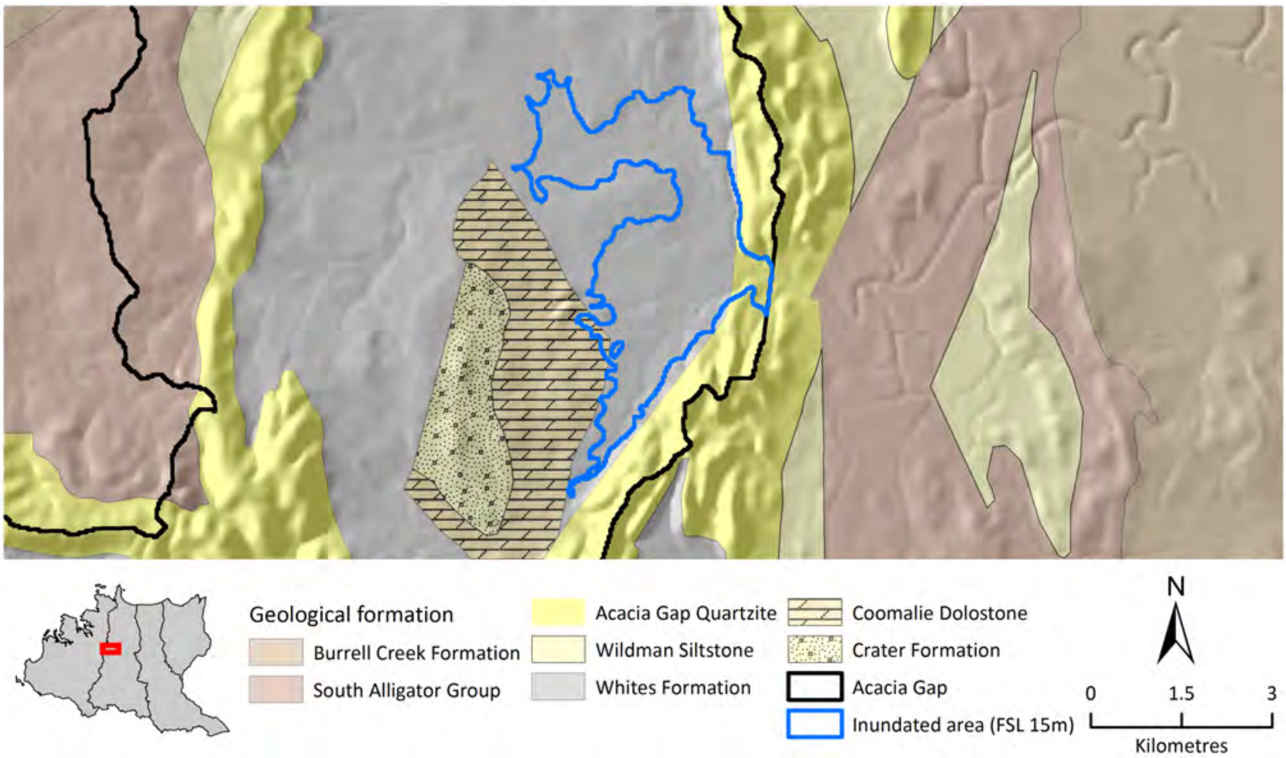
Apx Figure A-16 Acacia Gap dam site looking upstream



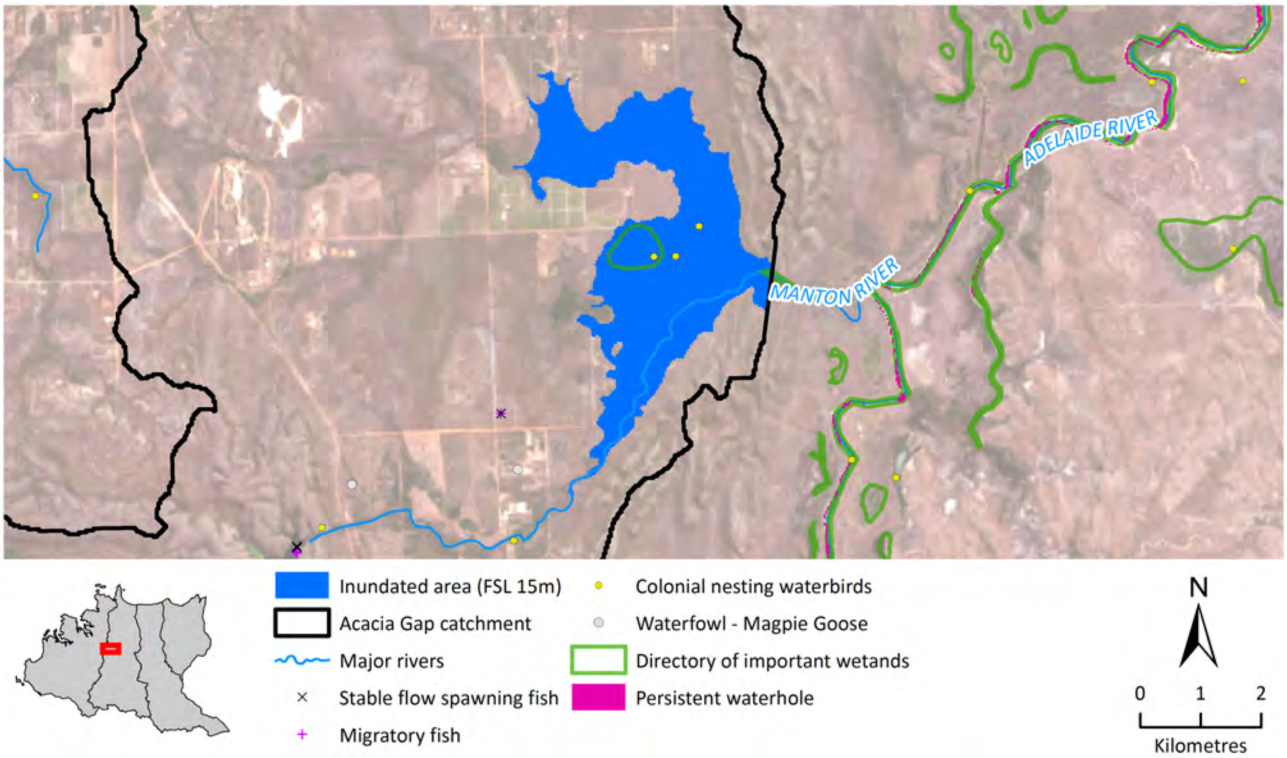
Apx Figure A-17 Location map of Acacia Gap, reservoir extent and catchment area



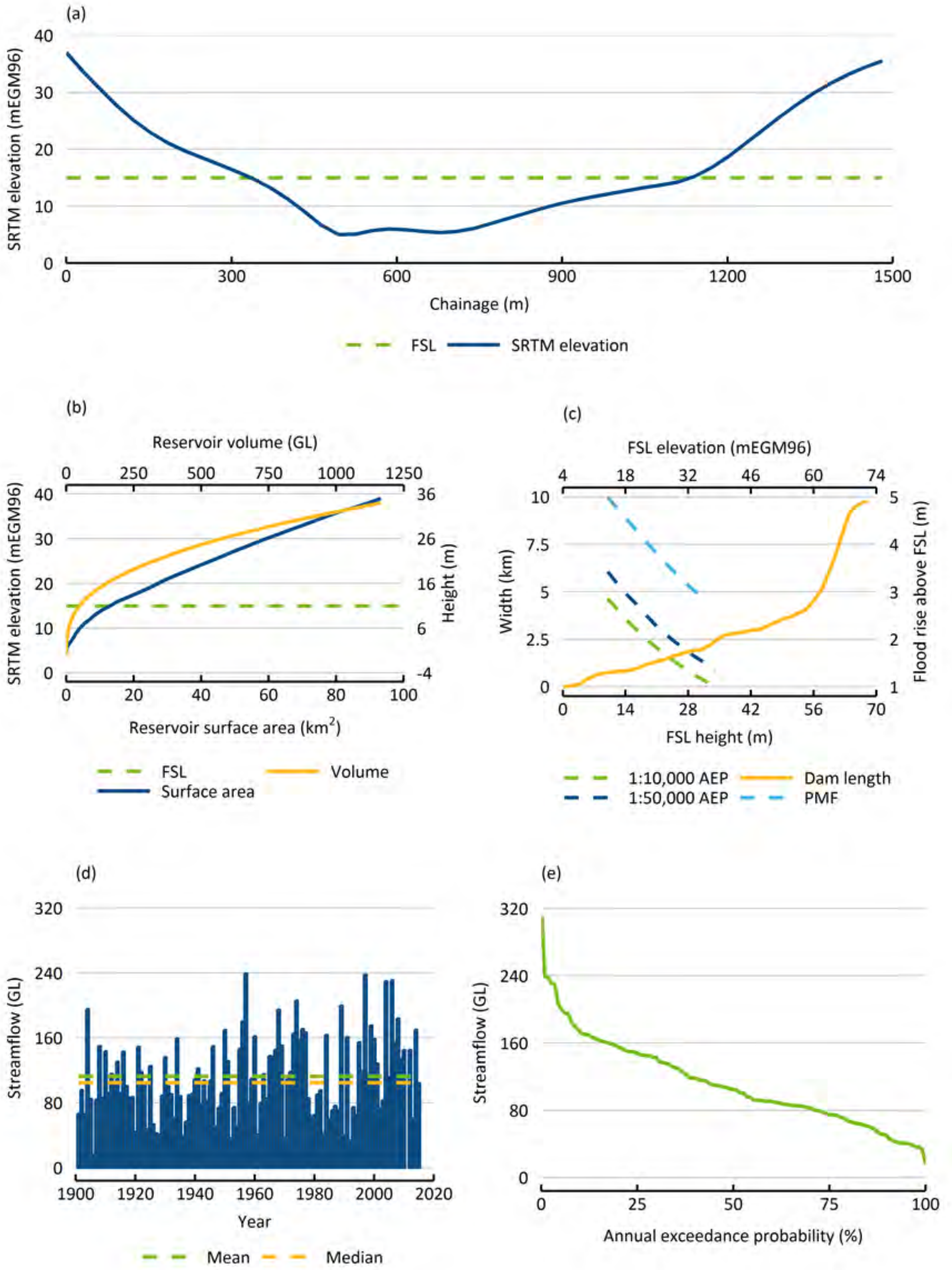
Apx Figure A-18 Acacia Gap reservoir and property boundaries



Apx Figure A-19 Geology underlying the potential Acacia Gap dam site and reservoir

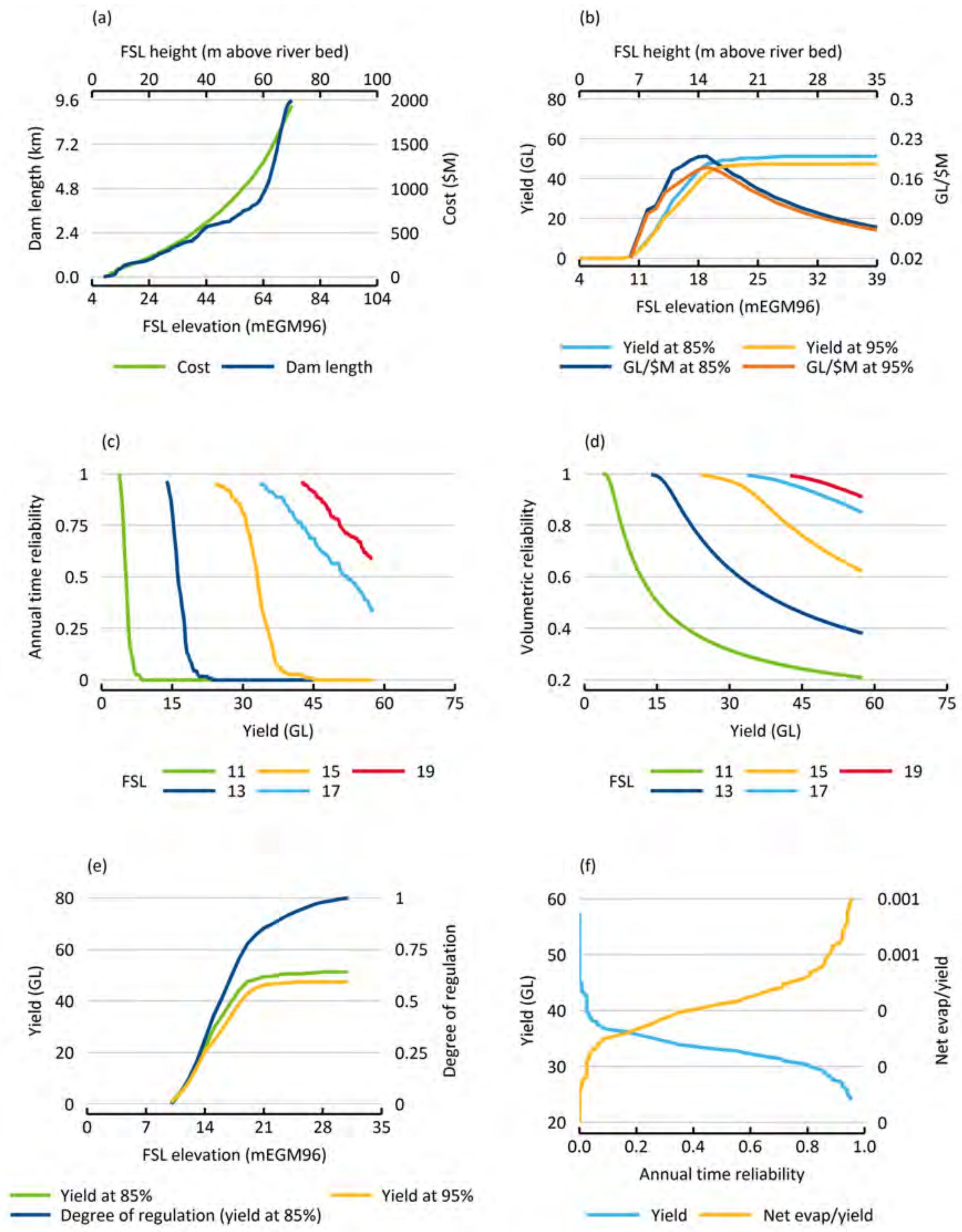


Apx Figure A-20 Known water-dependent ecological assets in the vicinity of the Acacia Gap dam site



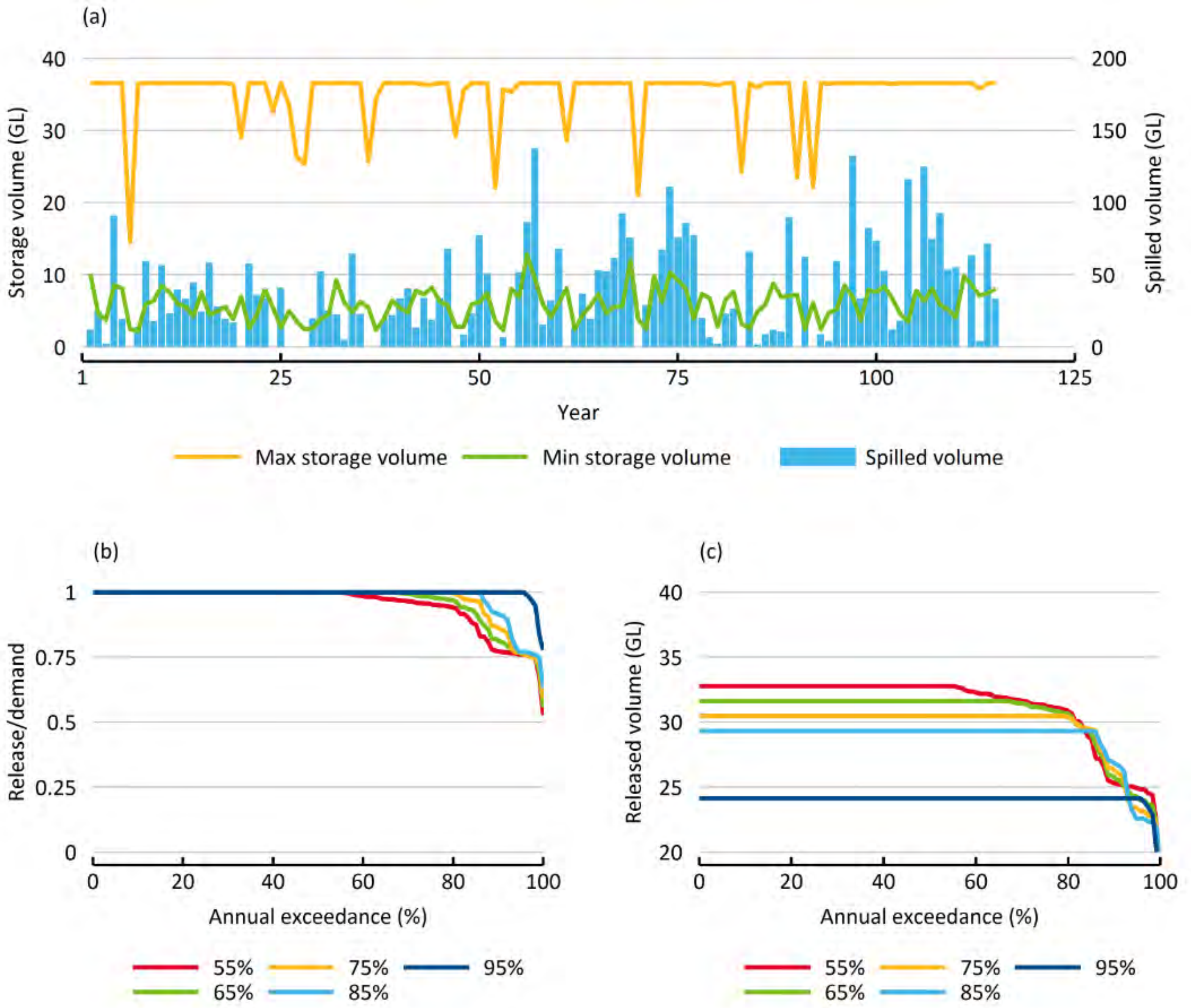
Apx Figure A-21 Acacia Gap potential dam site topographic dimensions and inflow hydrology

(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 events plotted against FSL; (d) annual streamflow; (e) annual flow exceedance.



Apx Figure A-22 Acacia Gap potential dam site cost, yield at the dam wall and evaporation

(a) Dam length and dam cost versus FSL; (b) dam yield at 85% and 95% annual time reliability and yield per $ million at 85% and 95% 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 85% and 95% 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 A-23 Acacia Gap potential dam site storage levels and yield

(a) Maximum and minimum annual storage trace at the selected FSL (FSL, 15 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

A.1.5 MARRAKAI DAM SITE ON THE ADELAIDE RIVER; AMTD 137.2 KM

PARAMETER	DESCRIPTION
Previous investigations	Previous investigations of the Marrakai dam site have included the following: SMEC (1979) Darwin water supply future source – appraisal study. Snowy Mountains Engineering Corporation, December 1979. AGP (1981) Marrakai dam studies – Objective 1 (Report on preferred dam site selection). Sir Alexander Gibb and Partners, August 1981. AGP (1982) Marrakai dam studies – Objective 2 (Geotechnical services). Sir Alexander Gibb and Partners, January 1982. GHD (1988) Estimated costs of potential dams in the Darwin region. Gutteridge Haskins & Davey Pty. Ltd. (now GHD), December 1988. PWA (1990) Marrakai dam site yield reappraisal, Jerome Paiwa. NT Power and Water Authority, 1990. GHD (1990) Marrakai dam site, preliminary geotechnical investigation, Reference 11080/00. Gutteridge Haskins and Davey Pty Ltd, June 1990.
Description of potential dam configuration	The potential Marrakai dam involves a large, shallow instream storage, which could supply a large amount of water to the Darwin area. In 1988 the Marrakai dam site was one of three preferred major potential dam options adopted by the Northern Territory Government. In 1990, the NT Cabinet approved that properties affected by the potential inundation area be acquired given that at the time, a Marrakai dam was considered to be the preferred future water supply option. The lands were subsequently acquired and are currently leased for a range of low-impact uses. **The following figures accompany this description of the site** The potential Marrakai dam site is shown in Apx Figure A-24. Apx Figure A-25 provides a map showing its location in the Darwin catchments, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Apx Figure A-26. Apx Figure A-27 and Apx Figure A-28 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Apx Figure A-29 to Apx Figure A-30.
Regional geology	The potential dam site and reservoir area are located in a geological province known as the Pine Creek Orogen, which is an area underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The rocks in the area have been intruded by granite, folded, faulted and uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the older rocks in the project area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on some of the slopes. The potential dam is located on an east-trending section of the Adelaide River where it has cut through an east-northeast-trending ridge of folded Precambrian rocks. The large relatively shallow reservoir covers a wide alluvial plain upstream of the ridge. The river is tidal to 6 km upstream of the potential dam site.
Site geology	The abutments of the main dam would be founded on weathered siltstone, shale and chert of the South Alligator Group. The 600-m wide valley floor is underlain by up to 20 m of alluvium, which is generally a fining up sequence ranging from gravels at depth to sandy clay and silt nearer the surface. More information on the foundation conditions for the dams and spillways is given by GHD (1990). Several saddle dams are likely to be required at low points on the ridge on each bank of the reservoir.
Reservoir rim stability and leakage potential	Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. A bentonite slurry trench may be required in the alluvium beneath the dam to reduce seepage losses.
Potential structural arrangement	The Marrakai dam site involves a wide flat floodplain with numerous lagoons. The river is incised to a depth of about 10 m and is tidal to about 6 km upstream of the site.

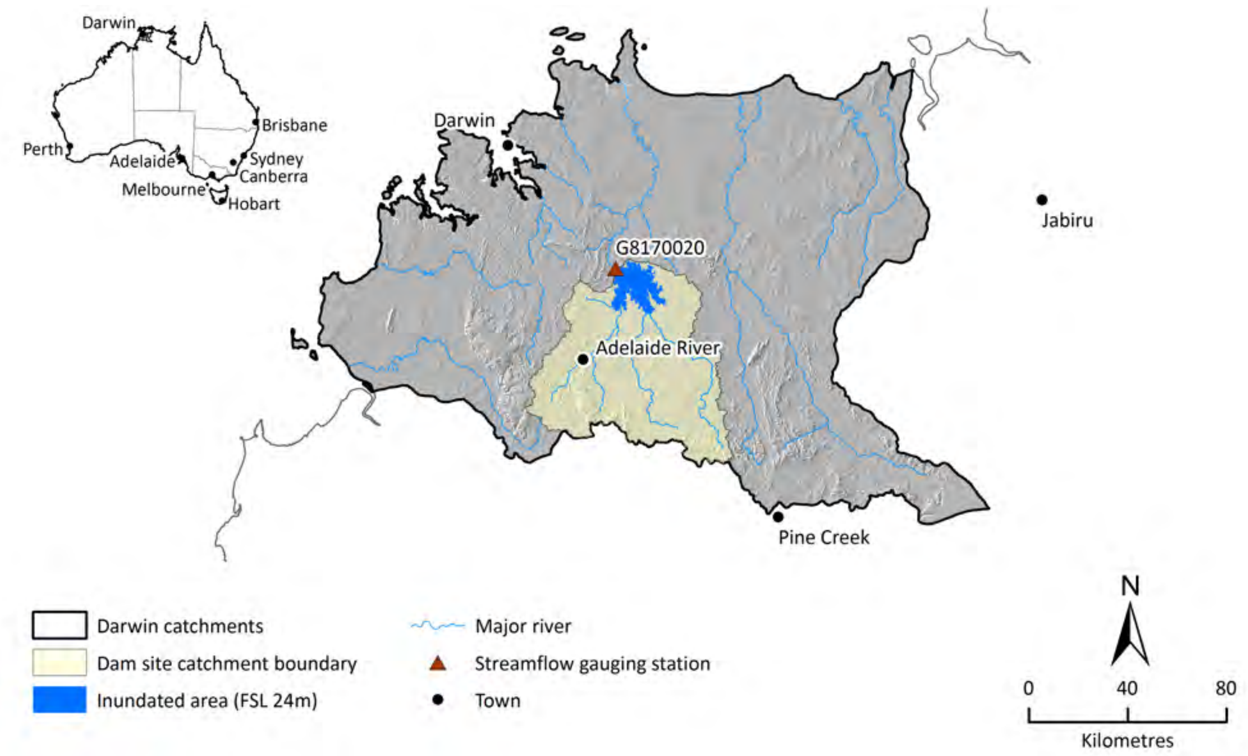
PARAMETER	DESCRIPTION
	SMEC (1979) concluded that the depth of alluvium across the floodplain could be 20 m or more. Rubbly outcrops are evident on the low abutments, the rock being a fine-grained sedimentary, closely jointed and erodible. The dam arrangement as proposed by SMEC (1979) involved an earthfill embankment dam with a central impervious clay core and an internal filter and horizontal drainage system. The upstream face was to be protected by rock riprap and the downstream face by topsoil and grass. Across the floodplain, it was assumed that the foundations would be excavated to a depth of 3 m with a 600-mm wide cement bentonite slurry filled trench cut off to a further depth of 3 m. Two spillways were proposed by SMEC (1979). A primary service spillway with crest length of 75 metres was proposed to be excavated through the right bank ridge on the assumption that better rock might be found in this area. It was assumed that the spillway would be fully lined and provided with an energy dissipater. An auxiliary spillway comprising a 225-m wide excavated channel was located through a natural saddle adjacent to the left abutment. It was proposed that the crest would be a level 1 m higher than FSL. Comment was made as to a possible erodible embankment (fuse plug) downstream of the crest to reduce the frequency of overtopping. It was noted that there was no geotechnical information in the auxiliary spillway area nor was there any discussion as to the erodibility of material in the discharge channel area. For the Northern Australia Water Resource Assessment it has been assumed that a similar zoned embankment dam would be required across the river section but that a deeper slurry trench cut off should be provided together with a series of pressure relief wells at the downstream toe. Additionally, to cope with the larger design floods since SMEC (1979), it has been assumed that the service spillway would need to be wider, nominally 150 m wide. To provide for diversion of flows during construction and for the permanent outlet works, SMEC (1979) assumed that four pipes, 2 m in diameter, would be installed in a channel excavated through a saddle to the east of the primary spillway, again where reasonably sound rock was expected. An intake tower would provide for selective withdrawal and a ‘dry’ pump station located downstream. The proposed diversion provision would probably provide reasonable immunity for dry-season flows but not for wet-season events. A possible construction program was not proposed by SMEC (1979). The allowance by SMEC (1979) in their estimate of cost for coffer dams and river diversion during construction was a nominal $300,000. For the purposes of the Assessment, it has been assumed that the foundation and main embankment section would need to be constructed in two sections over at least two dry seasons, each protected by a perimeter coffer dam, with the western section the first to be constructed. Given that the floodplain is inundated in most wet seasons, access to the site and dewatering issues could severely disrupt construction of the cross-river embankment, even for the sequence of construction now proposed. Given the risks involved, a much higher river diversion cost is expected. Access to the site would be via the Stuart Highway to the south of the Manton Dam turnoff. The road would then follow the Lake Bennett road with a further 3 km to access the left bank at the site. Access to the right bank outlet works and pump station would be over the main embankment crest and a bridge over the right bank spillway.
Availability of construction materials	Previous investigations indicate that there is more than 5 million m^3 of impervious fill in the alluvial plain within 2 km of the potential dam site. Some sand deposits and sources of riprap were also found and there is potential for quartzite quarries west of the site.
Catchment area	The catchment area upstream of the dam site is estimated to be 4341 km^2.
Flow data	Rainfall and river height data has been recorded at gauging station G8170020 Adelaide River – Dirty Lagoon since 1963 although there are a significant number of days of missing data. Catchment area at the gauging site is 4325 km^2. The station-site is within the tidal zone so that

PARAMETER	DESCRIPTION
	low-flow data are of uncertain accuracy. Additionally, because of the width of the floodplain, overbank flows are also likely to be poorly gauged. Summary data extracted from the Northern Territory Government Water Data Portal is as follows: Maximum recorded annual flow volume 4967 GL Mean recorded annual flow volume 1276 GL Median recorded annual flow volume 1167 GL Minimum recorded annual flow volume 52 GL
Storage capacity	Potential dams with FSL of 16, 18 and 20 m and capacities of 650, 1050 and 1500 GL, respectively were considered by GHD (1990). A yield study by Paiwa (1991) reported on expected yields for storages with FSL ranging from 16 to 24 m with probability of failure ranging from 0 to 5%. These results indicated that an optimum level of development was likely to be lower than 20 m since at the higher levels, yields only increased marginally, expected maximum interval between overflows rose dramatically (to 227 years at the 24 m level) as did expected time of storage filling (to 11 years at the 24 m level). Capacities calculated using the SRTM-H for FSL of 18, 20, 22 and 24 m EMG96 are reported below: FSL 18 mEMG96 Capacity 356 GL FSL 20 mEMG96 Capacity 642 GL FSL 22 mEMG96 Capacity 1029 GL FSL 24 mEMG96 Capacity 1520 GL
Reservoir yield at dam wall	FSL 18 mEMG96 Estimated yield at 85% annual time reliability 274 GL FSL 20 mEMG96 Estimated yield at 85% annual time reliability 530 GL FSL 22 mEMG96 Estimated yield at 85% annual time reliability 709 GL FSL 24 mEMG96 Estimated yield at 85% annual time reliability 861 GL
Open water evaporation	At FSL the surface area of the potential reservoir calculated using the SRTM-H is: FSL 18 mEMG96 11,711 ha FSL 20 mEMG96 16,666 ha FSL 22 mEMG96 21,901 ha FSL 24 mEMG96 27,462 ha Mean annual evaporation and mean annual net evaporation at FSL 24 mEMG96 at 85% annual reliability is 331.3 GL and 89.2 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.11.
Potential use of supply	**Agriculture** The alluvial plains of the Adelaide River below the confluence of the Adelaide and Margaret rivers typically has an incised main channel, a narrow levee, extensive level alluvial plains subject to occasional to regular flooding, and frequent drainage depressions and swamps. The alluvial plains are subject to annual flooding for extended periods. Soils on the level alluvial plains in the upper catchments are predominantly poorly drained, slowly permeable, hard-setting clay soils. Soils are generally unsuitable for irrigated cropping but may be suitable for dry-season rice and forage cropping. Soils are likely to be suitable for ringtanks. Very narrow levees with imperfectly drained, moderately permeable, mottled brown, massive, loamy soils (Kandosols) and friable loamy soils (Dermosols) are suitable for wetness tolerant horticultural crops. The generally long thin units associated with the levees may restrict irrigation layout and machinery use in some areas. Soils are unlikely to be suitable for ringtanks. See companion technical report on land suitability (Thomas et al., 2018). **Urban** The potential yield from a dam at the Marrakai site is likely to far exceed the future requirements of Darwin.

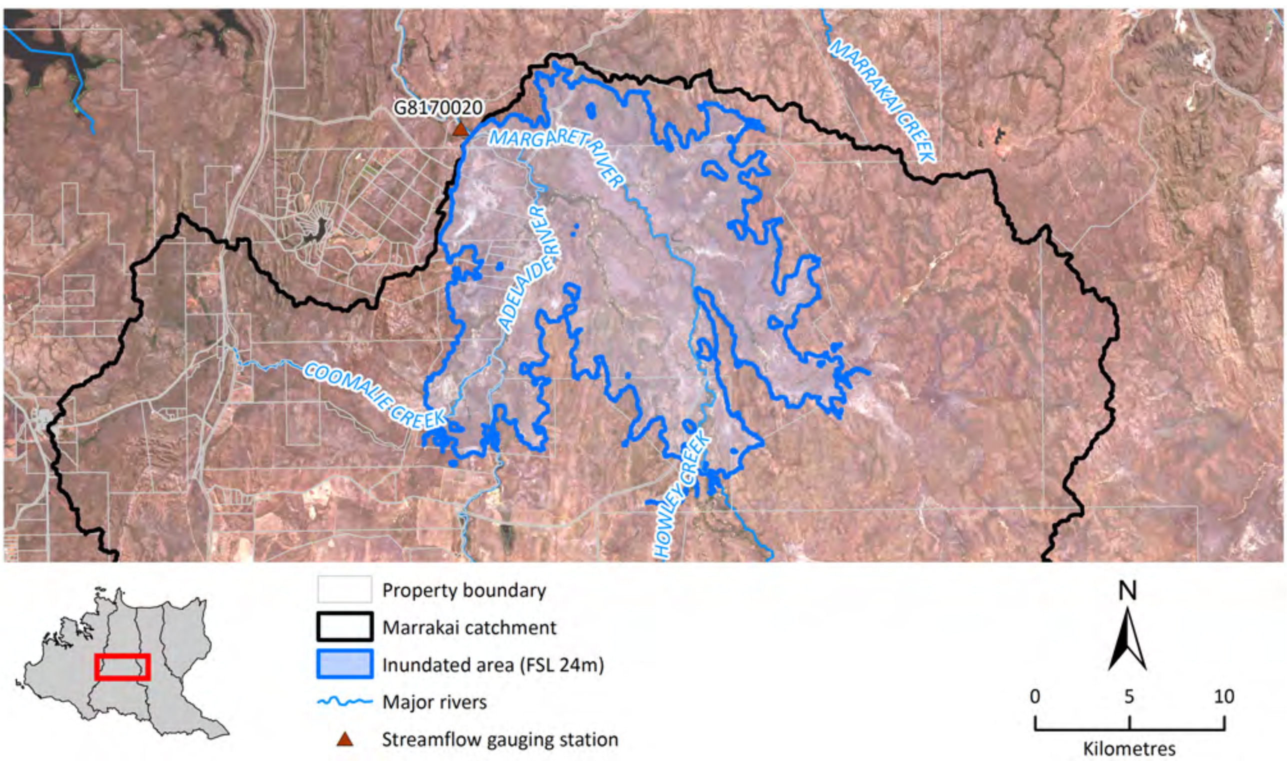
PARAMETER	DESCRIPTION			
Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)	0.1	0.5	0.8
	100 years (%)	0.2	1.5	2.6
	Years to fill	54,210	6,550	3,900
Storage impacts	A storage at FSL 24 mEMG96 would inundate more than 25 km of the Adelaide and Margaret river beds.			
Environmental considerations	**Barrier to movement of aquatic species** Fish whose movement may be impeded by a dam at this site include the barred grunter (*Amniataba percoides*), flyspecked (*Craterocephalus stercusmuscarum stercusmuscarum)*, mouth almighty *(Glossamia aprion)*, sooty grunter (*Hephaestus fuliginosus*), barramundi (*Lates calcarifer*), rainbowfish (*Melanotaenia*), bony herring (*Nematalosa erebi)*, black catfish (*Neosilurus ater*), freshwater longtom (*Strongylura krefftii*) and Hyrtl's catfish (*Neosilurus hyrtlii*). **Ecological implications of inundation** A dam development at this site would inundate a large area of the Adelaide River floodplain and numerous lagoons, which contain important fish habitats. At this potential dam site three species of national significance, which are also listed under the *Territory Parks and Wildlife Conservation Act* (NT), have been recorded. These are the endangered Gouldian finch (*Erythrura gouldiae*), the vulnerable patridge pigeon (*Geophaps smithii*) and the fawn antechinus (*Antechinus bellus*). The potential inundated area at FSL for this site (24 mEMG96) may affect these species by reducing their habitat. The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).			
Estimated cost	CSIRO generated preliminary estimates of cost based on a generalised costing algorithm. The costs for a selection of FSL are reported below: FSL 18 mEMG96 $337 million FSL 20 mEMG96 $429 million FSL 22 mEMG96 $531 million FSL 24 mEMG96 $657 million The above modelled costs were then further inflated by a nominal 30% as they are likely to be a considerable underestimate of the actual cost as they do not adequately reflect the poor foundation conditions or the considerable logistical challenges that constructing a dam at this site would involve. Discounting any additional costs due to geological complications, it is possible that the actual costs may be 50 to 100% higher than the modelled costs reported here. No further cost estimates were made at this site as part of the Assessment. An earlier cost estimate for a dam at this site ($65 million at FSL 20 mAHD in 1988, which is the equivalent of $125 million in 2017 using Queensland Roads and Bridge construction index) did not take into account the likely very-high costs involved in managing floods during construction nor significant costs now involved in dam construction such as environmental and heritage management costs, nor owner costs.			
Estimated cost/ML of supply	Based on the yields estimated by the CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm estimated cost/ML of supply are reported at the following FSL: FSL 18 mEMG96 $1230/ML FSL 20 mEMG96 $809/ML FSL 22 mEMG96 $749/ML FSL 24 mEMG96 $763/ML On the basis of these estimated costs of supply over this range of storage levels, a dam at FSL 24 mEMG96 was selected for reporting other criteria.			

PARAMETER	DESCRIPTION
Summary comment	In 1988 the Marrakai dam site was listed as one of three preferred storage sites adopted by the then Northern Territory Government. The potential yield from a dam at this site is likely to far exceed the future demand for water from Darwin and the amount of land downstream that could potentially be irrigated. Given the very-high construction risks, poor foundation conditions and the likely environmental issues involved with construction and operating a dam at this site, it was not short-listed for further consideration.

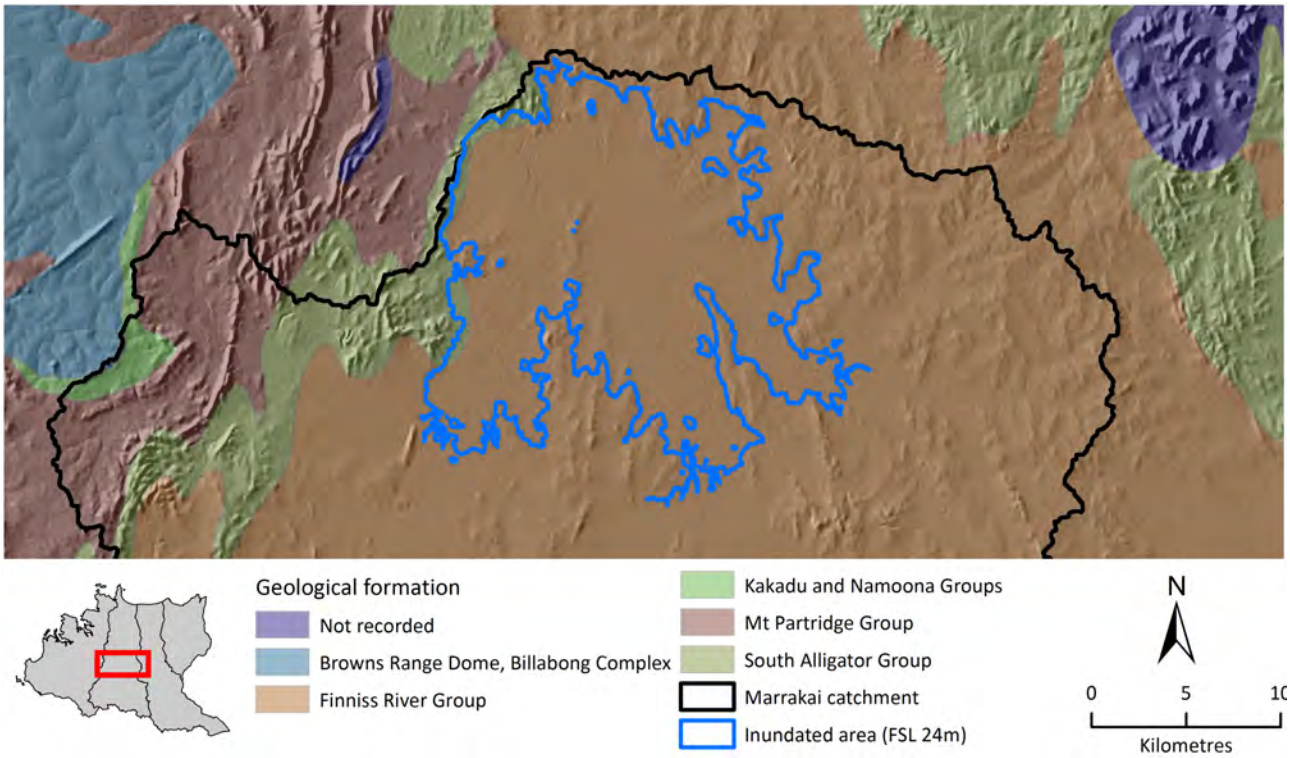
Apx Figure A-24 Marrakai dam site looking upstream



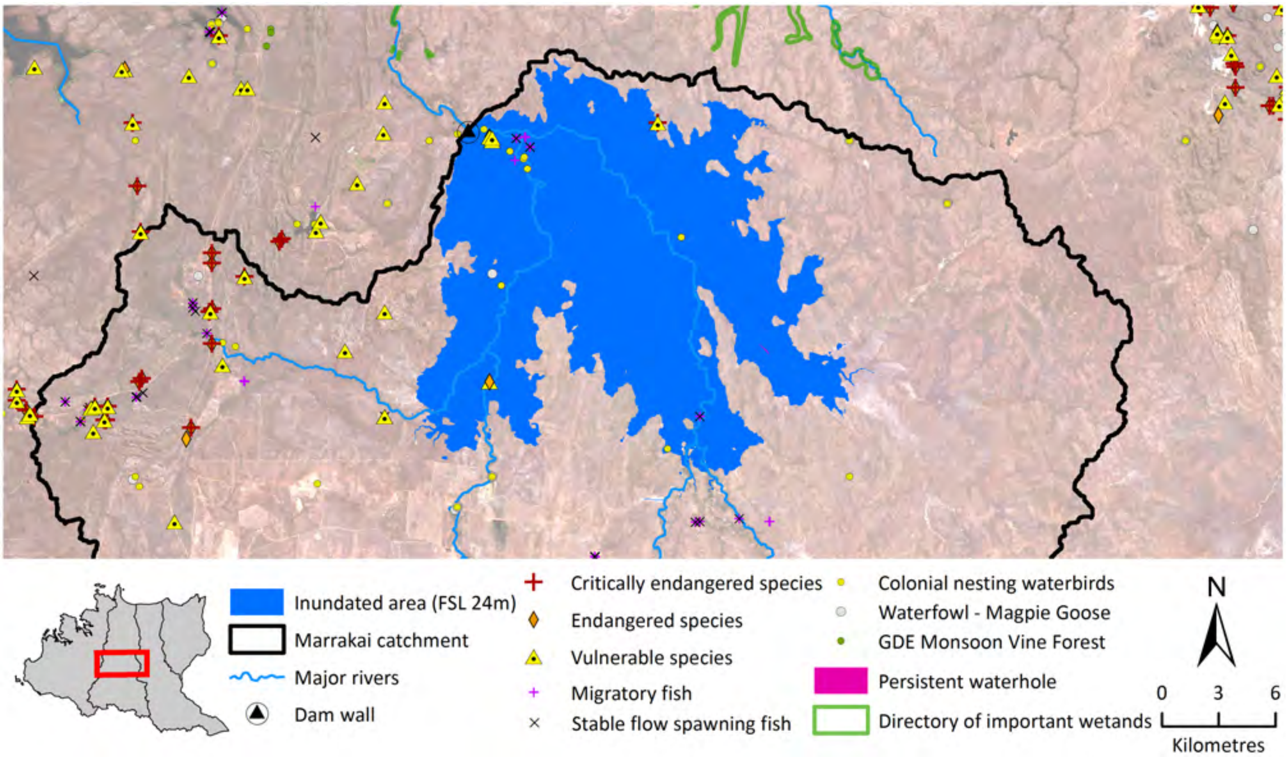
Apx Figure A-25 Location map of Marrakai dam site, reservoir extent and catchment area



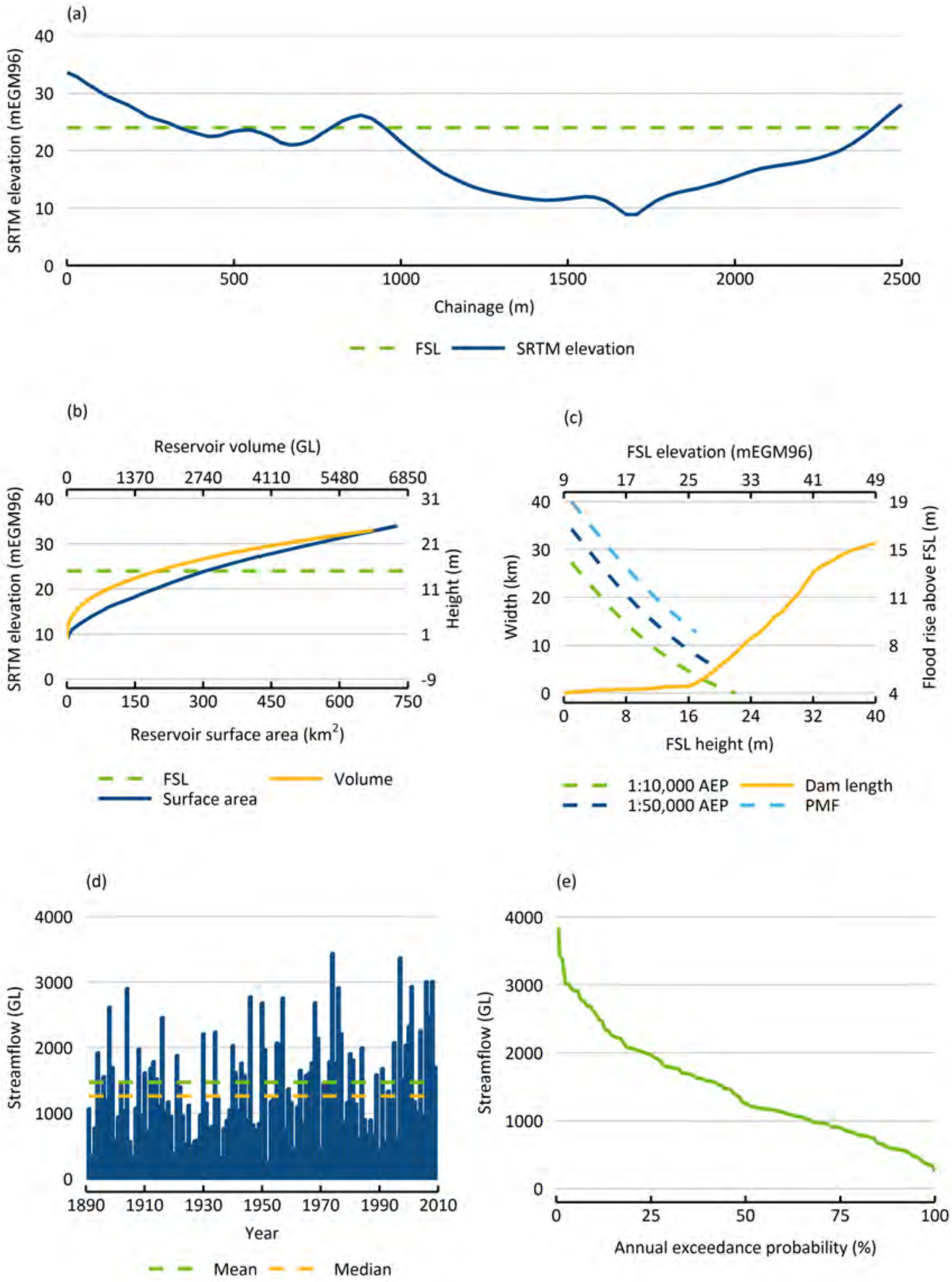
Apx Figure A-26 Marrakai dam site reservoir and property boundaries



Apx Figure A-27 Geology underlying the potential Marrakai dam site and reservoir

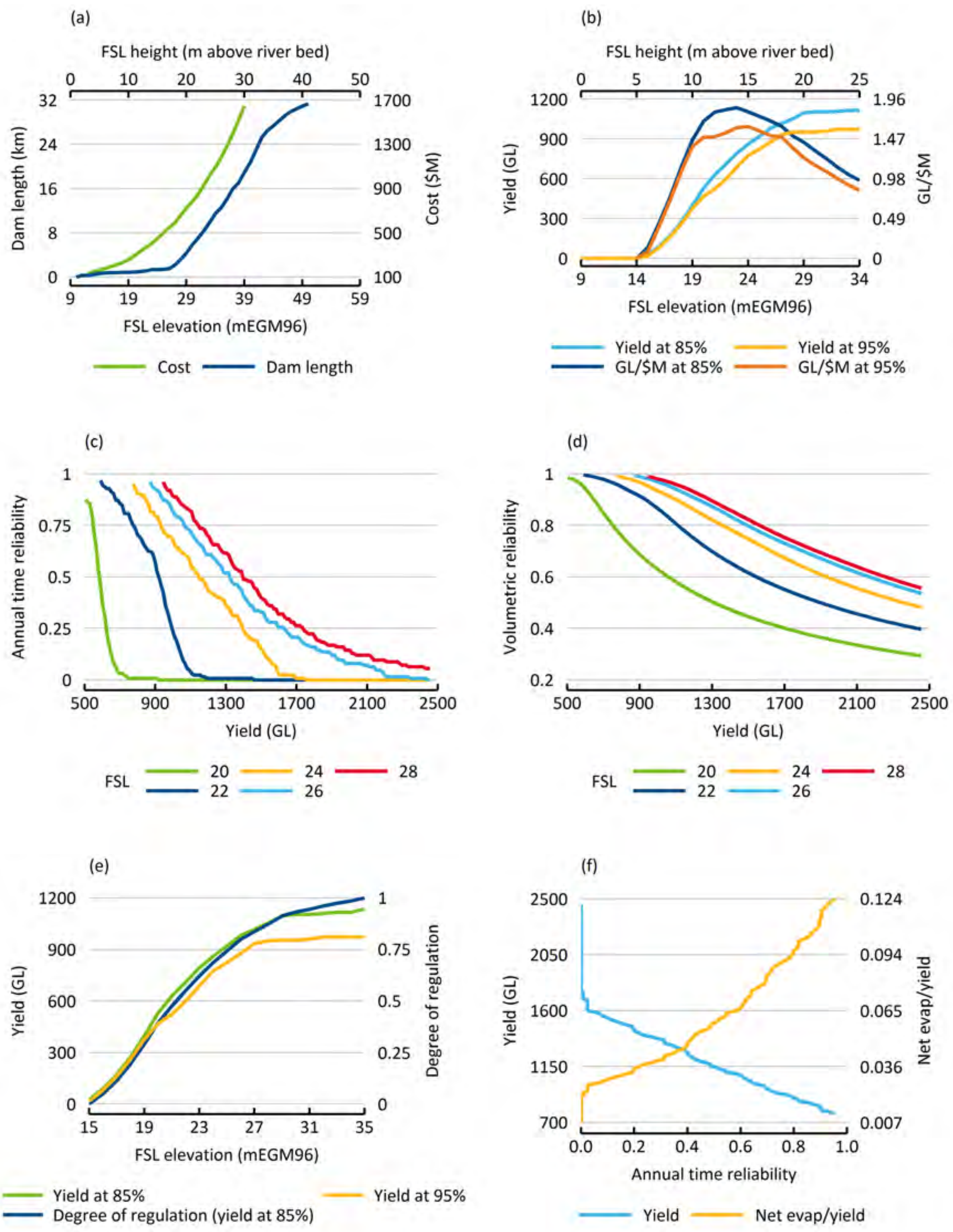


Apx Figure A-28 Known water-dependent ecological assets in the vicinity of the Marrakai dam site

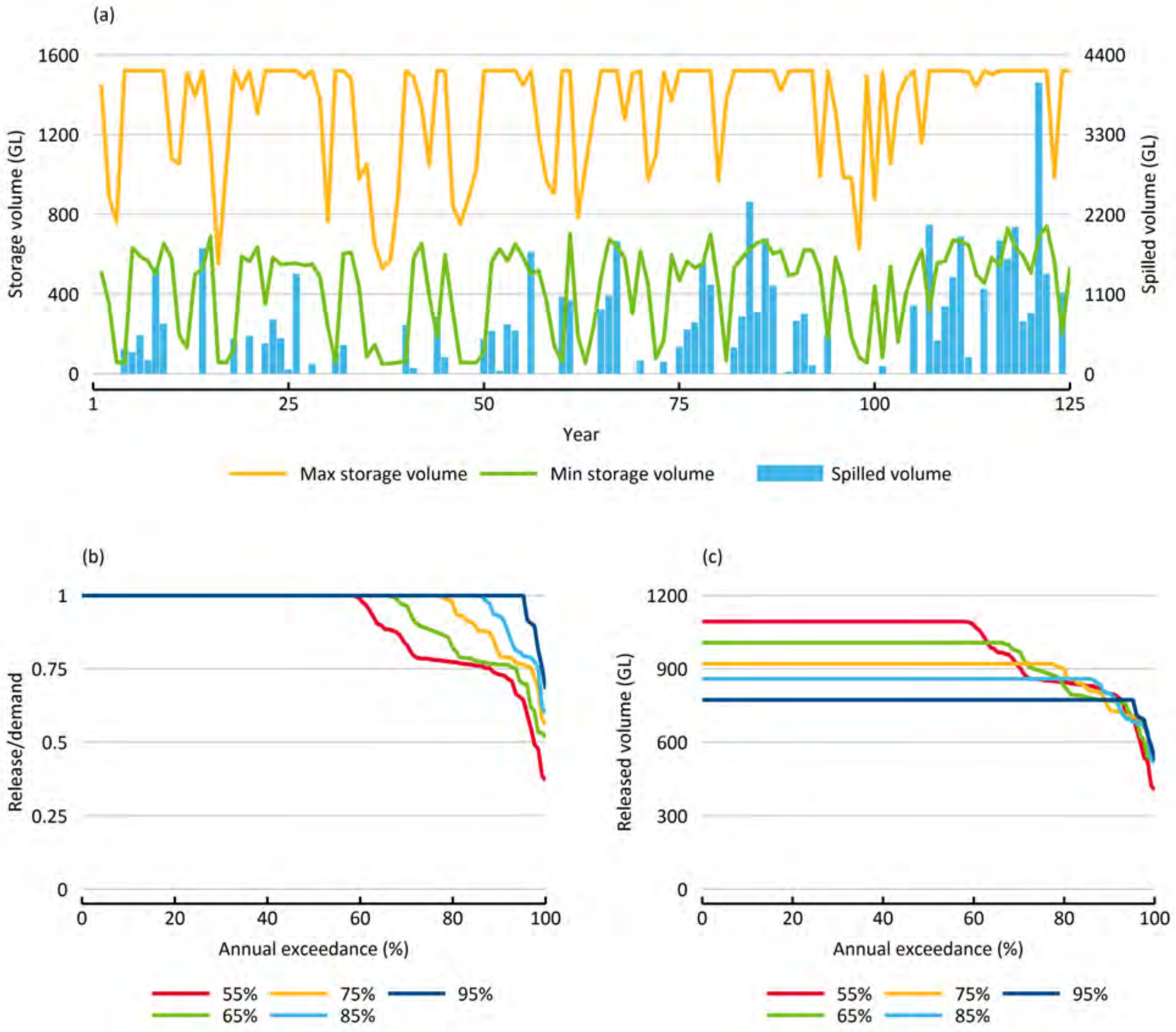


Apx Figure A-29 Marrakai potential dam site topographic dimensions and inflow hydrology

(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 events plotted against FSL; (d) annual streamflow; (e) annual flow exceedance.



Apx Figure A-30 Marrakai potential dam site cost, yield at the dam wall and evaporation
(a) Dam length and dam cost versus FSL; (b) dam yield at 85% and 95% annual time reliability and yield per $ million at 85% and 95% 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 85% and 95% 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 A-31 Marrakai potential dam site storage levels and yield

(a) Maximum and minimum annual storage trace at the selected FSL (FSL 24 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

A.1.6 MCKINLAY DAM SITE ON THE MCKINLAY RIVER; AMTD 48.8 KM

PARAMETER	DESCRIPTION
Previous investigations	No record of any previous investigations of this site have been located. The site was identified from an initial run of the CSIRO DamSite model.
Description of proposal	A potential dam at this site would involve a relatively shallow instream storage on the McKinlay River (a tributary of the Mary River), which potentially could provide supplies to downstream users including irrigation. **The following figures accompany this description of the site** The potential McKinlay dam site is shown in Apx Figure A-32. Apx Figure A-33 provides a map showing its location in the Darwin catchments, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Apx Figure A-34. Apx Figure A-35 and Apx Figure A-36 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Apx Figure A-37 to Apx Figure A-39.
Regional geology	The potential McKinlay dam site and reservoir area are located in a geological province known as the Pine Creek Orogen, which is an area underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The rocks in the area have been intruded by granite, folded, faulted and uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the older rocks in the area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on many of the slopes. The potential dam site and reservoir area are underlain by folded and faulted metamorphic rocks of the South Alligator and Finniss River Groups overlain in places by the less deformed coarse-grained sandstone of the Kombolgie Formation. Faults and fold axes in the older deformed rocks tend to strike between approximately north/south and north-west/south-east and bedding and foliation tend to dip steeply east to north-east or west to south. There are also southwest/northeast and east-west-trending faults. The overlying sandstone is less deformed and typically dips gently or moderately to the south-east. Alluvium occurs in the floor of the valleys and colluvium on the valley slopes.
Site geology	The potential McKinlay dam site is on a north-trending section of the river. According to geological maps, the abutments are underlain by coarse-grained sandstone of the Kombolgie Formation. The sandstone overlies greywacke shale and phyllite of the Burrell Creek Formation, which is likely to form the foundation of the dam in the valley floor and lower parts of the right abutment. The depth of alluvium in the valley floor and the depth of colluvium on the abutments is unknown.
Reservoir rim stability and leakage potential	Given the relatively subdued topography no significant reservoir rim stability issues are expected and if the foundations of the main dams are grouted leakage is not expected to be a major issue.
Proposed structural arrangement	The cross-river section is very wide. An uncontrolled RCC spillway could be located across the rocky pinnacle mid-section with earth and rockfill embankments on each side extending to the abutments. Earth and rockfill embankments would be used for the long saddle dams required. Access to the site would be by 45 km of new road branching from the Arnhem Highway on the western side of the Mary River crossing, which is approximately 100 km from Darwin.
Availability of construction materials	There have been no previous investigations of quarries close to the area or other potential sources of construction material.
Catchment area	Based on SRTM-H data, the catchment area upstream of the dam axis is 922 km^2.
Flow data	The nearest streamflow gauging station is G8180035 at the junction of the McKinlay and Mary rivers.

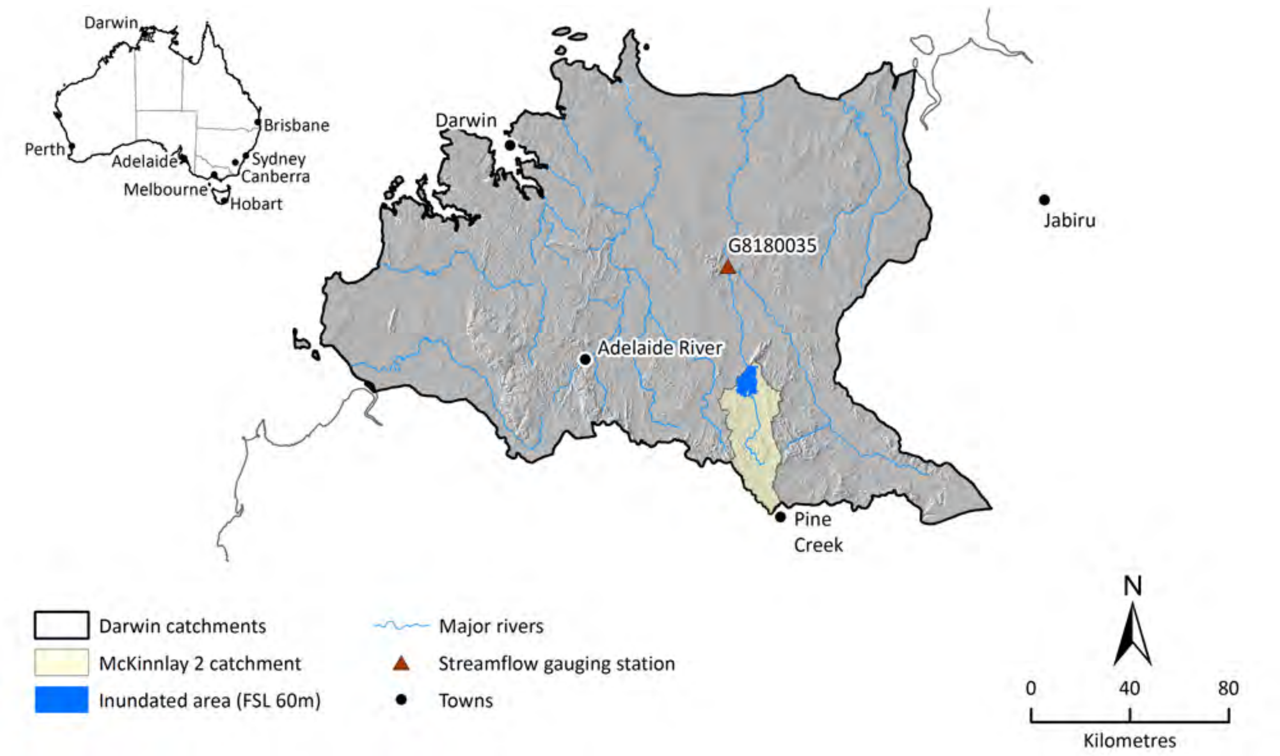
PARAMETER	DESCRIPTION
Storage capacity	Selected storage levels and capacities calculated using the SRTM-H are: FSL 58 mEMG96 Capacity 365 GL FSL 60 mEMG96 Capacity 512 GL FSL 62 mEMG96 Capacity 687 GL
Reservoir yield assessment	FSL 58 mEMG96 Estimated yield at 85% annual time reliability 127 GL FSL 60 mEMG96 Estimated yield at 85% annual time reliability 158 GL FSL 62 mEMG96 Estimated yield at 85% annual time reliability 172 GL
Open water evaporation	At FSL, the surface area of the potential reservoir would be: FSL 58 mEMG96 6689 ha FSL 60 mEMG96 8022 ha FSL 62 mEMG96 9564 ha Mean annual evaporation and mean annual net evaporation at FSL 60 mEMG96 at 85% annual reliability is 106 GL and 34 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.228.
Potential use of supply	**Agriculture** The alluvial plains upstream of the Mary and McKinlay rivers south of the Arnhem Highway typically have a deeply incised main channel, a distinct narrow levee, extensive level alluvial plains subject to occasional to regular flooding, and frequent drainage depressions and swamps. The duration of flooding increases downstream north of the highway on the Mary River, and is subject to annual flooding for extended periods. Soils on the level alluvial plains in the upper catchments are predominantly imperfectly to poorly drained, slowly permeable, structured gradational soils (Dermosols, Hydrosols) with hard-setting clay loam to silty clay loam surfaces over sodic, mottled, grey or brown clay subsoils. Hard-setting poorly drained clay soils also occur throughout the alluvial plains. South of the Arnhem Highway the ratio of imperfectly drained to poorly drained soils is estimated to be 60:40. North of the Arnhem Highway all soils are poorly drained and subject to annual flooding for extended periods. See companion technical report on land suitability (Thomas et al., 2018).
Estimated rates of reservoir sedimentation	(see table below)
Storage impacts	A storage at FSL 60 mEMG96 would inundate about 12 km of the McKinlay River bed.
Environmental considerations	There are a number of abandoned gold mine workings in the catchment area. **Barrier to movement of aquatic species** If a dam were constructed at this site it may impede the movement of fresh water turtle (*Chelodina rugosa* and *C. oblonga*) populations and the migration, movement or colonisation of the following fish species: barred grunter (*Amniataba percoides*), flyspecked (*Craterocephalus stercusmuscarum stercusmuscarum)*, mouth almighty *(Glossamia aprion)*, spangled perch (*Leiopotherapon unicolor*), western rainbowfish (*Melanotaenia australis)*, bony herring (*Nematalosa erebi)* and Hyrtl's catfish (*Neosilurus hyrtlii*). **Ecological implications of inundation** There were no records of species of national significance or species listed under the *Territory Parks and Wildlife Conservation Act* (NT). The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).

Estimated rates of reservoir sedimentation:

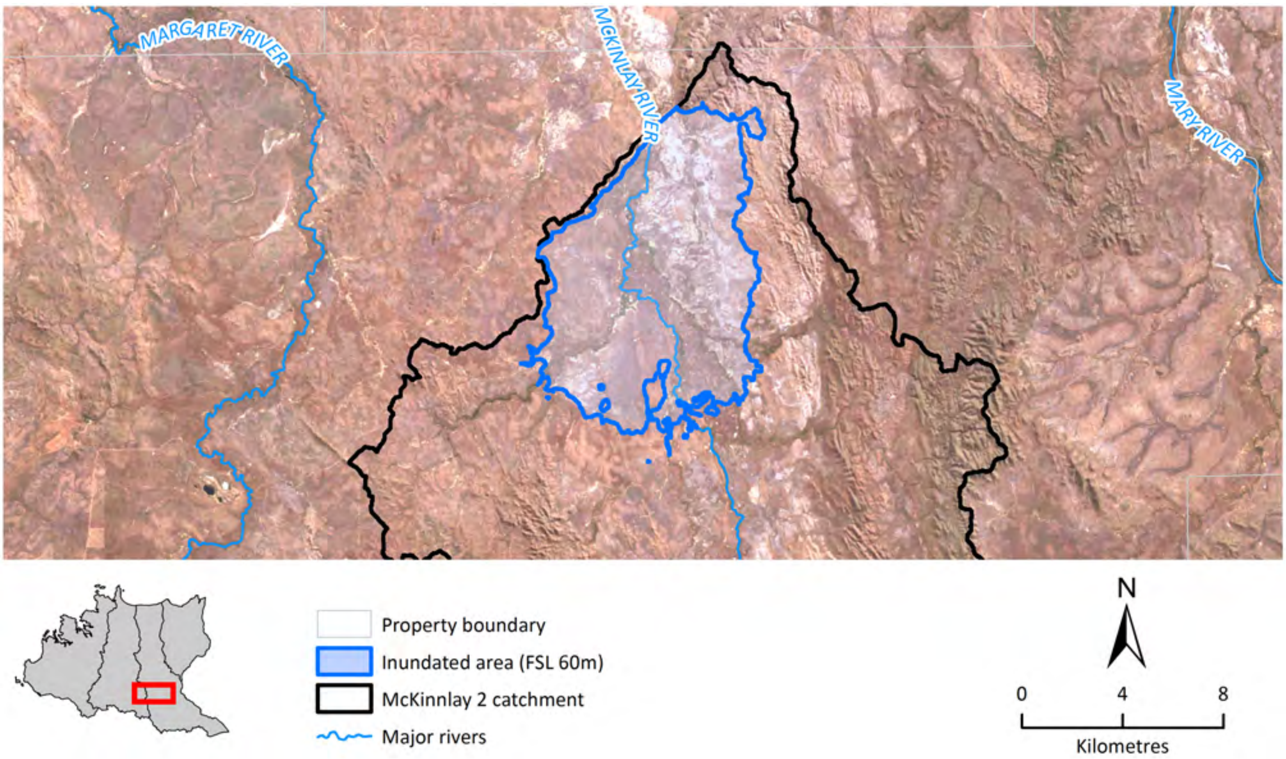
	Best case	Expected	Worst case
30 years (%)	0.0	0.3	0.5
100 years (%)	0.1	1.2	1.6
Years to fill	85,970	9,550	6,190

PARAMETER	DESCRIPTION
Estimated cost	CSIRO generated preliminary estimates of cost based on a generalised costing algorithm. The costs for a selection of FSL are reported below: FSL 58 mEMG96 $430 million FSL 60 mEMG96 $492 million FSL 62 mEMG96 $572 million These modelled costs estimates are likely to be within –20% and +50% of the true value. If geotechnical investigations found geological complications at the site dam costs may be substantially higher. No further cost estimates were made at this site as part of the Assessment.
Estimated cost/ML of supply	Based on the yields estimated by the CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm estimated cost/ML of supply are reported at the following FSL: FSL 58 mEMG96 $3386/ML FSL 60 mEMG96 $3114/ML FSL 62 mEMG96 $3326/ML On the basis of these estimated costs of supply over this range of storage levels, a dam at FSL 60 mEMG96 was selected for reporting other criteria.
Summary comment	Relative to other sites in the Darwin catchments, the McKinlay River dam site is remote and would be expensive to construct relative to its potential yield due to the width of the main wall and uncertain foundation conditions. For these reasons it was not short-listed for further consideration.

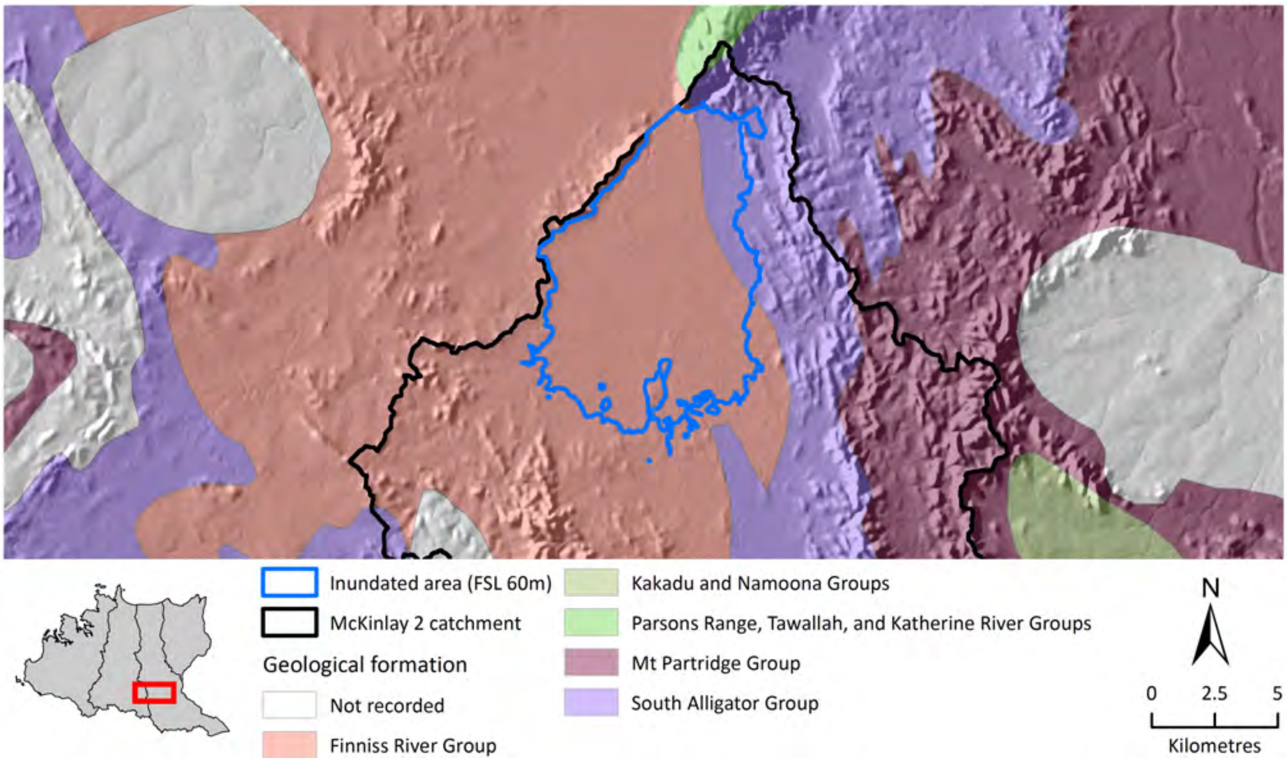
Apx Figure A-32 McKinlay dam site looking upstream



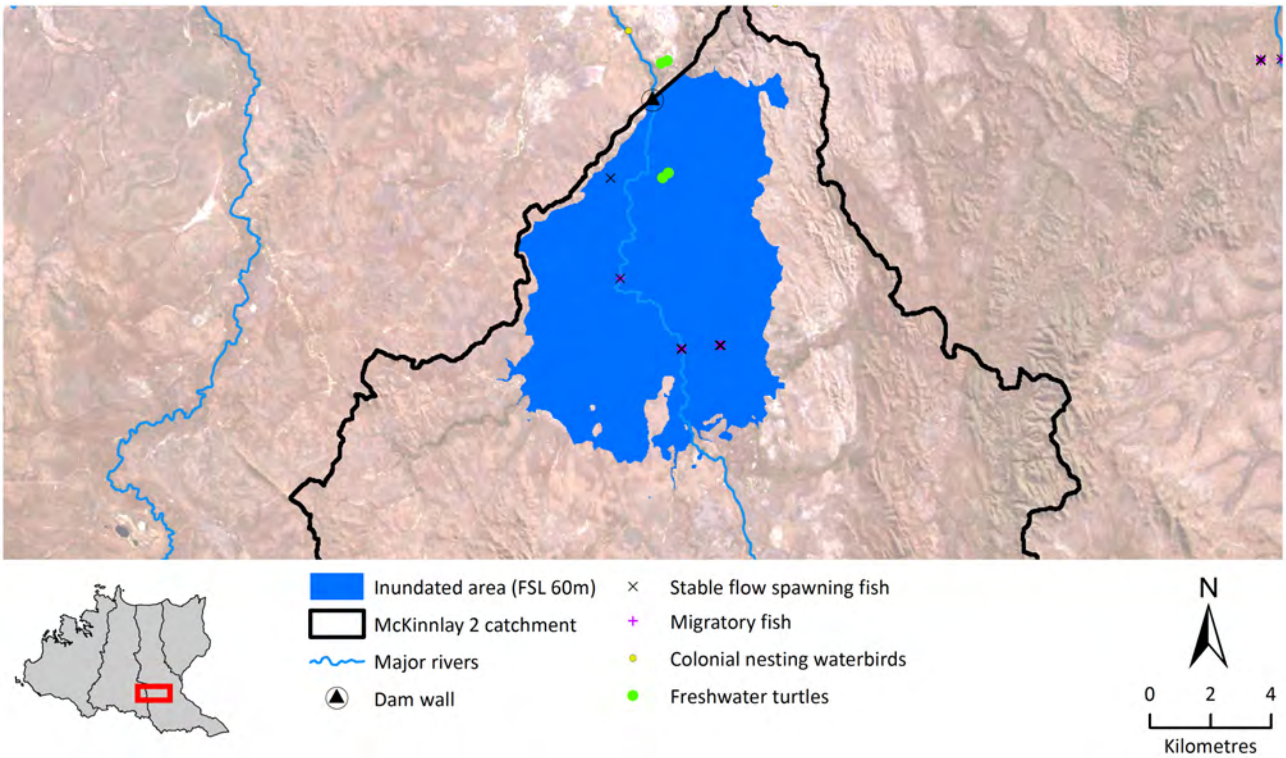
Apx Figure A-33 Location map of McKinlay dam site, reservoir extent and catchment area



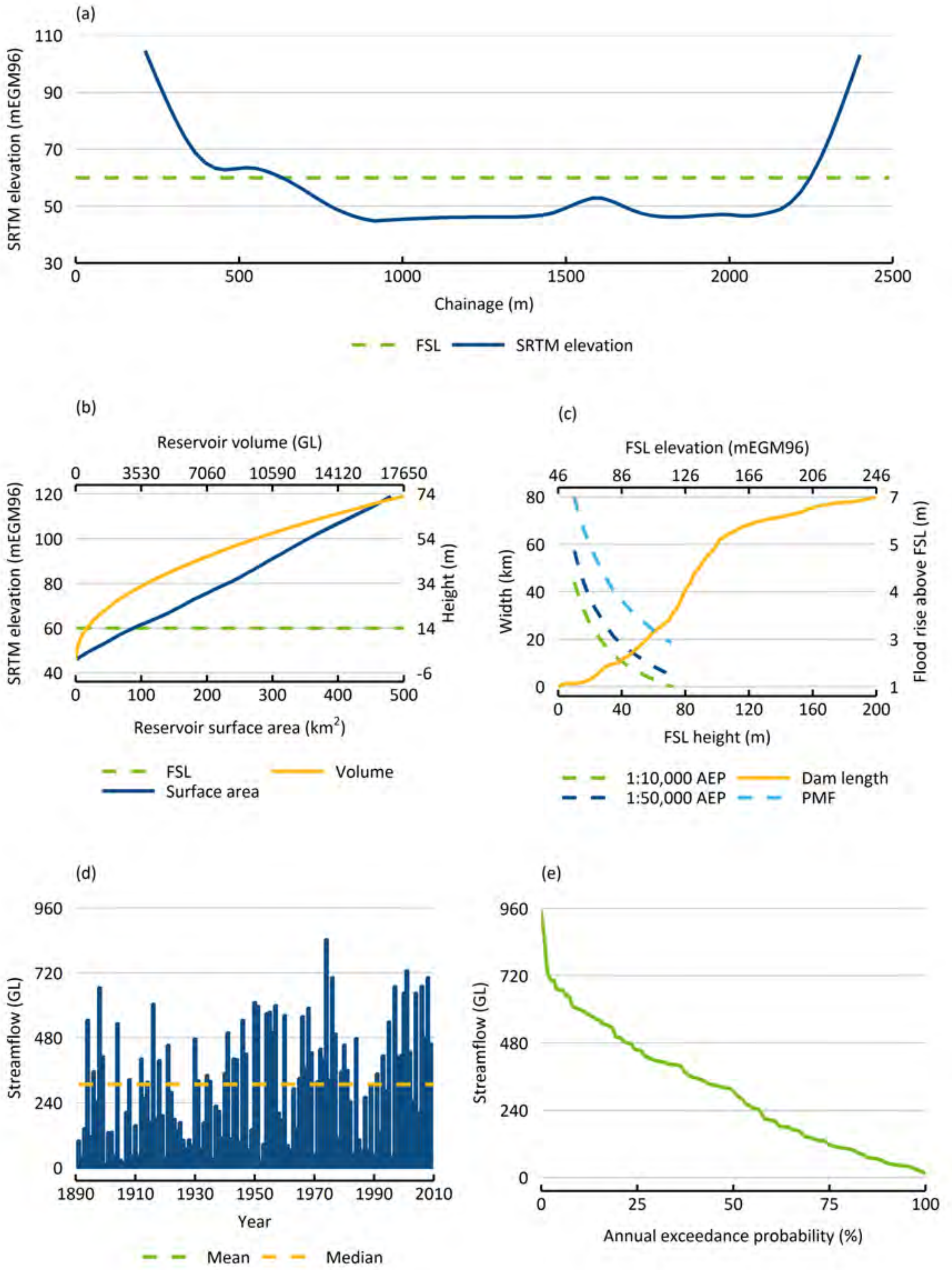
Apx Figure A-34 McKinlay dam site reservoir and property boundaries



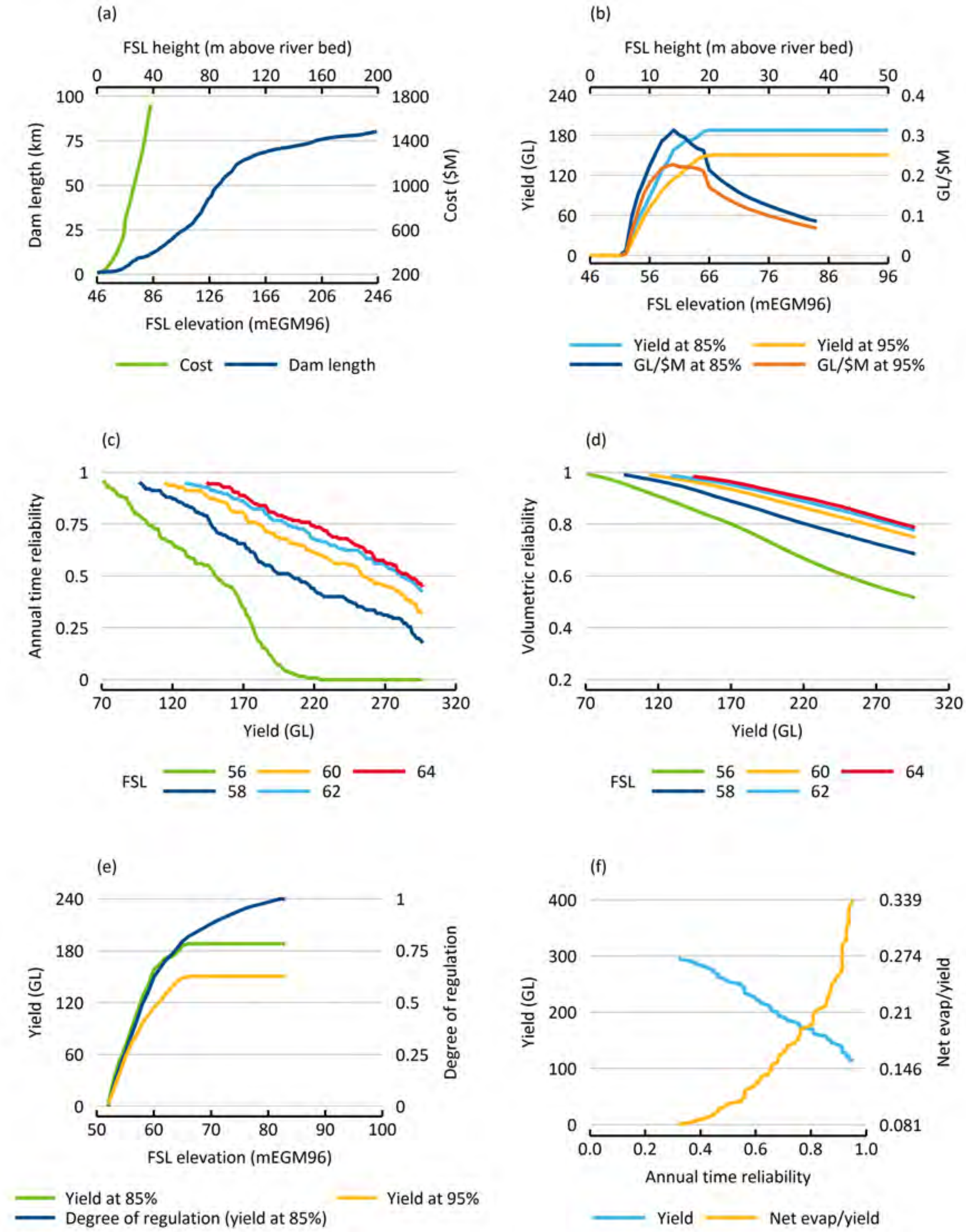
Apx Figure A-35 Geology underlying the potential McKinlay dam site and reservoir



Apx Figure A-36 Known water-dependent ecological assets in the vicinity of the McKinlay dam site

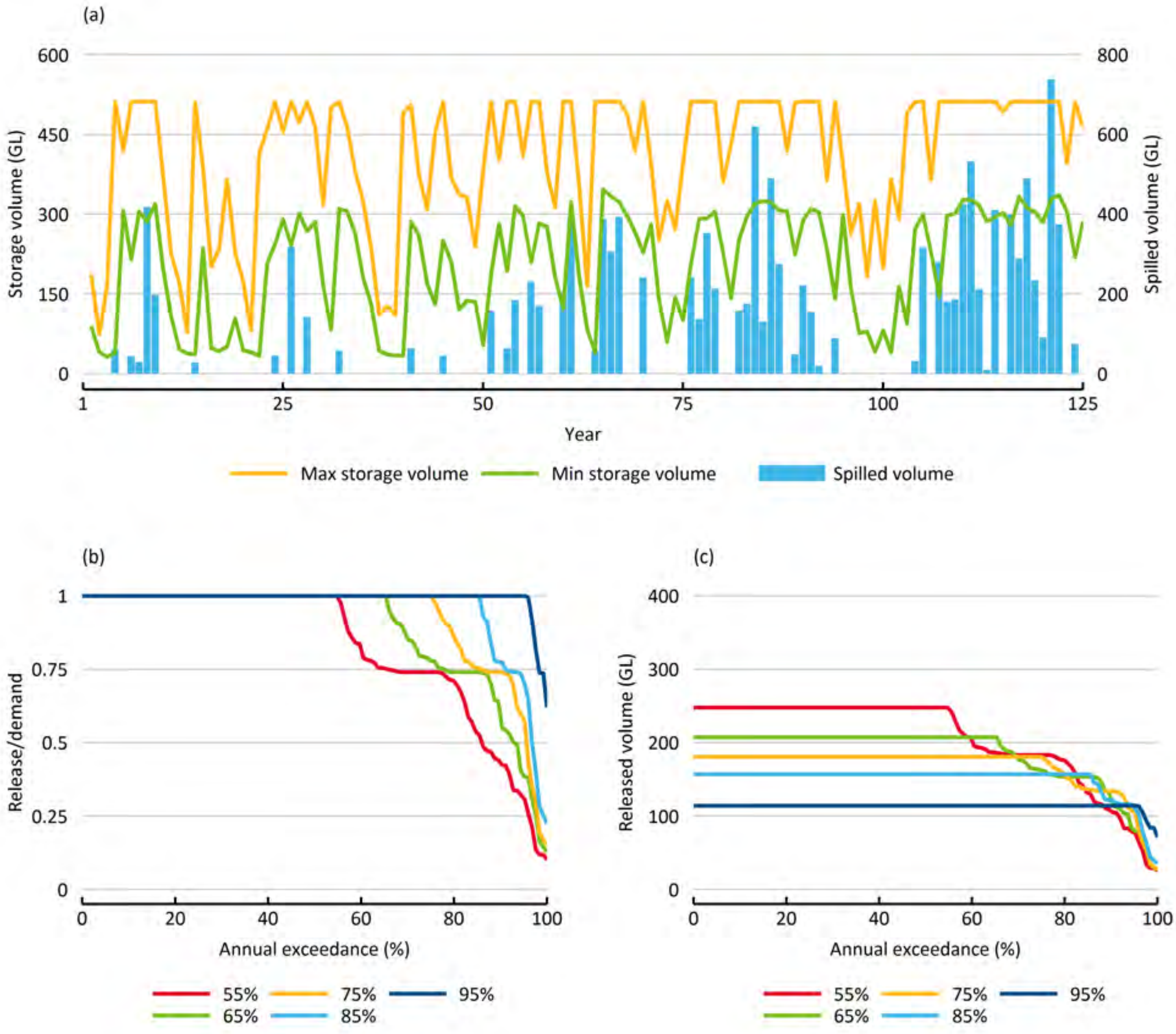


Apx Figure A-37 McKinlay potential dam site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and probable maximum flood events plotted against FSL; (d) annual streamflow; (e) annual flow exceedance.



Apx Figure A-38 McKinlay River potential dam site cost, yield at the dam wall and evaporation

(a) Dam length and dam cost versus FSL; (b) dam yield at 85% and 95% annual time reliability and yield per $ million at 85% and 95% 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 85% and 95% 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 A-39 McKinlay River potential dam site storage levels and yield

(a) Maximum and minimum annual storage trace at the selected FSL (FSL, 60 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

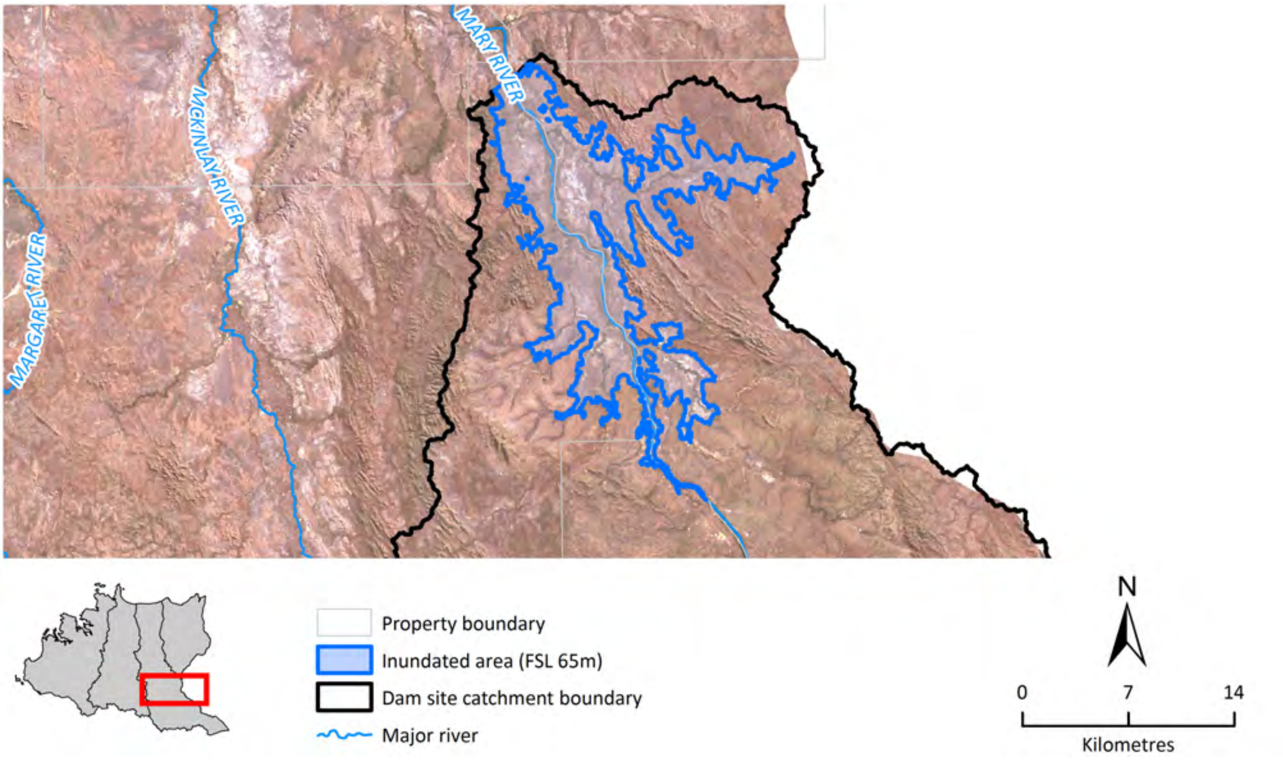
A.1.7 MARY RIVER DAM SITE ON THE MARY RIVER; AMTD 156.4 KM

PARAMETER	DESCRIPTION
Previous investigations	No record of any previous investigations of this site have been located. The site was identified from an initial run of the CSIRO DamSite model. The site is at the south-west corner boundary of the Mount Bundy military training area. As a result of military training exercises this was the only site not visited by the Assessment team.
Description of proposal	A potential dam at this site would involve a relatively large instream storage on the Mary River, which could potentially supply water to downstream users including for irrigation. **The following figures accompany this description of the site** Apx Figure A-40 provides a map showing its location in the Darwin catchments, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Apx Figure A-41. Apx Figure A-42 and Apx Figure A-43 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Apx Figure A-44 to Apx Figure A-46.
Regional geology	The potential Mary River dam site and reservoir area are located in a geological province known as the Pine Creek Orogen, which is an area underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The rocks in the area have been intruded by granite, folded, faulted and uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the older rocks in the project area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on many of the slopes. The dam site and storage area are underlain by folded and faulted metamorphic rocks of the South Alligator Group. Faults and fold axes strike approximately north/south and bedding and foliation tend to dip steeply east or west. Alluvium occurs in the floor of the valleys and colluvium on the valley slopes.
Site geology	There has been no previous investigation of the potential Mary River dam site. The site is on a north-trending section of the river. According to geological maps, the left abutment of the potential Mary River dam site is underlain by siltstone, shale and chert and the right abutment is underlain by siltstone, phyllite, chert and tuff. The depth of alluvium in the 400-m wide valley floor and the depth of colluvium on the abutments is unknown.
Reservoir rim stability and leakage potential	Given the subdued topography, no significant reservoir rim stability issues are expected and if the foundations of the dam foundations are grouted, leakage is not expected to be a significant issue.
Proposed structural arrangement	Assuming that a rock foundation was available at a reasonable depth across the river section, an RCC type dam with a wide central overflow spillway would be proposed with an earth and rockfill embankment section across the left bank section. Access to the site could be via 45 km of new road branching from the Arnhem Highway to the west of the Mary River crossing, which is approximately 110 km from Darwin. A bridge over the McKinlay River would be required.
Availability of construction materials	There have been no previous investigations of quarries close to the project area or of other potential sources of construction material.
Catchment area	The catchment area upstream of the dam site is 3063 km^2.
Flow data	The nearest streamflow gauging station is G8180035 at the junction of the McKinlay and Mary rivers.
Storage capacity	Selected storage levels and capacities calculated using the SRTM-H are: FSL 60 mEMG96 Capacity 647 GL FSL 65 mEMG96 Capacity 1312 GL FSL 70 mEMG96 Capacity 2313 GL

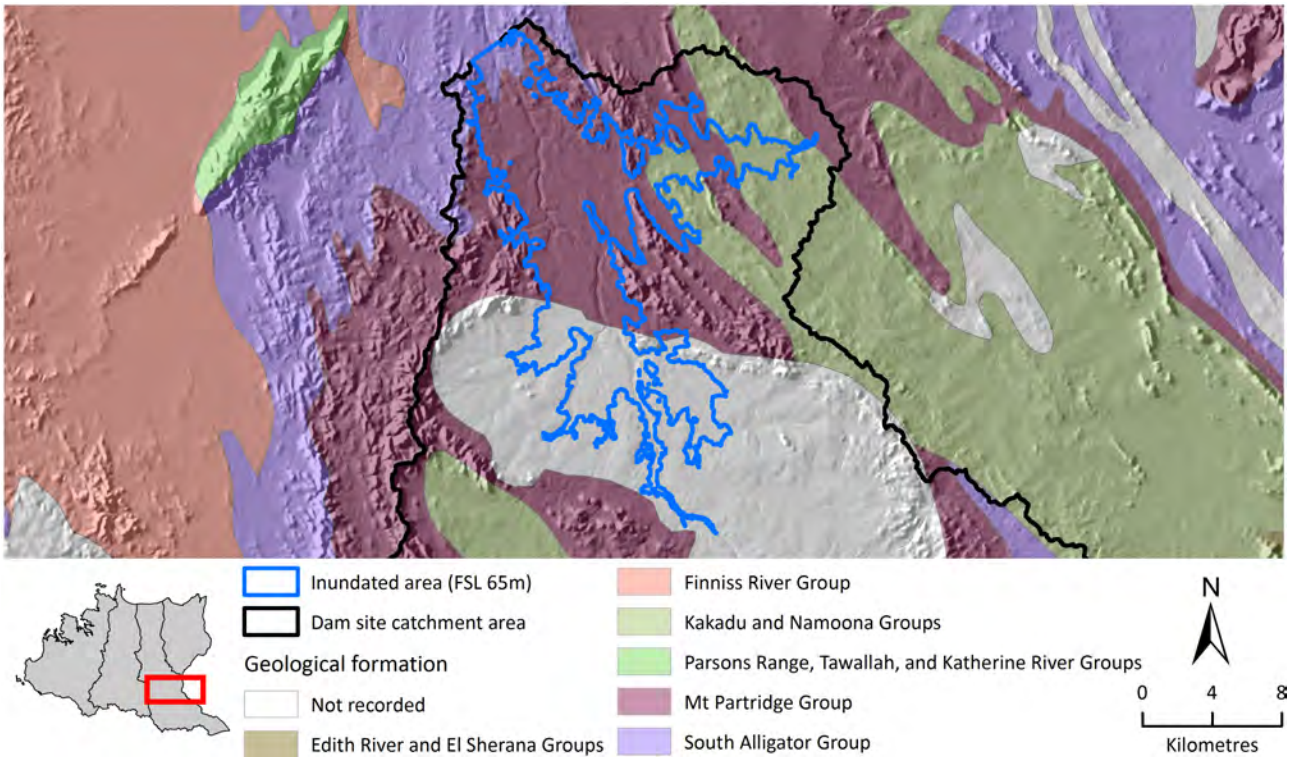
PARAMETER	DESCRIPTION
Reservoir yield assessment	FSL 60 mEMG96 Estimated yield at 85% annual time reliability 348 GL FSL 65 mEMG96 Estimated yield at 85% annual time reliability 492 GL FSL 70 mEMG96 Estimated yield at 85% annual time reliability 528 GL
Open water evaporation	At FSLl, the surface area of the storage based on SRTM-H data was estimated to be: FSL 60 mEMG96 10,357 ha FSL 65 mEMG96 16,488 ha FSL 70 mEMG96 23,554 ha Mean annual evaporation and mean annual net evaporation at FSL 65 mEMG96 at 85% annual reliability is 187 GL and 60 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.128.
Potential use of supply	**Agriculture** The alluvial plains upstream of the Adelaide River south of the Arnhem Highway typically has a deeply incised main channel, a distinct narrow levee, extensive level alluvial plains subject to occasional to regular flooding, and frequent drainage depressions and swamps. The duration of flooding increases downstream north of the highway on the Mary River, and is subject to annual flooding for extended periods. Soils on the level alluvial plains in the upper catchments are predominantly imperfectly to poorly drained, slowly permeable, structured gradational soils (Dermosols, Hydrosols) with hard-setting clay loam to silty clay loam surfaces over sodic, mottled, grey or brown clay subsoils. Hard-setting poorly drained clay soils also occur throughout the alluvial plains. North of the Arnhem Land Highway, all soils are poorly drained and subject to annual flooding. The imperfectly drained soils are suitable for sugarcane, rice and dry-season grain and forage cropping. Soils are likely to be suitable for ringtanks. Well-drained to moderately well-drained massive brown loamy soils (Kandosols) predominate on the narrow levees. The soils on the levees are suitable for all agriculture except furrow and flood irrigation methods. The generally long thin units associated with the levees may restrict irrigation layout and machinery use in some areas. Soils are unlikely to be suitable for ringtanks. See companion technical report on land suitability (Thomas et al., 2018).
Estimated rates of reservoir sedimentation	<table><tr><td></td><td>Best case</td><td>Expected</td><td>Worst case</td></tr><tr><td>30 years (%)</td><td>0.0</td><td>0.5</td><td>0.6</td></tr><tr><td>100 years (%)</td><td>0.2</td><td>1.6</td><td>2.1</td></tr><tr><td>Years to fill</td><td>66,260</td><td>7,930</td><td>4,770</td></tr></table>
Storage impacts	A storage at this site would be immediately upstream of the Mount Bundy military training area and inundate part of the Kakadu National Park, which abuts the river on the right bank side.
Environmental considerations	**Barrier to movement of aquatic species** A dam at this site could affect the migration, movement or colonisation of some fish species, particularly stable flow spawners such as barred grunter (*Amniataba percoides*), sooty grunter (*Hephaestus fuliginosus*), spangled perch (*Leiopotherapon unicolor*), bony herring (*Nematalosa erebi)*, barramundi (*Lates calcarifer*), western rainbowfish (*Melanotaenia australis*) and freshwater longtom (*Strongylura krefftii*). **Ecological implications of inundation** At this site three species listed under the *Parks and Wildlife Conservation Act* (NT) have been recorded: patridge pigeon (Geophaps smithii), fawn antechinus (Antechinus bellus) and pale field rat (Rattus tunneyi). The first two are of national significance. A reservoir at the selected FSL (65 mEMG96) may affect these species due to the loss of habitat. A reservoir at the selected FSL would inundate patches of Ramsar wetlands, which cover an area of 1483 ha and 9784 ha. These wetlands are also listed as an internationally important area for birds, such as Nankeen night heron (Nycticorax caledonicus).

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 (Pollino et al., 2018).
Estimated cost	CSIRO generated preliminary estimates of cost based on a generalised costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways and cost items for embankment type saddle dams. The costs for a selection of FSL are reported below: FSL 60 mEMG96 $611 million FSL 65 mEMG96 $756 million FSL 70 mEMG96 $988 million These modelled costs estimates are likely to be within –20% and +50% of the true value. If geotechnical investigations were to find geological complications at the site dam costs may be substantially higher. No further cost estimates were made at this site as part of the Assessment.
Estimated cost/ML of supply	Based on the yields estimated by the CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm estimated cost/ML of supply are reported at the following FSL: FSL 60 mEMG96 $1756/ML FSL 65 mEMG96 $1537/ML FSL 70 mEMG96 $1871/ML On the basis of these estimated costs of supply over this range of storage levels, a dam at FSL 65 mEMG96 was selected for reporting other criteria.
Summary comment	The Mary River dam site offers the second-highest yield of the options considered in the Darwin catchments. However, given the width of the site and the high costs of access and construction as well as potential impacts on the Mount Bundy military training area and the Kakadu and Mary River national parks, this site was not short-listed for further consideration.

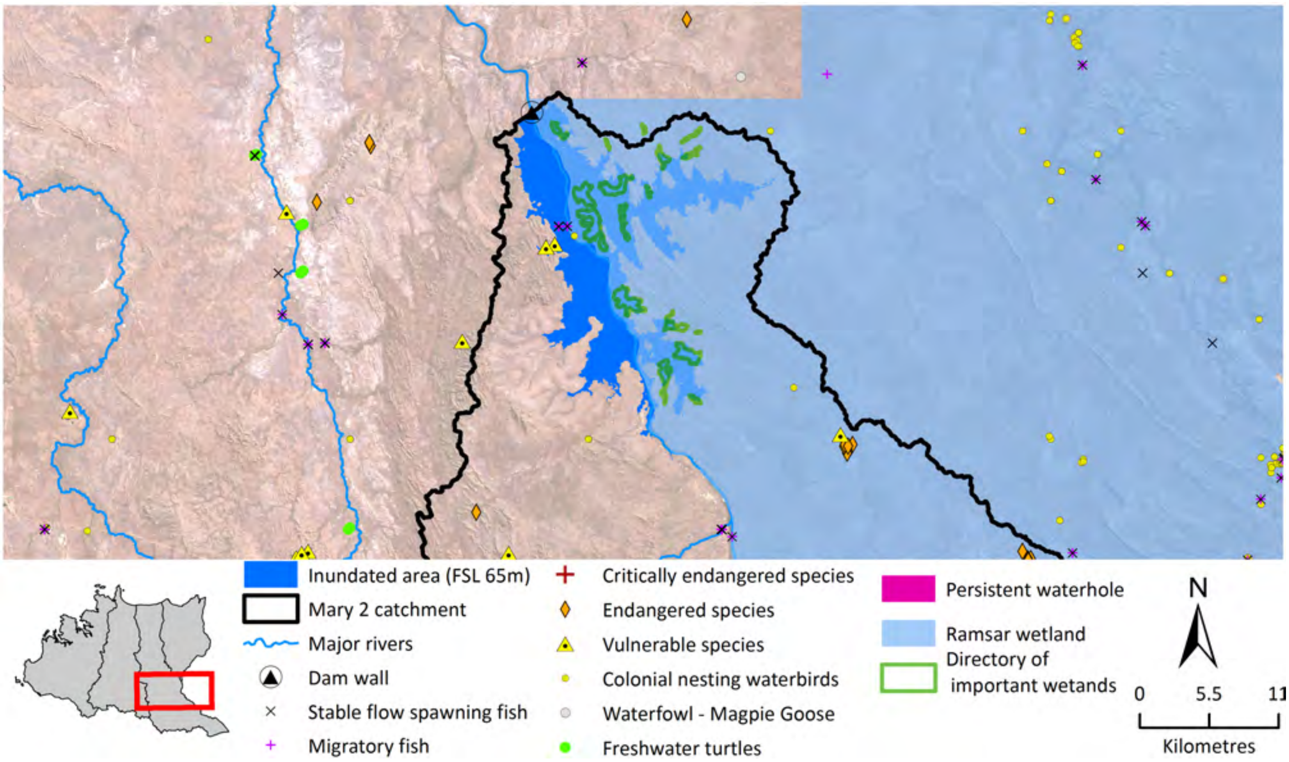
Apx Figure A-40 Location map of Mary River dam site, reservoir extent and catchment area



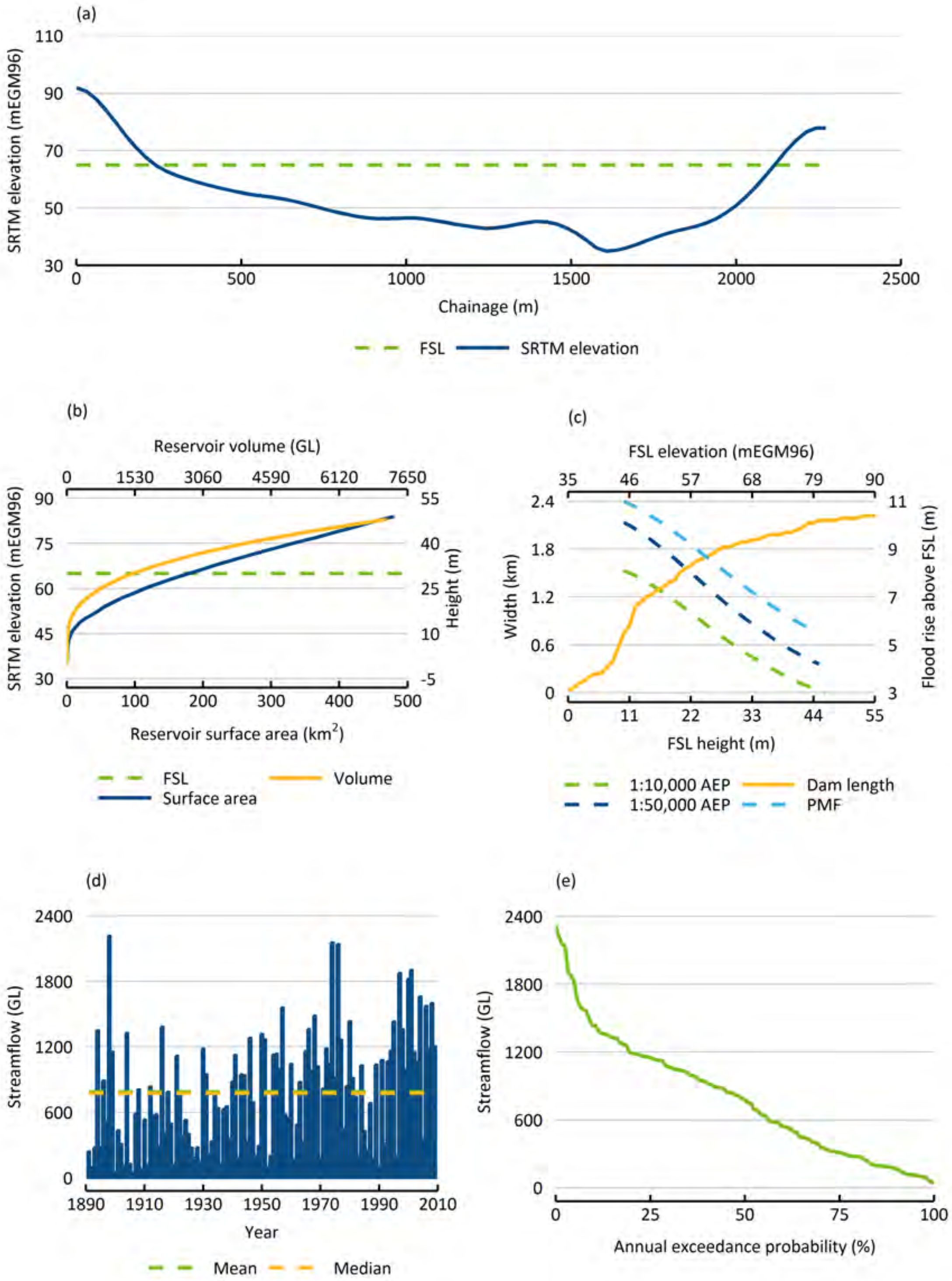
Apx Figure A-41 Mary River dam site reservoir and property boundaries



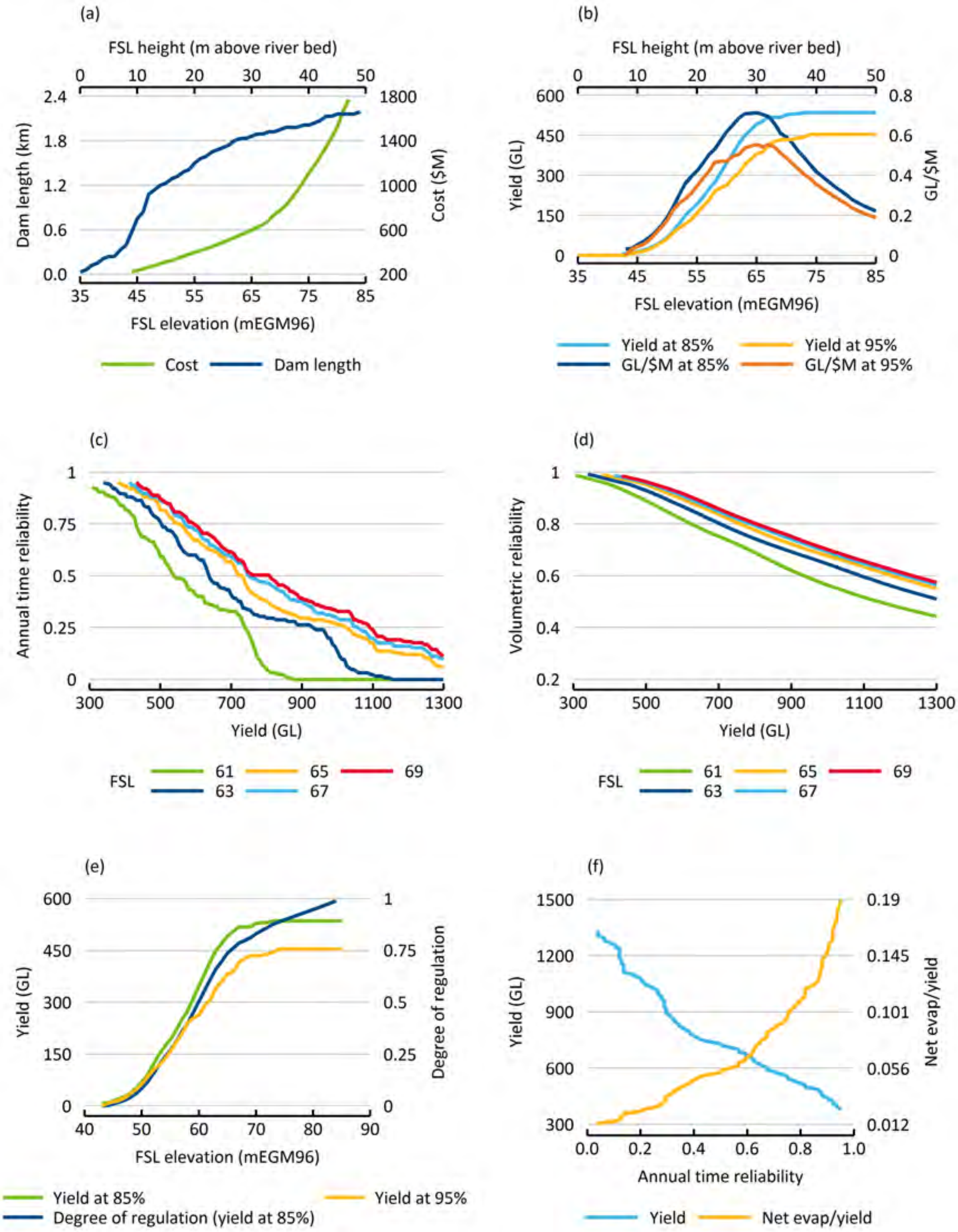
Apx Figure A-42 Geology underlying the Mary River dam site and reservoir



Apx Figure A-43 Known water-dependent ecological assets in the vicinity of the Mary River dam site

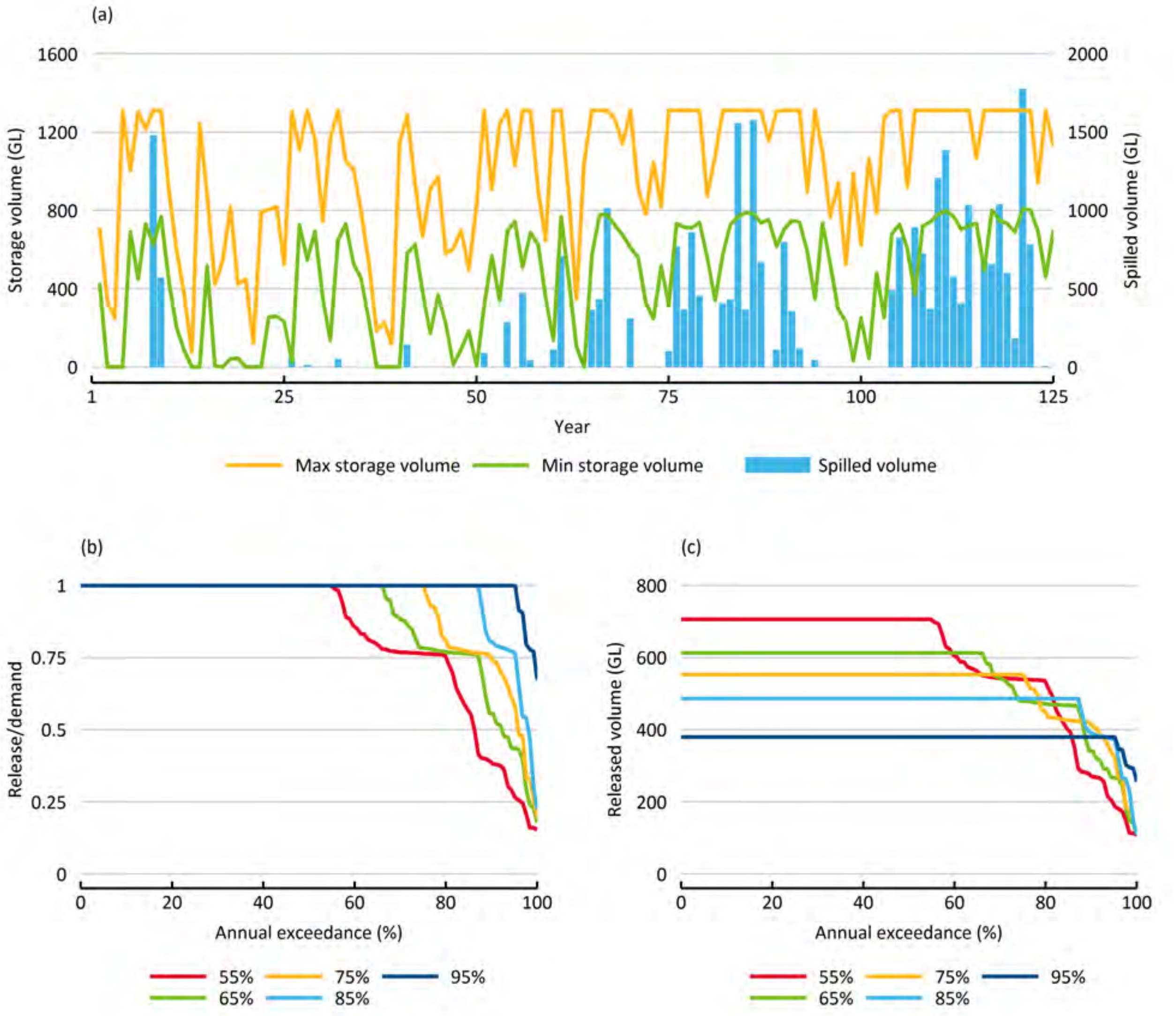


Apx Figure A-44 Mary River potential dam site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and probable maximum flood events plotted against FSL; (d) annual streamflow; (e) annual flow exceedance.



Apx Figure A-45 Mary River potential dam site cost, yield at the dam wall and evaporation

(a) Dam length and dam cost versus FSL; (b) dam yield at 85% and 95% annual time reliability and yield per $ million at 85% and 95% 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 85% and 95% 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 A-46 Mary River potential dam site storage levels and yield
(a) Maximum and minimum annual storage trace at the selected FSL (FSL, 65 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

Appendix B Non-short-listed sites in the Mitchell catchment

B.1 Non-short-listed sites in the Mitchell catchment

B.1.1 LYND UPSTREAM DAM SITE ON THE LYND RIVER; AMTD 151.9 KM

PARAMETER	DESCRIPTION
Previous investigations	There has been no previous investigation of this site. The site was identified from an initial run of the CSIRO DamSite.
Description of potential dam configuration	A potential dam at this site could supply water for irrigation development downstream. There are no known urban or mining demands that could be met by a dam at this site. **The following figures accompany this description of the site** The area in the vicinity of the potential Lynd upstream dam site is shown in Apx Figure B-1. Apx Figure B-2 provides a map showing its location in the Mitchell catchment, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Apx Figure B-3. Apx Figure B-4 and Apx Figure B-5 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Apx Figure B-6 to Apx Figure B-8.
Regional geology	The dam site and reservoir area are located in the Etheridge Province, which is part of the North Australian Craton. The Etheridge Province includes metamorphic and igneous rocks of Proterozoic age and large areas of volcanic rocks associated with large volcanic complexes of ignimbrites (welded pyroclastic flows) and lavas of Carboniferous to Permian age. According to geological maps, the dam site is underlain by volcanics (mainly rhyolitic ignimbrite and rhyolite) of the Scardons Volcanic Group, which have been uplifted and subject to long periods of weathering and erosion since they were formed. Some of the hills in the area are capped with quartzose sandstone of the Gilbert River Formation of Jurassic age. Soils over the area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on many of the slopes. The geological map indicates that faults in the volcanics trend north/south, north-east/south-west, east/west or east-southeast/west-northwest. Parts of the Lynd River and its tributaries tend to flow parallel to some of the faults indicating that the down cutting river has preferentially eroded channels along major defects in the rock mass in some places.
Site geology	The potential dam is on a west-northwest-trending section of the river. In the river channel near the dam axis there are large outcrops of pale pink and pale grey, distinctly weathered high strength ignimbrite. The valley floor at the potential dam site is about 300 m wide. The lower part of the right abutment is relatively flat but there are steeper slopes on the side of an escarpment about 300 m from the river. Most of the left abutment is also relatively flat with the steeper slopes of the escarpment about 500 m from the river. Residual soil may occur on the flatter parts of the abutments and there is probably colluvium on the escarpment slopes. According to the geological map the escarpments on both banks of the river are underlain by ignimbrite but they may be capped by near horizontal beds of sandstone of Jurassic age (above the likely full storage level). There are relatively large areas of fine to coarse-grained sand in the river channel and elsewhere in the valley floors. Sand also occurs in the river channel and valley floor upstream and downstream of the dam site. There are also some banks of gravel in the river channel.

PARAMETER	DESCRIPTION
	There are steeply dipping upstream/downstream (roughly east/west) joints in the outcrops at the dam site. There are also steep joints in other orientations and some irregular near horizontal defects. As a result of the stress relief and weathering effects in the near-surface rock mass on the steeper (escarpment) slopes on both abutments, joints and other defects are likely to be longer and more closely spaced and the near-surface rock mass is likely to be more permeable than in the less disturbed rock mass at greater depths. For initial costing purposes average foundation depths of 3 m could be assumed for the valley floor (although locally deeper excavation may be required if there is an upstream/downstream fault in the bed of the river). For initial costing purposes it is suggested that average foundation depths of 4 m could be assumed for the plinth foundations on the abutments and 2 m for the rockfill. Some of the loosened near-surface rock may be excavatable by bulldozers and excavators but drilling and blasting is likely to be required in places to reach a suitable foundation. Depending on storage level it is possible that saddle dams may be required on both banks of the reservoir. The saddle dams are likely to be underlain by volcanic rocks. The rocks are likely to be more weathered and weaker than the rocks observed at the main dam site. For initial costing purposes average foundation excavation depths of 3 m could be assumed for the core trenches of any saddle dams and 1 m for the shoulders of any saddle dams. The weathered materials may be excavatable by bulldozers or excavators to the full depths required at most of the saddle dams. The permeability and the stability of the foundations and abutments of the main dam (and saddle dams if required), and the potential for scour downstream of the spillway are largely related to the continuity and nature of the defects (e.g. faults and joints) in the rock mass, which will need to be investigated during feasibility studies but on present knowledge there is no reason for concern. It has been assumed that foundation grouting will be required for both the main dam and saddle dams.
Reservoir rim stability and leakage potential	Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. Given the lack of soluble rocks in the storage area and the lack of narrow, low, steep-sided saddles, reservoir leakage is unlikely to be a significant issue provided the dam foundations are grouted.
Potential structural arrangement	An RCC uncontrolled spillway centrally located across the main river channel with a crest level up to 51 m above bed level is proposed with retaining walls on both banks and concrete faced rockfill embankment sections on both abutments. Outlet works providing for selective withdrawal would be located on the right bank side. Access to the right bank area at the site would be from Chillagoe via the Bolwarra Road, which would need upgrading to improve alignment for some 70 km and then by a further 12 km of new road. The crossing at the Tate River would also need to be upgraded to provide improved flood immunity.
Availability of construction materials	The volcanic rocks in the area are likely to provide suitable aggregate for RCC and possibly for conventional concrete. A quarry in these rocks is also likely to be able to provide rockfill and riprap for the saddle dam and sand and aggregate suitable for the filters required in the saddle dams (if required). There is sand in the river channel near the dam site and in the river channel upstream and downstream of the dam site, which may be suitable for concrete and for filters. Cohesive earthfill for the core of saddle dams (if required) may be harder to find as natural soils in the area are relatively thin. Extremely weathered fine-grained rocks of Proterozoic age, which occur north and east of the dam site, residual soils and colluvium may provide suitable sources of core material.
Catchment area	Based on SRTM-H dataset the catchment area upstream of the dam site is estimated to be 4110 km^2.

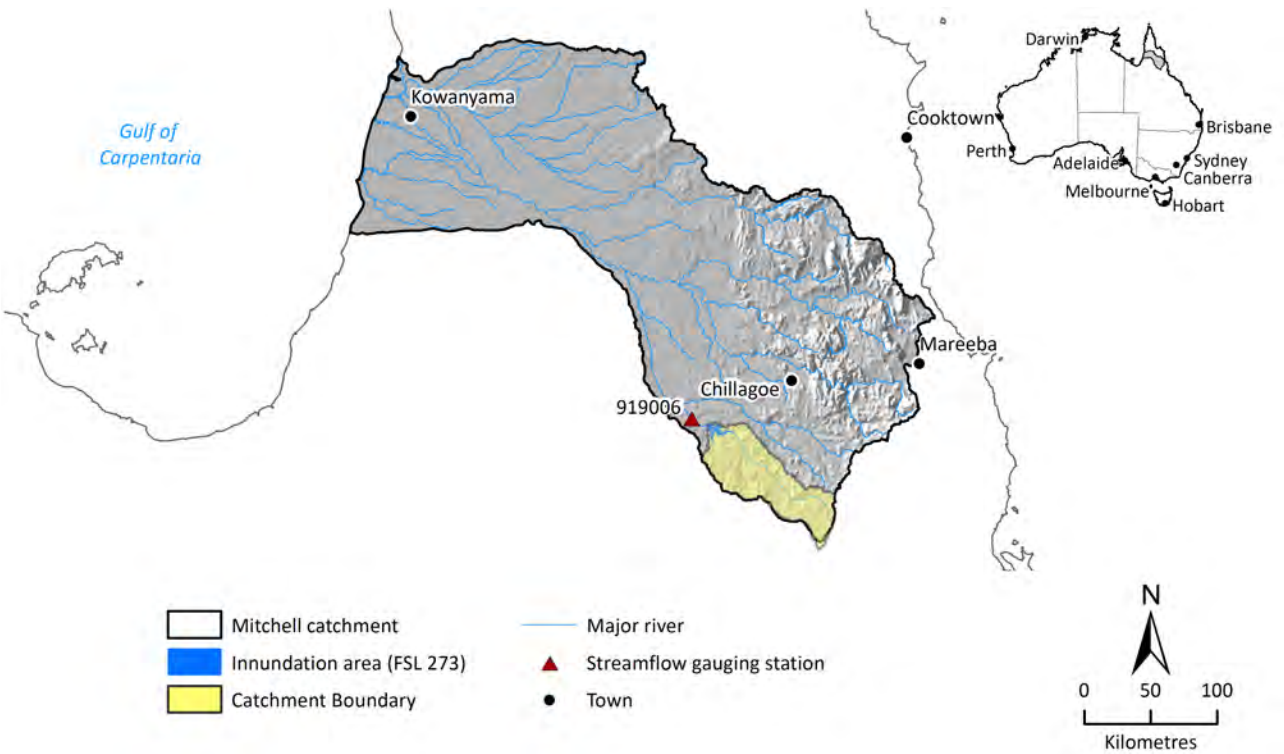
PARAMETER	DESCRIPTION
Flow data	Streamflow data are available for the Lynd River at GS 919006A, Lynd River at Torwood, AMTD 134.5 km, catchment area 4586 km^2. Data are available from 1968 until 1988. Over this period the following metrics were recorded: Maximum recorded annual flow volume 6324 GL Mean annual flow volume 939 GL Median annual flow volume 603 GL Minimum annual flow volume 44 GL
Storage capacity	Selected storage levels and reservoir capacities calculated using the SRTM-H are: FSL 273 mEMG96 Capacity 644 GL FSL 280 mEMG96 Capacity 1143 GL FSL 285 mEMG96 Capacity 1646 GL FSL 290 mEMG96 Capacity 2289 GL
Reservoir yield assessment at dam wall	FSL 273 mEMG96 Estimated yield at 85% annual time reliability 390 GL FSL 280 mEMG96 Estimated yield at 85% annual time reliability 477 GL FSL 285 mEMG96 Estimated yield at 85% annual time reliability 497 GL FSL 290 mEMG96 Estimated yield at 85% annual time reliability 520 GL
Open water evaporation	At FSL, the surface area of the storage based on SRTM-H data is estimated to be: FSL 273 mEMG96 5,722 ha FSL 280 mEMG96 8,737 ha FSL 285 mEMG96 11,404 ha FSL 290 mEMG96 14,351 ha Mean annual evaporation and mean annual net evaporation at FSL 273 mEMG96 at 85% annual reliability is 65.7 GL and 36.1 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.09.
Potential use of supply	**Agriculture** Upstream of the confluence with the Mitchell River, the Lynd River has occasionally flooded ‘narrow’ alluvial plains, which are generally deeply incised by the main channel resulting in relatively narrow plains. Soils are dominated by hard-setting clay loam surfaced brown gradational soils with strongly sodic, dispersive structured clay subsoil. These narrow plains are suitable for sugarcane and grain/forage crops, but the generally long thin units restrict irrigation layout and machinery use in most areas. Soils are likely to be suitable for ringtanks. Below the confluence of the Lynd and the Mitchell rivers, the regularly flooded ‘broad’ delta has numerous flood channels, which become more numerous and meandering closer to the coast. Soils are dominated by hard-setting clay loam surfaced brown gradational soils with strongly sodic, dispersive structured clay subsoil and hard-setting coarse structured grey cracking clay soils. Soils are suitable for sugarcane and dry-season grain and forage cropping, and likely to be suitable for ringtanks. Narrow levees, prior streams and elevated ‘old’ Tertiary-Quaternary alluvial plains have predominantly red and brown massive loamy soils suitable for a wide variety of spray-irrigated crops and horticultural crops. Soils are unlikely to be suitable for ringtanks. See companion technical report on land suitability (Thomas et al., 2018).

Estimated rates of reservoir sedimentation

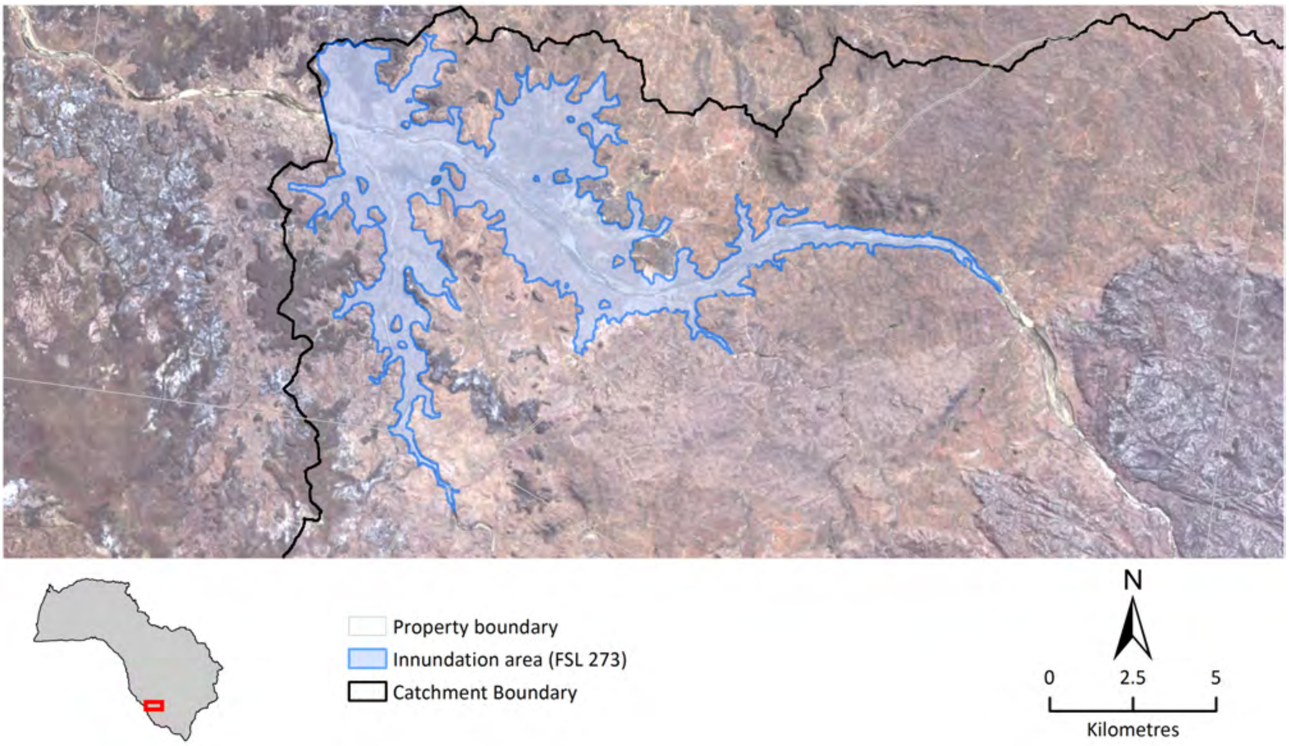
	Best case	Expected	Worst case
30 years (%)	0.1	1.0	1.7
100 years (%)	0.4	3.3	5.5
Years to fill	25,030	3,020	1,800

PARAMETER	DESCRIPTION
Storage impacts	The majority of the area that would be required lies within the Lawarra lease area 2/BW17, which has a total area of 155,000 ha. A proposed road, which would connect Georgetown in the Gilbert River Basin and Chillagoe, crosses the potential reservoir area. If a deviation were required around the upstream limit of the storage, construction of 36 km of new road would be required.
Environmental considerations	**Barrier to movement of aquatic species** A dam constructed at this site may restrict the migration, movement or colonisation of fish species such as barred grunter (*Amniataba percoides*), mouth almighty *(Glossamia aprion)*, sooty grunter (*Hephaestus fuliginosus*), spangled perch (*Leiopotherapon unicolor*), bony herring (*Nematalosa erebi)* and sleepy cod (*Oxyeleotris lineolata*). **Ecological implications of inundation** A reservoir with an FSL of 273 mEMG96 would inundate about 979 ha of threatened regional ecosystems. Four bird species of national significance have been recorded at this site, the vulnerable red goshawk (*Erythrotriorchis radiates*), and three migratory species, the rufous fantail (*Rhipidura rufifrons*), black-faced monarch (*Monarcha melanopsis*) and satin flycatcher (*Myiagra cyanoleuca*). The Chillagoe fine-lined slider (*Lerista storri*), a vulnerable reptile listed at a state level, is also found at this 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 (Pollino et al., 2018).
Estimated cost	CSIRO generated preliminary estimates of cost based on a generalised costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways and cost items for embankment type saddle dams. The costs for a selection of FSL are reported below: FSL 273 mEMG96 $750 million FSL 280 mEMG96 $993 million FSL 285 mEMG96 $1357 million FSL 290 mEMG96 $1787 million These modelled cost estimates are likely to be within –20% and +50% of the true value. If geotechnical investigations found geological complications at the site dam costs may be substantially higher. No further cost estimates at site were made as part of the Assessment.
Estimated cost/ML of supply	Based on the yields estimated by the CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm estimated cost/ML of supply are reported at the following FSL: FSL 273 mEMG96 $1921/ML FSL 280 mEMG96 $2084/ML FSL 285 mEMG96 $2730/ML FSL 290 mEMG96 $3436/ML On the basis of these estimated costs of supply over this range of storage levels, a dam at FSL 273 mEMG96 was selected for an assessment of water supply predominantly for irrigation.
Summary comment	The Lynd upstream dam site is situated in a relatively wide valley and has a high cost to yield ratio relative to the potential sites on the Walsh, Mitchell and Palmer rivers. It has a similar cost to yield ratio as the Lynd downstream site and is also similar in terms of having poor quality rock on the abutments and being remote. The site is slightly further from large contiguous areas of land suitable for irrigated agriculture than the downstream site. For these reasons the site was not short-listed.

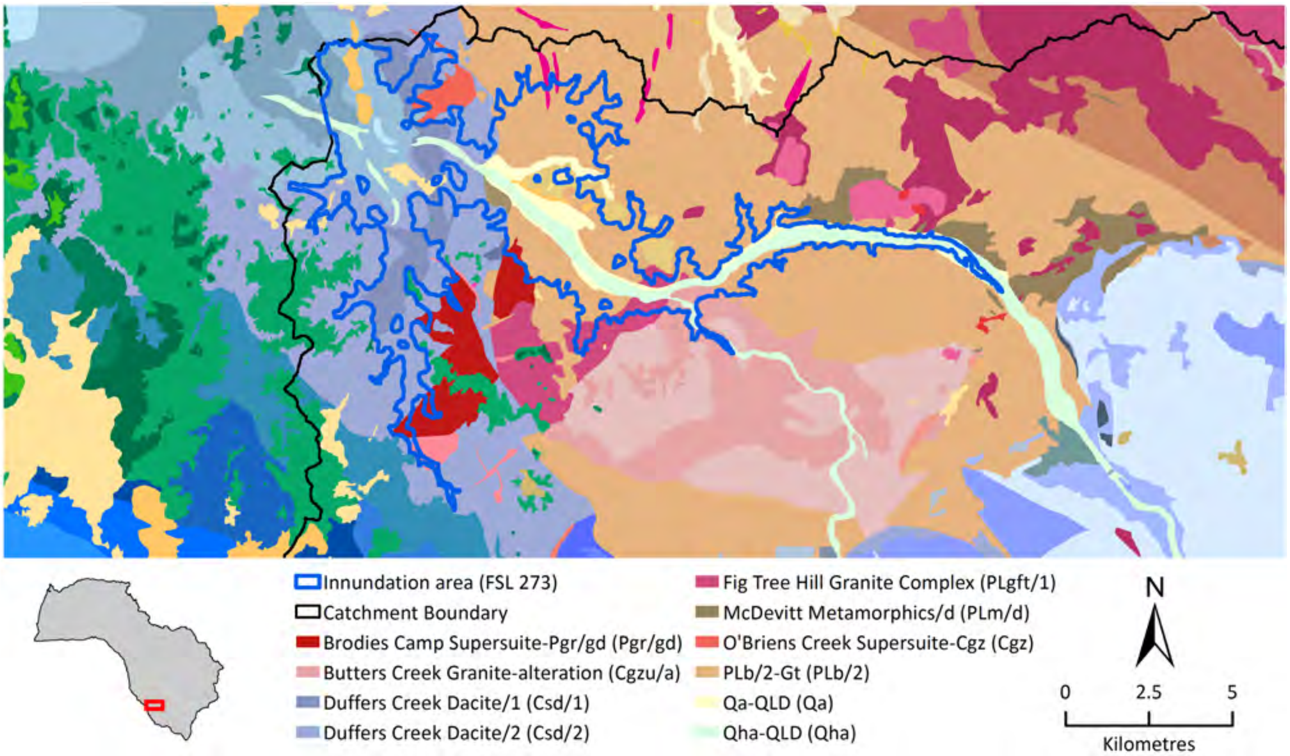
Apx Figure B-1 Lynd River in the vicinity of the Lynd River upstream dam site on the Lynd River



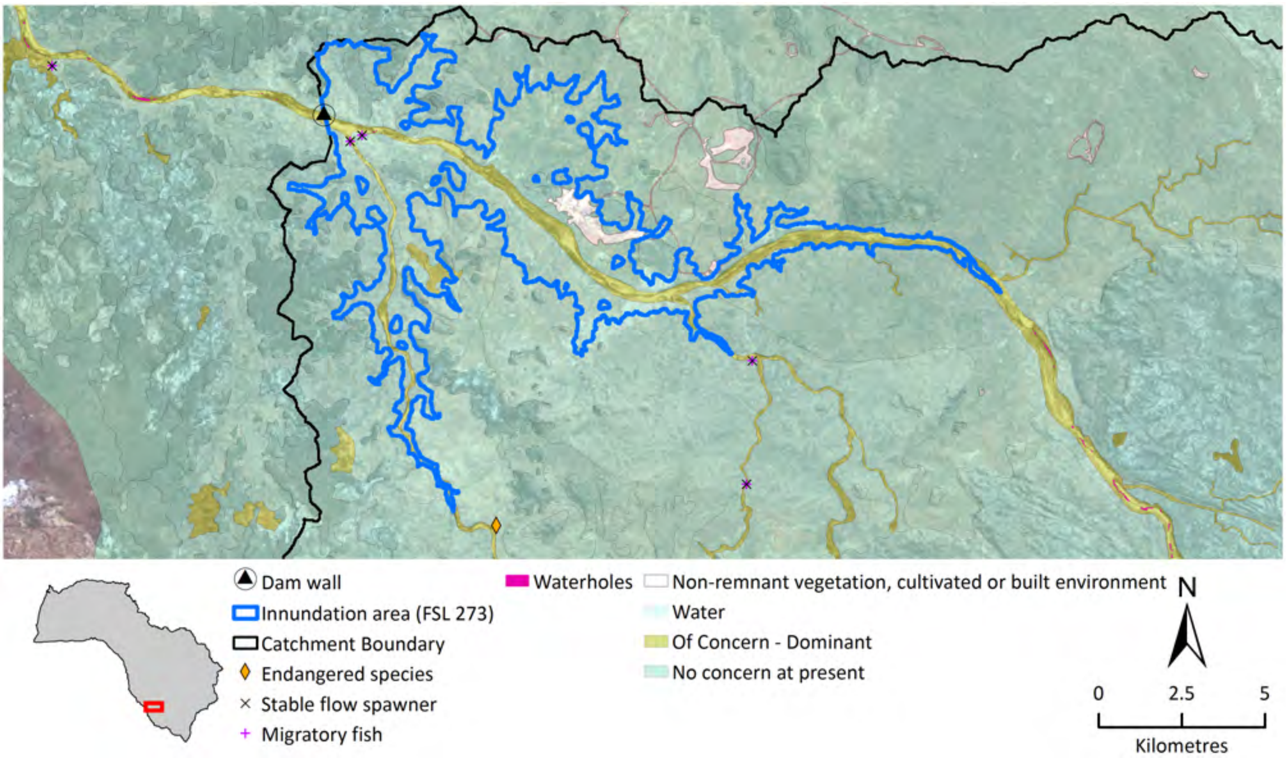
Apx Figure B-2 Location map of Lynd upstream dam site on the Lynd River, reservoir extent and catchment area



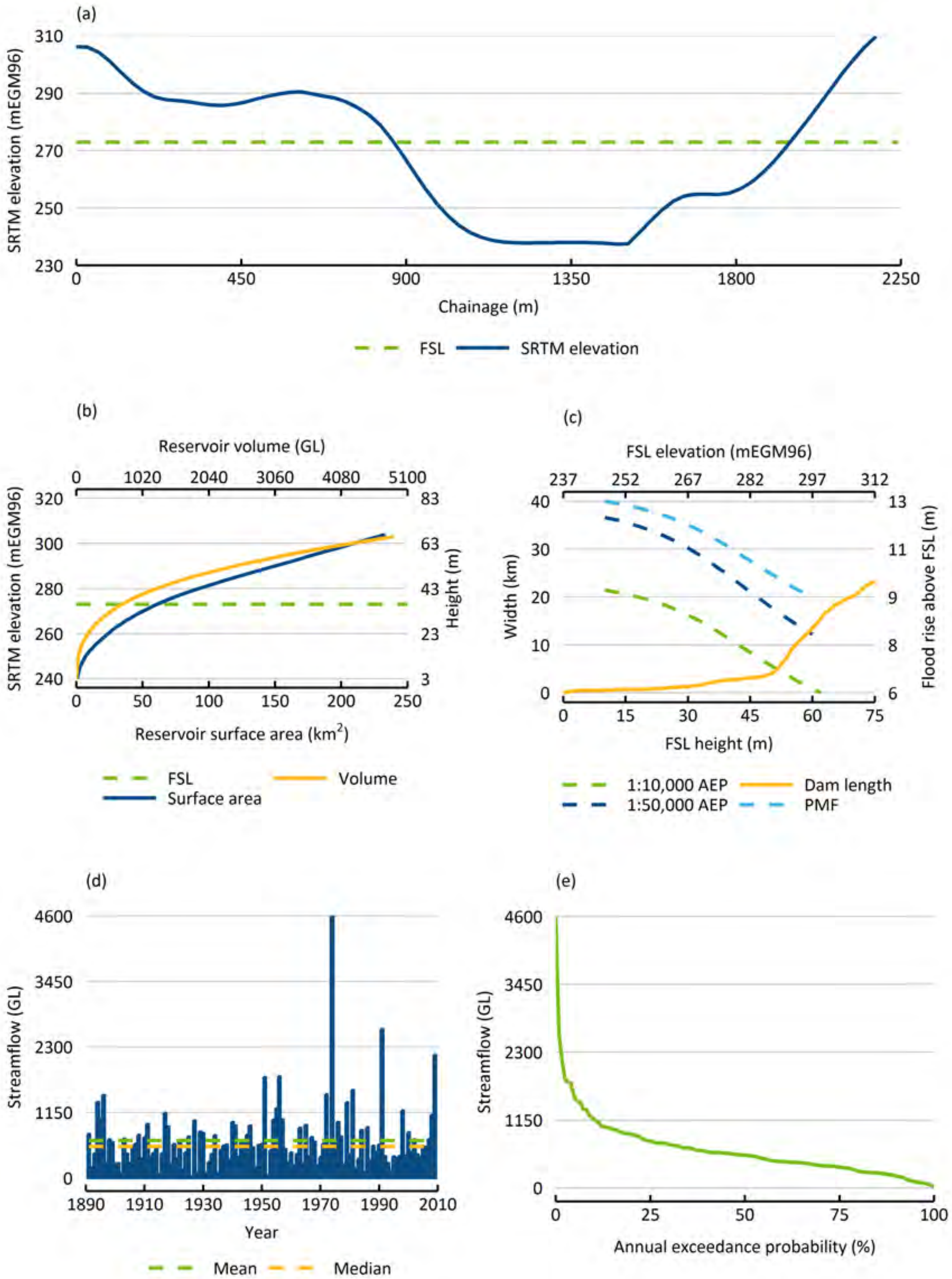
Apx Figure B-3 Lynd upstream dam site on the Lynd River reservoir and property boundaries



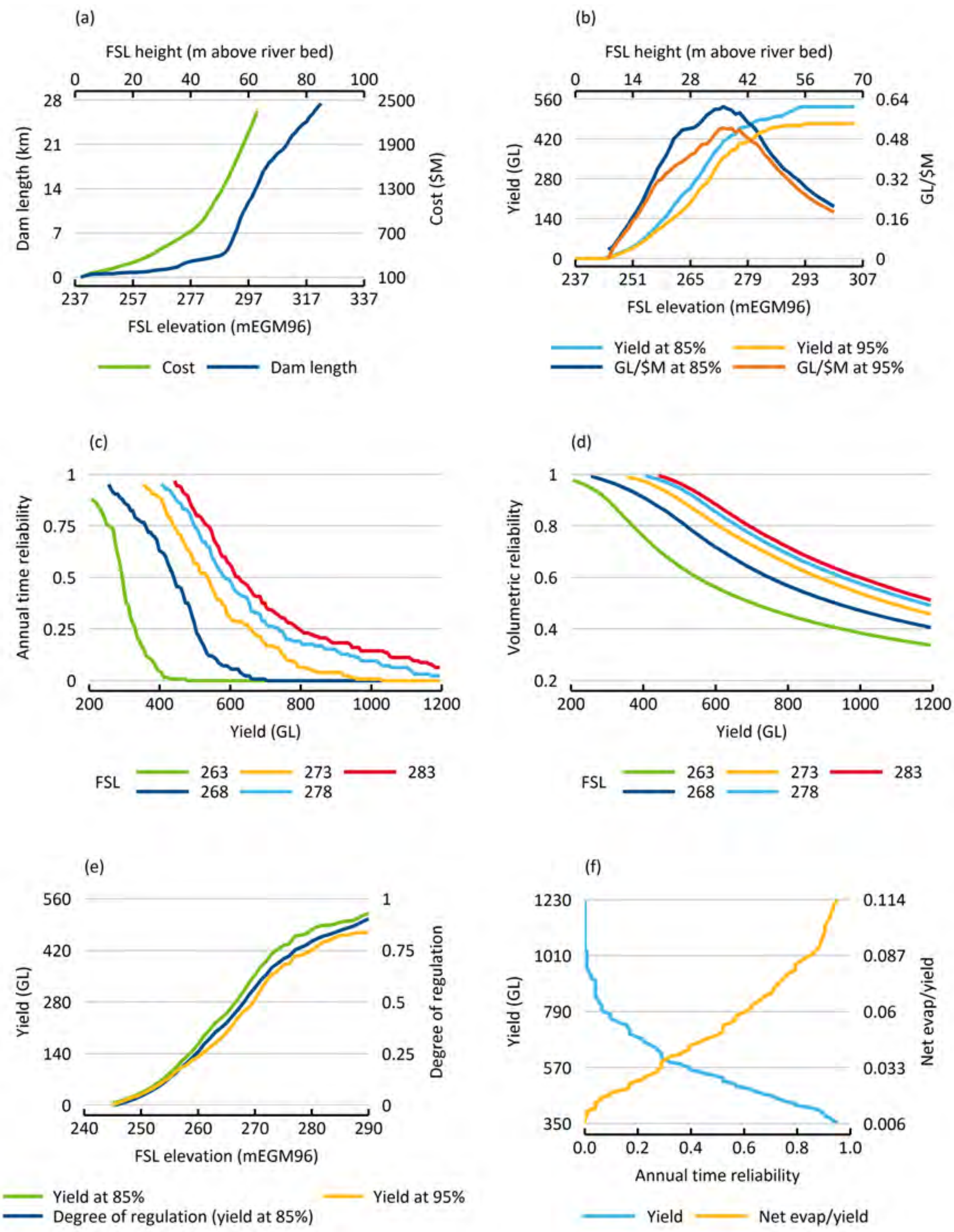
Apx Figure B-4 Geology underlying the Lynd upstream dam site on the Lynd River and reservoir



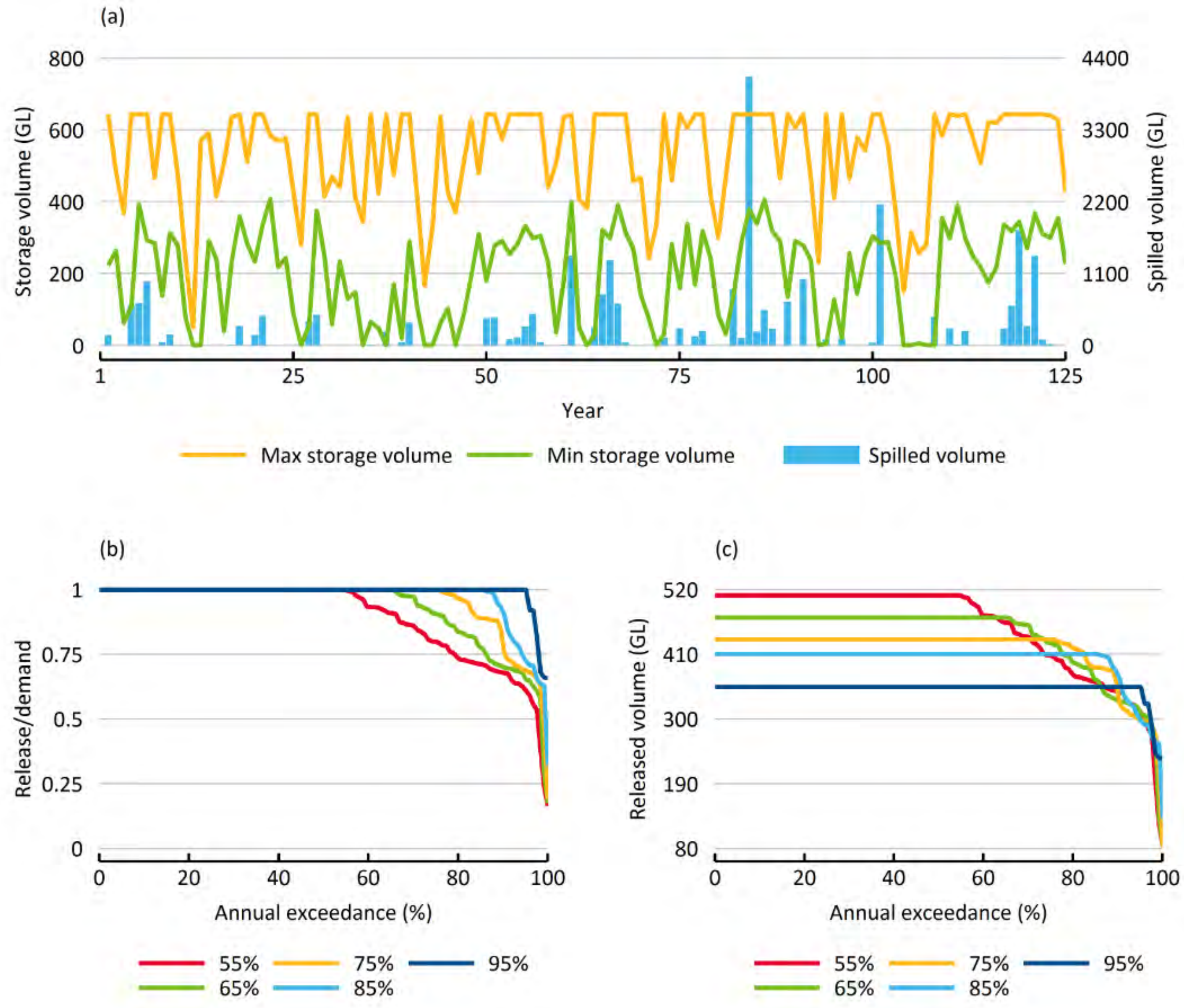
Apx Figure B-5 Regional ecosystem mapping and reservoir extent of the Lynd upstream dam site on the Lynd River and known water-dependent ecological assets



Apx Figure B-6 Lynd upstream dam site on the Lynd River 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 events plotted against FSL; (d) annual streamflow; (e) annual flow exceedance.



Apx Figure B-7 Lynd upstream dam site on the Lynd River cost, yield at the dam wall and evaporation
(a) Dam length and dam cost versus FSL; (b) dam yield at 85% and 95% annual time reliability and yield per $ million at 85% and 95% 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 85% and 95% 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-8 Lynd upstream dam site on the Lynd River storage levels and yield
(a) Maximum and minimum annual storage trace at the selected FSL (FSL, 273 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

B.1.2 LYND DOWNSTREAM DAM SITE ON THE LYND RIVER; ATMD 135.9 KM

PARAMETER	DESCRIPTION
Previous investigations	No record of any previous investigation of this site has been located. The site was identified from an initial run of the CSIRO DamSite model.
Description of potential dam configuration	A potential dam at this site could supply water for irrigation development downstream. There are no known urban or mining demands that could be met by a dam at this site. **The following figures accompany this description of the site** The Lynd River in the vicinity of the potential Lynd downstream dam site is shown in Apx Figure B-9. Apx Figure B-10 provides a map showing its location in the Mitchell catchment, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Apx Figure B-11. Apx Figure B-12 and Apx Figure B-13 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Apx Figure B-14 to Apx Figure B-16.
Regional geology	The potential dam site and reservoir area are located in the Etheridge Province, which is part of the North Australian Craton. The Etheridge Province includes metamorphic and igneous rocks of Proterozoic age and large areas of volcanic rocks associated with large volcanic complexes of ignimbrites (welded pyroclastic flows) and lavas of Carboniferous to Permian age. Both the older igneous and metamorphic rocks and the younger volcanic have been uplifted and subject to long periods of weathering and erosion since they were formed. In places in the Etheridge Province the older metamorphic rocks and the volcanics are overlain by near horizontal sedimentary rocks of Jurassic age associated with the Carpentaria Basin (which is part of the Great Artesian Basin). The potential dam site is located near the upstream end of a gorge cut through near horizontal sandstone of Jurassic age (the Gilbert River Formation) into the underlying volcanics (mainly rhyolitic ignimbrite and rhyolite) of the Scardons Volcanic Group. Soils over the area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on many of the slopes. The geological map indicates that faults in the volcanics trend north/south, north-east/south-west, east/west or east-southeast/west-northwest. Parts of the Lynd River and its tributaries tend to flow parallel to some of the faults indicating that the down cutting river has preferentially eroded channels along major defects in the rock mass in some places.
Site geology	The potential dam is on a north-west-trending section of the river. At the base of the right abutment upstream of the dam axis there are outcrops of pale pink and pale grey, distinctly weathered high strength ignimbrite. The valley floor at the potential dam site is about 250 m wide. The abutments are about 50 m high. The upper parts of both abutments consist of cliffs of sandstone. Colluvium, including sandstone boulders, occurs on the lower slopes of both abutments. According to the geological map the lower part of the left abutment and the valley floor are likely to be underlain by ignimbrite. There are relatively large areas of fine to coarse-grained sand in the river channel and elsewhere in the valley floors. The depth of sand above the underlying ignimbrite at the dam axis is not known but the geological map and the pattern of outcrop (e.g. at the base of the left bank upstream and outcrops in the valley floor further upstream) imply that the rock is probably at a progressively shallower depth further upstream of the proposed dam axis. The main defects in the sandstone exposed in the abutments are near horizontal bedding partings and two sets of near vertical joints (upstream/downstream and cross-valley). These defects divide the rock mass into roughly equidimensional or tabular blocks. Some of the steep joints were observed to be open. As a result of the stress relief and weathering effects in the near-surface rock mass on the steeper (escarpment) slopes on both abutments, joints and other defects are likely to be longer and more closely spaced and the near-surface rock mass is likely to be more permeable than in the less disturbed rock mass at greater depths. Based on the geological history and observations of the ignimbrite elsewhere in the area there are likely to be several sets of defects (including joints and faults) in the ignimbrite below the valley floor. The unconformity between the ignimbrite and the overlying sandstone was not directly observed but it is likely to be irregular and may include old channels which have a

PARAMETER	DESCRIPTION
	relatively high permeability. The nature of this unconformity would need to be investigated in feasibility and design stage studies for a dam at this site. For initial costing purposes average foundation depths of 8 m could be assumed for the valley floor (although locally deeper excavation may be required if there is an upstream/downstream fault in ignimbrite below the bed of the river) and that average foundation depths of 5 m could be assumed for the abutments. Care will have to be taken to ensure that all highly loosened open jointed rock in the abutment foundations is removed. Some of the loosened near-surface rock may be excavatable by bulldozers and excavators but drilling and blasting are likely to be required in places to reach a suitable foundation. The permeability and the stability of the foundations and abutments of the main dam (and saddle dams if required), and the potential for scour downstream of the spillway are largely related to the continuity and nature of the defects (e.g. faults and joints) in the rock mass, which would need to be investigated during feasibility studies. As discussed below the unconformity between the sandstone and the underlying ignimbrite is a possible source of leakage through the abutments. It has been assumed that foundation grouting will be required for dam.
Reservoir rim stability and leakage potential	Given the relatively subdued topography and the lack pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. It is possible that there could be seepage losses associated with the unconformity between the sandstone and the underlying volcanic rocks. This would have to be thoroughly investigated during further studies if this site were to be investigated further.
Potential structural arrangement	An RCC type dam including a central uncontrolled spillway with crest level up to 41 m above bed level is proposed across the river channel. An earth and rockfill embankment is required on the lower right bank side for the higher storage level options. Outlet works with selective withdrawal capability would be installed on the right bank side. Access to the right bank area at the site would be from Chillagoe via the Bolwarra Road, which would need upgrading to improve alignment for some 75 km and then by a further 22 km of new road required to replace a section of the Bolwarra Road that would be inundated by the storage. The crossing at the Tate River would also need to be upgraded to provide improved flood immunity.
Availability of construction materials	The volcanic rocks (mainly ignimbrite and rhyolite) in the area are likely to provide suitable aggregate for roller compacted concrete and possibly for conventional concrete. A quarry in these rocks is also likely to be able to provide rockfill and riprap for the saddle dam and sand and aggregate suitable for the filters required in the saddle dams (if required). There is sand in the river channel which may be suitable for concrete.
Catchment area	Based on SRTM-H data, the catchment area upstream of the dam axis is estimated to be 4554 km^2.
Flow data	Streamflow data are available for the Lynd River at GS 919006A, Lynd River at Torwood, AMTD 134.5 km, catchment area 4,586 km^2. Data are available from 1968 until 1988. Over this period: Maximum recorded annual flow volume 6324 GL Mean annual flow volume 939 GL Median annual flow volume 603 GL Minimum annual flow volume 44 GL
Storage capacity	Based on SRTM data, storage levels and capacities have been considered as follows: FSL 244 mEMG96 Capacity 352 GL FSL 246 mEMG96 Capacity 438 GL FSL 248 mEMG96 Capacity 542 GL FSL 252 mEMG96 Capacity 810 GL
Reservoir yield at dam wall	FSL 244 mEMG96 Estimated yield at 85% annual time reliability 306 GL FSL 246 mEMG96 Estimated yield at 85% annual time reliability 352 GL FSL 248 mEMG96 Estimated yield at 85% annual time reliability 406 GL FSL 252 mEMG96 Estimated yield at 85% annual time reliability 507 GL

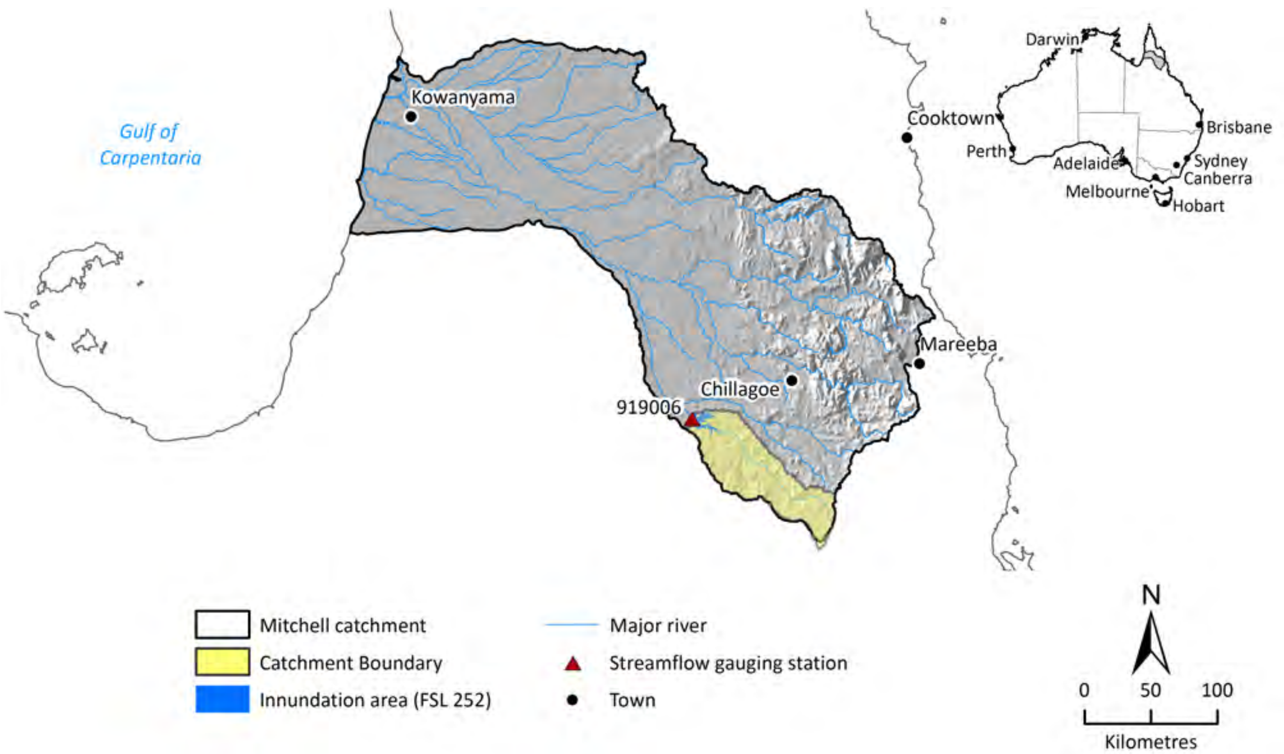
PARAMETER	DESCRIPTION
Open water evaporation	At FSL, the surface area of the storage based on SRTM data is estimated to be: FSL 244 mEMG96 3937 ha FSL 246 mEMG96 4732 ha FSL 248 mEMG96 5675 ha FSL 252 mEMG96 7781 ha Mean annual evaporation and mean annual net evaporation at FSL 252 mEMG96 at 85% annual reliability is 83.7 GL and 46.8 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.10.
Potential use of supply	**Agriculture** Upstream of the confluence with the Mitchell River, the Lynd River has occasionally flooded 'narrow' alluvial plains, which are generally deeply incised by the main channel resulting in relatively narrow plains. Soils are dominated by hard-setting clay loam surfaced brown gradational soils with strongly sodic, dispersive structured clay subsoil. These narrow plains are suitable for sugarcane and grain/forage crops, but the generally long thin units restrict irrigation layout and machinery use in most areas. Soils are likely to be suitable for ringtanks. Below the confluence of the Lynd and the Mitchell rivers, the regularly flooded 'broad' delta has numerous flood channels, which become more numerous and meandering closer to the coast. Soils are dominated by hard-setting clay loam surfaced brown gradational soils with strongly sodic, dispersive structured clay subsoil and hard-setting coarse structured grey cracking clay soils. Soils are suitable for sugarcane and dry-season grain and forage cropping, and likely to be suitable for ringtanks. Narrow levees, prior streams and elevated 'old' Tertiary-Quaternary alluvial plains have predominantly red and brown massive loamy soils suitable for a wide variety of spray-irrigated crops and horticultural crops. Soils are unlikely to be suitable for ringtanks. See companion technical report on land suitability (Thomas et al., 2018).
Estimated rates of reservoir sedimentation	(see table below)
Storage impacts	A storage developed to FSL 252 mEMG96 will inundate approximately 25 km of the Lynd River bed. The majority of the land that would be required is within the Lawarra lease area 2/BW17, total area 155,000 ha. The balance of the land required is within the Torwood lease area 5309/PH1681, total area 139,000 ha. As above, a section of the Bolwarra Road would be inundated by a storage at this site. A new relocated road 22 km in length around the northern side of the storage is proposed.
Environmental considerations	**Barrier to movement of aquatic species** A dam constructed at this site could affect the migration, movement or colonisation of fish species, particularly stable flow spawners such as the barred grunter (*Amniataba percoides*), flyspecked (*Craterocephalus stercusmuscarum stercusmuscarum)*, mouth almighty *(Glossamia aprion)*, sooty grunter (*Hephaestus fuliginosus*), spangled perch (*Leiopotherapon unicolor*), bony herring (*Nematalosa erebi)*, black catfish (*Neosilurus ater*), rainbowfish (*Melanotaenia splendida inornata* and *Melanotaenia* sp.), freshwater longtom (*Strongylura krefftii*), Hyrtl's catfish (*Neosilurus hyrtlii*) and the largetooth sawfish (*Pristis microdon*). The largetooth sawfish is listed as vulnerable in the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) and in the *Nature Conservation Act 1992* (Qld). **Ecological implications of inundation** About 26% (2515 ha) of threatened regional ecosystems would be inundated at an FSL of 252m. No listed species are recorded as occurring within the potential inundated area. However, this dam site presents records for red goshawk (*Erythrotriorchis radiates*), a species of national significance listed as vulnerable and also considered as endangered under the

Estimated rates of reservoir sedimentation:

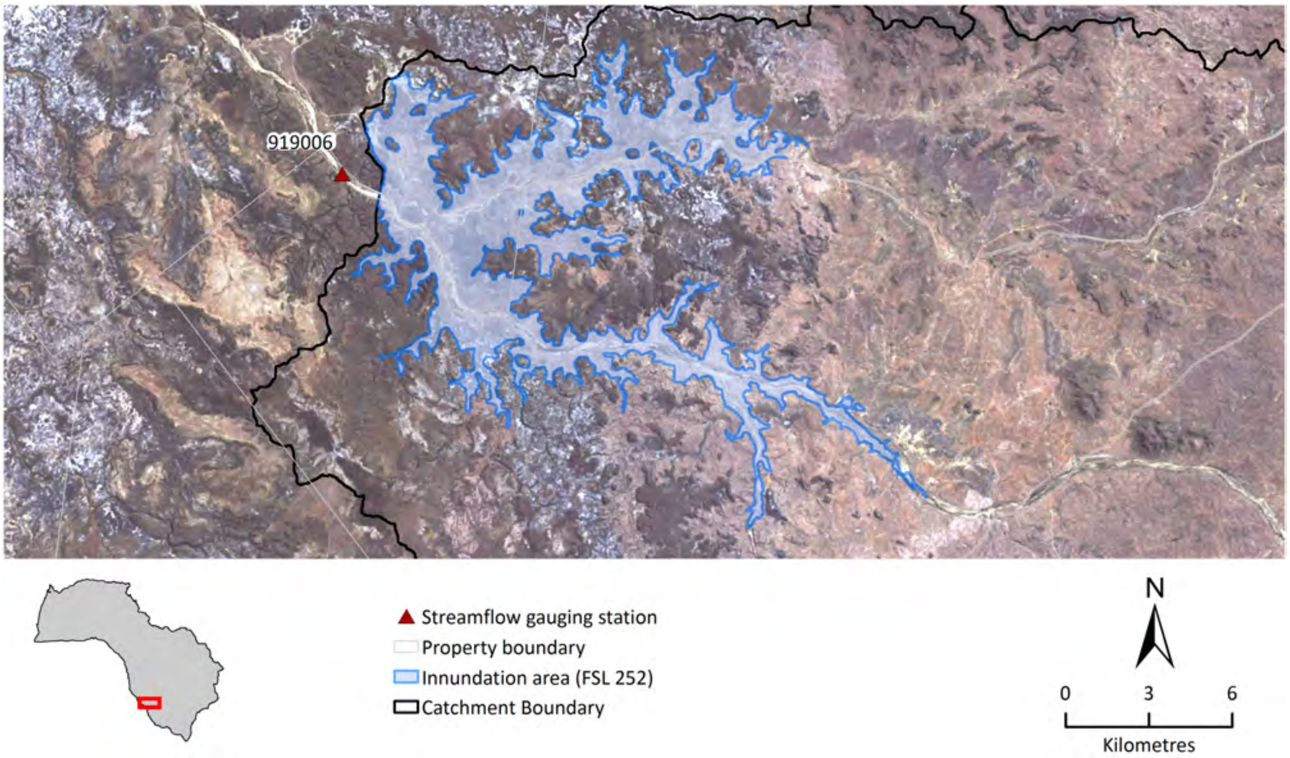
	Best case	Expected	Worst case
30 years (%)	0.1	0.9	1.5
100 years (%)	0.4	3.0	5.0
Years to fill	27,540	3,330	1,980

PARAMETER	DESCRIPTION
	Nature Conservation Act 1992 (Qld). The Chillagoe fine-lined slider (*Lerista storri*), a vulnerable reptile listed at a state level, is also found here. The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).
Estimated cost	CSIRO generated preliminary estimates of cost based on a generalised costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways and cost items for embankment type saddle dams. The costs for a selection of FSL are reported below: FSL 244 mEMG96 $512 million FSL 246 mEMG96 $559 million FSL 248 mEMG96 $611 million FSL 252 mEMG96 $731 million These modelled costs estimates are likely to be within –20% and +50% of the true value. If geotechnical investigations found geological complications at the site dam costs may be substantially higher. No further cost estimates were made at this site as part of the Assessment.
Estimated cost/ML of supply	Based on the yields estimated by the CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm estimated cost/ML of supply are reported at the following FSL: FSL 244 mEMG96 $1672/ML FSL 246 mEMG96 $1587/ML FSL 248 mEMG96 $1505/ML FSL 252 mEMG96 $1442/ML On the basis of these estimated costs of supply over this range of storage levels, a dam at FSL 252 mEMG96 was selected for an assessment of irrigation.
Summary comment	The Lynd downstream dam site is remote and is situated in a relatively wide valley and has poor quality rock on the abutments. Compared to potential sites on the Walsh, Mitchell and Palmer rivers the site has a high cost to yield ratio. The nearest large continuous areas of land suitable for irrigated agriculture occur below the junction of the Mitchell and Lynd rivers. For these reasons the site was not short-listed.

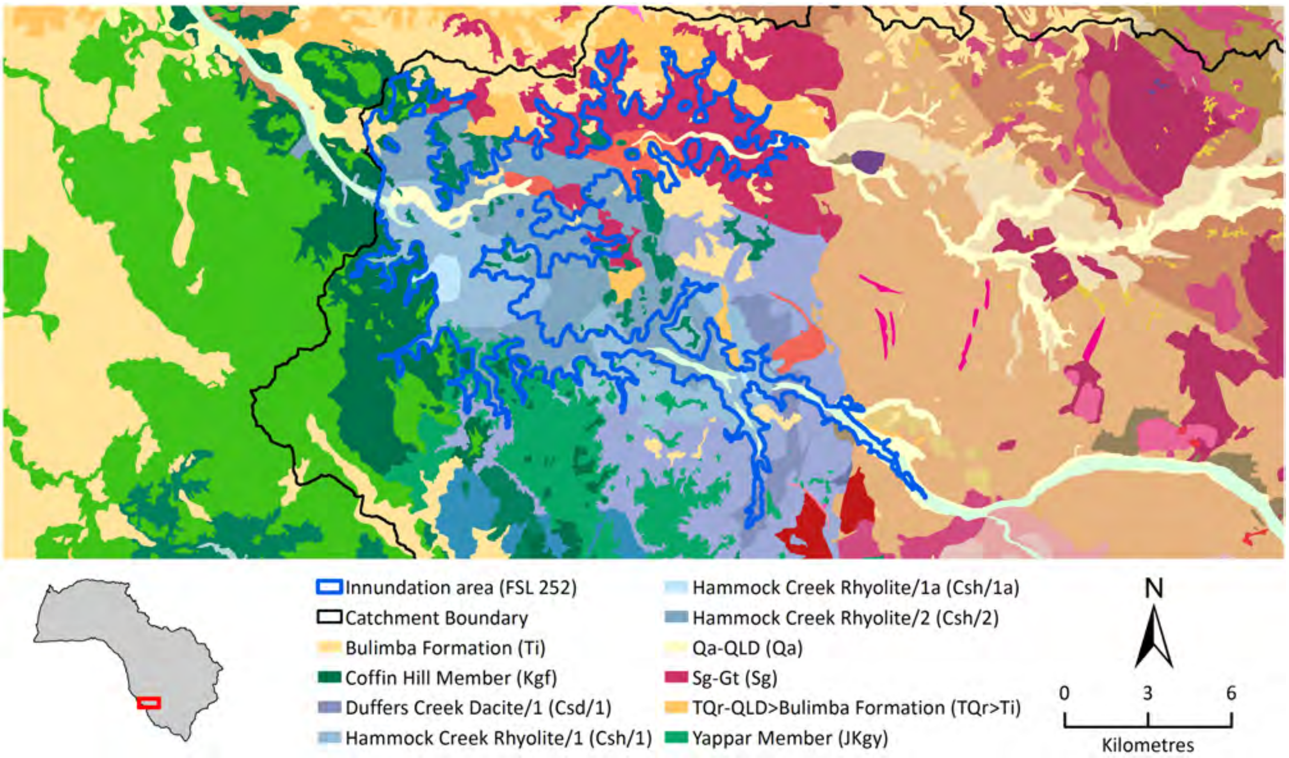
Apx Figure B-9 Lynd River downstream dam site on the Lynd River looking upstream



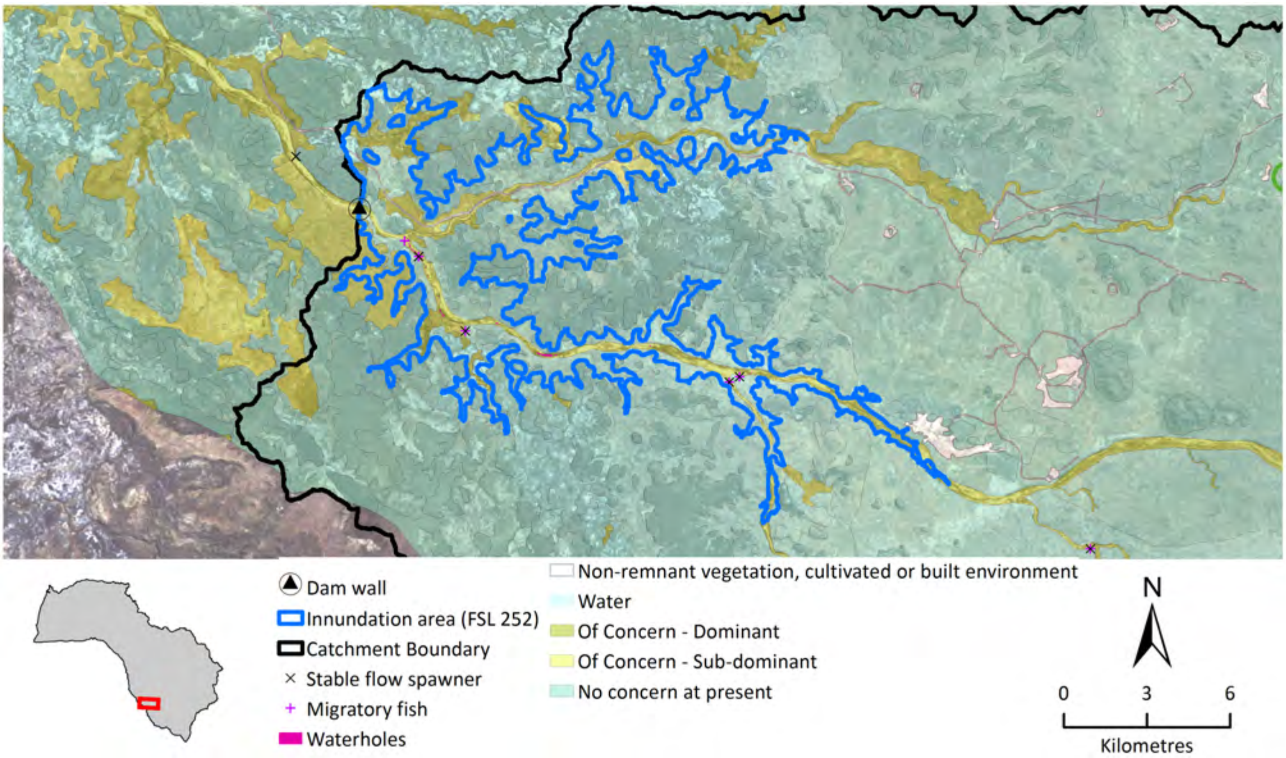
Apx Figure B-10 Location map of Lynd downstream dam site on the Lynd River, reservoir extent and catchment area



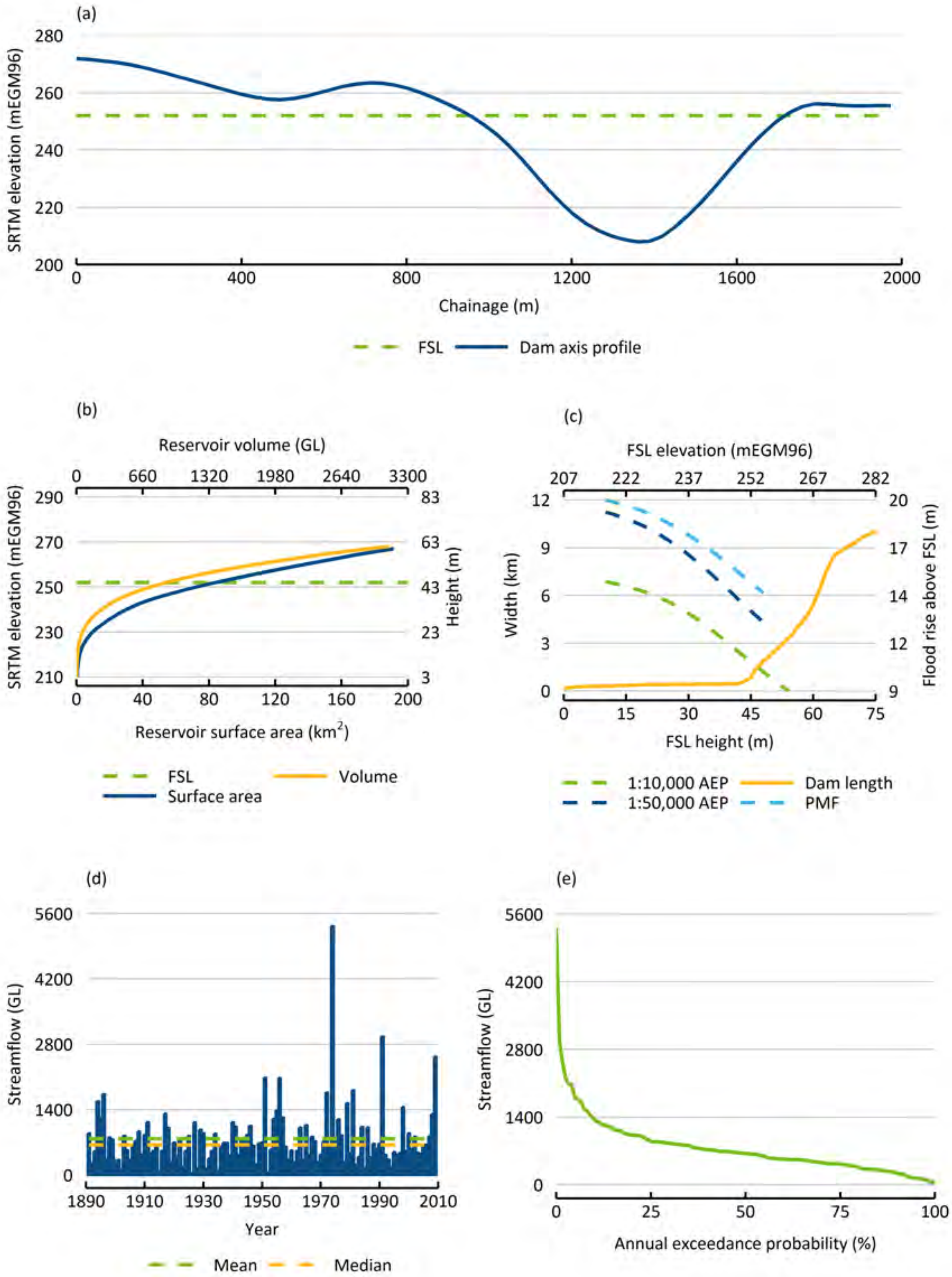
Apx Figure B-11 Lynd downstream dam site on the Lynd River reservoir extent and property boundaries



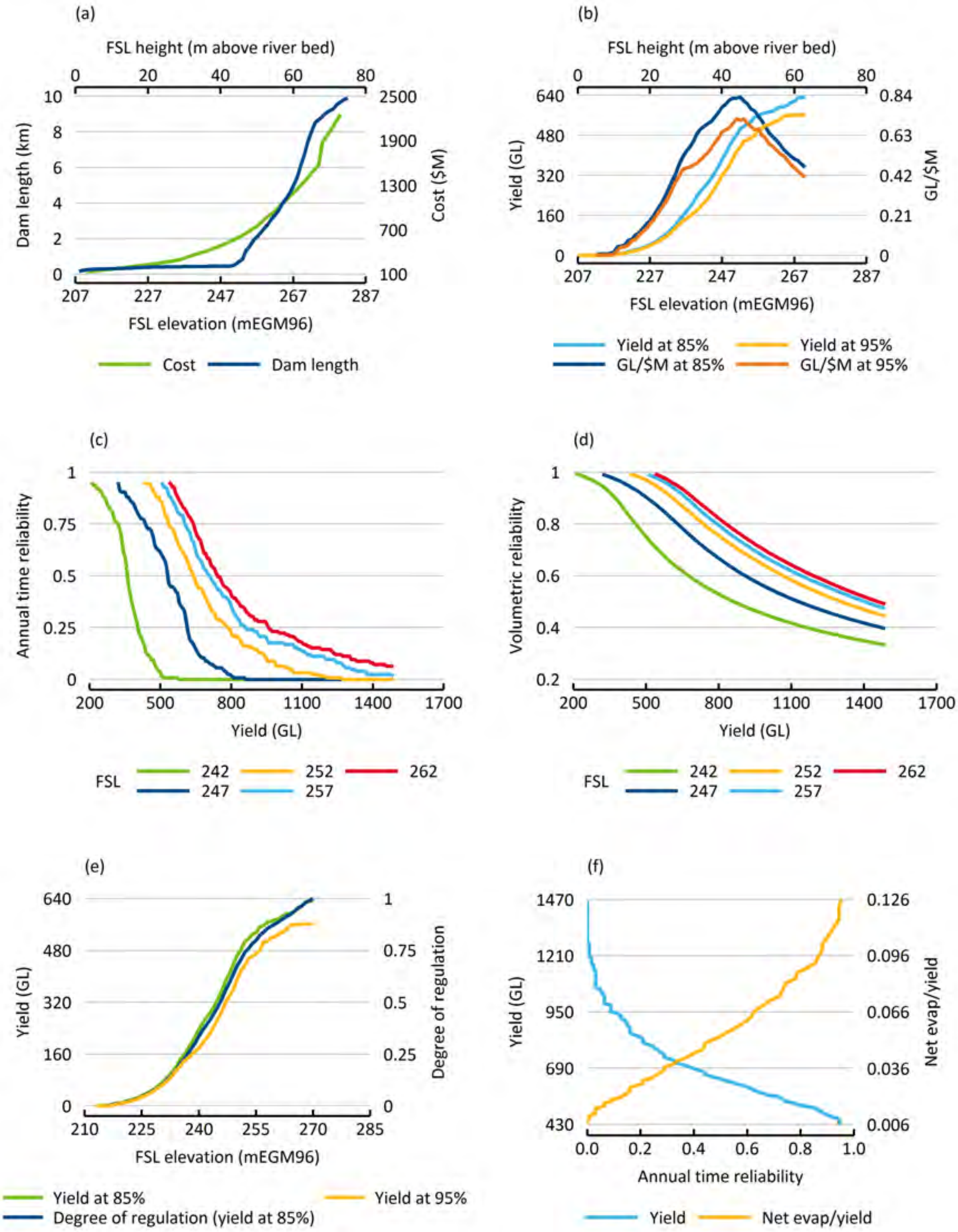
Apx Figure B-12 Geology underlying the Lynd downstream dam site on the Lynd River and reservoir



Apx Figure B-13 Regional ecosystem mapping and reservoir extent of the Lynd downstream dam site on the Lynd River and known water-dependent ecological assets

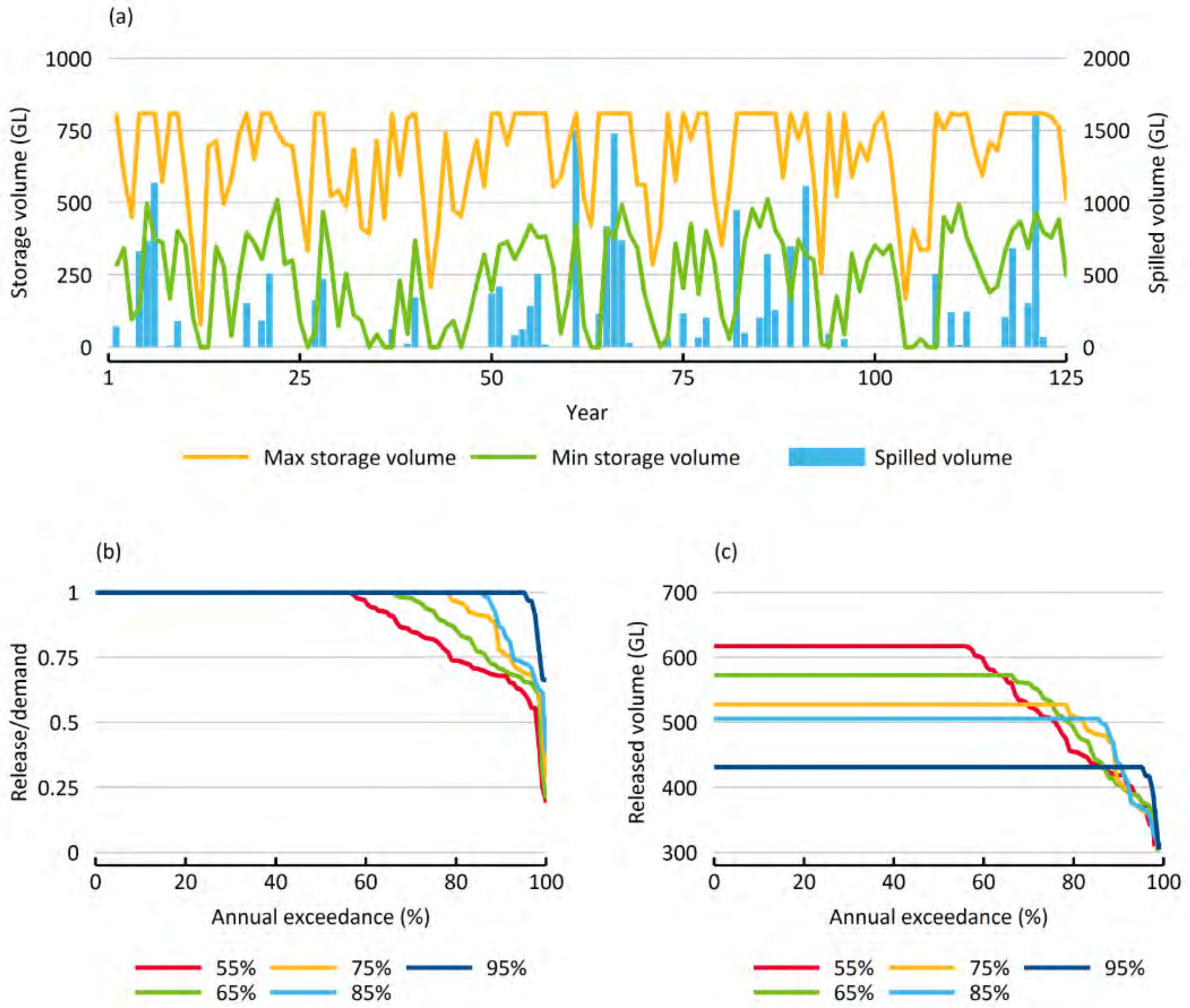


Apx Figure B-14 Lynd downstream dam site on the Lynd River site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and probable maximum flood events plotted against FSL; (d) annual streamflow; (e) annual flow exceedance.



Apx Figure B-15 Lynd downstream dam site on the Lynd River cost, yield at the dam wall and evaporation

(a) Dam length and dam cost versus FSL; (b) dam yield at 85% and 95% annual time reliability and yield per $ million at 85% and 95% 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 85% and 95% 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-16 Lynd downstream dam site on the Lynd River storage levels and yield
(a) Maximum and minimum annual storage trace at the selected FSL (FSL, 252 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

B.1.3 PALMER RIVER DAM SITE ON THE PALMER RIVER; AMTD 121.2 KM

PARAMETER	DESCRIPTION
Previous investigations	There has been no previous investigation of this site. The site was identified from an initial run of the CSIRO DamSite model.
Description of potential dam configuration	A potential dam at this site could potentially provide a water supply for irrigation development downstream. There are no known urban or mining demands that could be met by a dam at this site. **The following figures accompany this description of the site** The potential Palmer River dam site is depicted in Apx Figure B-17. Apx Figure B-18 provides a map showing its location in the Mitchell catchment, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Apx Figure B-19. Apx Figure B-20 and Apx Figure B-21 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Apx Figure B-22 to Apx Figure B-24.
Regional geology	The potential dam site and reservoir area are located in an area of folded and faulted sedimentary, metamorphic and igneous rocks of the Hodgkinson Province of mainly Ordovician to Devonian ages, which is part of the Mossman Orogen. The potential dam site and lower part of the reservoir is in the Chillagoe Subprovince, which is a narrow strip of folded and faulted rocks (including limestone) that crop out next to the Palmerville Fault along the western boundary of the Hodgkinsom Province. According to geological maps, limestone beds striking approximately north/south occur in the storage area within 3 km of the dam. The rocks in the Hodgkinson Province and the Chillagoe Subprovince have been intruded by granite, faulted, uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the project area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on many of the slopes. Bedding (and foliation in the metamorphic rocks) in the area tends to strike north/south (or north-northwest/south-southeast) and dip steeply west or east. There are major faults trending north/south to north-northwest/south-southeast in the area. The Palmerville Fault, which is a major regional fault, is about 4 km downstream of the proposed dam site. There are also east/west and northwest/southeast-trending lineaments in the project area, which are probably associated with joints or smaller faults. Parts of the Palmer River and its tributaries tend to flow parallel to the faults and lineaments, indicating that the down cutting river has preferentially eroded channels along major defects in the rock mass in some places.
Site geology	The potential dam site is on a west-trending section of the river where it cuts through a ridge of rocks belonging to the Mulgrave Formation of Ordovician age. According to geological maps, the Mulgrave Formation consists of mainly thin to medium bedded quartzose arenite with minor mudstone, siltstone, shale and chert. Outcrops of pale grey fresh to slightly weathered, very-high strength fine-grained arenite were observed in the valley floor. In the outcrops of arenite observed at the base of the left abutment the rock was pale brown, distinctly weathered and of high strength. The valley floor at the potential dam site is about 150 m wide. The right abutment is steeper and higher than the left abutment, which has gentler and more rounded slopes. The right abutment is covered in vegetation but outcrops are visible on the very steep lower slopes of the abutment. There are fewer outcrops on the left abutment and the gentler rounded slopes of the abutment and the ridge where there would need to be a saddle dam suggest that the rocks may be deeply weathered and may be overlain by more residual soil and colluvium than on the right abutment and right bank ridge. There are outcrops in the river bed and elsewhere on the valley floor. There are isolated (probably shallow) pockets of well graded fine to coarse-grained sand in places in the river channel and elsewhere on the valley floor near the dam axis. There are longer and wider deposits of sand in the channel and valley floor in places upstream and downstream of the dam but most of these deposits are also likely to be shallow. The most prominent defects observed at the site were bedding partings. The rocks are folded but tend to strike close to north/south and dip steeply (60° to 90°) upstream or downstream. Steeply dipping joints were also observed including some trending upstream/downstream (east/west). Some near horizontal defects were also observed in the valley floor. On the locally steep sides of the right abutment, stress relief is likely to have resulted in the inward

PARAMETER	DESCRIPTION
	(towards the river) movement (partly along shallow dipping defects) of the valley sides. This movement causes pre-existing defects (particularly steep joints parallel to the valley) to open and the formation and opening of new stress relief joints roughly parallel to, or flatter than the valley sides. There are likely to be open joints and bedding partings in the outcrops on the abutments. Transported material filling the joints may result in the formation of infilled seams. As a result of the stress relief and weathering effects in the near-surface rock mass on the right abutment, joints and other defects are likely to be longer and more closely spaced and the near-surface rock mass is likely to be more permeable than in the less disturbed rock mass at greater depths. For initial costing purposes average foundation depths of 3 m could be assumed for the valley floor (although locally deeper excavation may be required if there is an upstream/ downstream fault in the bed of the river). Average foundation depths of 3 m have been assumed for the right abutment and 4 m for the left abutment (because of the greater depth of colluvium). Some of the loosened near-surface rock may be excavatable by bulldozers and excavators but drilling and blasting is likely to be required in places to reach a suitable foundation. It is likely that a relatively long saddle dam may be required on the left of the reservoir. According to geological maps, potential saddle dams on the right bank are likely to be founded on arenite or mudstone of the Mulgrave Formation or metabasalt of the Chillagoe Formation. The rocks underlying all of the saddle dams are likely to be more weathered and weaker than the rocks observed at the main dam site. For initial costing purposes average foundation excavation depths of 3 m could be assumed for the core trenches of all of the saddle dams and 1 m for the shoulders of all of the saddle dams. The weathered materials may be excavatable by bulldozers or excavators to the full depths required at most of the saddle dams. The permeability and the stability of the foundations and abutments of the main dam and saddle dam, and the potential for scour downstream of the spillway, are largely related to the continuity and nature of the defects (e.g. faults and joints) in the rock mass, which will need to be investigated during feasibility studies but on present knowledge there is no reason for concern. It has been assumed that foundation grouting will be required for both the main dam and saddle dams.
Reservoir rim stability and leakage potential	Given the relatively subdued topography and the lack pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. Limestone beds are likely to cross the storage upstream of the dam but are unlikely to contribute to significant leakage.
Potential structural arrangement	Modest relief at this site limits the potential height of a dam, and therefore, potential capacity and yield. An RCC gravity dam with a central uncontrolled spillway and crest level up to 53 m above bed level is proposed across the river bed section with earth and rockfill embankments across the saddles on both abutments. The saddle dam requirements for the higher storage levels involve embankments with a total length of some 1.5 km and 24 m maximum height. Access to the right bank area at the site would be via the Palmerville Road, which branches from the Peninsula Development Road some 19 km north-west of Laura. Some 75 km of the Palmerville Road to the site would require upgrading to improve alignment and all-weather access. Approximately 5 km of new road would be required from the Palmerville Road to reach the right bank area at the site.
Availability of construction materials	The arenite in the area is likely to provide suitable aggregate for RCC and possibly for conventional concrete. A quarry in these rocks is also likely to be able to provide rockfill and riprap for the saddle dam and sand and aggregate suitable for the filters required in the saddle dams. There is some sand in the river channel near the dam site and there may be more in the river channel upstream and downstream of the dam site and in alluvial terraces in the area. Cohesive earthfill for the core of the saddle dam may be harder to find as natural soils in the area are relatively thin. Extremely weathered mudstone, metabasalt or other fine-grained material, residual soils and colluvium may provide suitable sources of core material.
Catchment area	Based on SRTM-H data, the catchment area at the dam site is estimated to be 3885 km^2.

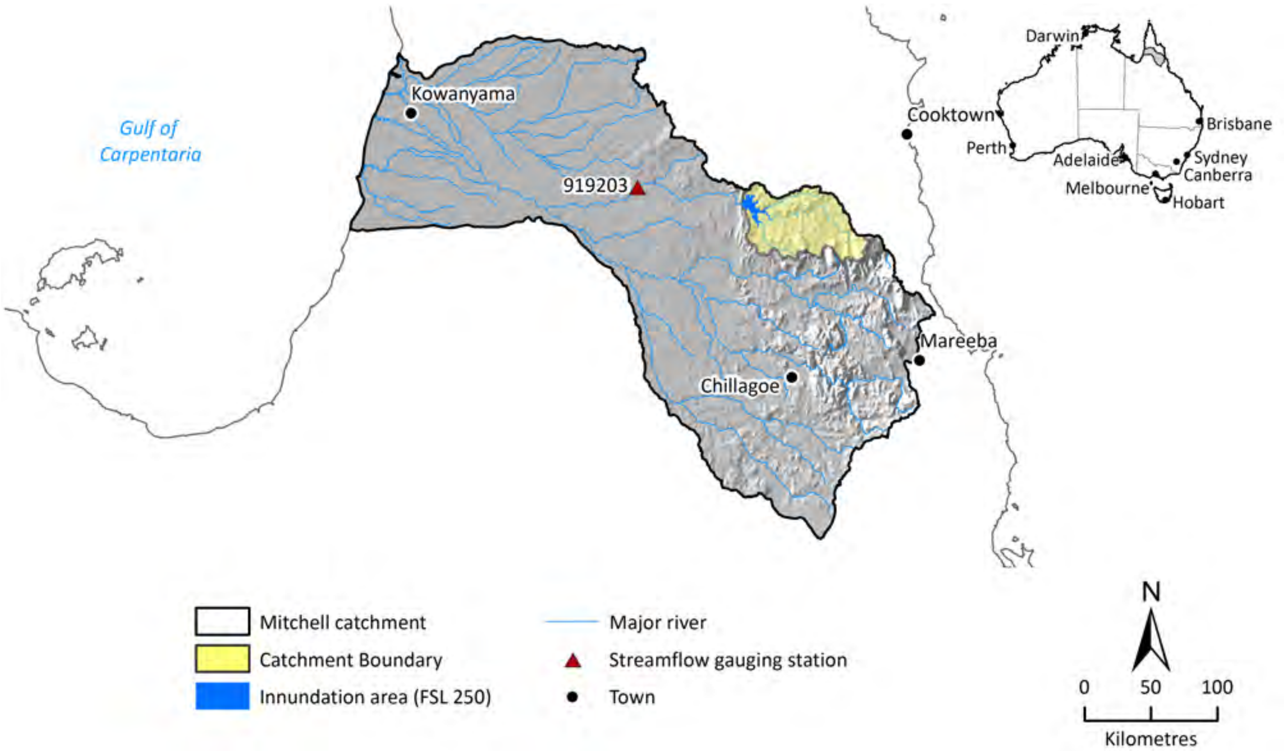
PARAMETER	DESCRIPTION
Flow data	Streamflow data are available for the Palmer River at GS 919202A on Palmer River, AMTD 216.9 km, catchment area 2169 km^2. Data are available from December 1968 to May 1988. Over this period: Maximum recorded annual flow volume 2089 GL Mean annual flow volume 616 GL Median annual flow volume 481 GL Minimum annual flow volume 54 GL
Storage capacity	Based on SRTM data storage levels and capacities have been considered as follows: FSL 245 mEMG96 Capacity 1003 GL FSL 250 mEMG96 Capacity 1444 GL FSL 255 mEMG96 Capacity 2004 GL
Reservoir yield at dam wall	FSL 245 mEMG96 Estimated yield at 85% annual time reliability 491 GL FSL 250 mEMG96 Estimated yield at 85% annual time reliability 553 GL FSL 255 mEMG96 Estimated yield at 85% annual time reliability 612 GL
Open water evaporation	At FSL, the surface area of the potential reservoir is: FSL 245 mEMG96 7,705 ha FSL 250 mEMG96 9,975 ha FSL 255 mEMG96 12,440 ha Mean annual evaporation and mean annual net evaporation at FSL 250 mEMG96 at 85% annual reliability is 114.2 GL and 51.0 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.097.
Potential use of supply	**Agriculture** Upstream of the confluence with the Mitchell River, the Palmer River has occasionally flooded 'narrow' alluvial plains, which are generally deeply incised by the main channel resulting in relatively narrow plains. Soils are dominated by hard-setting clay loam surfaced brown gradational soils with strongly sodic, dispersive structured clay subsoil. These plains are suitable for sugarcane and grain/forage crops. Soils are likely to be suitable for ringtanks. Below the confluence of the Palmer and the Mitchell rivers, the regularly flooded 'broad' delta has numerous flood channels, which become more numerous and meandering closer to the coast. Soils are dominated by hard-setting clay loam surfaced brown gradational soils with strongly sodic, dispersive structured clay subsoil and hard-setting coarse structured grey cracking clay soils. Soils are suitable for sugarcane and dry-season grain and forage cropping, and likely to be suitable for ringtanks. Narrow levees, prior streams and elevated 'old' Tertiary-Quaternary alluvial plains have predominantly red and brown massive loamy soils suitable for a wide variety of spray-irrigated crops and horticultural crops. Soils are unlikely to be suitable for ringtanks. See companion technical report on land suitability (Thomas et al., 2018).
Estimated rates of reservoir sedimentation	(see table below)
Storage impacts	The majority of the area that would be required lies within the Palmerville land lease area 14/SP250040 total area 134,000 ha. The upper sections of the storage extend into a national park area, the Palmer Goldfield Resource Reserve 1/CP907719 total area 16,200 ha and water would be stored between the banks adjacent to the historical Maytown (also described as Chelmsford), which was the centre of the Palmer goldfields development. A 16-km long section of a surveyed local road would also be inundated
Environmental considerations	**Barrier to movement of aquatic species**

Estimated rates of reservoir sedimentation:

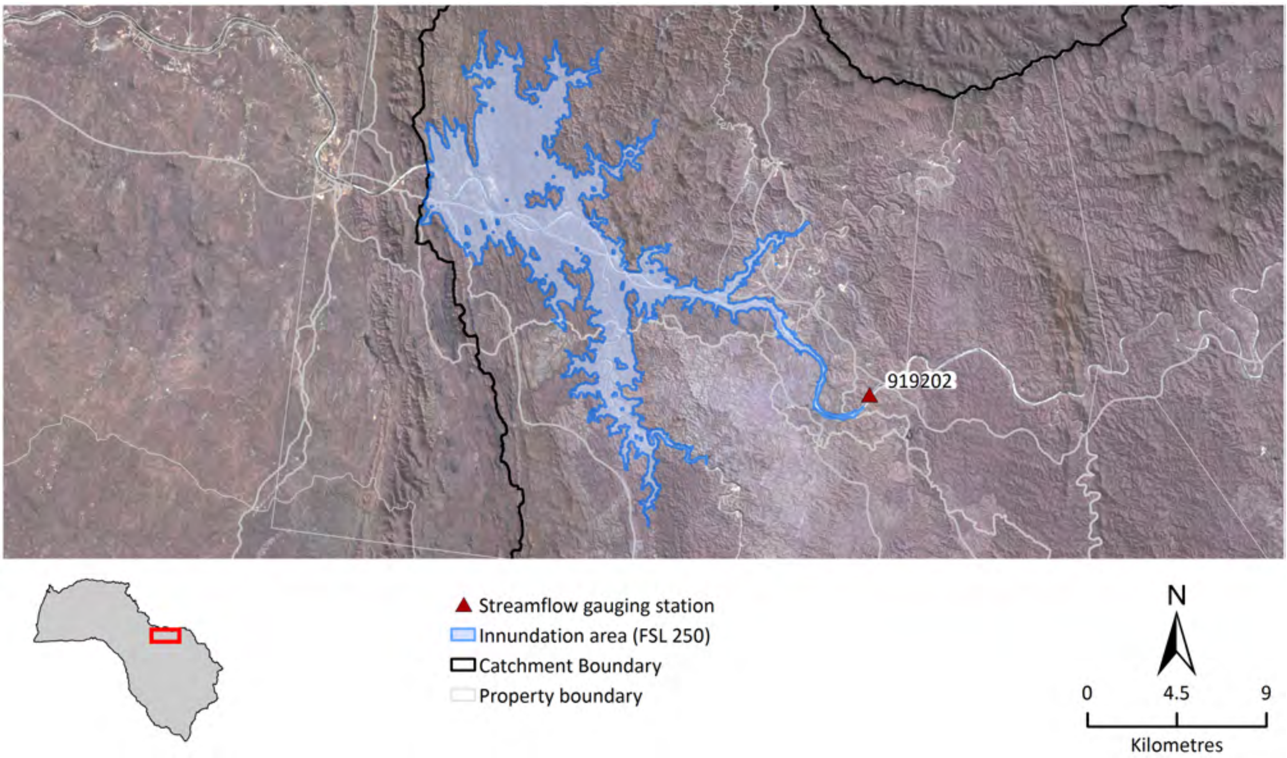
	Best case	Expected	Worst case
30 years (%)	0.1	0.5	0.7
100 years (%)	0.2	1.6	2.4
Years to fill	58,810	7,080	4,325

PARAMETER	DESCRIPTION
	A dam constructed at this site could affect the migration, movement or colonisation of the following fish species: the barred grunter (*Amniataba percoides*), mouth almighty *(Glossamia aprion)*, sooty grunter (*Hephaestus fuliginosus*), spangled perch (*Leiopotherapon unicolor*), bony herring (*Nematalosa erebi)*, black catfish (*Neosilurus ater*), rainbowfish (*Melanotaenia splendida inornata* and *Melanotaenia* sp.), freshwater longtom (*Strongylura krefftii*) and barramundi (*Lates calcarifer*). **Ecological implications of inundation** Within the vicinity of this site there are seven species of national significance, one of which is the endangered Gouldian finch (*Erythrura gouldiae*). As this species inhabits vegetation bordering watercourses, it may be susceptible to water storage developments. A reservoir at the selected FSL (250 mEMG96) would inundate about 5335 ha of regional ecosystems of concern. The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).
Estimated cost	CSIRO generated preliminary estimates of cost based on a generalised costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways and cost items for embankment type saddle dams. The costs for a selection of FSL are reported below: FSL 245 mEMG96 $602 million FSL 250 mEMG96 $690 million FSL 255 mEMG96 $781 million These modelled costs estimates are likely to be within –20% and +50% of the true value. If geotechnical investigations found geological complications at the site dam costs may be substantially higher. No further cost estimates were made at this site as part of the Assessment.
Estimated cost/ML of supply	Based on the yields estimated by the CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm estimated cost/ML of supply are reported at the following FSL: FSL 245 mEMG96 $1226/ML FSL 250 mEMG96 $1247/ML FSL 255 mEMG96 $1276/ML On the basis of these fairly similar estimated costs of supply over this range of storage levels, a dam at FSL 250 mEMG96 was selected for an assessment of irrigation.
Summary comment	The Palmer River dam site has a one of the lowest cost to yield ratios of the potential dam sites in the Mitchell catchment. However, the site is relatively remote and the nearest large contiguous areas of land suitable for irrigated agriculture are located a considerable distance downstream on more flood-prone areas below of the junction of the Mitchell and Palmer rivers. For these reasons the site was not short-listed.

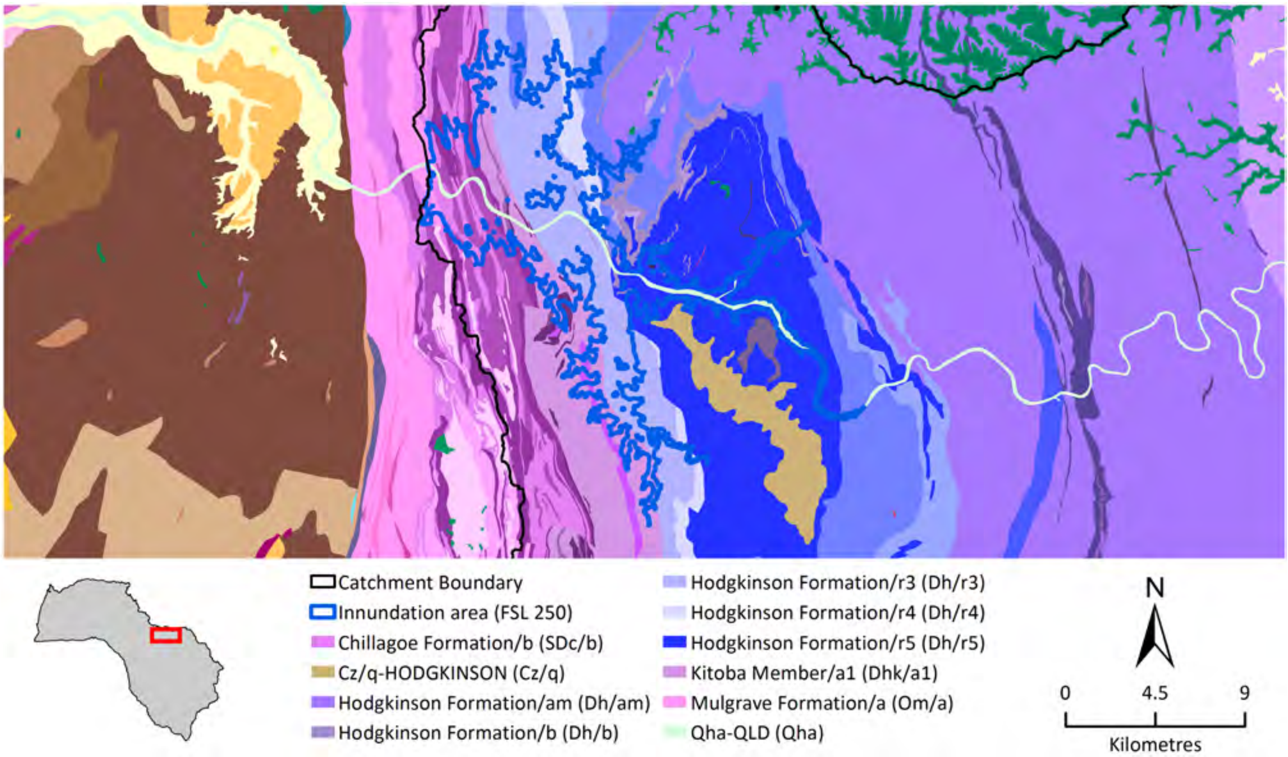
Apx Figure B-17 Palmer River dam site looking upstream



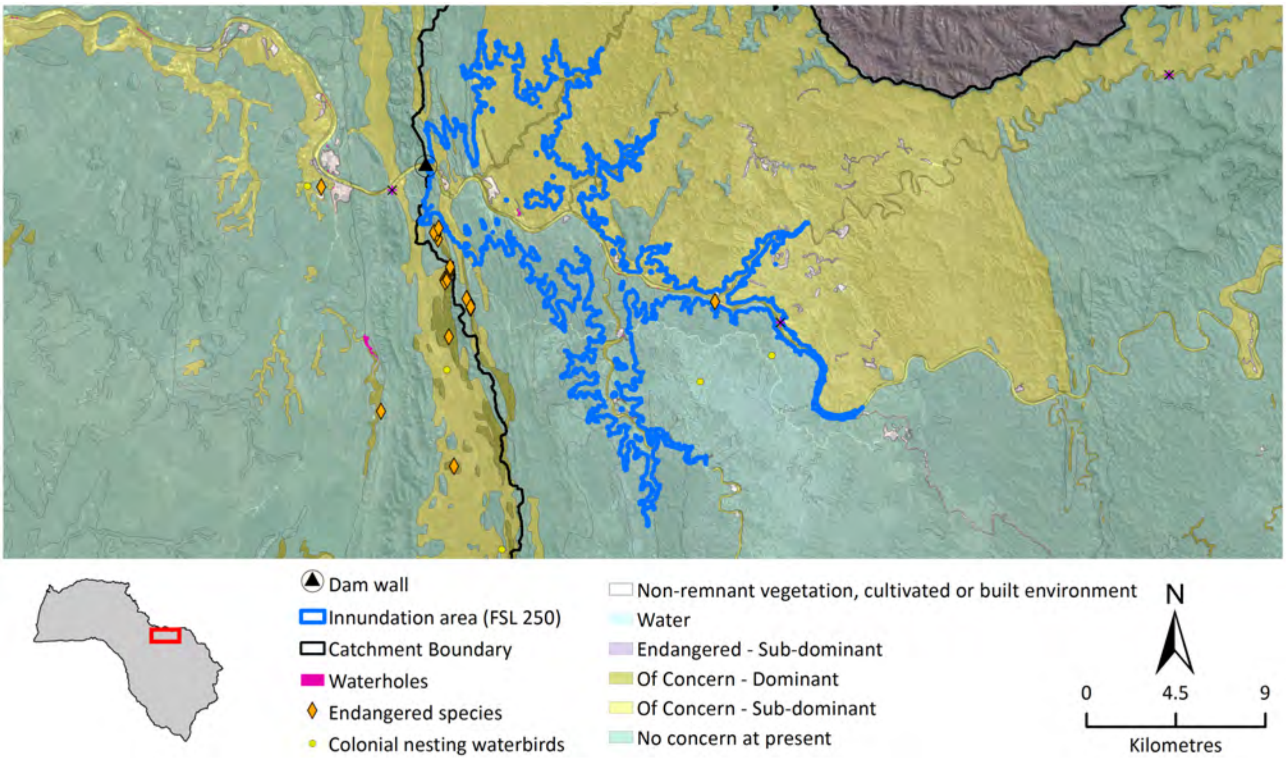
Apx Figure B-18 Location map of Palmer River dam site, reservoir extent and catchment area



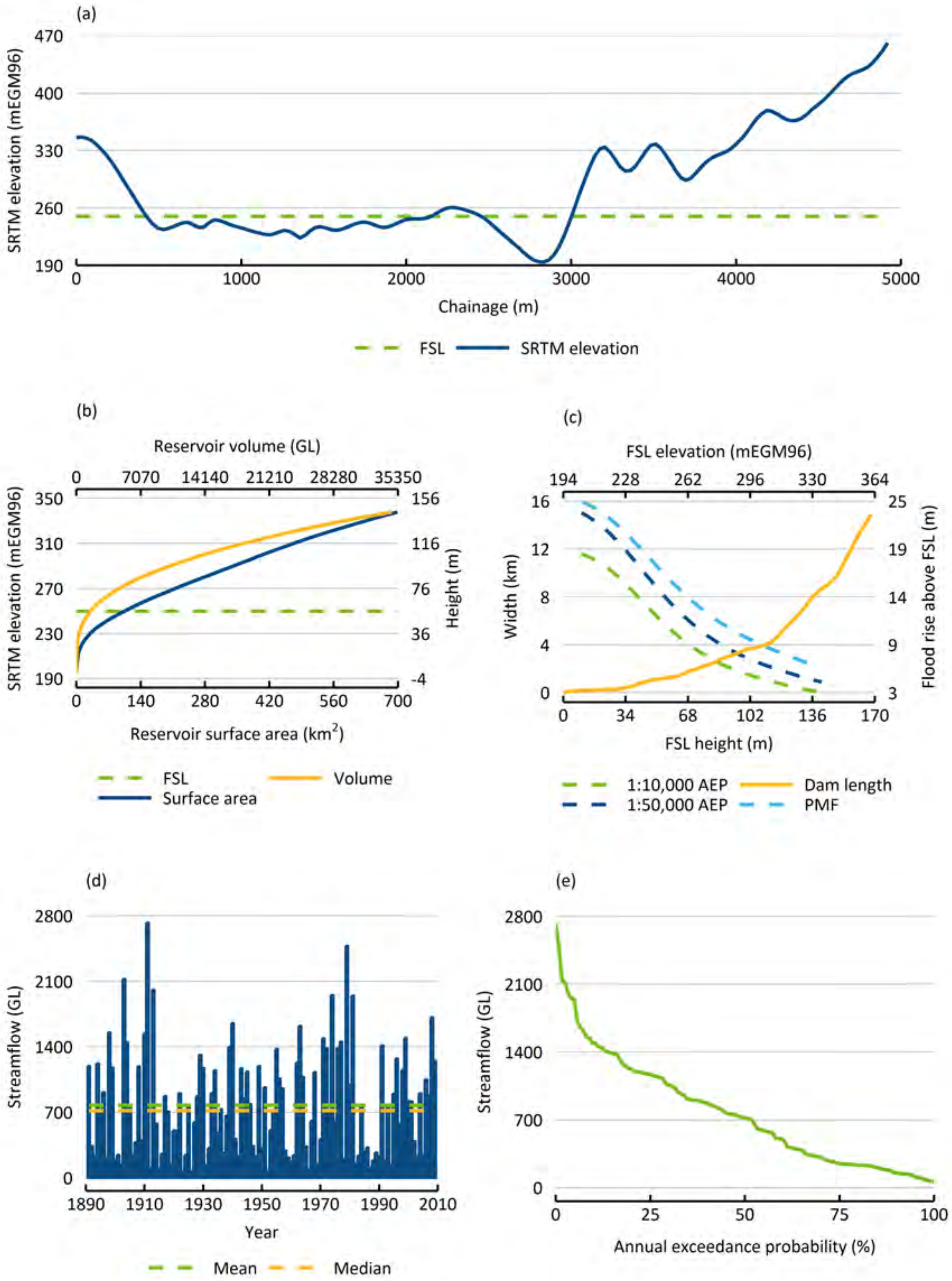
Apx Figure B-19 Palmer River dam site, reservoir extent and property boundaries



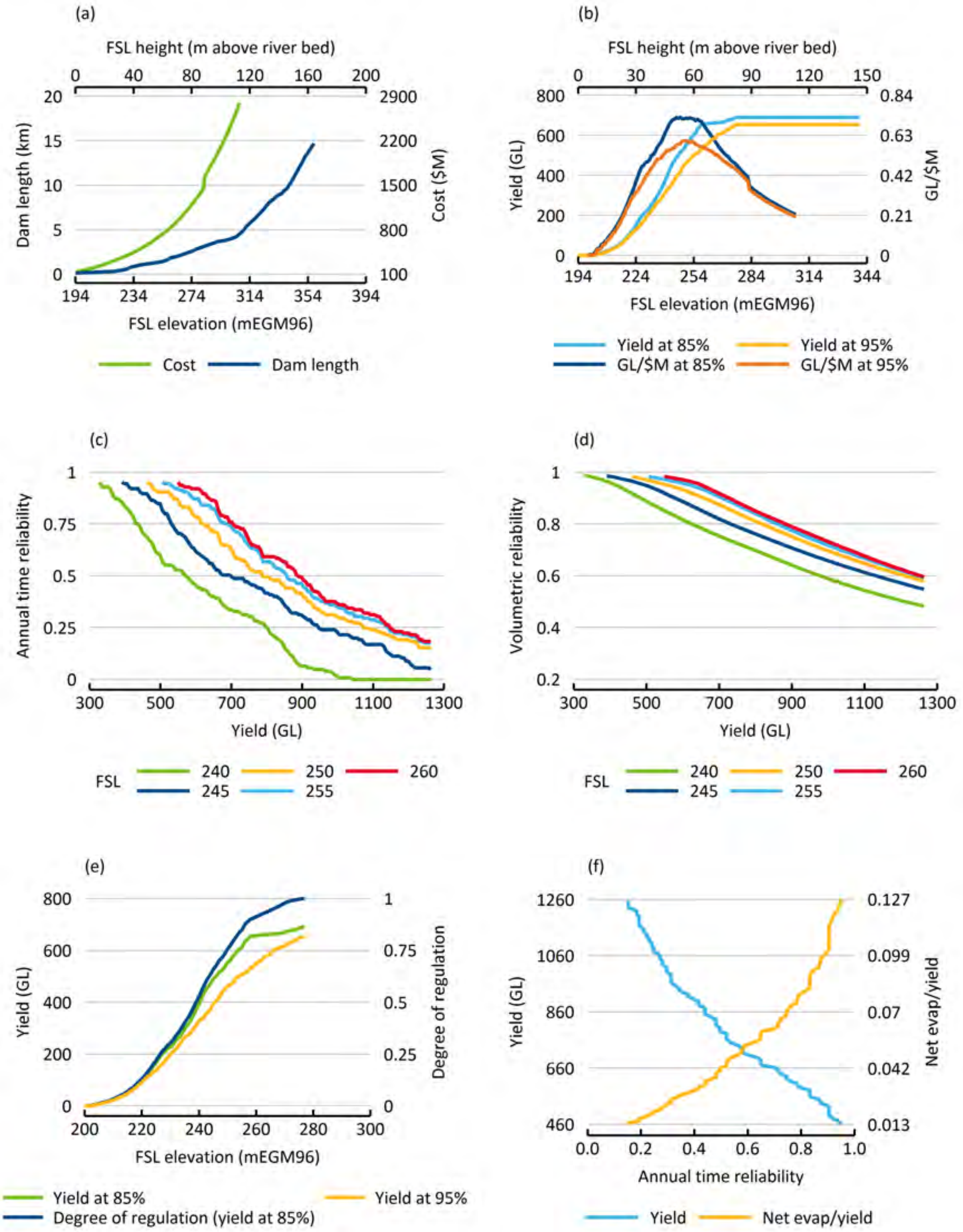
Apx Figure B-20 Geology underlying the Palmer River dam site and reservoir



Apx Figure B-21 Regional ecosystem mapping and reservoir extent of the Palmer River dam site and known water-dependent ecological assets

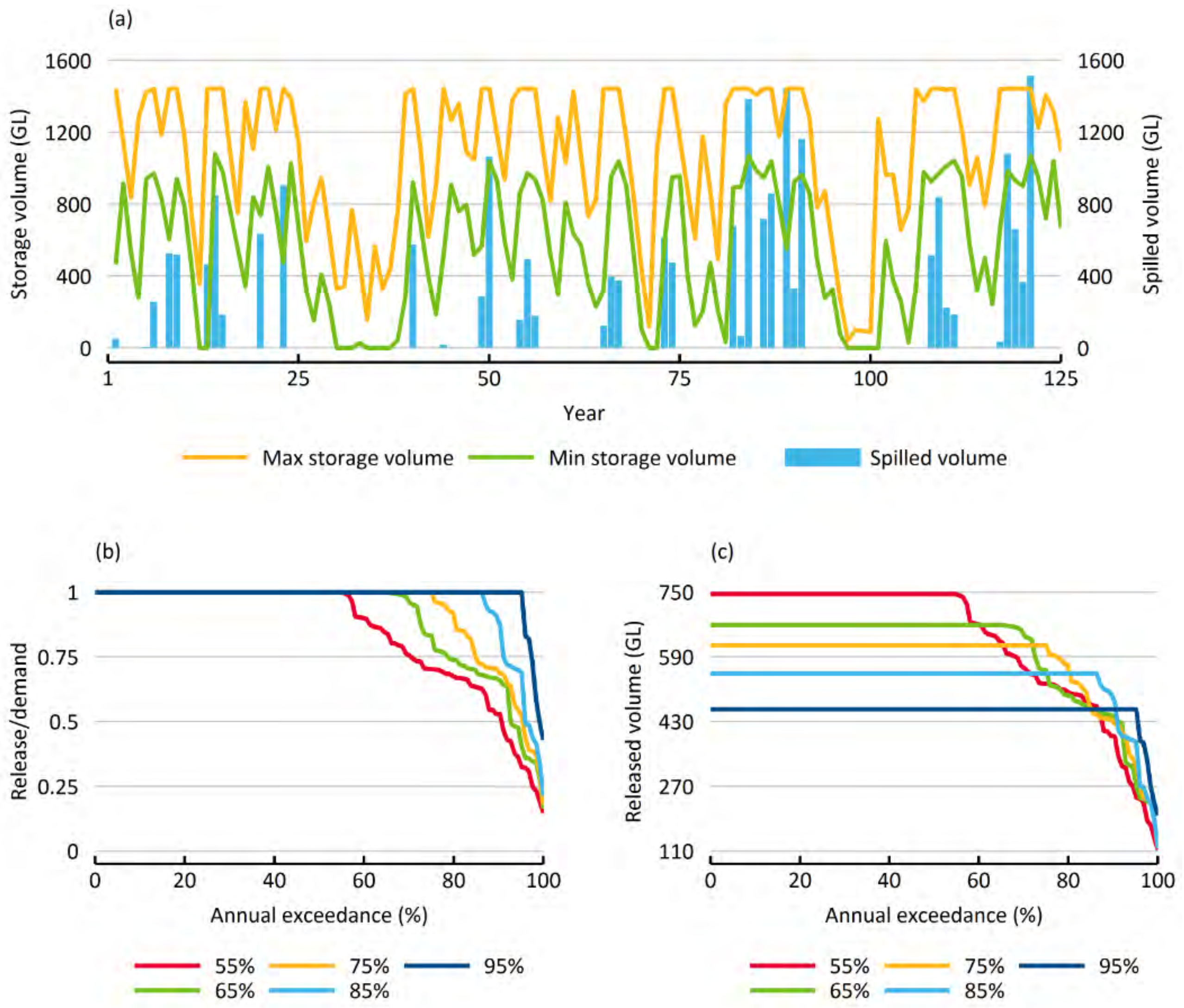


Apx Figure B-22 Palmer River potential dam site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and probable maximum flood events plotted against FSL; (d) annual streamflow; (e) annual flow exceedance.



Apx Figure B-23 Palmer River potential dam site cost, yield at the dam wall and evaporation

(a) Dam length and dam cost versus FSL; (b) dam yield at 85% and 95% annual time reliability and yield per $ million at 85% and 95% 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 85% and 95% 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-24 Palmer River potential dam site storage levels and yield

(a) Maximum and minimum annual storage trace at the selected FSL (FSL, 250 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

B.1.4 NULLINGA DAM SITE ON THE WALSH RIVER; AMTD 270.0 KM

PARAMETER	DESCRIPTION
Previous investigations	The site was first considered as a potential major storage for irrigation development in the Mareeba–Dimbulah area as an alternative to the Tinaroo Falls Dam. The latter site was ultimately adopted because of the higher rainfall experienced in its catchment area and its better location and elevation to service the proposed irrigation area. The potential Nullinga dam site was further considered as a nominated potential supply option as part of the Atherton Tablelands/Cairns Region planning study, which had been recommended as a priority study by the then government's Water Infrastructure Task Force, which reported in February 1997. Preliminary engineering studies were undertaken by SMEC and a preliminary environmental assessment was made by Hyder consultants. A concept design and updated cost estimates were prepared by SunWater in 2008. A preliminary business case is currently being prepared by Building Queensland with funding provided by the Australian Government. The first stage of the Assessment was an assessment of demand, which is being prepared by consultants Marsden Jacobs. **References:** Selected references include; DNRM (2002) Atherton Tableland Cairns region water supply planning study report. Department of Natural Resources and Mines, March 2002. Queensland Government (2007) Water resource (Mitchell) plan, 2007. GHD (2008) Flora and fauna baseline assessment-Nullinga water storage infrastructure project. GHD, June 2008. SunWater (2008) Nullinga concept investigation report – final draft. SunWater, November 2008. DNRM (2009) Mitchell resource operations plan. Department of Natural Resources and Mines, November 2009. Cairns Regional Council (2009) Report for overall water supply strategy for Cairns – planning report. Cairns Regional Council, May 2009. Cairns Regional Council (2015) Our water security – water security strategy – final report. Cairns Regional Council, March 2015. Australian Government (2015) Our north, our future; white paper on developing Northern Australia. Australian Government, June, 2015.
Description of potential dam configuration	A dam at the Nullinga site on the Walsh River could provide for an expansion of irrigated production of lands riparian to the Walsh River downstream as far as the Leafgold weir area, and with a delivery pipeline to the West Barron Main Channel could supply areas currently supplied from Tinaroo Falls Dam. This would free up supply from the dam, which then could be used to supplement supply to Cairns and to the Barron Gorge hydro-electric power station. **The following figures accompany this description of the site** The potential Nullinga dam site is depicted in Apx Figure B-25. Apx Figure B-26 provides a map showing its location in the Mitchell catchment, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Apx Figure B-27. Apx Figure B-28 and Apx Figure B-29 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Apx Figure B-30 to Apx Figure B-32. An FSL of 555 mEMG96 was selected for display in the figures as this is the highest level examined by SunWater (2008).
Regional geology	The potential dam site and reservoir area are located in an area of folded and faulted sedimentary, metamorphic and igneous rocks of the Hodgkinson Province of Silurian to Devonian ages, which forms part of the Mosaman Orogen. The older rocks of the Hodgkinson Formation have been intruded by granite, faulted, uplifted and subject to long periods of weathering and erosion since they were formed. Most of the storage is underlain by residual soil and colluvium of Tertiary and Quaternary age. Alluvium consisting mainly of sand and gravel occurs in the valley floor.

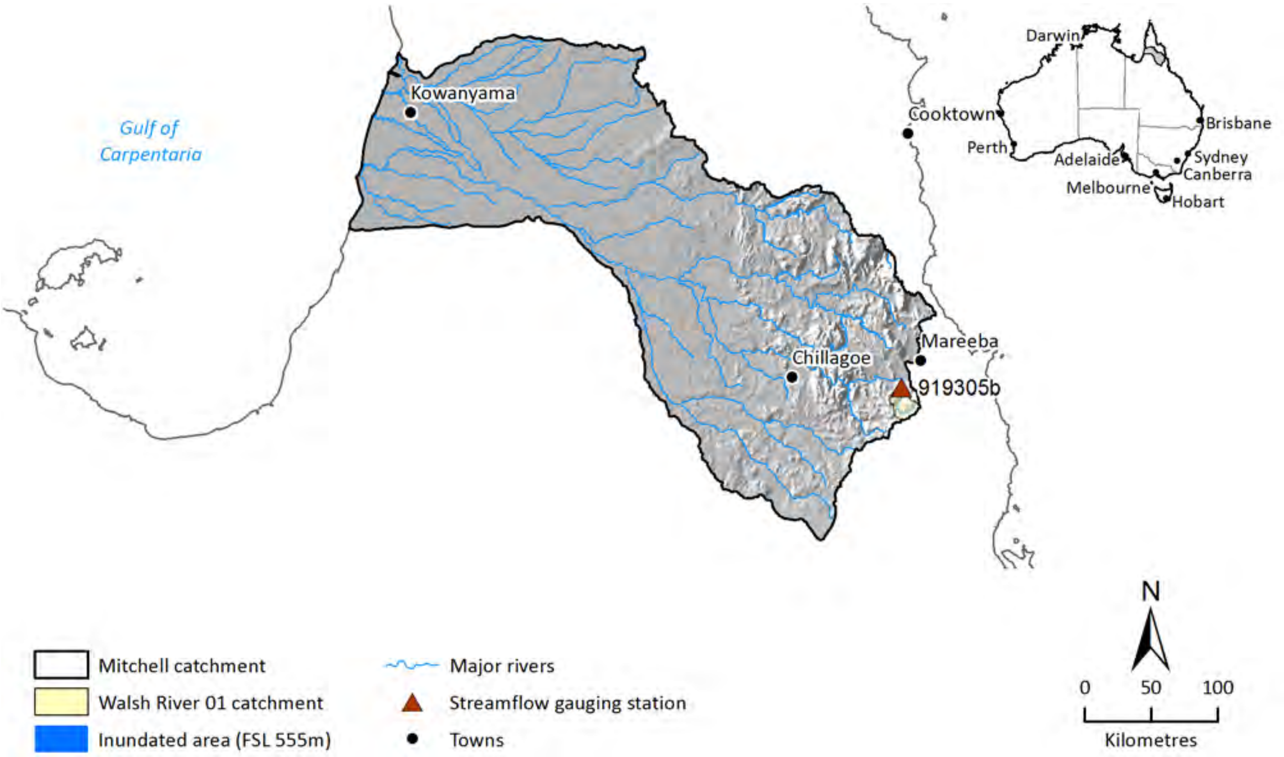
PARAMETER	DESCRIPTION
	Foliation bedding and dykes in the project area tend to strike north-west/south-east and there are also major faults in the same orientation. There are also north-northeast/south-southwest and east-west-trending faults and lineaments in the region.
Site geology	The potential dam site is on a north-northeast trending section of the Walsh River where it cuts through a northwest/southeast-trending ridge of the Parada Granite (which has been intruded by rhyolitic and dacitic dykes). Distinctly weathered granite is exposed in cuttings on both abutments and there are outcrops of fine-grained, slightly to distinctly weathered high to very-high strength granite in the valley floor. There are also sand and gravel deposits in the valley floor. The geological map indicates that there are steep northwest/southeast-trending dykes of rhyolite in the granite. Both abutments consist of relatively gentle rounded slopes and exposures of granite in track cuttings indicate that the rock is more weathered than in the valley floor. There are some gravels in the river channel and there may also be sand deposits in the valley. The site is located along a northwest-trending ridge comprising the Parada Granite, which is intruded by a series of rhyolitic and dacite dykes. The Parada Granite is described as a white, fine- to medium-grained biotite granite. Extensive drilling and shaft excavations in the early 1950s indicated that the river bed comprises coarse sand and gravel deposits up to 9 m deep overlying rock. The depth to sound rock on the right abutment varied between 3.35 and 7.3 m, and on the left abutment between 9.4 and 10.3 m. No record of any water pressure testing was located. Depending on the FSL adopted there may need to be a saddle dams on the left bank of the storage. The earlier investigations do not appear to have investigated the foundations of the saddle dam. Hydrological analysis undertaken as part of the Assessment indicates that the hydrological limit of the potential Nullinga dam site is approached at an FSL of 250 mEMG96.
Reservoir rim stability and leakage potential	Given the relatively subdued topography and the lack pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. Given the lack of soluble rocks in the storage area and the lack of narrow, low, steep-sided saddles, reservoir leakage is unlikely to be a significant issue provided the dam foundations are grouted.
Proposed structural arrangement	Three FSL were examined in SunWater's 2008 study, in each case an RCC type dam with a central fixed crest spillway was assumed. A zoned embankment saddle dam up to 19 m high would be required on the western side of the reservoir to contain storage and flood rise. A fish transfer facility and outlet works were proposed to be located on the left bank side.
Availability of construction materials	No materials testing was undertaken during the early investigations. SunWater reported that sufficient sources of coarse aggregate material should be available locally and that the Quaternary sand and gravel deposits could almost certainly be used.
Catchment area	Catchment area at the site is 326 km^2.
Flow data	Flow data at the site is available from station GS 919305B from 1956 to date, although very little data has been collected since 1991. Summary flow data are as follows: Maximum annual flow volume 714 GL Mean annual flow volume 105 GL Median annual flow volume 53 GL Minimum annual flow volume 5 GL
Storage capacity	Selected storage levels and reservoir capacities calculated using the SRTM-H are as follows: FSL 540 mEMG96 Capacity 145 GL FSL 550 mEMG96 Capacity 326 GL FSL 555 mEMG96 Capacity 443 GL
Reservoir yield	Estimates of reservoir yield at the dam wall made as part of the Assessment:

PARAMETER	DESCRIPTION
	FSL 540 mEMG96 Estimated yield at 85% annual time reliability 65 GL FSL 550 mEMG96 Estimated yield at 85% annual time reliability 84 GL FSL 555 mEMG96 Estimated yield at 85% annual time reliability 88 GL Estimates of reservoir yield made by DSITIA Queensland in 2008 were: FSL 540 mAHD Estimated yield 12.5 GL HP and 36 GL MP FSL 550 mAHD Estimated yield 12.5 GL HP and 59 GL MP FSL 555 mAHD Estimated yield 12.5 GL HP and 69 GL MP
Open water evaporation	At FSL, the surface area of the storage is: FSL 540 mEMG96 1431 ha FSL 550 mEMG96 2171 ha FSL 555 mEMG96 2524 ha Mean annual evaporation and mean annual net evaporation at FSL 540 mEMG96 at 85% annual reliability is 15.7 GL and 7.9 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.125.
Potential use of supply	**Agriculture** The soils suitable for irrigated cropping within the Assessment area have formed predominantly on gently undulating pediments derived from metamorphosed rocks; plains to undulating rises on basalts of the Atherton Tablelands; rises and pediments on granite; and recent and 'old' alluvial plains associated with the Walsh and Baron rivers and tributaries. Broadly across the entire Mareeba–Dimbulah Water Supply Scheme (MDWSS) area there is about 50,400 ha of land suitable for irrigated cropping, of which 22,690 ha is currently under irrigation. A total of 27,710 ha is suitable for potential irrigation. Large areas of non- irrigated suitable land exist downstream of the potential dam site. See companion technical report on land suitability (Thomas et al., 2018).
Estimated rates of reservoir sedimentation	<table><tr><td></td><td>Best case</td><td>Expected</td><td>Worst case</td></tr><tr><td>30 years (%)</td><td>0.0</td><td>0.6</td><td>0.6</td></tr><tr><td>100 years (%)</td><td>0.1</td><td>1.9</td><td>2.0</td></tr><tr><td>Years to fill</td><td>68,650</td><td>6,430</td><td>4,940</td></tr></table>
Storage impacts	All levels of development of a Nullinga dam would inundate an area of some 460 ha of land developed with centre pivot irrigation based on diversion of unregulated stream flows. The higher levels of a Nullinga dam storage development would inundate the existing Collins weir (FSL 545 mAHD), although it should be noted that the effective capacity of the weir has been reduced significantly by siltation and the weir is rarely used to supply water to the irrigation area. The Collins Weir Road on the left bank and Stankovich Drive on the right bank of the Walsh River may also need to be relocated.
Environmental considerations	Preliminary studies of environmental impacts have been undertaken by consultants Hyder and GHD. Much of the possible inundation area has been heavily modified by introduced flora and fauna species, by grazing activities and by a major irrigation development. **Barrier to movement of aquatic species** Within the potential inundated area, freshwater longtom (*Strongylura krefftii*) has been recorded. Also, near the proposed dam wall but outside of the inundated area, Hyrtl's catfish (*Neosilurus hyrtlii*), rainbowfish (*Melanotaenia splendida inornata*), sooty grunter (*Hephaestus fuliginosus*), spangled perch (*Leiopotherapon unicolor*) and mouth almighty *(Glossamia aprion*) are found. Relative to the size of the Mitchell catchment, the catchment area of the potential Nullinga dam site is very small. **Ecological implications of inundation**

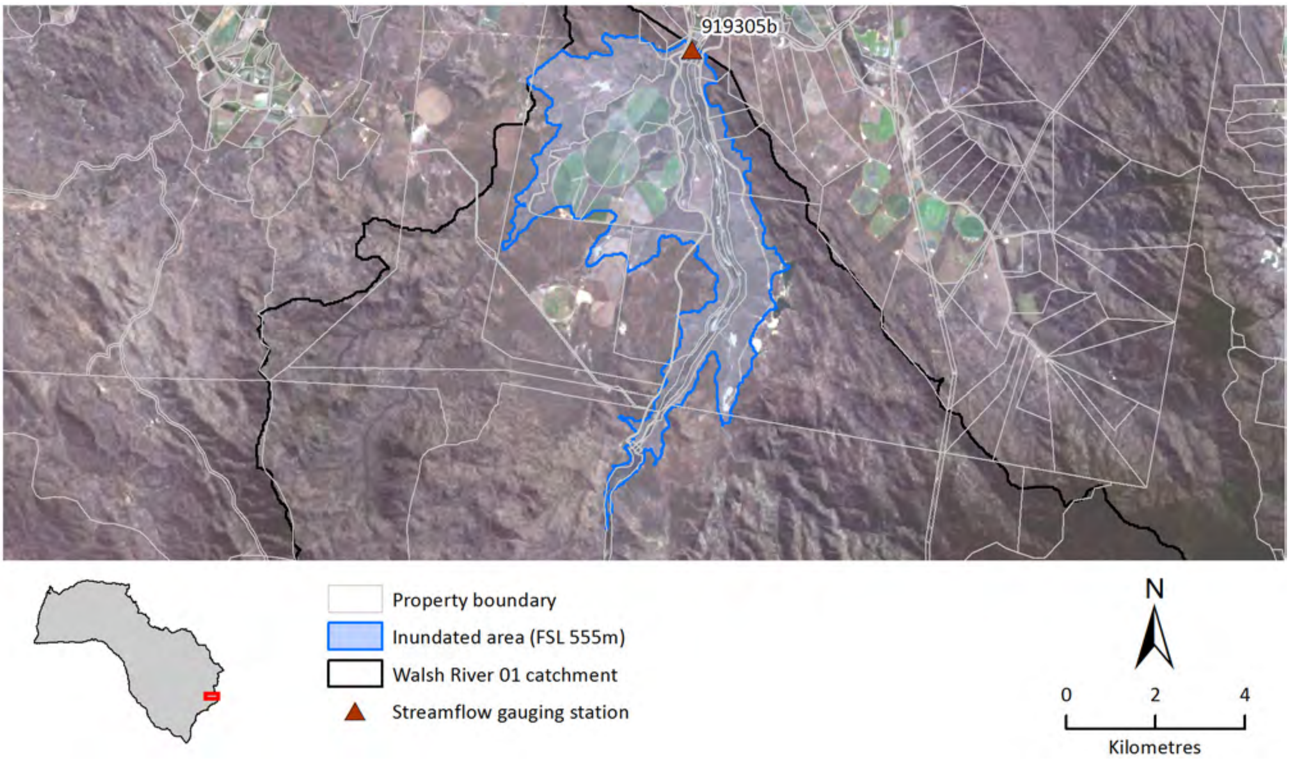
PARAMETER	DESCRIPTION
	Although this is the smallest site of all, the potential inundated area at FSL for this site (540 m) could affect 22% (309 ha) of the regional ecosystems of concern. In terms of threatened species, no records of listed species overlap the inundated area. However, within the catchment a plethora of national significant species are found, such as the endangered northern quoll (*Dasyurus hallucatus*), Day's frog (*Litoria dayi*) and *Litoria nannotis*. Also, the vulnerable magnificent broodfrog (*Pseudophryne covacevichae*), greater glider (*Petauroides volans*) and red goshawk (*Erythrotriorchis radiates*) are found here. The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).
Estimated cost	CSIRO generated preliminary estimates of cost based on a generalised costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways and cost items for embankment type saddle dams. The costs for a selection of FSL are reported below: FSL 540 mEMG96 $349 million FSL 550 mEMG96 $502 million FSL 555 mEMG96 $588 million These modelled costs estimates are likely to be within –20% and +50% of the true value. If geotechnical investigations found geological complications at the site dam costs may be substantially higher. No further cost estimates were made at this site as part of the Assessment. SunWater (2008) estimated the cost of the Nullinga dam options in 2008. These are reported as the original estimates in 2008 dollars and as part of the Assessment were indexed to 2017 dollars using the Queensland Road and Bridge construction index (i.e. using a multiplier of 1.2063): FSL 540 mEMG96 Estimated cost $274.5 million (2008) and $331.1 million (2017) FSL 550 mEMG96 Estimated cost $384.6 million (2008) and $464.0 million (2017) FSL 555 mEMG96 Estimated cost $442.7 million (2008) and $534.0 million (2017)
Estimated cost/ML of supply	Based on the yields estimated by the CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm estimated cost/ML of supply are reported at the following FSL: FSL 540 mEMG96 $5353/ML FSL 550 mEMG96 $5948/ML FSL 555 mEMG96 $6720/ML On the basis of these estimated costs of supply over this range of storage levels, a dam at FSL 540 mEMG96 was selected for reporting other criteria. Based on SunWater's cost estimates indexed to 2017 and DSITI 2008 yield estimates the estimated cost of supply/ML of yield for the three nominated FSL are: FSL 540 mEMG96 $6827/ML FSL 550 mEMG96 $6890/ML FSL 555 mEMG96 $6552/ML (Note the estimated cost/ML of supply was simply calculated by adding the volumes of MP and HP water together).
Summary comment	The Nullinga dam site on the upper Walsh River was first examined as an alternative to the Tinaroo Falls Dam as the major storage development in the MDWSS area. The latter site was ultimately adopted because of the higher rainfall experienced in its catchment area and its better location and elevation to service the proposed irrigation area. Since the Nullinga site was first considered, considerable irrigation development has occurred within the inundation area. A dam at the Nullinga site on the Walsh River could provide for an expansion of irrigated production of lands riparian to the Walsh River downstream as far as the Leafgold weir area and with a delivery pipeline to the West Barron Main Channel could supply areas currently supplied from Tinaroo Falls Dam. This would free up supply from the dam, which then could be used to supplement supply to Cairns and to the Barron Gorge hydro-electric power station. Although the site has a high cost to yield ratio, its proximity to the existing MDWSS and its potential to ensure the long-term security of the Cairns water supply have led to interest in its possible development.

PARAMETER	DESCRIPTION
	A preliminary business case is currently being prepared by Building Queensland with funding provided by the Australian Government.

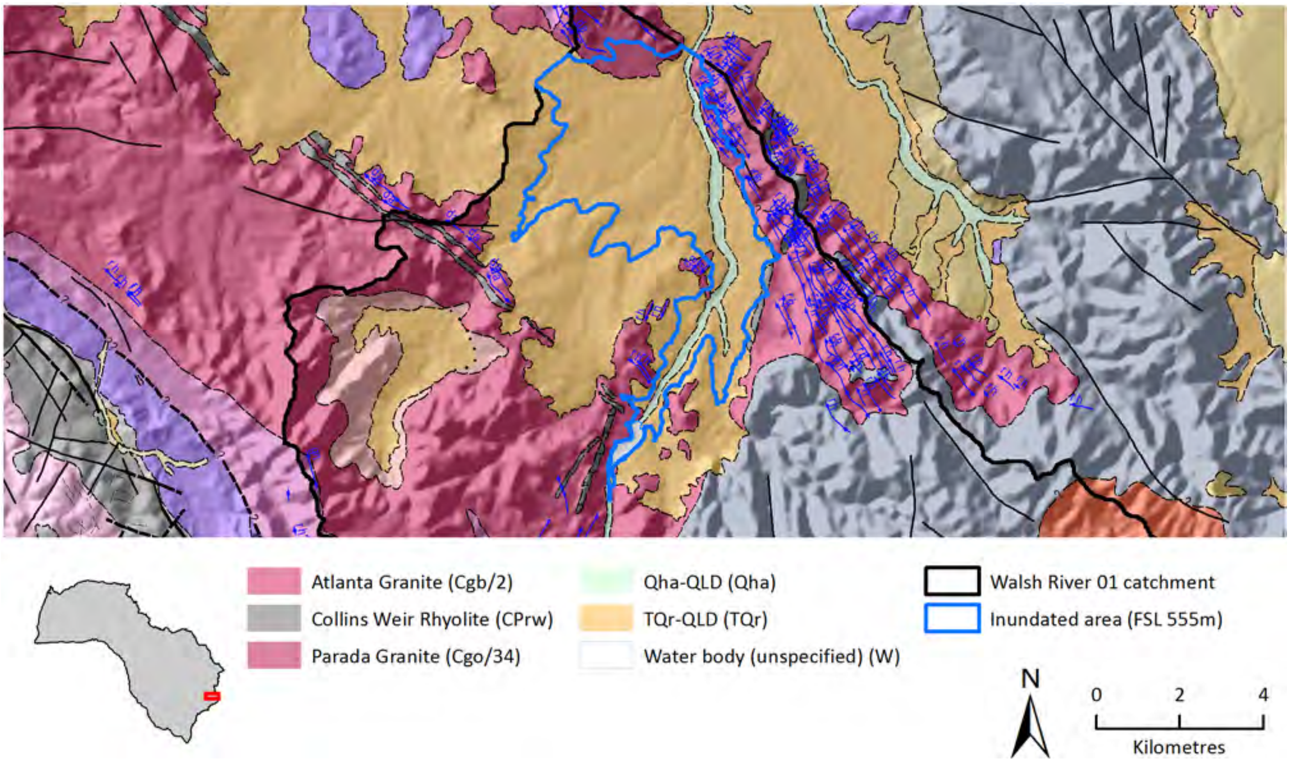
Apx Figure B-25 Nullinga dam site on the Walsh River looking upstream



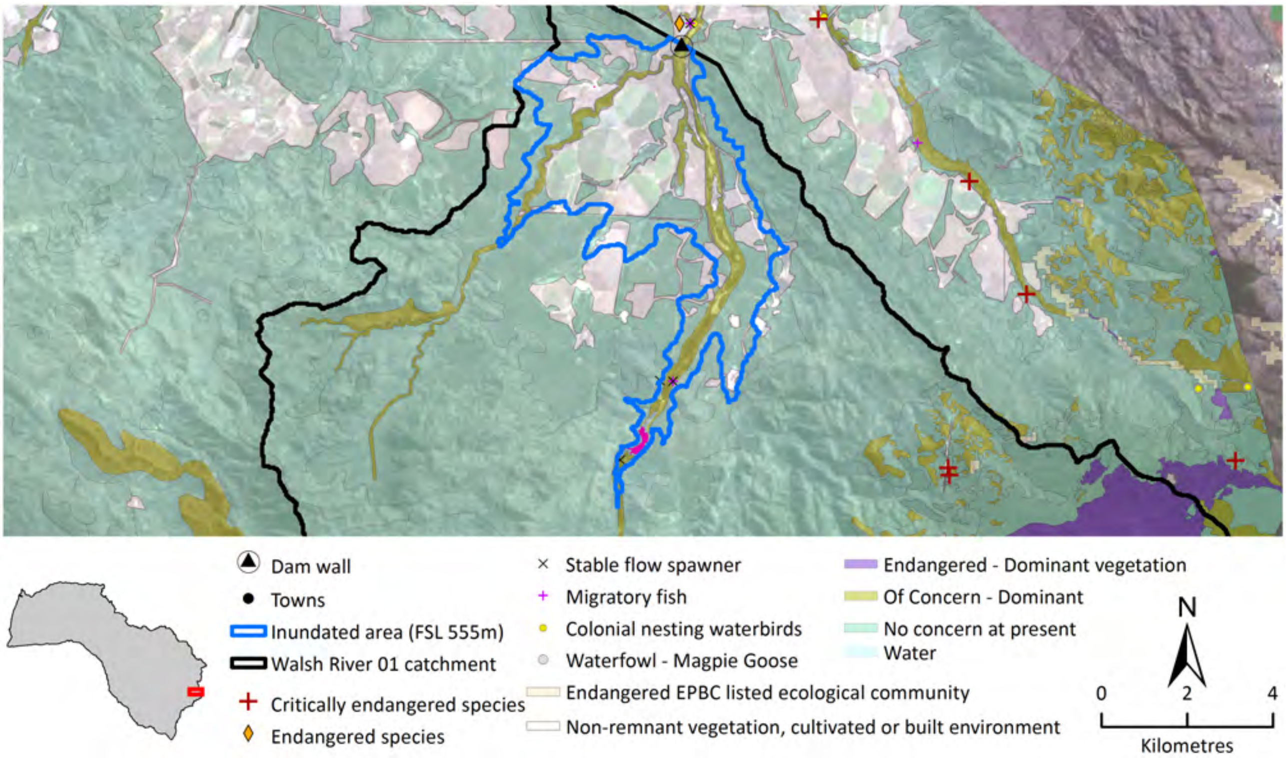
Apx Figure B-26 Location map of Nullinga dam site on the Walsh River, reservoir extent and catchment area



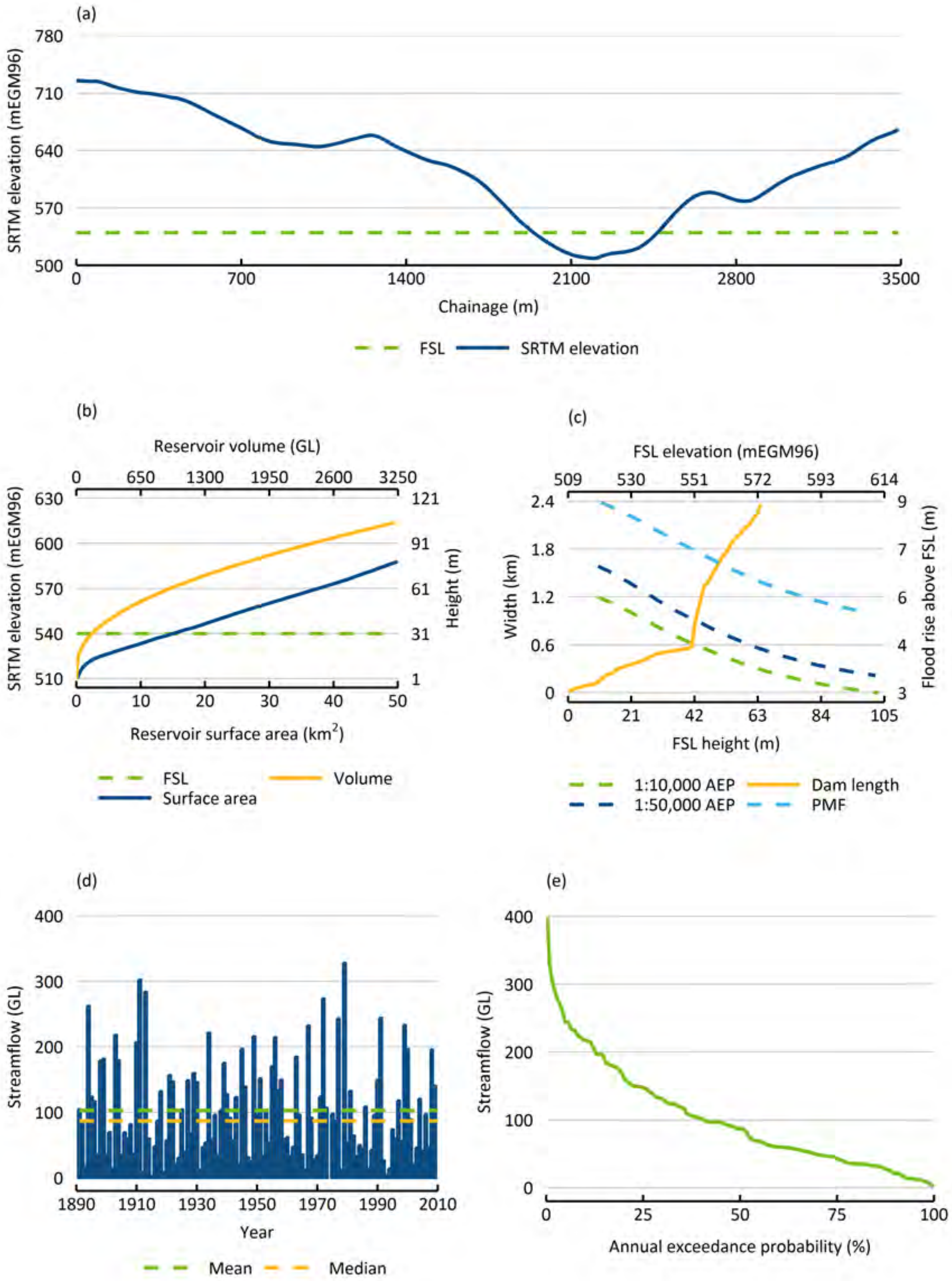
Apx Figure B-27 Nullinga dam site on the Walsh River reservoir extent and property boundaries



Apx Figure B-28 Geology underlying the Nullinga dam site on the Walsh River dam site and reservoir

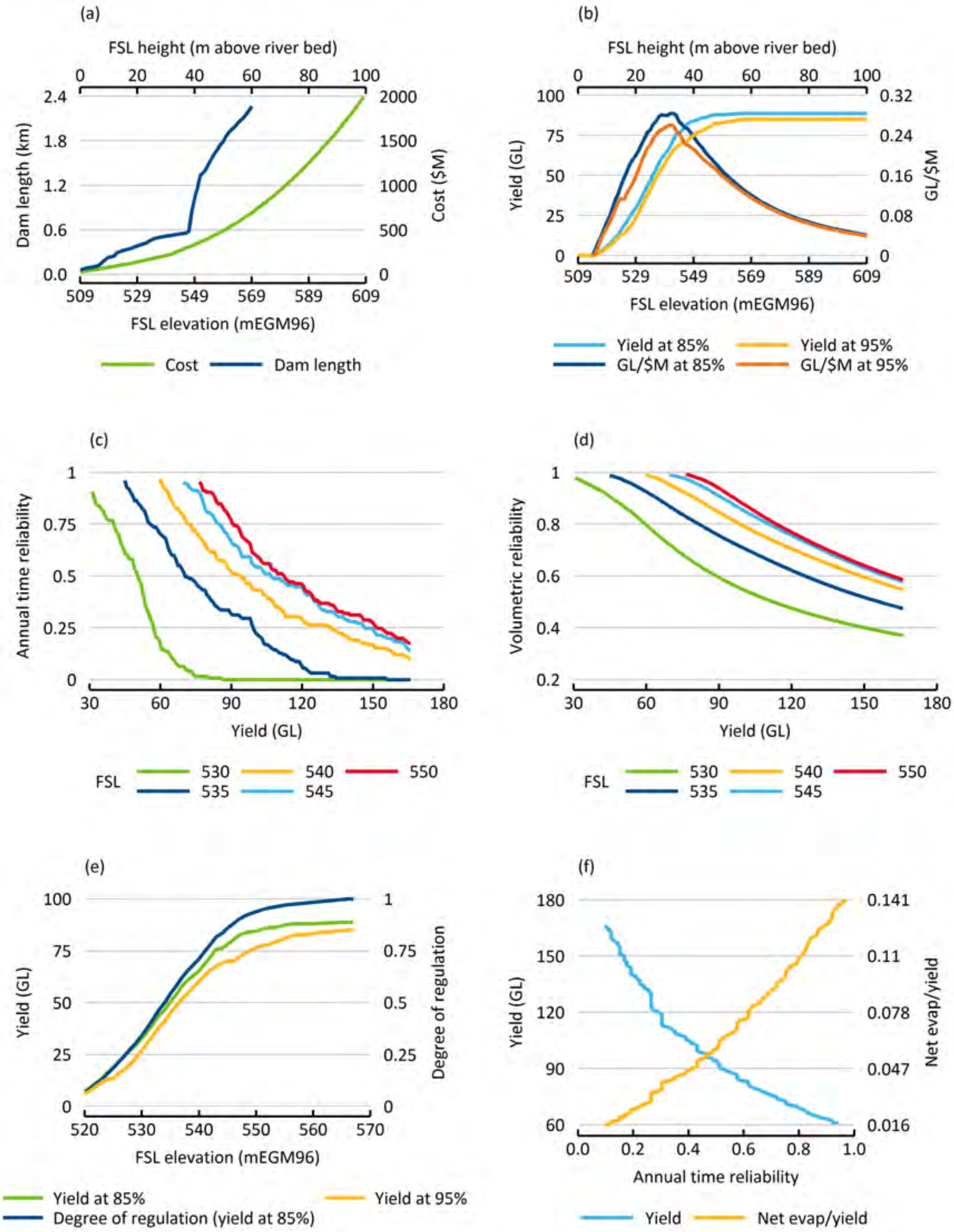


Apx Figure B-29 Regional ecosystem mapping and reservoir extent of the Nullinga dam site on the Walsh River and known water-dependent ecological assets



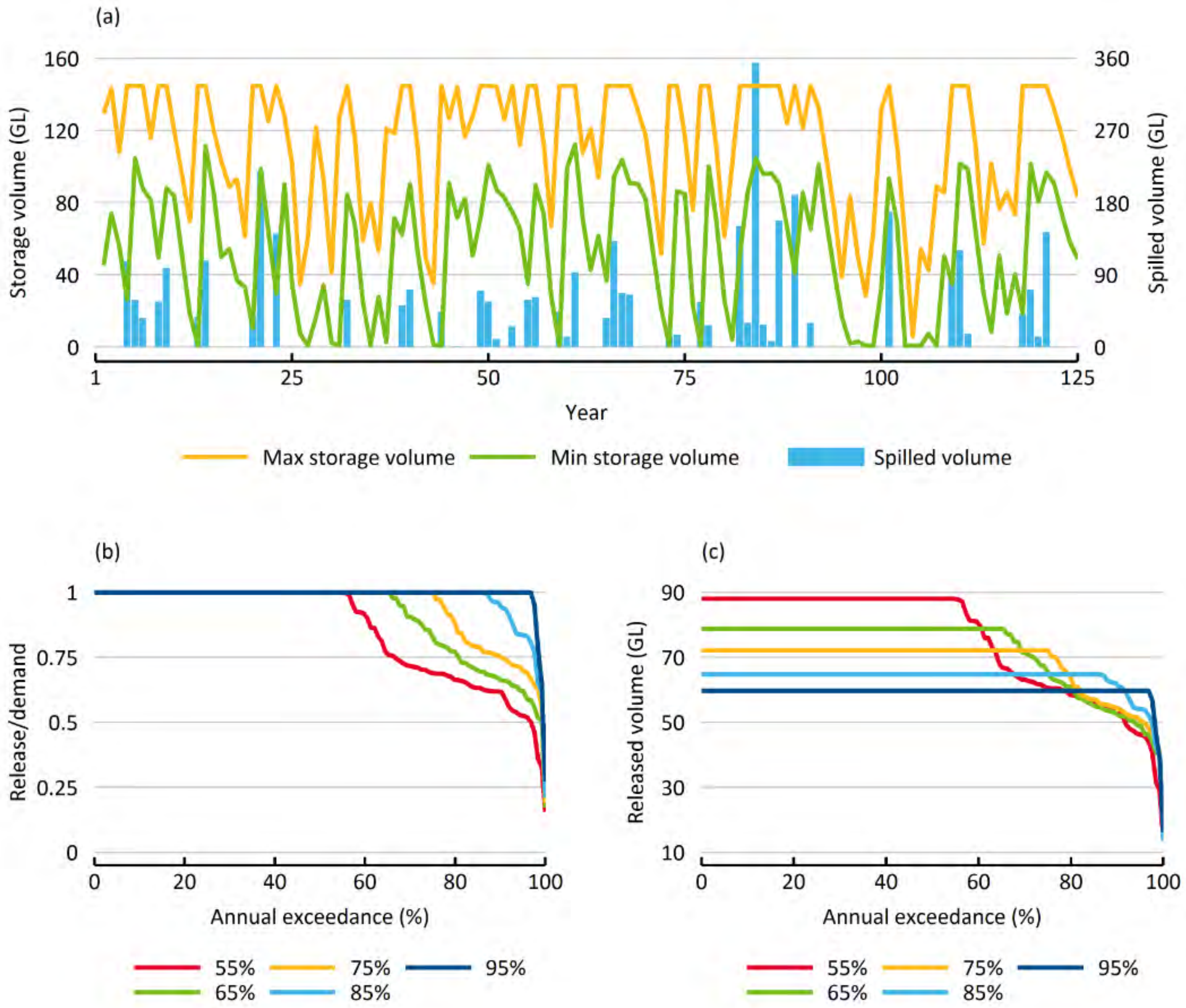
Apx Figure B-30 Nullinga potential dam site on the Walsh River topographic dimensions and inflow hydrology

(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 events plotted against FSL; (d) annual streamflow; (e) annual flow exceedance.



Apx Figure B-31 Nullinga potential dam site on the Walsh River cost, yield at the dam wall and evaporation

(a) Dam length and dam cost versus FSL; (b) dam yield at 85% and 95% annual time reliability and yield per $ million at 85% and 95% 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 85% and 95% 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-32 Nullinga potential dam site on the Walsh River storage levels and yield

(a) Maximum and minimum annual storage trace at the selected FSL (FSL, 540 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

B.1.5 LAKE MITCHELL DAM ON THE MITCHELL RIVER; AMTD 597.2 KM

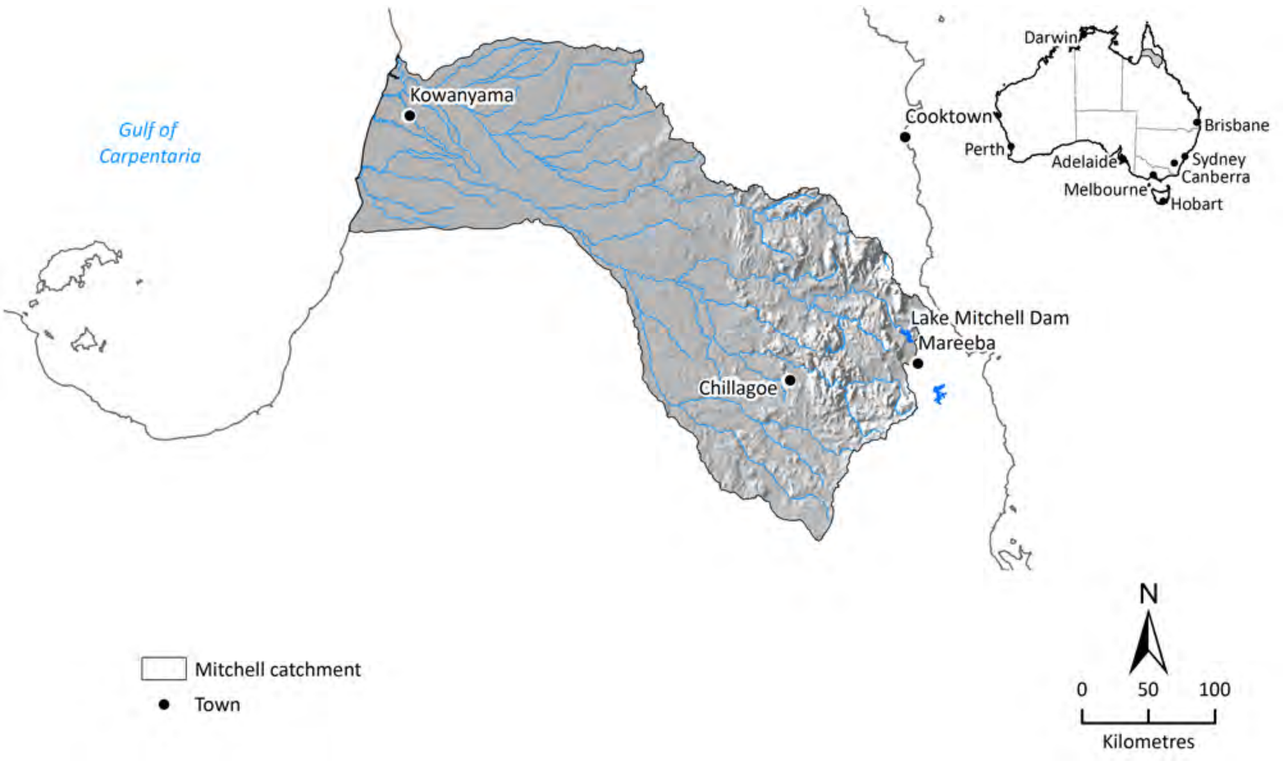
PARAMETER	DESCRIPTION
Background	Lake Mitchell Dam, which is also known as Southedge Dam and as Quaid's Dam, is a privately-developed dam located approximately 27 km north-northwest of Mareeba in far north Queensland. The dam was completed in 1987. The dam's owners are the Southedge Daintree Pastoral Company and the Weymouth Pastoral Company. No use has been made of the dam since its completion. It is understood that its intended use was to support commercial and residential development with associated recreation. A further dam on the Mitchell River, Northedge dam, with a capacity of 275 GL, has been previously proposed. If developed, the reservoir associated with this dam would back up close to the toe of Lake Mitchell Dam. **The following figures accompany this description of the site** The Lake Mitchell Dam is shown in Apx Figure B-33. Apx Figure B-34 provides a map showing its location in the Mitchell catchment, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Site topography and dam hydrology are shown in Apx Figure B-35 and Apx Figure B-36. **References** Register of large dams in Queensland. Australian National Committee on Large Dams. Various technical reports held by Dam Safety, Department of Energy and Water Supply, Queensland.
Regional geology	The dam and reservoir area are located in a geological province known as the Mossman Orogen, which is an area of folded and faulted sedimentary, metamorphic and igneous rocks of Silurian to Permian age. Most of the reservoir area is residual soil, colluvium and alluvium of Tertiary and Quaternary age.
Site geology	The existing dam is located on a north-trending section of the Mitchell River. There is a saddle dam on the right bank of the reservoir. CSIRO has not reviewed any information on the design and construction of the dam but it appears likely that parts of the dams may be founded on alluvium, colluvium and residual soils that overlie the rock.
Reservoir rim stability and leakage potential	Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. Given the lack of soluble rocks in the storage area and the lack of narrow, low, steep-sided saddles, reservoir leakage is unlikely to be a significant issue provided the dam foundations are grouted.
Structural arrangement	The main cross-river embankment is an earthfill embankment 16.5 metres high and 530 m long with riprap protection on the upstream face and grass protection on the downstream face. A vertical sand chimney filter connects to a blanket drain to the downstream toe. A secondary embankment is also of earthfill construction and is 1150 m long. The outlet is a 1.8 m × 1.5 m cast in-situ reinforced concrete box conduit under the dam controlled by an upstream vertical slide gate. The control structure does not appear to have any trash rack or bulkhead gate provisions. Two spillways are located on the left bank abutment, Spillway A with a concrete control slab, the other, Spillway B, with a low rockfill embankment control set at a higher level than Spillway A. The discharge channels of both spillways back to the Mitchell River are unlined. The dam has an outlet to the river, which is a reinforced concrete conduit under the main embankment controlled by a vertical upstream slide gate. It is unknown whether it is operational and reliable. Photographs of the dam suggest that there may not be trash racks or bulkhead gate provisions.

PARAMETER	DESCRIPTION
Source of construction materials	Earthfill for embankment construction was sourced from a number of borrow areas mainly upstream of the embankments.
Catchment area	Catchment area at the site is 321 km^2.
Flow data	The nearest gauging station to the dam on the Mitchell River is GS 919003A Mitchell River at OK Bridge. This station is at AMTD 408.8 km and has a much larger catchment area of 7724 km^2 than that of Lake Mitchell Dam. GS 919005, Fonthill on Rifle Creek (a tributary of the Mitchell River) at AMTD 5.2 km has a similar catchment area to that at the dam, 366 km^2, and the flow record would be indicative of that experienced at the dam prior to its construction. Summary flow volumes at the Fonthill gauge are as follows: Maximum annual flow volume 754 GL Mean annual flow volume 209 GL Medium annual flow volume 188 GL Minimum annual flow volume 20 ML
Storage capacity	Storage capacity of Lake Mitchell Dam is 159 GL.
Reservoir yield at dam wall	As above, it is understood that its intended use was to support commercial and residential development with associated recreation and as such, a potential supply yield has not previously been estimated. The Mitchell water plan, however, provides for a reserve volume of 20 GL/y in the Mitchell River section upstream of the Rifle Creek junction, which includes the dam storage. The reliability of any such supply would be highly dependent on whether it was accessed from the dam or from run of river flows not supplemented by the dam. At the FSL 387 mEMG96 the Assessment calculated the reservoir has a potential yield in 85% of years of 46.2 GL at the dam wall.
Open water evaporation	The storage inundation area at FSL (387 mEMG96) is 3546 ha. Mean annual evaporation and mean annual net evaporation at FSL 387 mEMG96 at 85% annual reliability is 29.3 GL and 12.9 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.293.
Potential use of supply	**Agriculture** Soils are dominated by mottled yellow hard-setting loamy surfaced sodic texture contrast soils (Sodosols) on the alluvial plains with minor areas of alluvial soils on levees and prior streams. These Sodosols are similar to the alluvial plains lower in the catchment with similar suitability for sugarcane, dry-season grain and forage crops. These areas receive higher rainfall than the lower catchment and are subject to seasonal wetness. The lower slopes and pediments derived from the Hodgkinson Formation adjacent to the alluvial plains have very hard-setting loamy surfaced mottled Sodosols very prone to gully erosion and not recommended for cropping. If the Lake Mitchell Dam owners agreed to supply water at a comparable price to that currently charged by SunWater it is technically feasible that water could be pumped to the MDWSS areas around Mareeba. **Residential/commercial** It is understood that its intended use was to support commercial and residential development with associated recreation

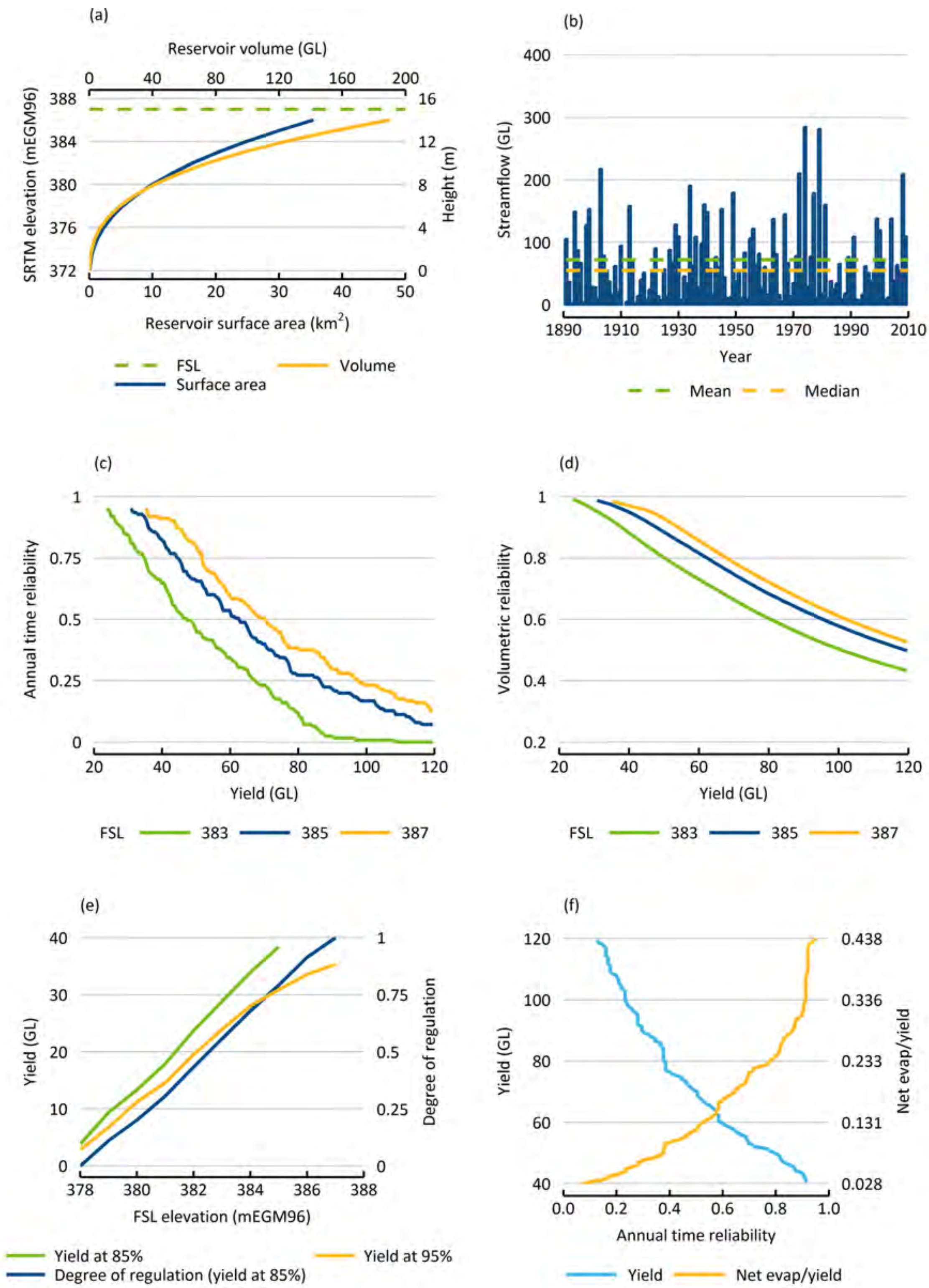
Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)	0.0	0.5	0.5
	100 years (%)	0.1	1.7	1.8
	Years to fill	76,730	7,160	5,525

PARAMETER	DESCRIPTION
Storage impacts	Existing dam. The land inundated by the storage was owned by the developer prior to construction of the dam.
Cost	The cost of the dam to the developer is not known.
Cost/ML of supply	Original cost is not known.
Summary comment	Lake Mitchell Dam is an existing privately-owned development on the headwaters of the Mitchell River. Originally intended to support commercial and residential development with associated recreation, the dam has never been used. There are small areas of soil downstream that could be used for irrigation development. If the Lake Mitchell Dam owners agreed to supply water at a price comparable to that charged by SunWater it is technically feasible that water could be pumped from Lake Mitchell to parts of the MDWSS near Mareeba. The existing Water Plan provides for a general reserve volume of 20 GL/y in the Mitchell River section upstream of the Rifle Creek junction, which includes the dam.

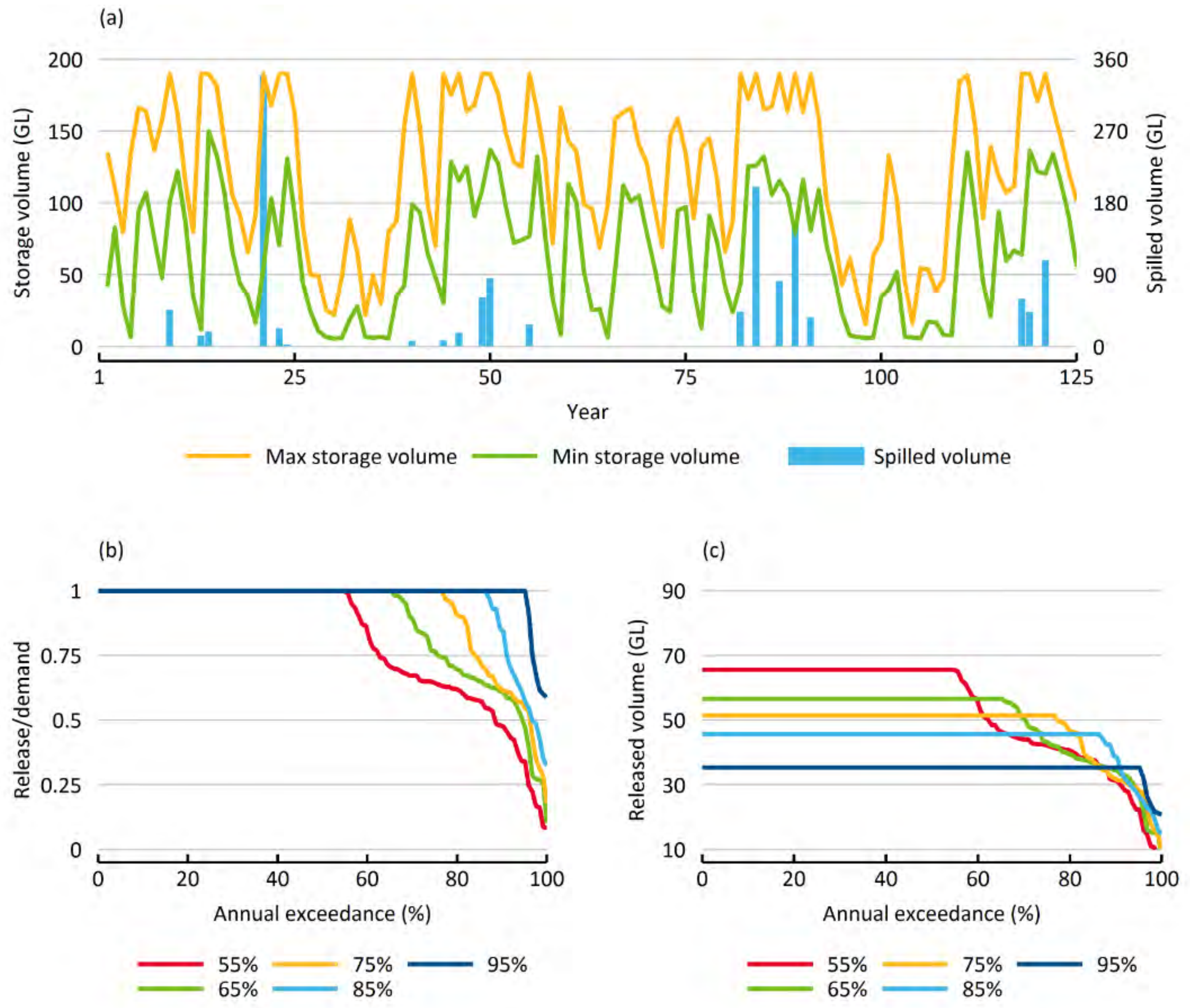
Apx Figure B-33 Lake Mitchell Dam looking downstream



Apx Figure B-34 Location map of Lake Mitchell Dam, reservoir extent and catchment area



Apx Figure B-35 Lake Mitchell topographic dimensions, inflow hydrology and yield
(a) Reservoir volume, surface area and height relationship; (b) annual streamflow; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% 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-36 Lake Mitchell storage levels and yield

(a) Maximum and minimum annual storage trace at the selected FSL (FSL, 387 mEMG96) 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, 65, 75, 85 and 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, 65, 75, 85 and 95% of years at the selected FSL.

Appendix C Detailed costing for the short-listed potential dam sites in the Darwin catchments

C.1.1 MOUNT BENNETT DAM SITE ON THE FINNISS RIVER; AMTD 80.0 KM

Apx Table C-1 Mount Bennett dam site on the Finniss River – direct construction costs

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
General				
Environmental management	lump sum			400,000
Cultural heritage management	lump sum			500,000
Community consultation	lump sum			200,000
				-
Mobilisation and demobilisation				-
Establishment of workforce accommodation	lump sum			3,500,000
Establishment of survey control	lump sum			300,000
Establish construction power supply	lump sum			-
Establish communications	lump sum			200,000
Mobilisation of major plant	lump sum			3,000,000
Demobilisation of major plant	lump sum			750,000
Demobilisation of workforce accommodation	lump sum			1,400,000
Clear site and 50% of storage area	ha	3,200	1,900	6,080,000
Mobilise/demobilise site laboratory	lump sum			350,000
				-
Access				-
Access road to site from the Mt Finnis road	km	17	700,000	11,900,000
Establish site access roads	lump sum			2,000,000
Rehabilitation of roads on construction completion	lump sum			650,000
Road relocations in storage area	km			-
				-
Construction				-
Material sources				-
Remove quarry overburden	lump sum			300,000
Develop quarry	lump sum			450,000
Access road to quarry	km	2	500,000	1,000,000
Access road to sand gravel sources	km	6	500,000	3,000,000
				-

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Diversion and care of river				-
Excavate RB diversion channel (rock)	cu m	12,000	70	840,000
Excavation for coffer dams	cu m	25,000	16	400,000
Place material for coffer dams	cu m	39,000	28	1,092,000
Dewatering	lump sum			200,000
Divert river	lump sum			200,000
Removal of coffer dams	cu m	14,000	16	224,000
Foundations cross river section				-
Excavate sand from river bed	cu m	4,800	10	48,000
Excavate rock from abutments	cu m	61,370	38	2,332,060
Detailed excavation	cu m	615	200	123,000
Detailed clean up	sq m	8,550	100	855,000
Dental concrete	cu m	615	480	295,200
				-
Foundation grouting cross river section				-
Concrete to grouting plinth	cu m	450	520	234,000
Reinforcement to grout plinth	tonne	18	5,750	103,500
Drill grout holes	m	2,210	115	254,150
Supply and install standpipes	no	215	140	30,100
Hook ups and pressure tests	no	215	370	79,550
Pressure grouting	bags	4,620	40	184,800
RCC dam river section				
Mobilise RCC placement plant	lump sum			2,250,000
Demobilise RCC placement plant	lump sum			630,000
Trial mixes	lump sum			250,000
RCC backfill to river bed below dam spillway and apron	cu m	16,000	230	3,680,000
Conventional concrete to faces	cu m	5,510	510	2,810,100
RCC concrete to dam wall	cu m	41,150	280	11,522,000
Gallery floor units and precast slabs	m	170	2900	493,000
Conventional concrete to spillway crest	cu m	1,335	520	694,200
Reinforcement to spillway crest	tonne	54	7,250	391,500
Conventional concrete to spillway crest	cu m	2,250	400	900,000
Reinforcement to spillway apron	tonne	90	7,000	630,000
Conventional concrete to end sill	cu m	250	700	175,000
Reinforcement to end sill	tonne	10	8,200	82,000
Drill-holes for apron anchors	m	2,400	70	168,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Supply and install apron anchors	tonnes	19	7,500	142,500
Conventional concrete to training walls	cu m	800	650	520,000
Reinforcement to training walls	tonne	40	8,000	320,000
Drill drainage holes	m	1,800	120	216,000
Water stops – supply and install	m	340	50	17,000
Backfill on abutments	cu m	6,350	30	190,500
Instrumentation HW/TW recorders etc.	lump sum			230,000
Miscellaneous metalwork	lump sum			115,000
Outlet works				-
Intake tower concrete	cu m	504	900	453,600
Intake tower reinforcement	tonne	30	6,900	207,000
Intake tower guides and seals	tonne	12	16,000	192,000
Trashracks	tonne	21	16,000	336,000
Selective withdrawal baulks	tonne	27	14,000	378,000
Bulkhead gate	tonne	15	12,000	180,000
Hoist crane, install and commission	lump sum			225,000
Ladders and platforms	lump sum			80,000
Supply and install outlet conduit 2.4 m 12 pl	tonne		12,000	-
Outlet conduits concrete encasement	cu m	150	400	60,000
Outlet conduits concrete reinforcement	tonne	8	5,000	40,000
Outlet works concrete	cu m	150	900	135,000
Reinforcement to outlet works	tonne	9	7,000	63,000
Outlet works pipework	lump sum			250,000
Butterfly valves and actuators	no	2	370,000	740,000
Fixed cone regulating valves	no	2	425,000	850,000
Outlet works hoist crane	lump sum			300,000
Miscellaneous metalwork	lump sum			200,000
Electrical installations	lump sum			300,000
				-
Fish transfer facility				**-**
Concrete to intake channels, hopper chamber and valve pit	cu m	500	900	450,000
Reinforcement to intake channels, hopper chamber and valve pit	tonne	25	7,000	175,000
Fish attraction pipework, valves and diffusers	lump sum			500,000
Fish traps	lump sum			250,000
Fish lift hopper	no			250,000
Hopper tracks	lump sum			250,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Overhead crane at crest	lump sum			300,000
Monitoring equipment	lump sum			350,000
Electrical and mechanical installations	lump sum			250,000
Fish lift commissioning	lump sum			300,000
Breakneck Pass Saddle Dam				
Foundation excavation	cu m	44,200	25	1,105,000
Drill grout holes	m	1,005	115	115,575
Supply and install standpipes	no	106	140	14,840
Hook ups and pressure tests	no	106	370	39,220
Pressure grouting	bags	2,100	40	84,000
Foundation clean up and treatment	sq m	1,580	115	181,700
Place Zone 1 core material	cu m	15,800	25	395,000
Place Zone 2A and 2B filter materials	cu m	24,500	30	735,000
Place Zone 3 rockfill material	cu m	78,600	30	2,358,000
Place Zone 3B upstream face	cu m	7,000	35	245,000
Left Bank Saddle Dam No 1				
Foundation excavation	cu m	58,000	25	1,450,000
Drill grout holes	m	5,900	115	678,500
Supply and install standpipes	no	675	140	94,500
Hook ups and pressure tests	no	675	370	249,750
Pressure grouting	bags	12,000	40	480,000
Foundation clean up and treatment	sq m	4,000	115	460,000
Place Zone 1 core material	cu m	67,200	25	1,680,000
Place Zone 2A and 2B filter materials	cu m	86,300	28	2,416,400
Place Zone 3 rockfill material	cu m	95,600	28	2,676,800
Place Zone 3B upstream face	cu m	25,900	33	854,700
Left Bank Saddle Dam No 2				
Foundation excavation	cu m	5,900	30	177,000
Miscellaneous fill	cu m	8,400	25	210,000
Place Zone 3B upstream face	cu m	2,300	35	80,500
Left Bank Saddle Dam No 3				
Foundation excavation	cu m	3,500	30	105,000
Miscellaneous fill	cu m	2,400	30	72,000
Place Zone 3B upstream face	cu m	1,000	30	30,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
				-
Left Bank Saddle Dam No 4	lump sum			20,000
				-
Permanent downstream access crossing	lump sum			1,500,000
				-
Total direct construction costs (TDC)				**96,475,245**

Apx Table C-2 Mount Bennett dam site on the Finniss River – on-site overheads costs

ON-SITE OVERHEADS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Project and field staff	lump sum	3% of TDC		2,894,257
Staff recruitment and training	lump sum	0.6% of TDC		578,851
Camp operations	lump sum	3.5% of TDC		3,376,634
Site office expenses	lump sum	0.6% of TDC		578,851
Site water and power expenses	lump sum	0.1% of TDC		96,475
Site communication, IT expenses	lump sum	0.45% of TDC		434,139
Site cleaning, rubbish removal	lump sum	0.04% of TDC		38,590
Project control testing	lump sum			900,000
Misc. travel expenses	lump sum	0.2% of TDC		192,950
Insurances, public liability	lump sum	3.4% OF TDC		3,280,158
Total on-site overheads (OSO)				**12,370,907**
Total direct and on-site overhead costs				**108,846,152**
Profit and off-site overheads 10% of TDC and OSO				**10,884,615**
Total out turn costs (TOC)				**119,730,767**

Apx Table C-3 Mount Bennett dam site on the Finniss River – owner costs

OWNER COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Investigation and design				
Preliminary design	lump sum	0.5% of TDC		482,376
Geotechnical and materials	lump sum	2.0% of TDC		1,929,505
Hydraulic model study	lump sum			300,000
Detailed design and documentation	lump sum	2.5% of TDC		2,411,881
Acquisition and approvals				
Environmental assessment and approvals	lump sum			3,000,000
Cultural heritage	lump sum			3,000,000
Native title	lump sum			1,000,000
Storage area acquisition	ha	8,800	1,000	8,800,000
Storage area access relocations	lump sum			-
Surveys and legal	lump sum			750,000
Permanent on-site buildings and services	lump sum			-
Principal's insurances (1.1% of TOC)	lump sum			1,317,038
Owner's management and supervision (0.15% of TOC)	lump sum			179,596
Total owner costs				**23,170,397**
TOTAL PROJECT COSTS (TPC)				**142,901,164**
Risk adjustment				**47,157,384**
TOTAL CAPITAL COST				**$190 million**

C.1.2 UPPER ADELAIDE RIVER DAM SITE ON THE ADELAIDE RIVER; AMTD 199.2 KM

Apx Table C-4 Upper Adelaide River dam site on the Adelaide River – direct construction costs

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
General				
Environmental management	lump sum			350,000
Cultural heritage management	lump sum			600,000
Community consultation	lump sum			200,000
Mobilisation and demobilisation				
Establishment of workforce accommodation	lump sum			3,000,000
Establishment of survey control	lump sum			250,000
Establish construction (and permanent) power supply	lump sum			
Establish communications	lump sum			150,000
Mobilisation of major plant	lump sum			3,000,000
Demobilisation of major plant	lump sum			750,000
Demobilisation of workforce accommodation	lump sum			1,200,000
Clear site and 50% of storage area	ha	2,000	2,000	4,000,000
Mobilise/demobilise site laboratory	lump sum			250,000
Access				
Access road to site from Stuart Highway	km	3.5	800,000	2,800,000
Establish site access roads	lump sum			1,500,000
Rehabilitation of roads on construction completion	lump sum			500,000
Construction				
Material sources				
Remove quarry overburden	lump sum			300,000
Develop quarry	lump sum			450,000
Access road to quarry	km	2	500,000	1,000,000
Access road to sand gravel sources	km	4	500,000	2,000,000
Diversion and care of river				
Excavate LB diversion channel (rock)	cu m	13,500	60	810,000
Excavation for coffer dams	cu m	32,000	16	512,000
Place material for coffer dams	cu m	40,000	28	1,120,000
Dewatering	lump sum			250,000
Divert river	lump sum			250,000
Removal of coffer dams	cu m	8,000	16	128,000
Foundations cross river section				

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Excavate sand from river bed	cu m	9,000	10	90,000
Excavate rock from abutments	cu m	216,950	35	7,593,250
Detailed excavation	cu m	2,170	200	434,000
Detailed clean up	sq m	29,600	100	2,960,000
Dental concrete	cu m	2,170	450	976,500
Foundation grouting cross river section				
Concrete to grouting plinth	cu m	450	520	234,000
Reinforcement to grout plinth	tonne	18	5,750	103,500
Drill grout holes	m	3,590	115	412,850
Supply and install standpipes	no	217	140	30,380
Hook ups and pressure tests	no	330	370	122,100
Pressure grouting	bags	7,500	40	300,000
RCC dam river section				
Mobilise RCC placement plant	lump sum			2,750,000
Demobilise RCC placement plant	lump sum			770,000
Trial mixes	lump sum			300,000
RCC backfill to river bed below dam spillway and apron	cu m	9,330	225	2,099,250
Conventional concrete to faces	cu m	8,970	510	4,574,700
RCC concrete to dam wall	cu m	106,120	260	27,591,200
Gallery floor units and precast slabs	m	200	2900	580,000
Conventional concrete to spillway crest	cu m	1,600	520	832,000
Reinforcement to spillway crest	tonne	64	7,250	464,000
Conventional concrete to spillway crest	cu m	3,240	400	1,296,000
Reinforcement to spillway apron	tonne	130	7,000	910,000
Conventional concrete to end sill	cu m	290	700	203,000
Reinforcement to end sill	tonne	11.6	8,200	95,120
Drill-holes for apron anchors	m	3,460	70	242,200
Supply and install apron anchors	tonnes	27	7,500	202,500
Conventional concrete to training walls	cu m	1,420	650	923,000
Reinforcement to training walls	tonne	71	8,000	568,000
Drill drainage holes	m	3,015	120	361,800
Water stops – supply and install	m	340	50	17,000
Backfill on abutments	cu m	6,290	30	188,700
Instrumentation HW/TW recorders etc.	lump sum			230,000
Miscellaneous metalwork	lump sum			115,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Outlet works				
Intake tower concrete	cu m	610	900	549,000
Intake tower reinforcement	tonne	37	6,900	255,300
Intake tower guides and seals	tonne	20	16,000	320,000
Trashracks	tonne	25	16,000	400,000
Selective withdrawal baulks	tonne	30	14,000	420,000
Bulkhead gate	tonne	16	12,000	192,000
Hoist crane, install and commission	lump sum			160,000
Ladders and platforms	lump sum			100,000
Supply and install outlet conduit 1500 mm 12 pl	tonne	28	12,000	336,000
Outlet conduits concrete encasement	cu m	338	400	135,200
Outlet conduits concrete reinforcement	tonne	17	5,000	85,000
Concrete to outlet works	cu m	150	900	135,000
Reinforcement to outlet works	tonne	9	7,000	63,000
Outlet works pipework	lump sum			250,000
Butterfly valves and actuators	no	2	275,000	550,000
Fixed cone regulating valves	no	2	315,000	630,000
Outlet works hoist crane	lump sum			300,000
Miscellaneous metalwork	lump sum			200,000
Electrical installations	lump sum			300,000
Fish transfer facility				
Concrete to intake channels, hopper chamber and valve pit	cu m	500	900	450,000
Reinforcement to intake channels, hopper chamber and valve pit	tonne	25	7,000	175,000
Fish attraction pipework, valves and diffusers	lump sum			500,000
Fish traps	lump sum			250,000
Fish lift hopper	no			250,000
Hopper tracks	lump sum			350,000
Overhead crane at crest	lump sum			300,000
Monitoring equipment	lump sum			350,000
Electrical and mechanical installations	lump sum			250,000
Fish lift commissioning	lump sum			300,000
Right Bank Saddle Dam				
Foundation excavation	cu m	3,070	30	92,100
Place miscellaneous fill	cu m	5,525	25	138,125
Place Zone 3B upstream face	cu m	1,500	35	52,500

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Permanent downstream access crossing	lump sum			2,000,000
Total direct construction costs				**94,778,275**

Apx Table C-5 Upper Adelaide River dam site on the Adelaide River – on-site overheads costs

ON-SITE OVERHEADS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Project and field staff	lump sum	3% of TDC		2,843,348
Staff recruitment and training	lump sum	0.6% of TDC		568,670
Camp operations	lump sum	3.5% of TDC		3,317,240
Site office expenses	lump sum	0.6% of TDC		568,670
Site water and power expenses	lump sum	0.1% of TDC		94,778
Site communication, IT expenses	lump sum	0.45% of TDC		426,502
Site cleaning, rubbish removal	lump sum	0.04% of TDC		37,911
Project control testing	lump sum			900,000
Misc. travel expenses	lump sum	0.2% of TDC		189,557
Insurances, public liability	lump sum	3.4% OF TDC		3,222,461
Total on-site overheads				**12,169,137**
Total direct and on-site overhead costs				**106,947,412**
Profit and off-site overheads 10% of TDC and OSO				**10,694,741**
Total out turn costs (TOC)				**117,642,153**

Apx Table C-6 Upper Adelaide River dam site on the Adelaide River – owner costs

OWNER COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Investigation and design				
Preliminary design	lump sum	0.5% of TDC		588,211
Geotechnical and materials	lump sum	2.0% of TDC		2,352,843
Hydraulic model study	lump sum			350,000
Detailed design and documentation	lump sum	2.5% of TDC		2,941,054
Acquisition and approvals				
Environmental assessment and approvals	lump sum			3,000,000
Cultural heritage	lump sum			3,000,000
Native title	lump sum			1,000,000
Storage area acquisition	ha	4,700	500	2,350,000
Storage area access relocations	lump sum			500,000
Surveys and legals	lump sum			600,000
Permanent on-site buildings and services	lump sum			1,000,000
Principal's insurances (1.1% of TOC)	lump sum			1,294,064
Owner's management and supervision (0.15% of TOC)	lump sum			176,463
Total owner costs				**19,152,635**
TOTAL PROJECT COSTS (TPC)				**136,794,788**
Risk adjustment				**45,142,280**
TOTAL CAPITAL COST				**$182 million**

Appendix D Detailed costings for the short-listed potential dam sites in the Mitchell catchments

D.1.1 ELIZABETH CREEK DAM SITE ON ELIZABETH CREEK; AMTD 37.2 KM

Apx Table D-1 Elizabeth Creek dam site on Elizabeth Creek – direct construction costs

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
General				
Environmental management	lump sum			400,000
Cultural heritage management	lump sum			350,000
Community consultation	lump sum			100,000
Mobilisation and demobilisation				
Establishment of workforce accommodation	lump sum			3,000,000
Establishment of survey control	lump sum			200,000
Establish construction power supply (temporary)	lump sum			2,250,000
Establish communications	lump sum			250,000
Mobilisation of major plant	lump sum			2,500,000
Demobilisation of major plant	lump sum			625,000
Demobilisation of workforce accommodation	lump sum			1,200,000
Clear site and 50% of storage area	ha	760	2,000	1,520,000
Mobilise/demobilise site laboratory	lump sum			250,000
Access				
Access road to site from Burke Development Road	km	15	700,000	10,500,000
Establish site access roads	lump sum			1,000,000
Rehabilitation of roads on construction completion	lump sum			330,000
Road relocations in storage area	km			
CONSTRUCTION				
Material sources				
Remove quarry overburden	lump sum			200,000
Develop quarry	lump sum			350,000
Access road to quarry	km	2	400,000	800,000
Access road to sand gravel sources	km	4	400,000	1,600,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
RIVER DAM WALL				
Diversion and care of river				
Excavate diversion channel (rock)	cu m	13,000	60	780,000
Excavation for coffer dams	cu m	24,000	16	384,000
Place material for coffer dams	cu m	39,000	28	1,092,000
Dewatering	lump sum			150,000
Divert river	lump sum			200,000
Removal of coffer dams	cu m	15,000	16	240,000
Foundations				
Excavate sand from river bed	cu m	4,200	10	42,000
Excavate rock from abutments	cu m	49,200	38	1,870,000
Detailed excavation	cu m	490	200	98,000
Detailed clean up	sq m	12,640	100	1,264,000
Dental concrete	cu m	490	480	235,000
Foundation grouting				
Concrete to grouting plinth	cu m	495	540	267,000
Reinforcement to grout plinth	tonne	20	6,000	120,000
Drill and grout holes	m	4,390	120	527,000
Supply and install standpipes	no	228	140	32,000
Hook ups and pressure tests	no	550	140	77,000
Pressure grouting	bags	9,220	45	415,000
RCC dam				
Mobilise RCC placement plant	lump sum			2,750,000
Demobilise RCC placement plant	lump sum			775,000
Trial mixes	lump sum			250,000
Conventional concrete to faces	cu m	12,090	510	6,166,000
RCC concrete to dam wall	cu m	145,310	260	37,780,000
Gallery floor units and precast slabs	m	250	2900	725,000
Conventional concrete to spillway crest	cu m	1,800	520	936,000
Reinforcement to spillway crest	tonne	72	7,250	522,000
Conventional concrete to spillway crest	cu m	2,250	390	877,000
Reinforcement to spillway apron	tonne	90	6,900	621,000
Conventional concrete to end sill	cu m	260	680	177,000
Reinforcement to end sill	tonne	10	8,000	80,000
Drill-holes for apron anchors	m	2,730	70	191,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Supply and install apron anchors	tonnes	22	7,500	165,000
Conventional concrete to training walls	cu m	1,395	650	907,000
Reinforcement to training walls	tonne	70	8,000	560,000
Drill drainage holes	m	4,200	120	504,000
Water stops – supply and install	m	394	50	20,000
Backfill on abutments	cu m	7,400	30	222,000
Instrumentation HW/TW recorders etc.	lump sum			230,000
Miscellaneous metalwork	lump sum			115,000
Outlet works				
Intake tower concrete	cu m	620	900	558,000
Intake tower reinforcement	tonne	38	6,900	262,000
Intake tower guides and seals	tonne	20	16,000	320,000
Trashracks	tonne	20	16,000	320,000
Selective withdrawal baulks	tonne	26	14,000	364,000
Bulkhead gate	tonne	8	12,000	96,000
Hoist crane, install and commission	lump sum		160,000	
Ladders and platforms	lump sum			100,000
Supply and install 2 by DN 900 dia. conduits 8 mm plate MSCL pipes	tonne	11	12,000	132,000
Outlet conduits concrete encasement	cu m	160	400	64,000
Outlet conduits concrete reinforcement	tonne	8	5,000	40,000
Concrete to outlet works floor and walls	cu m	150	900	135,000
Reinforcement to outlet works	tonne	9	7,000	63,000
Outlet works pipework	lump sum			250,000
Butterfly valves and actuators 900 mm dia	no	2	175,000	300,000
Fixed cone regulating valves 750 mm dia.	no	2	200,000	400,000
Outlet works hoist crane				250,000
Electrical hydraulic installations	lump sum			300,000
Fish transfer facility				
Concrete to intake channels, hopper chamber and valve pit	cu m	500	900	450,000
Reinforcement to intake channels, hopper chamber and valve pit	tonne	25	7,000	175,000
Fish attraction pipework, valves and diffusers	lump sum			500,000
Fish traps	lump sum			250,000
Fish lift hopper	no			250,000
Hopper tracks	lump sum			425,000
Overhead crane at crest	lump sum			300,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Monitoring and control equipment	lump sum			350,000
Electrical and mechanical installations	lump sum			250,000
Fish lift commissioning	lump sum			300,000
Downstream access crossing	lump sum			**1,600,000**
Total direct construction costs (TDC)				**98,755,000**

Apx Table D-2 Elizabeth Creek dam site on Elizabeth Creek – on-site overhead costs

ON-SITE OVERHEADS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Project and field staff	lump sum	3% of TDC		2,962,650
Staff recruitment and training	lump sum	0.6% of TDC		592,530
Camp operations	lump sum	3.5% of TDC		3,456,425
Site office expenses	lump sum	0.6% of TDC		592,530
Site water services	lump sum	0.06% of TDC		59,253
Operating cost temporary power supply	lump sum			3,635,000
Site communication, IT expenses	lump sum	0.45% of TDC		444,398
Site cleaning, rubbish removal	lump sum	0.04% of TDC		39,502
Project control testing	lump sum			600,000
Misc. travel expenses	lump sum	0.2% of TDC		197,510
Insurances, public liability	lump sum	3.4% OF TDC		3,357,670
Total on-site overheads (OSO)				**15,937,468**
TDC and OSO costs				**114,692,468**
Profit and off-site overheads 10% of TDC and OSO				**11,469,247**
Total out turn costs (TOC)				**126,161,714**

Apx Table D-3 Elizabeth Creek dam site on Elizabeth Creek – owner costs

OWNER COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Investigation and design				
Preliminary design	lump sum	0.5% of TDC		493,775
Geotechnical and materials	lump sum	2.0% of TDC		1,975,100
Hydraulic model study	lump sum			400,000
Detailed design and documentation	lump sum	2.5% of TDC		2,468,875
Acquisition and approvals				
Environmental assessment and approvals	lump sum			2,500,000
Cultural heritage	lump sum			1,000,000
Native title	lump sum			350,000
Storage area acquisition	ha	1,865	100	186,000
Storage area access relocations	km	12	300,000	3,600,000
Surveys and legals	lump sum			500,000
Permanent on-site buildings and services	lump sum			500,000
Principal's insurances (1.1% of TOC)	lump sum			1,387,779
Owner’s management and supervision (0.15% of TOC)	lump sum			189,243
Total owner costs				**15,550,771**
TOTAL PROJECT COSTS (TPC)				**141,712,486**
Risk adjustment				**46,765,120**
TOTAL CAPITAL COST				**$189 million**

D.1.2 PINNACLES DAM SITE ON THE MITCHELL RIVER; AMTD 423.9 KM

Apx Table D-4 Pinnacles dam site on the Mitchell River – direct construction costs

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
General				
Environmental management	lump sum			600,000
Cultural heritage management	lump sum			600,000
Community consultation	lump sum			200,000
Mobilisation and demobilisation				
Establishment of workforce accommodation	lump sum			5,500,000
Establishment of survey control	lump sum			350,000
Establish construction power supply (temporary)	lump sum			2,900,000
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			2,200,000
Clear site and 50% of storage area	ha	7,300	1,600	11,680,000
Mobilise/demobilise site laboratory	lump sum			400,000
Access				
Access road to site – Bellevue Road upgrade	km	26.5	300,000	7,950,000
Access road to site – new road from Bellevue Road	km	15	700,000	10,500,000
Establish site access roads	lump sum			1,500,000
Rehabilitation of roads on construction completion	lump sum			500,000
Road relocations in storage area	km			
CONSTRUCTION				
Material sources				
Remove quarry overburden	lump sum			400,000
Develop quarry	lump sum			600,000
Access road to quarry	km	2	500,000	1,000,000
Access road to sand gravel sources	km	4	500,000	2,000,000
Access road to earthfill sources	km	2	350,000	700,000
RIVER DAM WALL				
Diversion and care of river				
Excavate diversion channel (rock)	cu m	91,000	45	4,095,000
Excavation for coffer dams	cu m	86,000	15	1,290,000
Place material for coffer dams	cu m	162,000	25	4,050,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Dewatering	lump sum			350,000
Divert river	lump sum			500,000
Removal of coffer dams	cu m	76,000	15	1,140,000
Foundations				
Excavate sand from river bed	cu m	18,700	9	168,000
Excavate rock from abutments	cu m	159,000	34	5,406,000
Detailed excavation	cu m	1,590	180	286,000
Detailed clean up	sq m	37,700	90	3,393,000
Dental concrete	cu m	1,590	450	715,000
Foundation grouting				
Concrete to grouting plinth	cu m	975	520	507,000
Reinforcement to grout plinth	tonne	40	5,750	230,000
Drill grout holes	m	12,648	110	1,391,000
Supply and install standpipes	no	435	130	57,000
Hook ups and pressure tests	no	1,445	130	188,000
Pressure grouting	bags	26,560	40	1,062,000
RCC dam				
Mobilise RCC placement plant	lump sum			4,250,000
Demobilise RCC placement plant	lump sum			1,200,000
Trial mixes	lump sum			400,000
Conventional concrete to faces	cu m	39,710	510	20,252,000
RCC concrete to dam wall	cu m	789,290	250	197,322,000
Gallery floor units and precast slabs	m	470	2900	1,363,000
Conventional concrete to spillway crest	cu m	2,420	520	1,258,000
Reinforcement to spillway crest	tonne	97	7,250	703,000
Conventional concrete to spillway crest	cu m	5,040	390	1,966,000
Reinforcement to spillway apron	tonne	202	6,900	1,394,000
Conventional concrete to end sill	cu m	410	680	279,000
Reinforcement to end sill	tonne	17	8,000	136,000
Drill-holes for apron anchors	m	5,376	70	376,000
Supply and install apron anchors	tonnes	42	7,500	315,000
Conventional concrete to training walls	cu m	3,350	600	2,010,000
Reinforcement to training walls	tonne	167	8,000	1,336,000
Drill drainage holes	m	12,560	115	1,444,000
Water stops – supply and install	m	875	45	39,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Backfill on abutments	cu m	16,300	30	489,000
Instrumentation HW/TW recorders etc.	lump sum			230,000
Miscellaneous metalwork	lump sum			115,000
RB retaining wall				
Foundation clean up	sq m	1,260	115	145,000
Conventional facing concrete	cu m	910	450	410,000
RCC concrete to wall	cu m	10,980	265	2,910,000
Outlet works				
Intake tower concrete	cu m	1,170	900	1,053,000
Intake tower guide columns	cu m	410	1,800	738,000
Intake tower reinforcement	tonne	80	6,900	552,000
Intake tower guides and seals	tonne	200	14,000	2,800,000
Trashracks	tonne	85	16,000	1,360,000
Selective withdrawal baulks	tonne	110	14,000	1,549,999
Wheeled bulkhead gate	tonne	25	16,000	400,000
Hoist crane, install and commission		lump sum		300,000
Ladders and platforms	lump sum			200,000
Form outlet sluices	sq m	1,060	200	212,000
Form access to sluice operating decks and shafts	sq m	900	200	180,000
Supply and install steel liner upstream of gates	tonnes	16	16,000	256,000
Install radial gate seating frames and trunnions	item	2	75,000	150,000
Supply and install radial gates	item	2	80,000	160,000
Hydraulic and electrical installations	lump sum			450,000
Outlet sluice dissipator concrete	cu m	1,340	600	804,000
Outlet sluice dissipator reinforcement	tonne	67	7,000	469,000
Fish transfer facility				
Concrete to intake channels, hopper chamber and valve pit	cu m	500	900	450,000
Reinforcement to intake channels, hopper chamber and valve pit	tonne	25	7,000	175,000
Fish attraction pipework, valves and diffusers	lump sum			500,000
Fish traps	lump sum			250,000
Fish lift hopper	no			250,000
Hopper tracks	lump sum			800,000
Overhead crane at crest	lump sum			300,000
Monitoring and control equipment	lump sum			350,000
Electrical and mechanical installations	lump sum			250,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Fish lift commissioning	lump sum			300,000
RB saddle dam				
Foundation excavation	cu m	262,300	22.5	5,902,000
Drill and grout holes	m	13,688	110	1,506,000
Supply and install standpipes	no	1,230	120	148,000
Hook ups and pressure tests	no	2,100	120	252,000
Pressure grouting	bags	28,740	40	1,150,000
Foundation clean up and treatment	sq m	17,400	110	1,914,000
Place Zone 1 material	cu m	446,000	22.5	10,035,000
Place Zone 2A material US and DS	cu m	217,500	27.5	5,981,000
Place Zone 2B material US and DS	cu m	217,500	27.5	5,981,000
Place Zone 3 material	cu m	1,831,400	25	45,875,000
Place Zone 3B upstream face	cu m	130,400	32.5	4,238,000
Downstream access crossing	lump sum			**2,400,000**
Total direct construction costs (TDC)				**420,015,999**

Apx Table D-5 Pinnacles dam site on the Mitchell River – on-site overhead costs

ON-SITE OVERHEADS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Project and field staff	lump sum	3% of TDC		12,600,480
Staff recruitment and training	lump sum	0.6% of TDC		2,520,096
Camp operations	lump sum	3.5% of TDC		14,700,560
Site office expenses	lump sum	0.6% of TDC		2,520,096
Site water services	lump sum	0.06% of TDC		252,010
Operating cost temporary power supply	lump sum			4,542,000
Site communication, IT expenses	lump sum	0.45% of TDC		1,890,072
Site cleaning, rubbish removal	lump sum	0.04% of TDC		168,006
Project control testing	lump sum			2,500,000
Misc. travel expenses	lump sum	0.2% of TDC		840,032
Insurances, public liability	lump sum	3.4% OF TDC		14,280,544
Total on-site overheads (OSO)				**56,813,896**
TDC and OSO costs				**476,829,895**
Profit and off-site overheads 10% of TDC and OSO				**47,682,989**
Total out turn costs (TOC)				**524,512,884**

Apx Table D-6 Pinnacles dam site on the Mitchell River – owner costs

OWNER COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Investigation and design				
Preliminary design	lump sum	0.5% of TDC		2,100,080
Geotechnical and materials	lump sum	2.0% of TDC		8,400,320
Hydraulic model study	lump sum			500,000
Detailed design and documentation	lump sum	2.5% of TDC		10,500,400
Acquisition and approvals				
Environmental assessment and approvals	lump sum			4,000,000
Cultural heritage	lump sum			1,500,000
Native title	lump sum			500,000
Storage area acquisitions	ha	13,100	100	1,310,000
Relocation storage area roads	km	12	300,000	3,600,000
Surveys and legal	lump sum			3,000,000
Permanent on-site buildings and services	lump sum			1,000,000
Principal's insurances (1.1% of TOC)	lump sum			5,769,642
Owner's management and supervision (0.15% of TOC)	lump sum			786,769
Total owner costs				**42,967,211**
TOTAL PROJECT COSTS (TPC)				**567,480,095**
Risk adjustment				**187,268,431**
TOTAL CAPITAL COST				**$755 million**

D.1.3 ROOKWOOD DAM SITE ON THE WALSH RIVER; AMTD 121.3 KM

Apx Table D-7 Rookwood dam site on the Walsh River – direct construction costs

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
General				
Environmental management	lump sum			450,000
Cultural heritage management	lump sum			600,000
Community consultation	lump sum			200,000
Mobilisation and demobilisation				
Establishment of workforce accommodation	lump sum			4,500,000
Establishment of survey control	lump sum			200,000
Establish construction power supply (temporary)	lump sum			2,900,000
Establish communications	lump sum			250,000
Mobilisation of major plant	lump sum			3,000,000
Demobilisation of major plant	lump sum			750,000
Demobilisation of workforce accommodation	lump sum			1,800,000
Clear site and 50% of storage area	ha	5,300	1,800	9,540,000
Mobilise/demobilise site laboratory	lump sum			350,000
Access				
Access to site from Burke Development Road	km	3	750,000	2,250,000
Establish site access roads	lump sum			2,500,000
Rehabilitation of roads on construction completion	lump sum			500,000
Construction				
Material sources				
Remove quarry overburden	lump sum			800,000
Develop quarry	lump sum			1,200,000
Access road to quarry	km	2	500,000	1,000,000
Access road to sand gravel sources	km	4	500,000	2,000,000
Diversion and care of river				
Excavate LB diversion channel (rock)	cu m	61,000	50	3,050,000
Excavation for coffer dams	cu m	48,000	15	720,000
Place material for coffer dams	cu m	68,000	25	1,700,000
Dewatering	lump sum			300,000
Divert river	lump sum			400,000
Removal of coffer dams	cu m	20,000	15	300,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Foundations cross river section				
Excavate sand from river bed	cu m	4,800	9	43,000
Excavate rock from abutments	cu m	415,500	34	14,127,000
Detailed excavation	cu m	4,150	180	747,000
Detailed clean up	sq m	42,360	90	3,812,000
Dental concrete	cu m	4,150	450	1,867,000
Foundation grouting cross river section				
Concrete to grouting plinth	cu m	1,088	520	566,000
Reinforcement to grout plinth	tonne	44	5,750	253,000
Drill grout holes	m	14,685	110	1,615,000
Supply and install standpipes	no	497	130	65,000
Hook ups and pressure tests	no	1,368	130	178,000
Pressure grouting	bags	30,840	40	1,234,000
RCC dam river section				
Mobilise RCC placement plant	lump sum			4,250,000
Demobilise RCC placement plant	lump sum			1,200,000
Trial mixes	lump sum			400,000
Conventional concrete to faces	cu m	42,130	500	21,065,000
RCC concrete to dam wall	cu m	792,905	240	190,297,000
Gallery floor units and precast slabs	m	570	2900	1,653,000
Conventional concrete to spillway crest	cu m	3,210	510	1,637,000
Reinforcement to spillway crest	tonne	128	7,250	928,000
Conventional concrete to spillway apron	cu m	6,300	390	2,457,000
Reinforcement to spillway apron	tonne	252	6,900	1,739,000
Conventional concrete to end sill	cu m	610	680	415,000
Reinforcement to end sill	tonne	25	8,000	200,000
Drill-holes for apron anchors	m	6,720	70	470,000
Supply and install apron anchors	tonnes	53	7,500	398,000
Conventional concrete to training walls	cu m	2,745	600	1,647,000
Reinforcement to training walls	tonne	137	8,000	1,096,000
Drill drainage holes	m	14,345	115	1,650,000
Water stops – supply and install	m	945	45	43,000
Backfill on abutments	cu m	16,500	30	495,000
Instrumentation HW/TW recorders etc.	lump sum			230,000
Miscellaneous metalwork	lump sum			115,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Outlet works				
Intake tower concrete	cu m	1,104	900	994,000
Intake tower guide columns	cu m	100	1,800	180,000
Intake tower reinforcement	tonne	60	6,900	414,000
Intake tower guides and seals	tonne	115	14,000	1,610,000
Trashracks	tonne	50	16,000	800,000
Selective withdrawal baulks	tonne	65	14,000	910,000
Wheeled bulkhead gate	tonne	15	16,000	240,000
Hoist crane, install and commission		lump sum		275,000
Ladders and platforms	tonne			175,000
Form outlet sluices	sq m	440	250	110,000
Form access to sluice operating decks and shafts	sq m	750	200	150,000
Supply and install steel liner upstream of gates	tonne	10.5	16,000	168,000
Install radial gate seating frames and trunnions	Item	2	60,000	120,000
Supply and install radial gates	Item	2	65,000	130,000
Hydraulic and electrical installations	lump sum			400,000
Outlet sluice dissipator concrete	cu m	690	600	414,000
Outlet sluice dissipator reinforcement	tonne	35	7,000	245,000
Fish transfer facility				
Concrete to intake channels, hopper chamber and valve pit	cu m	500	900	450,000
Reinforcement to intake channels, hopper chamber and valve pit	tonne	25	7,000	175,000
Fish attraction pipework, valves and diffusers	lump sum			500,000
Fish traps	lump sum			250,000
Fish lift hopper	no			250,000
Hopper tracks	lump sum			720,000
Overhead crane at crest	lump sum			300,000
Monitoring equipment	lump sum			350,000
Electrical and mechanical installations	lump sum			250,000
Fish lift commissioning	lump sum			300,000
Right Bank Saddle Dam No. 1				
Foundation excavation	cu m	2,540	22.5	57,100
Miscellaneous fill	cu m	5,800	25	145,000
Place Zone 3B upstream face	cu m	1,020	33	33,700
Right Bank Saddle Dam No. 2				
Foundation excavation	cu m	109,500	22	2,409,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Drill grout holes	m	6,150	120	738,000
Supply and install standpipes	no	880	110	97,000
Hook ups and pressure tests	no	880	120	106,000
Pressure grouting	bags	12,300	40	492,000
Foundation clean up and treatment	sq m	9,000	100	900,000
Place Zone 1 core material	cu m	140,900	20	2,818,000
Place Zone 2A and 2B filter materials	cu m	210,000	25	5,250,000
Place Zone 3 rockfill material	cu m	473,000	23	10,879,000
Place Zone 3B upstream face	cu m	63,000	30	1,890,000
Saddle Dam No. 3				
Foundation excavation	cu m	9,810	22.5	220,700
Miscellaneous fill	cu m	43,600	20	872,000
Place Zone 3B upstream face	cu m	5,060	33	167,000
Saddle Dam No. 4				
Foundation excavation	cu m	27,200	22.5	612,000
Drill grout holes	m	510	120	61,000
Supply and install standpipes	no	85	110	9,000
Hook ups and pressure tests	no	85	120	10,000
Pressure grouting	bags	1,020	40	41,000
Foundation clean up and treatment	sq m	1,700	100	187,000
Place Zone 1 core material	cu m	32,900	22	724,000
Place Zone 2A and 2B filter materials	cu m	46,800	27	1,264,000
Place Zone 3 rockfill material	cu m	48,900	25	1,223,000
Place Zone 3B upstream face	cu m	14,000	33	554,000
Saddle Dam No .5				
Foundation excavation	cu m	30,700	22	675,400
Drill grout holes	m	1,320	120	158,000
Supply and install standpipes	no	220	110	24,000
Hook ups and pressure tests	no	220	120	26,000
Pressure grouting	bags	2,640	40	106,000
Foundation clean up and treatment	sq m	1,830	100	201,300
Place Zone 1 core material	cu m	35,600	22	783,000
Place Zone 2A and 2B filter materials	cu m	56,000	27	1,512,000
Place Zone 3 rockfill material	cu m	80,800	25	2,020,000
Place Zone 3B upstream face	cu m	16,800	33	554,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Saddle Dam No. 6				
Foundation excavation	cu m	106,700	22	2,347,400
Drill grout holes	m	3,825	120	459,000
Supply and install standpipes	no	765	110	84,000
Hook ups and pressure tests	no	765	120	92,000
Pressure grouting	bags	7,650	40	306,000
Foundation clean up and treatment	sq m	7,400	100	740,000
Place Zone 1 core material	cu m	159,700	20	3,194,000
Place Zone 2A and 2B filter materials	cu m	105,300	25	2,632,000
Place Zone 3 rockfill material	cu m	570,200	23	13,115,000
Place Zone 3B upstream face	cu m	63,200	30	1,896,000
Saddle Dam No. 7				
Foundation excavation	cu m	16,100	22.5	362,200
Drill grout holes	m	810	120	97,000
Supply and install standpipes	no	135	110	15,000
Hook ups and pressure tests	no	135	120	16,000
Pressure grouting	bags	1,620	40	65,000
Foundation clean up and treatment	sq m	980	100	107,800
Place Zone 1 core material	cu m	19,400	22	427,000
Place Zone 2A and 2B filter materials	cu m	14,000	27	378,000
Place Zone 3 rockfill material	cu m	47,000	25	1,175,000
Place Zone 3B upstream face	cu m	8,400	33	277,000
Saddle Dam No. 8				
Foundation excavation	cu m	49,000	22	1,078,000
Drill grout holes	m	2,850	120	342,000
Supply and install standpipes	no	310	110	34,000
Hook ups and pressure tests	no	310	120	37,000
Pressure grouting	bags	5,700	40	228,000
Foundation clean up and treatment	sq m	3,400	100	374,000
Place Zone 1 core material	cu m	80,300	20	1,606,000
Place Zone 2A and 2B filter materials	cu m	48,600	25	1,215,000
Place Zone 3 rockfill material	cu m	310,600	23	7,144,000
Place Zone 3B upstream face	cu m	29,200	30	876,000
Saddle Dam No. 9				
Foundation excavation	cu m	9,400	22.5	211,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Miscellaneous fill	cu m	57,900	20	1,158,000
Place Zone 3B upstream face	cu m	4,800	33	158,000
Saddle Dam No. 10				
Foundation excavation	cu m	18,600	22.5	418,000
Miscellaneous fill	cu m	64,800	20	1,296,000
Place Zone 3B upstream face	cu m	9,700	33	320,000
Permanent downstream access crossing				**3,000,000**
Total direct construction costs (TDC)				**394,131,600**

Apx Table D-8 Rookwood dam site on the Walsh River – on-site overhead costs

ON-SITE OVERHEADS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Project and field staff	lump sum	3% of TDC		11,823,948
Staff recruitment and training	lump sum	0.6% of TDC		2,364,790
Camp operations	lump sum	3.5% of TDC		13,794,606
Site office expenses	lump sum	0.6% of TDC		2,364,790
Site water services	lump sum	0.1% of TDC		394,132
Operating cost temporary power supply	lump sum	0.06% of TDC		236,479
Site communication, IT expenses	lump sum			5,452,000
Site cleaning, rubbish removal	lump sum	0.45% of TDC		1,773,592
Project control testing	lump sum			1,500,000
Misc. travel expenses	lump sum	0.2% of TDC		788,263
Insurances, public liability	lump sum	3.4% OF TDC		13,400,474
Total on-site overheads (OSO)				**53,893,074**
Total direct and on-site overhead costs				**448,024,674**
Profit and off-site overheads 10% of TDC and OSO				**44,802,467**
Total out turn costs (TOC)				**492,827,141**

Apx Table D-9 Rookwood dam site on the Walsh River – owner costs

OWNER COSTS	UNIT	QUNANTITY	RATE ($)	AMOUNT ($)
Investigation and design				
Preliminary design	lump sum	0.5% of TDC		1,970,658

OWNER COSTS	UNIT	QUNANTITY	RATE ($)	AMOUNT ($)
Geotechnical and materials	lump sum	2.0% of TDC		7,882,632
Hydraulic model study	lump sum			500,000
Detailed design and documentation	lump sum	2.5% of TDC		9,853,290
Acquisition and approvals				
Environmental assessment and approvals	lump sum			5,000,000
Cultural heritage	lump sum			3,000,000
Native title	lump sum			1,000,000
Storage area acquisition	ha	13,040	100	1,304,000
Relocation of storage area roads	km	12	300,000	6,000,000
Surveys and legal	lump sum			3,000,000
Permanent on-site buildings and services	lump sum			1,000,000
Principal's insurances (1.1% of TOC)	lump sum			5,421,099
Owner’s management and supervision (0.15% of TOC)				739,241
Total owner costs				
TOTAL PROJECT COSTS (TPC)				**492,827,141**
Risk adjustment				**162,632,957**
TOTAL CAPITAL COST				**$655 million**

D.1.4 CHILLAGOE DAM SITE ON THE WALSH RIVER; AMTD169.8 KM

Apx Table D-10 Chillagoe dam site on the Walsh River – direct construction costs

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
General				
Environmental management	lump sum			450,000
Cultural heritage management	lump sum			600,000
Community consultation	lump sum			200,000
Mobilisation and demobilisation				
Establishment of workforce accommodation	lump sum			4,500,000
Establishment of survey control	lump sum			300,000
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	1,550	2,000	3,100,000
Mobilise/demobilise site laboratory	lump sum			400,000
Access				
Access road to site from Mareeba Chillagoe Road	km	23	650,000	14,950,000
Crooked Creek crossing	lump sum			2,000,000
Establish site access roads	lump sum			1,800,000
Rehabilitation of roads on construction completion	lump sum			600,000
CONSTRUCTION				
Material sources				
Remove quarry overburden	lump sum			400,000
Develop quarry	lump sum			600,000
Access road to quarry	km	2	500,000	1,000,000
Access road to sand gravel sources	km	4	500,000	2,000,000
Access road to earthfill sources	km	2	350,000	700,000
Diversion and care of river				
Excavate LB diversion channel (rock)	cu m	54,000	50	2,700,000
Excavation for coffer dams	cu m	189,000	15	2,835,000
Place material for coffer dams	cu m	243,000	25	6,075,000
Dewatering	lump sum			250,000
Divert river	lump sum			350,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Removal of coffer dams	cu m	54,000	15	810,000
Foundations cross river section				
Excavate sand from river bed	cu m	20,000	9	180,000
Excavate rock from abutments	cu m	302,800	34	10,295,000
Detailed excavation	cu m	3,030	180	545,000
Detailed clean up	sq m	49,200	90	4,428,000
Dental concrete	cu m	3,030	450	1,363,000
Foundation grouting cross river section				
Concrete to grouting plinth	cu m	1,420	520	738,000
Reinforcement to grout plinth	tonne	57	5,750	328,000
Drill grout holes	m	21,730	110	2,390,000
Supply and install standpipes	no	630	130	82,000
Hook ups and pressure tests	no	2,240	130	291,000
Pressure grouting	bags	45,600	40	1,824,000
RCC dam river section				
Mobilise RCC placement plant	lump sum			4,350,000
Demobilise RCC placement plant	lump sum			1,220,000
Trial mixes	lump sum			400,000
Conventional concrete to faces	cu m	50,715	490	24,850,000
RCC concrete to dam wall	cu m	830,255	230	190,959,000
Gallery floor units and precast slabs	m	720	2850	2,052,000
Conventional concrete to spillway crest	cu m	4,000	500	2,000,000
Reinforcement to spillway crest	tonne	160	7,200	1,152,000
Conventional concrete to spillway crest	cu m	8,100	390	3,159,000
Reinforcement to spillway apron	tonne	324	6,900	2,236,000
Conventional concrete to end sill and splitter piers	cu m	840	680	571,000
Reinforcement to end sill and splitter piers	tonne	34	8,000	272,000
Drill-holes for apron anchors	m	8,640	70	605,000
Supply and install apron anchors	tonnes	68	7,500	510,000
Conventional concrete to training walls	cu m	2,500	600	1,500,000
Reinforcement to training walls		m	8,000	1,000,000
Drill drainage holes	m	20,000	115	2,300,000
Water stops – supply and install	m	1,175	45	53,000
Backfill on abutments	cu m	24,000	30	720,000
Instrumentation HW/TW recorders etc.	lump sum			230,000

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Miscellaneous metalwork	lump sum			115,000
Outlet works				
Intake tower concrete	cu m	1,050	900	945,000
Intake tower reinforcement	tonne	65	6,900	448,000
Intake tower guides and seals	tonne	26	16,000	416,000
Trashracks	tonne	50	16,000	800,000
Selective withdrawal baulks	tonne	65	14,000	910,000
Bulkhead gate	tonne	20	12,000	240,000
Hoist crane, install and commission				250,000
Ladders and platforms	lump sum			130,000
Supply and install outlet conduit 2.4 m 16 pl	tonne	88	12,000	1,056,000
Outlet conduits concrete encasement	cu m	690	400	276,000
Outlet conduits concrete reinforcement	tonne	35	5,000	175,000
Concrete to outlet works	cu m	520	900	468,000
Reinforcement to outlet works	tonne	26	7,000	182,000
Outlet works pipework	lump sum			450,000
Butterfly valves and actuators	no	2	370,000	740,000
Fixed cone regulating valves	no	2	425,000	850,000
Outlet works hoist crane	lump sum			400,000
Electrical hydraulic installations	lump sum			400,000
Fish transfer facility				
Concrete to intake channels, hopper chamber and valve pit	cu m	500	900	450,000
Reinforcement to intake channels, hopper chamber and valve pit	tonne	25	7,000	175,000
Fish attraction pipework, valves and diffusers	lump sum			500,000
Fish traps	lump sum			250,000
Fish lift hopper	no			250,000
Hopper tracks	lump sum			655,000
Overhead crane at crest	lump sum			300,000
Monitoring equipment	lump sum			350,000
Electrical and mechanical installations	lump sum			250,000
Fish lift commissioning	lump sum			300,000
Saddle Dam No 3				
Foundation excavation	cu m			
Miscellaneous fill	cu m			
Place Zone 3B upstream face	cu m			

DIRECT CONSTRUCTION COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Permanent downstream access crossing	**lump sum**			**3,500,000**
Total direct construction costs (TDC)				**334,379,000**

Apx Table D-11 Chillagoe dam site on the Walsh River – on-site overheads costs

ON-SITE OVERHEADS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Project and field staff	lump sum	3% of TDC		10,031,370
Staff recruitment and training	lump sum	0.6% of TDC		2,006,274
Camp operations	lump sum	3.5% of TDC		11,703,265
Site office expenses	lump sum	0.6% of TDC		2,006,274
Site water services	lump sum	0.06% of TDC		200,627
Operating cost temporary power supply	lump sum			4,532,000
Site communication, IT expenses	lump sum	0.45% of TDC		1,504,706
Site cleaning, rubbish removal	lump sum	0.04% of TDC		1,337,516
Project control testing	lump sum			1,500,000
Misc. travel expenses	lump sum	0.2% of TDC		668,758
Insurances, public liability	lump sum	3.4% OF TDC		11,368,886
Total on-site overheads (OSO)				**46,859,676**
Total direct and on-site overhead costs				**381,238,676**
Profit and off-site overheads 10% of TDC and OSO				**38,123,868**
Total out turn costs (TOC)				**419,362,543**

Apx Table D-12 Chillagoe dam site on the Walsh River – owner costs

OWNER COSTS	UNIT	QUANTITY	RATE ($)	AMOUNT ($)
Investigation and design				
Preliminary design	lump sum	0.5% of TDC		1,671,895
Geotechnical and materials	lump sum	2.0% of TDC		6,687,580
Hydraulic model study	lump sum			500,000
Detailed design and documentation	lump sum	2.5% of TDC		8,359,475
Acquisition and approvals				
Environmental assessment and approvals	lump sum			4,500,000
Cultural heritage	lump sum			2,000,000
Native title	lump sum			700,000
Storage area acquisition	ha	3,300	100	330,000
Storage area access relocations	lump sum			500,000
Surveys and legals	lump sum			1,000,000
Permanent on-site buildings and services	lump sum			750,000
Principal's insurances (1.1% of TOC)	lump sum			4,612,988
Owner's management and supervision (0.15% of TOC)	lump sum			629,044
Total owner costs				**32,240,982**
TOTAL PROJECT COSTS (TPC)				**451,603,525**
Risk adjustment				**149,029,163**
TOTAL CAPITAL COST				**$601 million**

Appendix E Petrology report of the short-listed sites

Pontifex & Associates Pty Ltd

MINERALOGY — PETROLOGY

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MINERALOGICAL REPORT No. 10608

by Ian R. Pontifex MSc.

29th March 2017

TO: Alan Moon
2 Strathmont Avenue
Gilles Plains SA 5086

YOUR REFERENCE: Samples personally delivered 7/3/17
CSIRO Order No. 4000049162

MATERIAL: Six rock samples, various locations NT and Queensland.

WORK REQUESTED: Thin section preparation and description, opinion on suitability for use as concrete aggregate.

SAMPLES & SECTIONS: To be returned to Alan Moon

DIGITAL COPY: Emailed 29/3/17 to:
<moon.alan@bigpond.com>

PONTIFEX & ASSOCIATES PTY LTD

E.1 Introduction (and opinion on potential alkali–aggregate reaction (AAR))

This report provides petrographic descriptions of six thin sections from rock samples received from Alan Moon, 7 March 2017, with sample numbers and locations as follows:

Apx Table E-1 Sample reference labels and locations

REFERENCE LABEL	LOCATION
QM2	Queensland –Pinnacles dam site on the Mitchell River
QM3	Queensland – Rookwood dam site on the Walsh River
QW4	Queensland – Chillagoe dam site on the Walsh River
NTA	Northern Territory – AROWS offstream (Adelaide River)
NTMB	Northern Territory – Mount Bennett dam site on the Finniss River
NTW	Northern Territory – Upper Adelaide River dam site on the Adelaide River

These samples are reported (by Alan Moon) to represent rock types collected from locations being investigated as possible dam sites for water storage, and representing potential sources of rock for use in concrete aggregate.

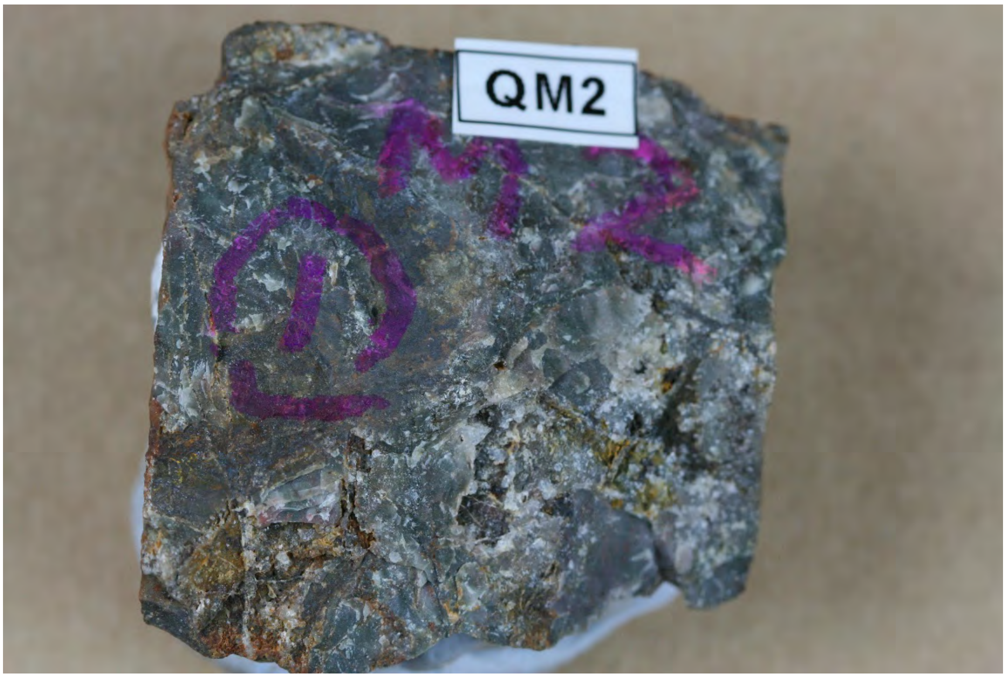
In this report a macro photo ‘introduces’ each rock sample as received, and an independent description of each thin section is followed by representative photomicrographs. A brief summary at the end of each description provides an interpreted rock classification, also a brief opinion on the suitability of each for use in concrete aggregate, and other possible engineering purposes, more-or-less consistent with guidelines published as Australian Standards ASTM, C294.

Aspects of these interpretations include visual estimates of gross mineralogy, comment on durability, macro-textures, and secondary (alteration) minerals. Attention is also drawn to potentially alkali–silica reactive minerals if used in concrete (alkali–aggregate reaction, AAR), as seen objectively by the petrography.

These opinions should not be regarded as exclusively absolute, but in all cases (e.g. chert in QM2 and cryptocrystalline/chalcedonic groundmass in the rhyolitic rock QW4) a check testing for any likelihood of AAR should be undertaken to confirm or refute the presence of significant amounts of suspect minerals capable of this reaction.

E.2 Individual petrographic descriptions

E.2.1 QM2: QUEENSLAND PINNACLES DAM SITE ON THE MITCHELL RIVER



Apx Figure E-1 QM2: Macro photo of chert

Macroscopic description

Some exposed surfaces on this small sample are polished/glossy/limonitic, yellowish-tan coloured. Other recent broken surfaces are very irregular and dark grey, ultrafine compact and siliceous and confidently identified as a chert, typically extremely hard and tough. A fresh saw-cut surface exposes numerous random quartz veinlets.

Petrographic/microscopic description

The thin section confirms a chert composition, dominated (at least 75%) by homogeneous, compact and massive cryptocrystalline silica, petrographically identified as chalcedony (SiO_2) and/or opaline silica, with individual 'grain size' of ~20 micron.

This massive chert incorporates numerous veins/veinlets from 0.2 mm to rarely 1.5 mm wide, randomly oriented and intersecting to create a chaotic network. All of these form an integral part of the hard tough whole siliceous mass without any predictable breaking patterns.

Several randomly crosscutting later apparent shears consist of partly recrystallised, and locally micro-brecciated, extremely fine quartz mosaic, together with sporadic discontinuous limonite staining, all part of the overall hard, tough siliceous whole rock.

Accessory (~5%), very small (0.1 mm) crystals of black-opaque goethite ± hematite, possibly oxidised former pyrite or magnetite, are randomly scattered as individuals, also in small local clusters. Minor (5%) small patches of ultrafine porous limonite are randomly scattered, and possibly represent oxidised ex-carbonate. Rare fresh carbonate also occurs.

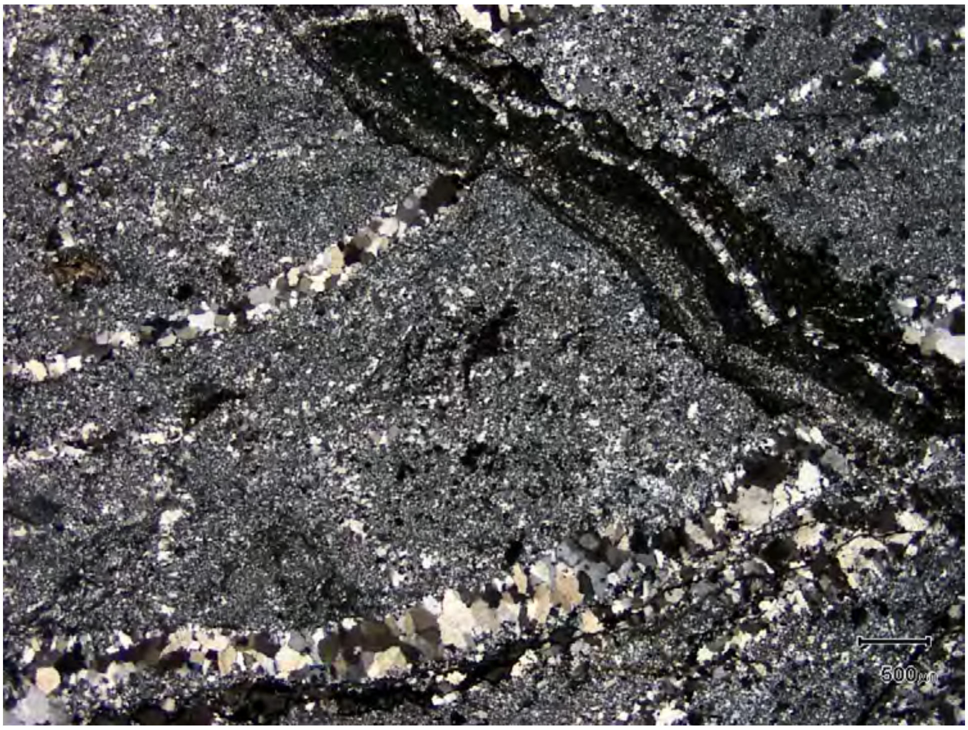
A summary of the gross mineralogical composition is in

Apx Table E-2 Summary of the gross mineralogical composition

Gross mineral composition	Percentage
Chalcedonic, cryptocrystalline and massive quartz, dominating the whole-rock (chert) matrix	75%
Slightly coarser quartz micro-mosaic, in numerous randomly intersecting veinlets	15%
Ilmonite/goethite, as very small oxidised possible ex-magnetite or ex-pyrite	~5%
Minor small patches and grains of possible oxidised carbonate, also sparse fresh carbonate, together	~5%

Summary, and opinion on suitability for concrete aggregate

This sample QM2 is classified as chert, overwhelmingly dominated by massive compact cryptocrystalline SiO_2, typically very hard, tough and durable. This form of silica is reported (e.g. in ASTM, designation C295-90) as potentially deleterious in rock for use as concrete aggregate, where it may cause alkali–silica reaction. Further testing is required to assess this possibility.



Apx Figure E-2 QM2
Thin section (TS), crossed nicols (X nic), magnification (×20). Relatively low magnification showing typical field of view of this chert, dominated by an extensive matrix of micro/cryptocrystalline quartz, incorporating numerous quartz veinlets, and a later vein in north-east quadrant of apparent recrystallised quartz clouded by iron-oxide ‘dust’, possibly healing a fracture.

Apx Figure E-3 QM2

TS, X nic, higher magnification (×50), showing detail of whole-rock cherty matrix, incorporating veins/veinlets of quartz, and accessory very small black-opaque secondary iron-oxide, possibly oxidised ex-magnetite or pyrite. Trace bright fresh carbonate in a veinlet, south-east corner.

E.2.2 QW3: QUEENSLAND – CHILLAGOE DAM SITE ON THE WALSH RIVER

Apx Figure E-4 QW3: Macro photo of rhyolite (or rhyodacite)

Macroscopic description

This very small hand specimen (25 mm × 30 mm) is a pinkish-grey irregularly 'nobbly' massive rock, which on a cut surface is seen to consist of small (2 mm) roundish phenocrysts scattered within a much finer crystalline matrix/groundmass. Treating the flat cut surface with sodium cobaltinitrite produces a yellow stain throughout the groundmass, indicating 'dominant' extremely fine potash feldspar; this also indicates minor phenocrysts of K-spar. Rare (one or two) feldspar crystals are altered to white clay.

Petrographic/microscopic description

Examination of the thin section confirms that this is a microporphyric volcanic rock, with numerous small scattered, subrounded/subhedral, small micro-phenocrysts of embayed quartz and of potash feldspar, each forming 10 to 15% of the whole rock. There are also 7 to 10% micro-phenocrysts of plagioclase feldspar and of rare oxidised magnetite crystals. These feldspar phenocrysts have small internal cloudy patches of weak clay alternation.

The other approximate 60% of this rock consists of a whole-rock fine crystalline groundmass, as a somewhat diffuse micro-mosaic of potash feldspar; also minor equally diffuse quartz and plagioclase, (but difficult to specifically resolve optically). The transmitted light also indicates weak to moderate cloudiness in the groundmass, apparently due to dispersed clay, 'alteration', together with hematite 'dust', which produces the macroscopic reddish-brown colour. This groundmass, although fine crystalline, is not specifically cryptocrystalline, and there is no evidence of volcanic glass.

Estimated gross mineralogy is:

Apx Table E-3 QW3 – Estimated gross mineralogy

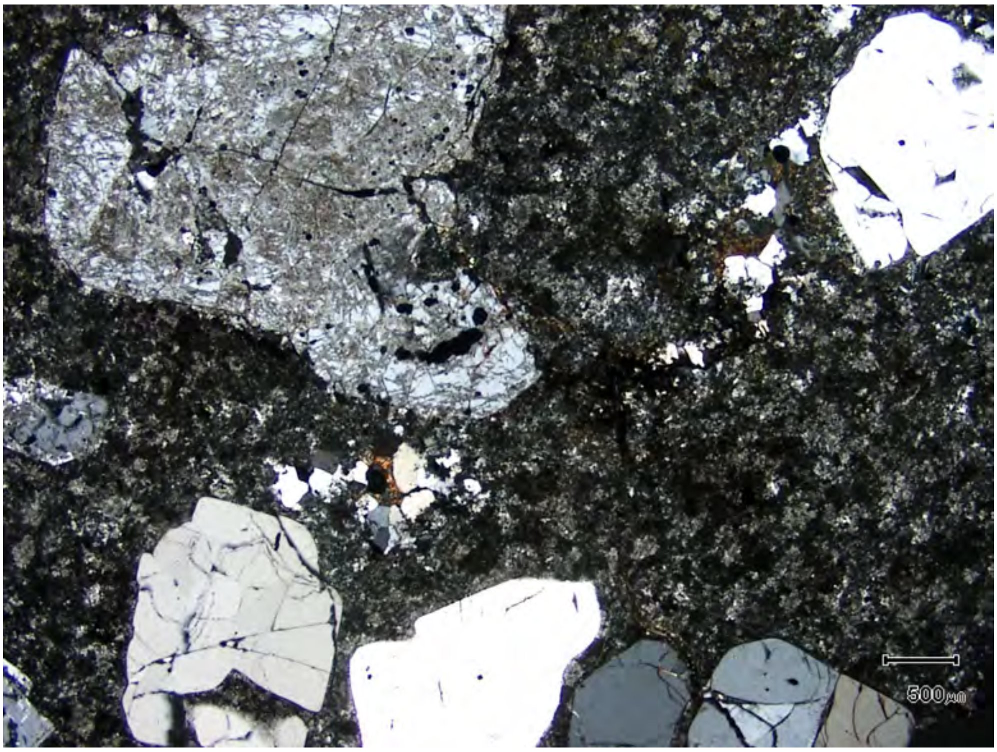
Gross mineral composition	Percentage
Quartz (phenocrysts)	10–15%
K-spar (phenocrysts)	15%
Plagioclase (phenocrysts)	10%
Possible clay alteration in feldspars	<5%
Groundmass, mix of microcrystalline K-spar > quartz	60%

Summary, and opinion on suitability for concrete aggregate

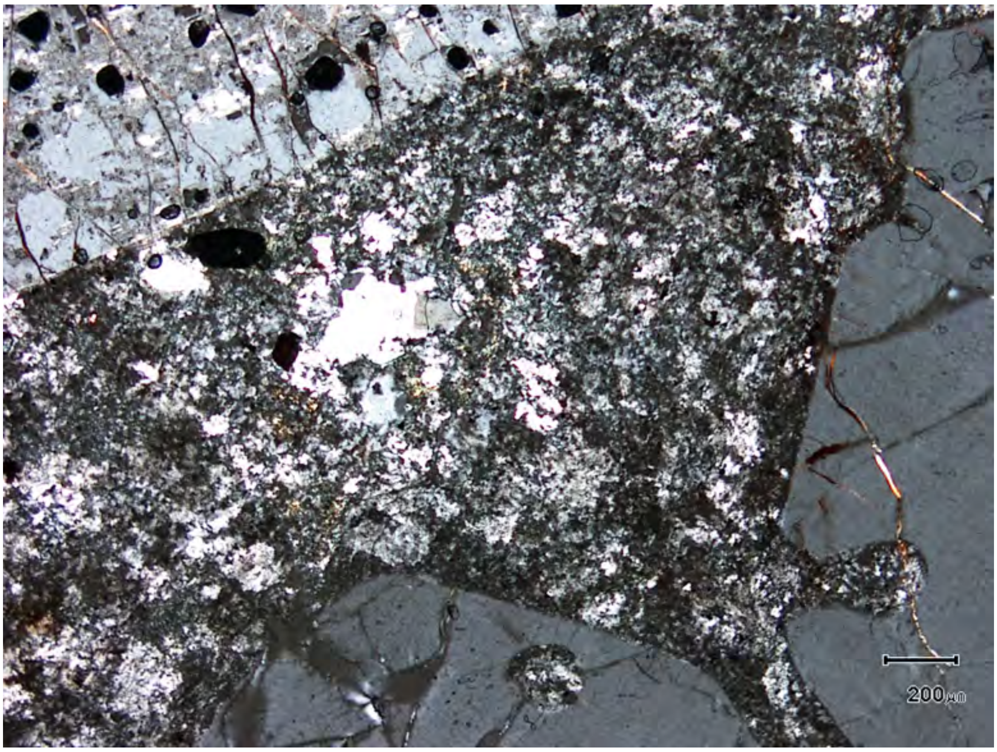
The whole (quartz)–felsic composition of this QW3 rock, and the scattered small phenocrysts, indicates an igneous/volcanic classification, with a probable best fit of rhyolite, less likely a rhyodacite. Field relationships (if known) would be useful to distinguish between a probable extrusive (lava) or possible high-level intrusive, such as a dyke rock.

There appear to be no components which may cause alkali reaction in concrete.

The only alteration is relatively minor cloudiness of sparse apparent clays within feldspar phenocrysts (and groundmass) that would seem to be innocuous with regard to use of this rock within concrete (or road surfacing material).

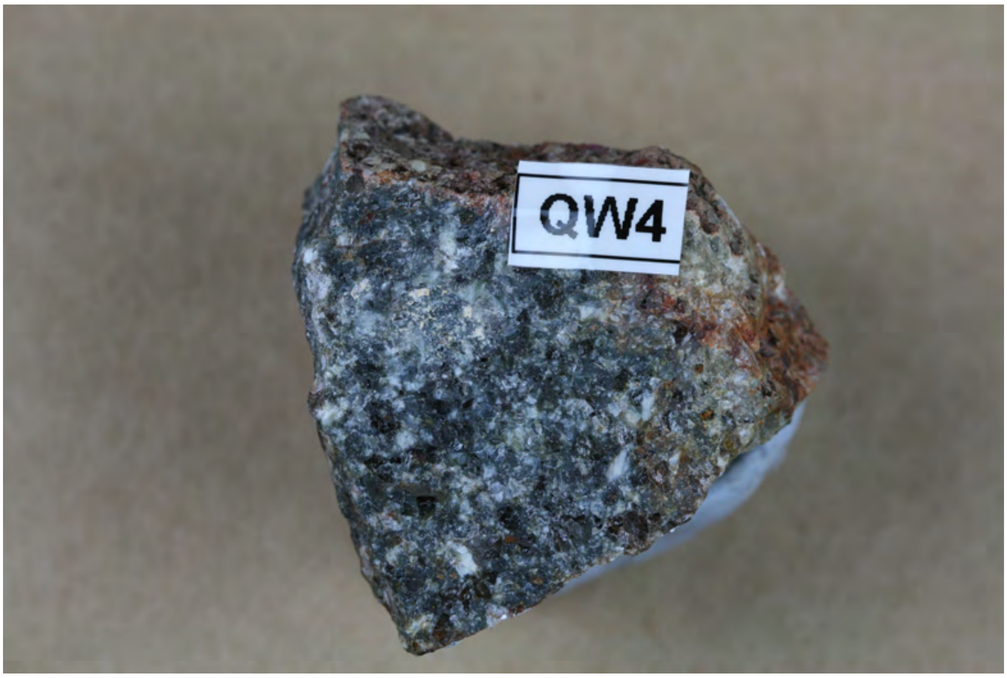


Apx Figure E-5 QW3
TS, X nic, (×20). Several subhedral and embayed quartz phenocrysts across bottom of this figure, and in north-east corner. Larger single phenocryst of grey orthoclase-feldspar in north-west quadrant. All in massive microcrystalline groundmass of K-spar > quartz.



Apx Figure E-6 QW3
TS, X nic, slightly higher magnification than Apx Figure E-5, (×50), showing detail of microcrystalline groundmass of K-spar >> quartz, which is diffuse-cloudy, probably due to minor dispersed clays. Also margins of phenocrysts, K-spar in north-west corner, embayed quartz in south-east half of this photo.

E.2.3 QW4: QUEENSLAND – ROOKWOOD DAM SITE ON THE WALSH RIVER



Apx Figure E-7 QW4: Macro photo of rhyolite or rhyodacite

Macroscopic description

Under binocular microscope, a fresh broken surface of this sample is seen to be fairly homogeneous, with ~25% of evenly scattered glassy-looking subhedral crystals of quartz, 2 mm to rarely 5 mm size. Less clearly defined ~25% milky-white crystals of probable feldspar, of similar size, are also randomly and quite evenly scattered. These crystals occur within a 'siliceous-looking' darkish grey extremely fine matrix/groundmass, which classifies them as phenocrysts. A flat saw-cut surface treated with sodium cobaltinitrite results in the matrix/groundmass, and some feldspar crystals, taking a yellow stain indicating K-spar. There are also minor small dark crystals, some of which are brownish, apparently altered/oxidised Fe-rich silicate crystals.

Petrographic/microscopic description

The thin section confirms the single crystals as (small) phenocrysts, somewhat crowded within a groundmass, which is ultrafine cryptocrystalline. The single clear crystals of quartz, with a subhedral morphology, commonly have diagnostic embayed margins. The scattered feldspar crystals are mostly orthoclase (K-spar) with rarer plagioclase. Many of these are internally weakly clouded/'dusty', due to incipient deuteric clay alteration.

Small (1 mm to 2 mm), scattered dark crystals are identified as the mafic mineral pyroxene, forming ~7% of the whole rock. These are typically altered to dark-green 'chloritic-clays', interpreted as uralite (secondary fibrous amphibole) ± smectitic clays. Some of these altered pyroxene crystals are also oxidised to yellowish-brown limonite, and some are (basically) accompanied by accessory very small crystals of black-opaque magnetite.

The whole-rock groundmass, as is noted above, is ultrafine cryptocrystalline. The sodium cobaltinitrite test producing a yellow stain indicates K-spar, but the optical microscopy indicates minor almost certain intricately mixed chalcedonic silica, but optical microscopy cannot establish relative abundances. Estimated gross mineralogical is:

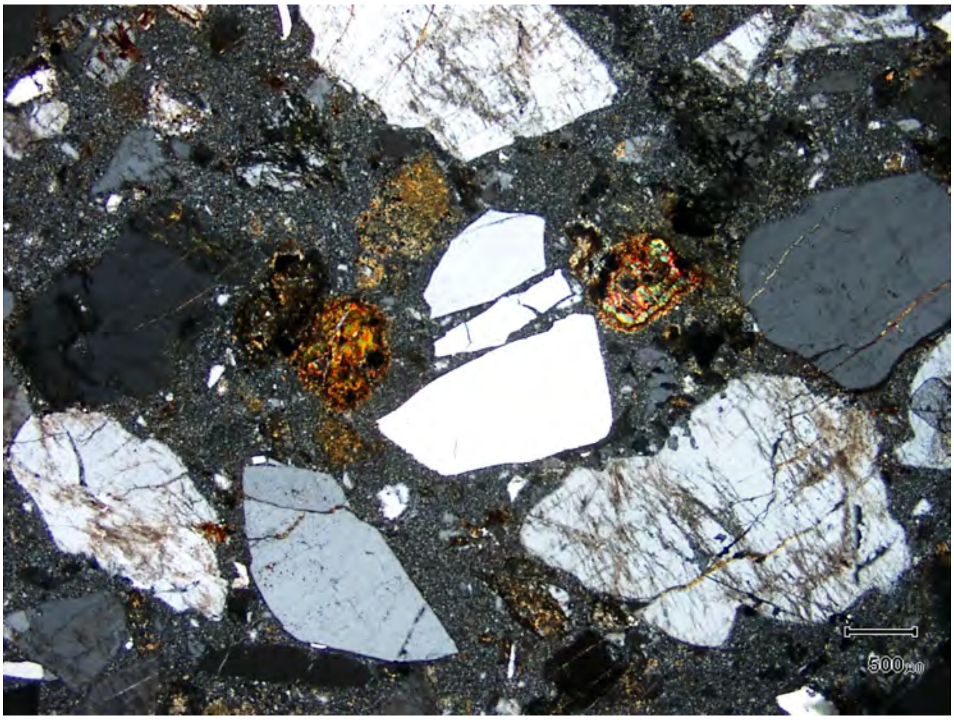
Apx Table E-4 QW4 – Estimated gross mineralogical

Gross mineral composition	Percentage
Quartz (phenocrysts)	25%
K-spar (phenocrysts)	20–25%
Plagioclase (phenocrysts)	10%
Original pyroxene (phenocrysts)	5%
Clay, incipient alteration in some crystals	<5%
Uralite/smectite secondary deuteric replacing and rimming pyroxene crystals	5%
Groundmass, cryptocrystalline mixed K-spar > quartz	35%

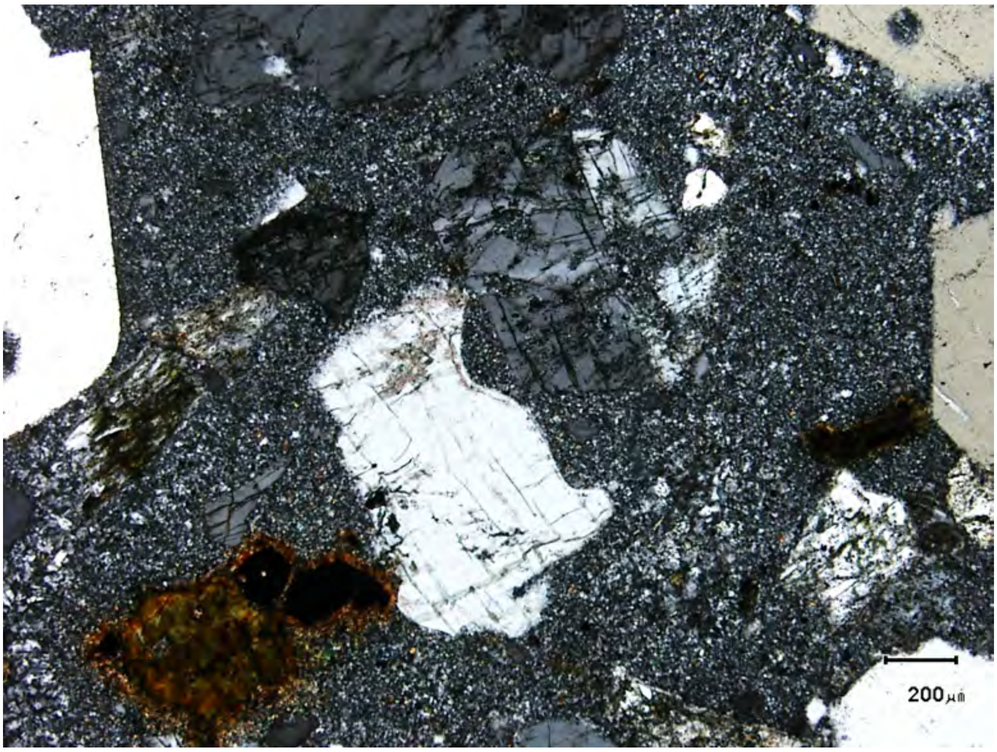
Summary, and opinion on suitability for concrete aggregate

This rock is classified as an igneous/volcanic rock, dacite or rhyodacite. The diagnostic components are scattered phenocrysts of quartz > K-spar > plagioclase > smaller original pyroxene, all in a cryptocrystalline groundmass of K-spar > quartz. Alteration is limited to minor deuteric/secondary, pyroxene replacing and rimming the minor pyroxenes, and sparse incipient clay within some feldspars.

The ubiquitous cryptocrystalline groundmass of quartz + K-spar, as described above, is regarded as potentially deleterious for use of this rock concrete aggregate, as listed in ASTM Designation C295-90, to possibly cause AAR.



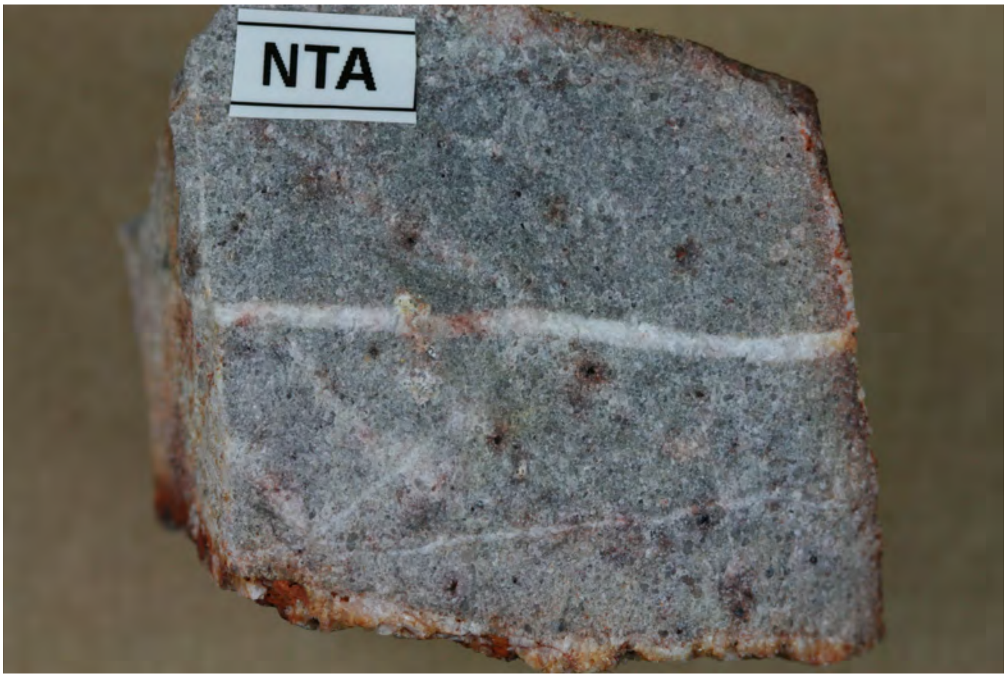
Apx Figure E-8 QW4
TS, X nic, (×20). Quartz and K-spar phenocrysts, also three smaller (coloured) phenocrysts of altered pyroxene. All crowded without massive cryptocrystalline groundmass of K-spar > quartz.



Apx Figure E-9 QW4

TS, X nic, (×50), showing detail of massive cryptocrystalline groundmass of K-spar >> quartz. Phenocrysts of quartz and K-spar, and one oxidised pyroxene in south-west corner.

E.2.4 NTA: NORTHERN TERRITORY – AROWS OFFSTREAM STORAGE



Apx Figure E-10 NTA: Macro photo

Macroscopic description

A fresh broken surface of this hand specimen examined macroscopically (and ×10 binocular microscope), is seen to be mid-grey reasonably homogeneous, massive, very hard, tough and durable quartz-rich rock, and classified as a quartzite. At the ×10 magnification, the overwhelming abundant quartz, (at least 90%), is seen as a compact competent aggregate of subrounded quartz grains, mostly about 1.0 mm size. Several white thin planar veins of quartz occur within this mass, and one forms a natural exposed weathered surface, which is semi-polished and crowded with small 'pock-marks', apparently weathered-out material grains (such as carbonate). These are no distinctive macro-textures or structures overriding this massive quartzite.

Petrographic/microscopic description

The thin section confirms a fairly homogeneous massive and compact mosaic aggregate of mostly subrounded single crystals quartz grains. This aggregate is more-or-less massive, but with a weakly developed sedimentary bedding, manifest as about 30% relatively coarse (and moderately sorted) grains about 0.5 mm size, vaguely layered within a greater proportion of smaller subrounded quartz grains, reasonably well sorted, ~0.2 mm average size.

This combination, together with moderately tight interlocking grains, and microscopic sutured intergranular contacts, results in a substantially 'strong' (and tough) quartzite, without any suggested overriding weakness.

Relatively sparse (overall 7–10%) interstitial extremely fine clay-sericite occurs sporadically throughout the aggregate.

Accessory (several), scattered single cubic replica/boxwork of limonite are interpreted to represent completely oxidised former pyrite crystals.

Gross mineralogy of this rock is therefore relatively simple:

Apx Table E-5 NTA – Gross mineralogy

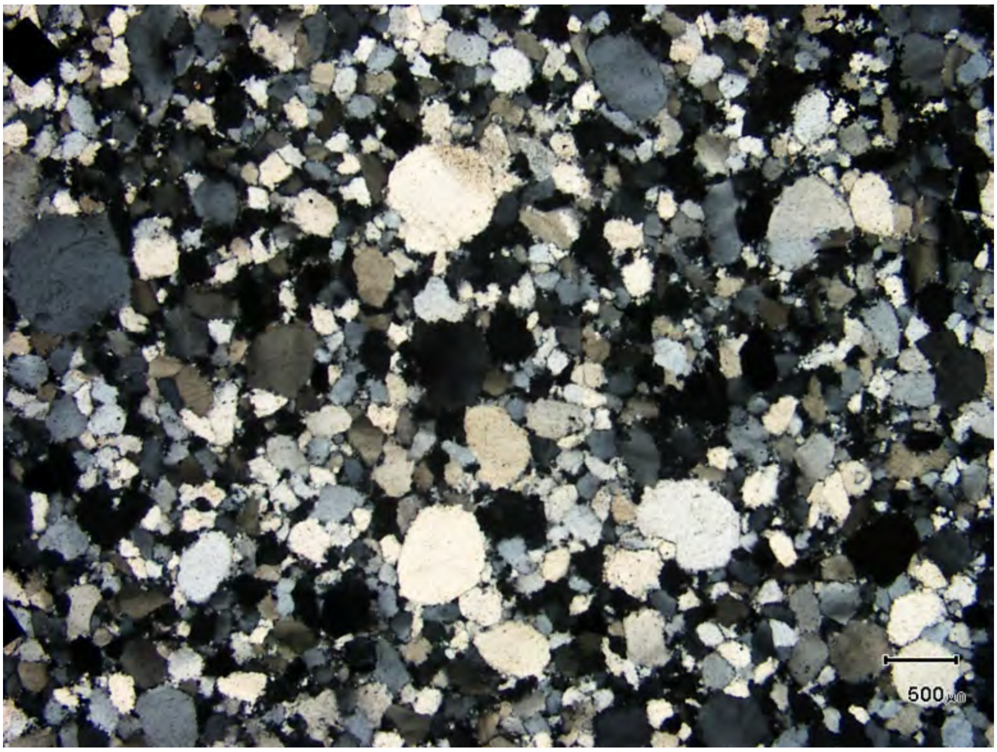
Gross mineral composition	Percentage
Quartz, 2 grain size forming a low-grade metamorphic quartzitic aggregate	>90%
Clay-sericite, minor/interstitial	7–10%
Oxidised pyrite	1–2%

Summary, and opinion on suitability for concrete aggregate

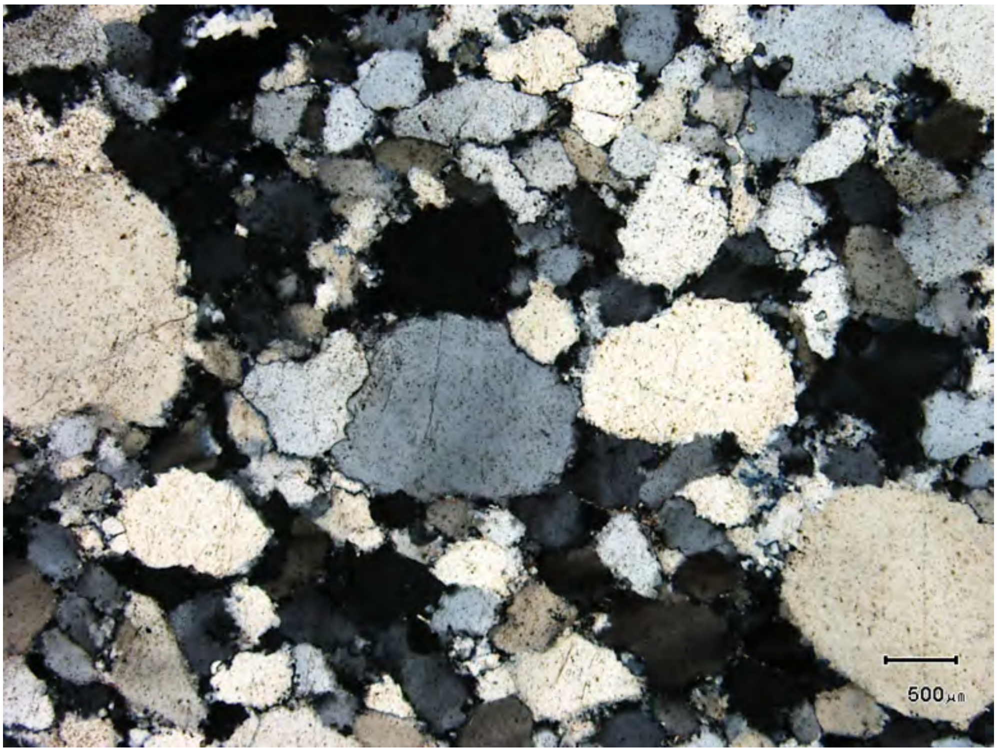
This rock is classified a relatively homogeneous and 'pure', low-grade metamorphic quartzite, derived from a precursor of medium- to coarse-grained quartz sandstone. It is tough, hard and durable, and suspected to be quite readily milled/crushed to an appropriate equant size for concrete aggregate.

Crushing would produce highly siliceous fines (dust), together with minor clay-sericite. This rock is 'massive' without textures or structures, (such as foliations), which would determine specific preferred particle size or shape.

The nature of this dominant low-grade metamorphic quartzite would seem unlikely to cause AAR in concrete aggregate (i.e. it is not cherty, cryptocrystalline, opaline, or glassy, and not metamorphically stressed or strained). The 'clay' content is extremely low and there are no carbonates. Further testing should be used to confirm this opinion.

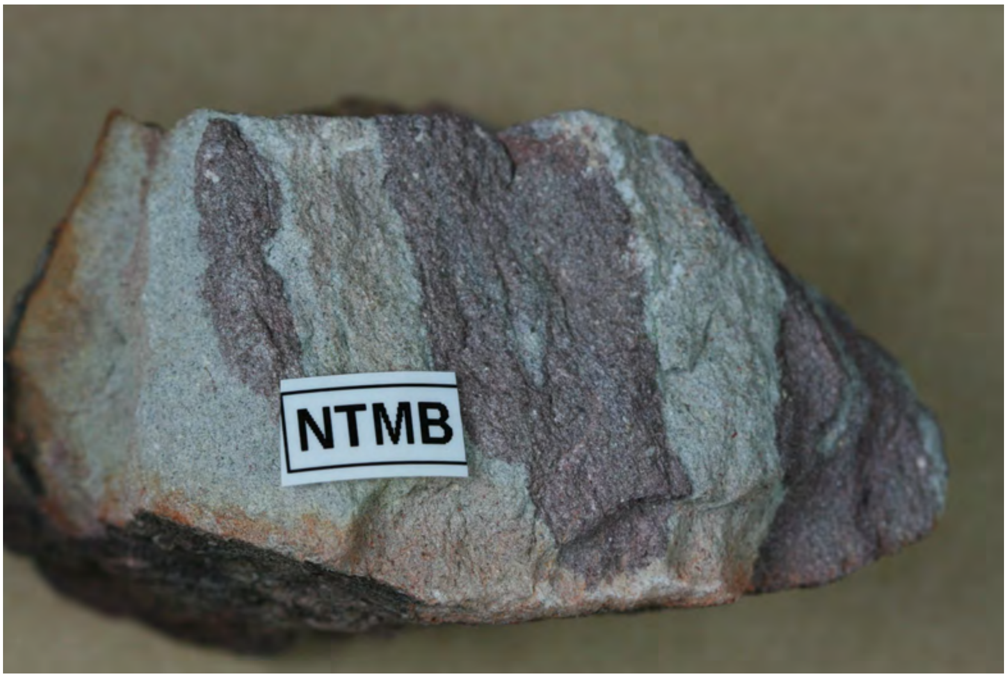


Apx Figure E-11 NTA
TS, X nic, (×20). Typical of field of view of this quartzite, with rounded/subrounded relatively ‘large’ quartz vaguely layered (bedded), within more extensive relatively finer, compact quartzite mosaic.



Apx Figure E-12 NTA
TS, X nic, (×50). Higher magnification to show micro-sutured intergranular contacts forming a tough compact aggregate.

E.2.5 NTMB: NORTHERN TERRITORY – MOUNT BENNETT (FINNISS RIVER)



Apx Figure E-13 NTMB: Macro photo

Macroscopic description

This hand specimen shown in the macro photo, viewed at low magnification is assessed as a mostly homogeneous, indurated sedimentary siltstone to fine-grained sandstone. A weak to moderate foliation on at least one crudely flat surface, also traced on a 'vertical' saw-cut surface, coincide with the orientation of two beds to 10 mm thick shown in the macro photo.

Petrographic/microscopic description

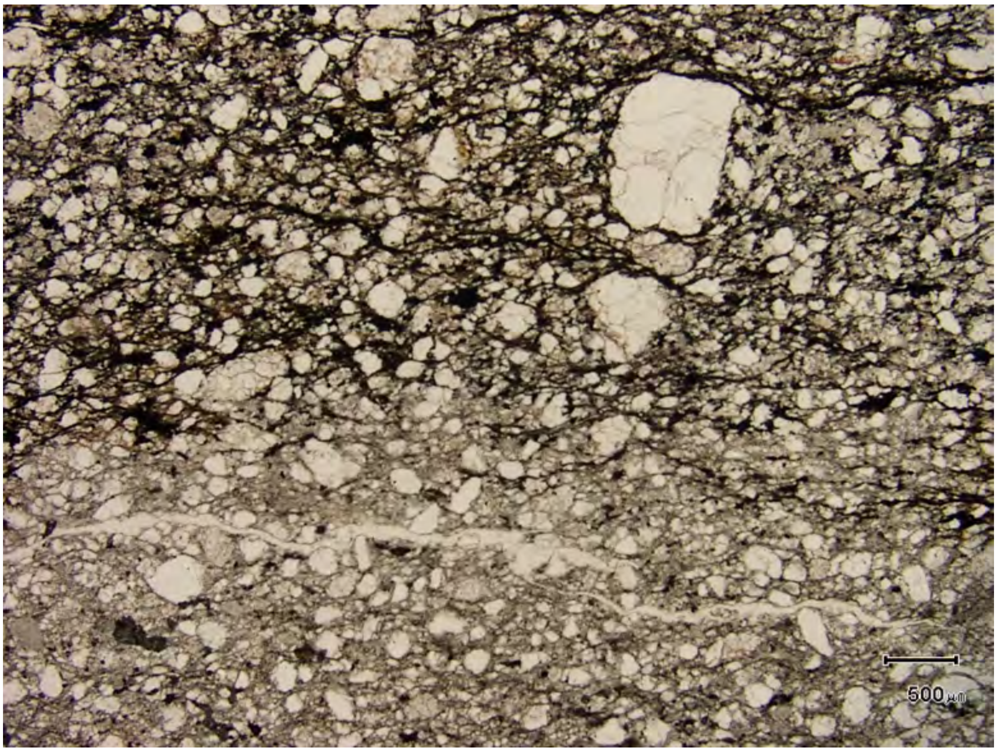
The thin section across the bedding and the coinciding closely spaced foliations noted above reveals basically the same components in all layers, and constituting a homogeneous layered/bedded sedimentary sequence. This consists of original coarse-grained quartz sand (~30 volume %), within a 70% mix of finer quartz sand and silt grains, (35%), together with clay-rich sediment. Low-grade regional metamorphism has converted the clays to close-spaced parallel muscovite foliae (35%), intricately between somewhat loosely packed silt and sand grains.

The dark colour confined to the lenticular layers contain up to 15% small 'grains', threads and stringers of secondary goethite ± earthy hematite, evenly scattered along the micaceous foliae, within the same proportions of sediment as listed above. The genesis of these dark grains is uncertain but may be selected grains of ex-carbonate.

Summary, and opinion on suitability for concrete aggregate

This rock is a metamorphosed sedimentary rock, originally composed of (detrital) quartz silt to coarser-grained sand, together with clays. Broadly it may be classified as a relatively low-grade metasediment more specifically a quartz muscovite schist.

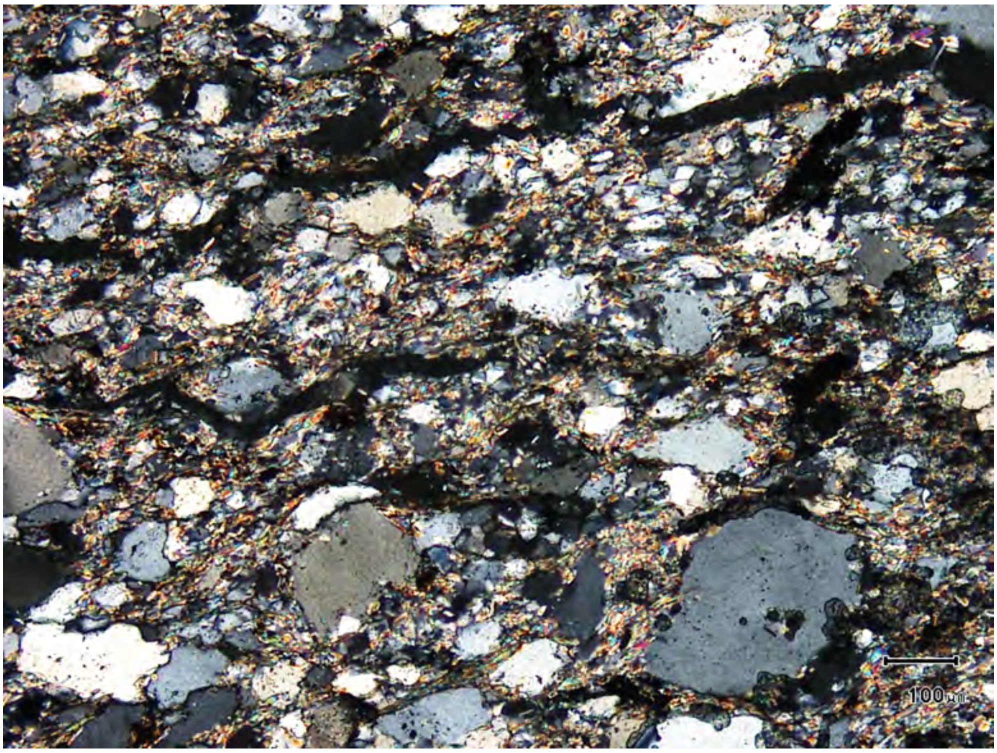
Although presenting as a reasonably indurated rock, the bonding strength between the loose-packed quartz grains and micaceous foliae is expected to be relatively weak. If this rock is proposed for concrete aggregate, the size shape and strength of individual chips needs to be determined by further testing for suitability. Milling and crushing would be expected to produce abundant fines derived largely from the muscovite-rich foliae, also a weakness of the integrated muscovite foliae within the more durable loosely packed quartz grains may be a problem.



Apx Figure E-14 NTMB
TS, ordinary light, (i.e. not X nicols as in all photos above), (×20). Shows a bedding plane contact between a top bed which is permeated by secondary Fe-oxide, along bedding and coinciding foliation, against a lower bed of this sediment, without Fe-oxide.

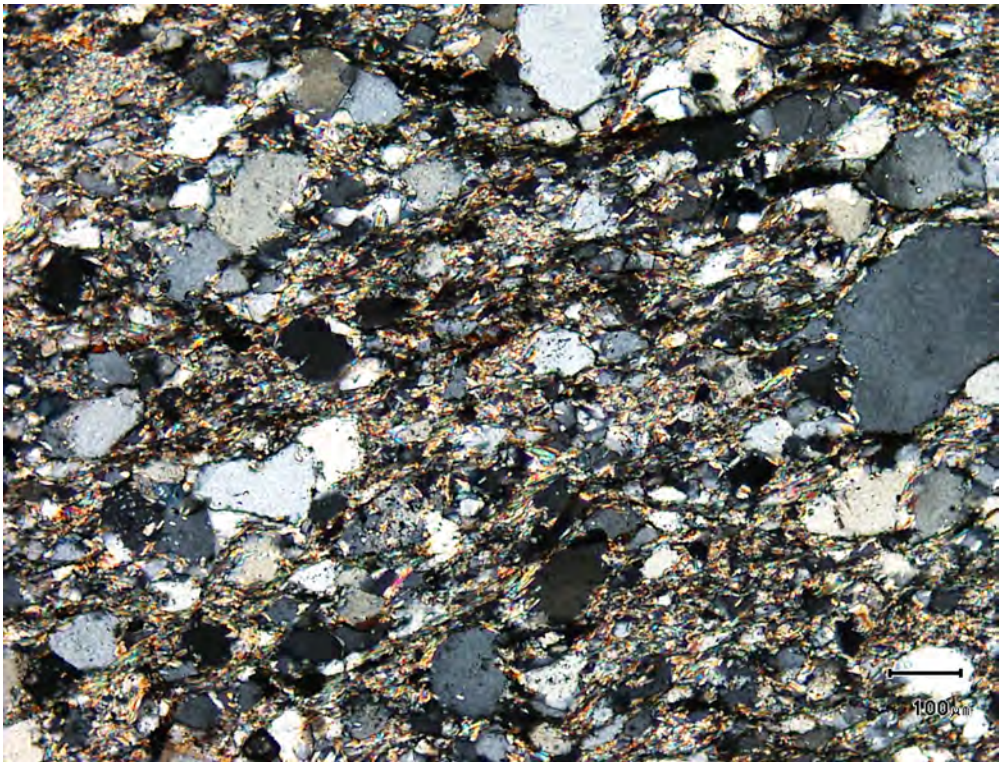
Apx Figure E-15 NTMB

TS, same as photo above, but cross nicols highlights the composition and texture of detrital quartz grains, fine to coarse, also interstitial fine muscovite/sericite.



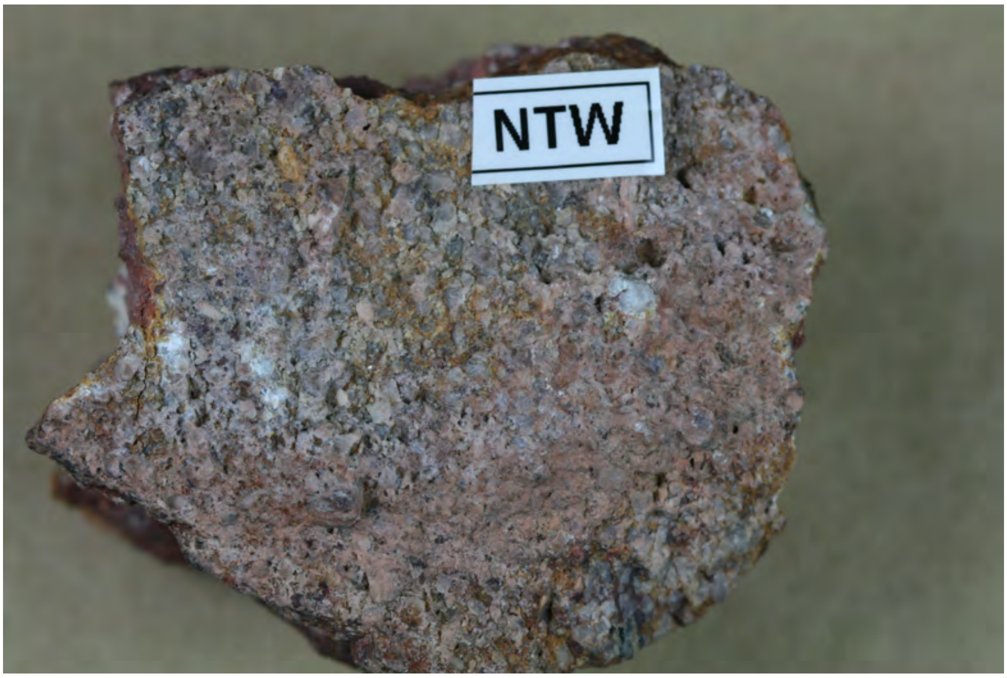
Apx Figure E-16 NTMB

TS, X nic, higher magnification (×100) to highlight fine muscovite interstitial to loose-packed detrital quartz grains.



Apx Figure E-17 NTMB
TS, X nic, (×100), to highlight fine muscovite interstitial to loose-packed detrital quartz grains.

E.2.6 NTW: NORTHERN TERRITORY –UPPER ADELAIDE RIVER DAM SITE



Apx Figure E-18 NTW: Macro photo

Macroscopic description

Low magnification examination of this hand specimen reveals a massive rock, with an approximate 60% of a fairly homogeneous, loose-packed aggregate of predominantly sub-angular very coarse quartz grains mostly ~2.0 mm size. The other approximately 40% is seen as a ubiquitous intergranular matrix of pinkish-brown iron-stained finer grained material that cannot be specifically identified by macro observation. This rock is regarded as quite strongly indurated.

Petrographic/microscopic description

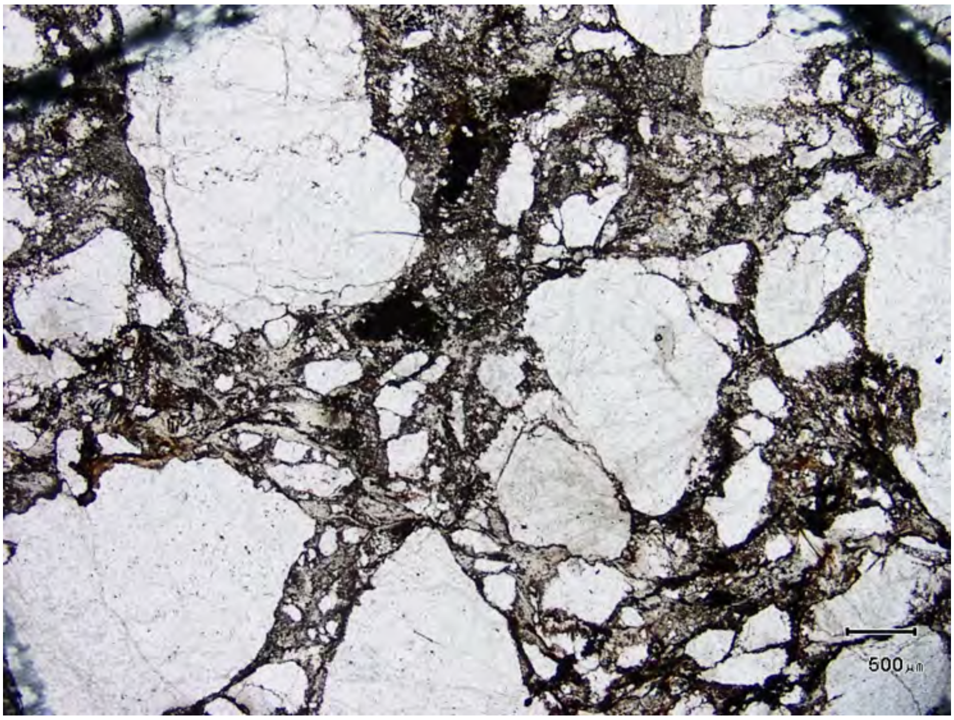
The thin section confirms an approximate 60% of this sample composed sub-angular quartz grains, 1.5 mm to 2.0 mm in size as randomly disposed and loose-packed individuals. There are also minor lithic clasts of this size with internal quartz ± sericite micro-mosaic.

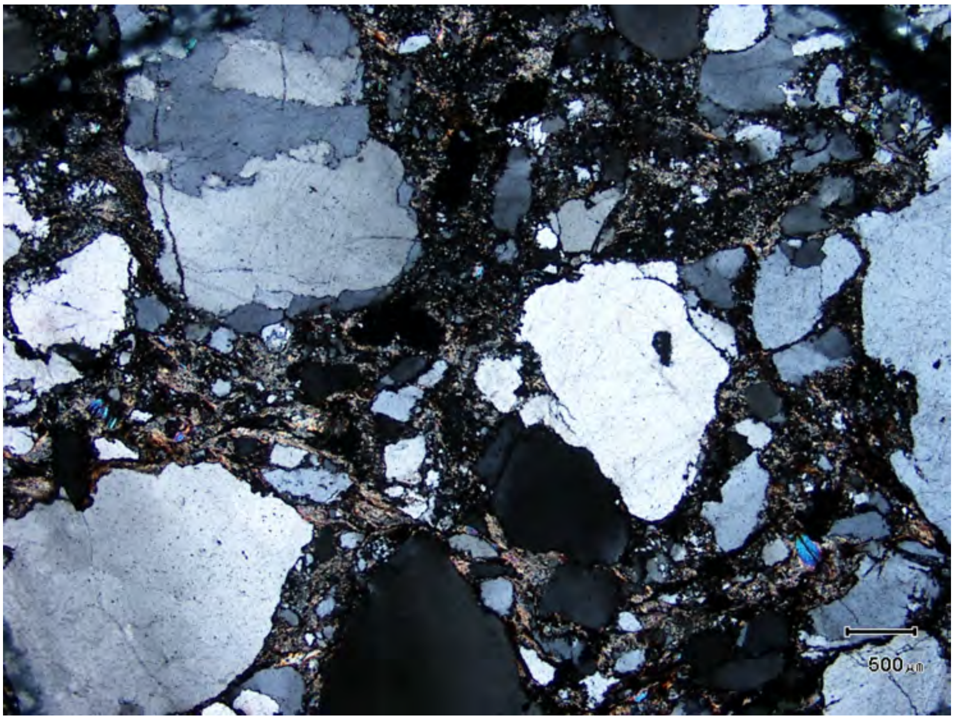
Intergranular matrix supporting these grains constitutes ~40% of this rock, and consists of a subequal somewhat heterogeneous mix of poorly sorted silt to medium sand size angular quartz grains, and sporadic sericite as patches, short thin lenses and stringers. Also scattered are small lithic clasts of variable concentrations of sericite ± clays and secondary Fe-oxides. Later stage permeation of secondary brownish goethite, and earthy hematite occurs mostly within the sericite-rich matrix. There also accessory detrital muscovite flakes. Bonding between the very coarse quartz grains and the heterogeneous matrix is interpreted to be ‘weak’.

Summary, and opinion on suitability for concrete aggregate

This rock is petrographically classified generally as a sedimentary rock (without any particular ‘toughening’ by metamorphism). More specifically it may be classified as a very coarse-grained quartz sandstone with a heterogeneous matrix of finer quartz-sericite permeated by secondary supergene iron oxide.

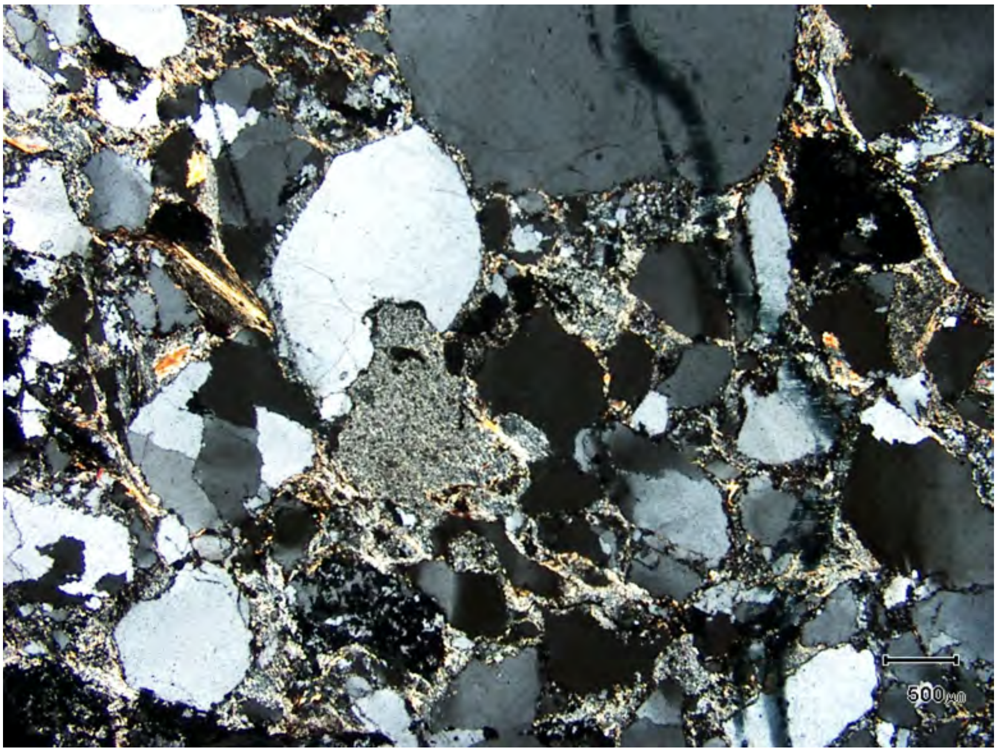
With regard to milling/crushing of this rock, the bonding between loose-packed coarse quartz grains and finer matrix is likely to be relatively weak and would perhaps be of questionable quality (and relative quantity) of durable aggregate presumably required for concrete aggregate. Further testing is required to determine the suitability of gravel-size rock chips. There are no components which would be expected to cause AAR.



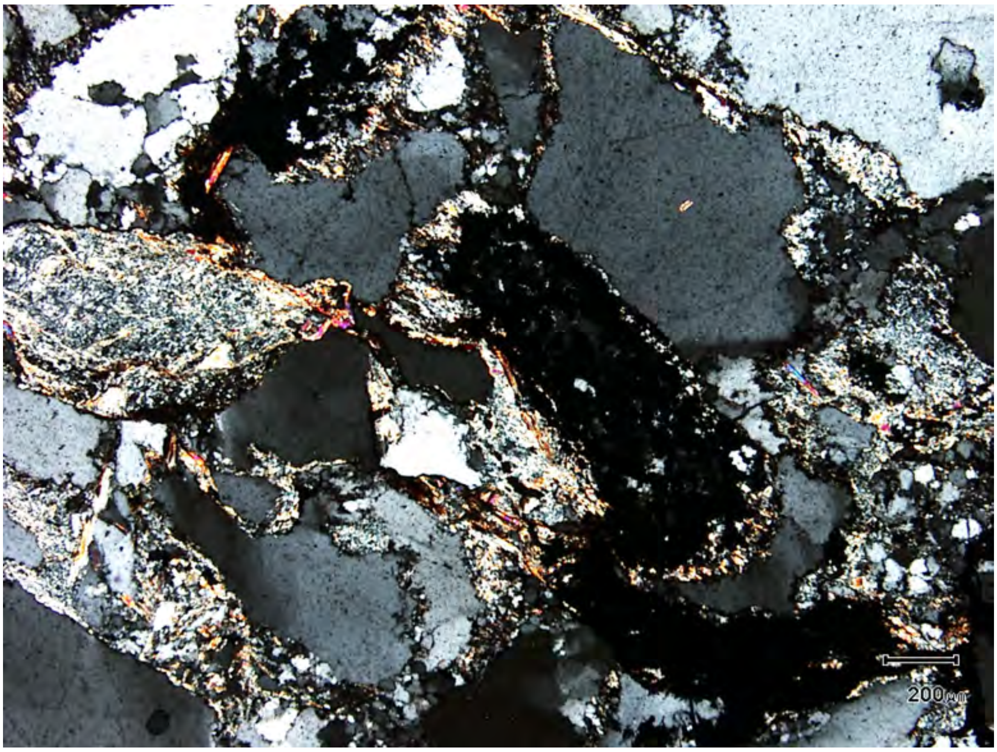


Apx Figure E-19 and Apx Figure E-20 NTW

TS, OL and X nic, (×20). Two examples of heterogeneity of this very coarse sandstone of loose-packed/coarse quartz grains, with matrix of finer quartz particles and sericite.



Apx Figure E-21 NTW
TS, X nic, (×20), showing heterogeneity of 'weak' intergranular matrix largely of clay-micas, and even minor clasts of clay-sericite (e.g. central in this photo).



Apx Figure E-22 NTW
TS, X nic. Same as Apx Figure E-21 NTW but higher magnification (×50).

Appendix F Reservoir sediment infill analysis

F.1 Sediment yield and rate of reservoir infill

The approach adopted for assessing the risk of reservoir sedimentation for water storages in the Flinders and Gilbert catchments was to develop an empirical relationship between sediment yield and catchment area, based on a review of studies from northern Australia. This approach is summarised here but is described in detail in the companion Flinders and Gilbert Agricultural Resource Assessment technical report on sediment yield (Tomkin, 2013). Resource, time and data limitations precluded the use of other methods.

Previous studies of sediment erosion and transport in catchments have shown that sediment yields tend to increase non-linearly with catchment area. For example, Wasson (1994) showed empirical relationships between sediment yield and catchment area for 12 regions across Australia including the monsoonal Northern Territory undisturbed ($y = 55 \times 0.86$), monsoonal Northern Territory moderately undisturbed ($y = 17 \times 0.9$) and the Ord River ($y = 96 \times 1.12$). It is recognised that fitting an empirical relationship to catchment area can be unsuitable for large catchments with extensive lowland floodplains or alluvial fans, since sediment yields and discharge can reach a maximum at the apex of deposition and then decline with distance downstream. However, all potential water storages assessed in the Flinders and Gilbert catchments were located in the mid- to upper reaches where there was more favourable topography for siting large dams.

A non-linear (power) function was fitted to the sediment yield and catchment area data from ten studies derived by Tomkins (2013), and as shown in Figure 2.9. Discharge was not considered as a predicative variable since few of the studies provided details on mean annual discharge. The function was fitted to all of the data except those from the South and East Alligator rivers, because they formed a strong downward leverage on the function. Furthermore, by excluding the Alligator River data the power function fitted nearly perfectly the data from the only study undertaken in the Assessment area (i.e. Flinders River at Glendower). Overall this was judged to be a reasonable approach for providing preliminary estimates of sediment yields for the dams in the Assessment area.

To incorporate the effect of geology on sediment yields, the power function sediment yields were adjusted using the subjective approach indicated in Apx Table F-1. As a precautionary principal it is thought likely that the adjusted sediment yields err on the side of being conservative.

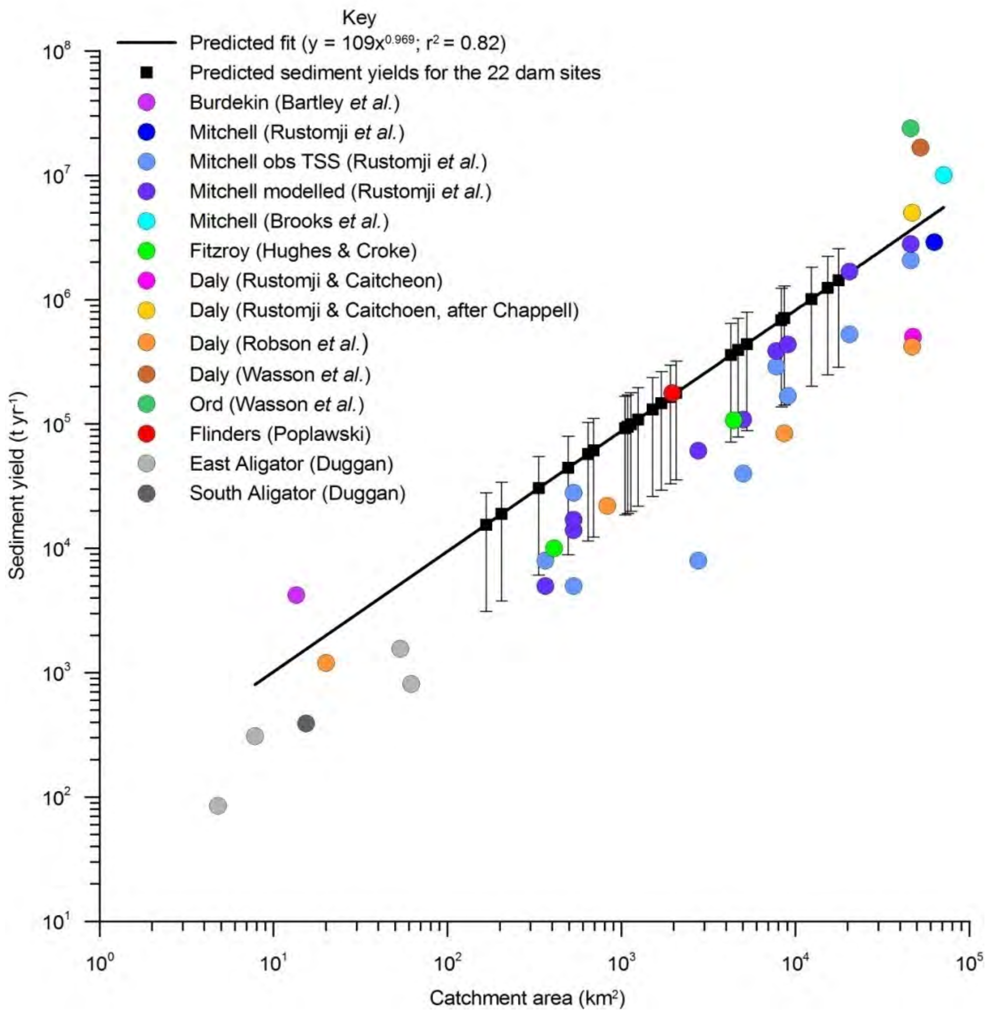
The rates of sediment infilling for dams in the Assessment area were determined for 1, 10, 30, 100 and 1000 years using linear scaling. For each dam the number of years to 100% sedimentation was also computed to provide an indication of the maximum life. Dam trapping efficiencies were based on the values provided by Poplawski (1985) for Glendower Dam and Lewis (2009, 2013) for the Burdekin Falls Dam. A 60% overall trap efficiency was considered the minimum based on the Burdekin Falls Dam data, while a 100% overall trapping efficiency was considered the maximum. On the basis of available information from literature, a trapping efficiency of 90% was adopted for all dams.

Apx Table F-1 Adjustment to sediment yields derived from power function

EXPERT JUDGMENT (BASED ON CATCHMENT GEOLOGY)	ADJUSTMENT TO POWER FUNCTION SEDIMENT YIELD
Considerable overestimate	–40%
Overestimate	–25%
Slight overestimate	–10%
Reasonable	0%
Slight underestimate	+10%
Underestimate	+25%
Considerable underestimate	+40%

Computations of the minimum (best case), maximum (worst case) and expected rate of sediment infill for the dams were made using the following values:

- Expected – adjusted sediment yield with a 90% dam trapping efficiency.
- Best case – minimum predicted sediment yield with a 60% dam trapping efficiency.
- Worst case – maximum predicted sediment yield with a 100% dam trapping efficiency.



Apx Figure F-1 Sediment yield data from rivers in northern Australia and predicted sediment yields for the 22 potential dam sites

From companion Flinders and Gilbert Agricultural Resource Assessment technical report on sediment yield (Tomkins, 2013). The average uncertainty of the predictions (±79%) is shown by the error bars.

Apx Table F-2 Adjustments to sediment yield power function in the Darwin catchments
Suggested adjustment based on expert (geological) knowledge.

POTENTIAL DAM SITE	ADJUSTMENT	COMMENT
Mount Bennett dam site	+0%	
Upper Adelaide River dam site	+0%	Shales, small areas of Cretaceous sandstones
Acacia Gap dam site	–10%	
AROWS offstream storage	–25%	Non-erodible quartz geology
Marrakai dam site	+0%	
McKinlay River dam site	+10%	
Mary River dam site	+25%	Relatively large areas of Cretaceous sandstones and granites (potential for high sediment production)
Darwin River Dam	+0%	
Manton Dam	+0%	

Apx Table F-3 Adjustments to sediment yield power function in the Mitchell catchment
Suggested adjustment based on expert (geological) knowledge.

POTENTIAL DAM SITE	ADJUSTMENT	COMMENT
Elizabeth Creek dam site on Elizabeth Creek	+0%	Very small areas of granite, catchment has low relief.
Pinnacles dam site on the Mitchell River	+10%	Largely Hodgkinson Formation (moderate sediment potential) with small areas of granite on steeper landscapes (potential for high sediment production) in upper part of catchment.
Rookwood dam site on the Walsh River	+0%	Areas of steeper relief are volcanic geology, which has low potential sediment production. Small areas of granite on low relief landscape.
Chillagoe dam site on the Walsh River	+0%	Areas of steeper relief are volcanic geology, which has low potential sediment production.
Lynd downstream dam site on the Lynd River	+0%	Small areas of granite on low relief landscape. Jurassic sandstone occupy very small proportion of catchment.
Lynd upstream dam site on the Lynd River	+0%	Small areas of granite on low relief landscape. Jurassic sandstone occupy very small proportion of catchment.
Palmer River dam site	+10%	Largely Hodgkinson Formation (moderate sediment potential) with small areas of granite on steeper landscapes (potential for high sediment production) in upper part of catchment.
Nullinga dam site on the Walsh River	+25%	Moderate areas of unconsolidated sediments (potential for high sediment production) and granites on steeper landscapes (potential for high sediment production).
Lake Mitchell on the Mitchell River	+25%	Large areas of unconsolidated sediments (potential for high sediment production).

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