FLINDERS AND GILBERT AGRICULTURAL RESOURCE ASSESSMENT
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Assessment of surface water storage options in the Flinders and Gilbert catchments

A technical report to the Australian Government from the CSIRO Flinders and Gilbert Agricultural Resource Assessment, part of the North Queensland Irrigated Agriculture Strategy

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Citation

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Important disclaimer

Flinders and Gilbert Agricultural Resource Assessment acknowledgments

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The Strategy was guided by two committees:

(i) the **Program Governance Committee**, which included the individuals David Crombie (GRM International), Scott Spencer (SunWater, during the first part of the Strategy) and Paul Woodhouse (Regional Development Australia) as well as representatives from the following organisations: Australian Government Department of Infrastructure and Regional Development; CSIRO; and the Queensland Government.

(ii) the **Program Steering Committee**, which included the individual Jack Lake (Independent Expert) as well as representatives from the following organisations: Australian Government Department of Infrastructure and Regional Development; CSIRO; the Etheridge, Flinders and McKinlay shire councils; Gulf Savannah Development; Mount Isa to Townsville Economic Development Zone; and the Queensland Government.

This report was reviewed by Dr Ian Prosser (CSIRO).

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Director's foreword

Northern Australia comprises approximately 20% of Australia's land mass but remains relatively undeveloped. It contributes about 2% to the nation's gross domestic product (GDP) and accommodates around 1% of the total Australian population.

Recent focus on the shortage of water and on climate-based threats to food and fibre production in the nation's south have re-directed attention towards the possible use of northern water resources and the development of the agricultural potential in northern Australia. Broad analyses of northern Australia as a whole have indicated that it is capable of supporting significant additional agricultural and pastoral production, based on more intensive use of its land and water resources.

The same analyses also identified that land and water resources across northern Australia were already being used to support a wide range of highly valued cultural, environmental and economic activities. As a consequence, pursuit of new agricultural development opportunities would inevitably affect existing uses and users of land and water resources.

The Flinders and Gilbert catchments in north Queensland have been identified as potential areas for further agricultural development. The Flinders and Gilbert Agricultural Resource Assessment (the Assessment), of which this report is a part, provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of agricultural development in these two catchments as part of the North Queensland Irrigated Agricultural Strategy. The Assessment seeks to:

- identify and evaluate water capture and storage options
- identify and test the commercial viability of irrigated agricultural opportunities
- assess potential environmental, social and economic impacts and risks.

By this means it seeks to support deliberation and decisions concerning sustainable regional development.

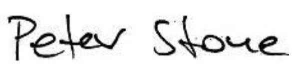
The Assessment differs from previous assessments of agricultural development or resources in two main ways:

- It has sought to 'join the dots'. Where previous assessments have focused on single development activities or assets – without analysing the interactions between them – this Assessment considers the opportunities presented by the simultaneous pursuit of multiple development activities and assets. By this means, the Assessment uses a whole-of-region (rather than an asset-by-asset) approach to consider development.
- The novel methods developed for the Assessment provide a blueprint for rapidly assessing future land and water developments in northern Australia.

Importantly, the Assessment has been designed to lower the barriers to investment in regional development by:

- explicitly addressing local needs and aspirations
- meeting the needs of governments as they regulate the sustainable and equitable management of public resources with due consideration of environmental and cultural issues
- meeting the due diligence requirements of private investors, by addressing questions of profitability and income reliability at a broad scale.

Most importantly, the Assessment does not recommend one development over another. It provides the reader with a range of possibilities and the information to interpret them, consistent with the reader's values and their aspirations for themselves and the region.



Dr Peter Stone, Deputy Director, CSIRO Sustainable Agriculture Flagship

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Shortened forms

AEM	airborne electromagnetic
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
AHMS	Archaeological and Heritage Management Solutions
APSIM	Agricultural Production Systems Simulator
AWRC	Australian Water Resources Council
BoM	Bureau of Meteorology
CGE	Computable General Equilibrium
CPI	consumer price index
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	digital elevation model
DEM-H	hydrologically corrected digital elevation model
DEWS	Department of Energy and Water Supply
FSL	full supply level
GAB	Great Artesian Basin
GCM-ES	global climate model output empirically scaled to provide catchment-scale variables
GCMs	global climate models
GIS	geographic information system
JCU	James Cook University
mEGM96	Earth Gravitational Model 1996
NAC	Northern archaeological Consultancies
NQIAS	North Queensland Irrigated Agriculture Strategy
ONA	the Australian Government Office of Northern Australia
OSS	off stream storage
OWL	the Open Water Likelihood algorithm
PAWC	plant available water capacity
PE	potential evaporation
PE	potential evaporation
PMF	Probable maximum flood
PMP	Probable maximum precipitation
RCP	representative concentration pathway
RORB	runoff routing program
RTK	real time kinematic

Sacramento	a rainfall-runoff model
SALI	the Soil and Land Information System for Queensland
SfM	structure from motion
SILO	Database of climate
SLAs	statistical local areas
SML	surface mixing layer
SRTM	shuttle radar topography mission
TRaCK	Tropical Rivers and Coastal Knowledge Research Hub
WRON	CSIRO's Water Resource Observation Network
YYR	Yield-reliability relationship
Zeu	euphotic depth
Zsml	surface mixing layer

Units

MEASUREMENT UNITS	DESCRIPTION
GL	gigalitres, 1,000,000,000 litres
keV	kilo-electronvolts
kL	kilolitres, 1000 litres
km	kilometres, 1000 metres
L	Litres
m	Metres
mAHD	metres above Australian Height Datum
MeV	mega-electronvolts
mg	milligrams
MJ/m^2	megajoules per metre square
ML	megalitres, 1,000,000 litres

Geologic timeline

Eon	Era	Period	Epoch	Age (Ma)
PHANEROZOIC	CENOZOIC	Quaternary	Holocene	0.01
			Pleistocene	2.6
		Neogene	Pliocene	5.3
			Miocene	23
		Paleogene	Oligocene	34
			Eocene	56
			Paleocene	66
	MESOZOIC	Cretaceous		145
		Jurassic		201
		Triassic		252
	PALAEOZOIC	Permian		299
		Carboniferous		359
		Devonian		419
		Silurian		444
		Ordovician		485
		Cambrian		541
Supereon	**Eon**	**Era**		**Age**
PRECAMBRIAN	PROTEROZOIC	Neo		1000
		Meso		1600
		Paleo		2500
	ARCHAEAN			4000

Major events

- Major glaciations
- Man
- Eruption of basalt in North Queensland
- Karumba Basin deposited
- Deep weathering in North-Eastern Australia
- Rise of East Australian highlands
- Marine inundation of Eastern and Central Australia
- Great Artesian Basin deposited
- Last major episode of orogenic mountain building (Eastern Australia)
- Intrusion of granite and deposition of volcanic rocks in Kennedy Province
- First land plants
- Marine inundation of Northern and Central Australia
- Georgina Basin deposited
- Oxygen rich atmosphere
- Deposition then deformation of Mt Isa and Georgetown Inliers
- Oxygen poor atmosphere

Preface

The Flinders and Gilbert Agricultural Resource Assessment (the Assessment) aims to provide information so that people can answer questions such as the following in the context of their particular circumstances in the Flinders and Gilbert catchments:

- What soil and water resources are available for irrigated agriculture?
- What are the existing ecological systems, industries, infrastructure and values?
- What are the opportunities for irrigation?
- Is irrigated agriculture economically viable?
- How can the sustainability of irrigated agriculture be maximised?

The questions – and the responses to the questions – are 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 must be read as a whole if they are to reliably inform discussion and decision making on regional development.

The Assessment is producing a series of reports:

- Technical reports present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the 12 research activities (outlined below) has a corresponding technical report.
- Each of the two catchment reports (one for each catchment) synthesises key material from the technical reports, providing well-informed but non-scientific readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture.
- Two overview reports – one for each catchment – are provided for a general public audience.
- A factsheet provides key findings for both the Flinders and Gilbert catchments for a general public audience.

All of these reports are available online at <http://www.csiro.au/FGARA>. 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.

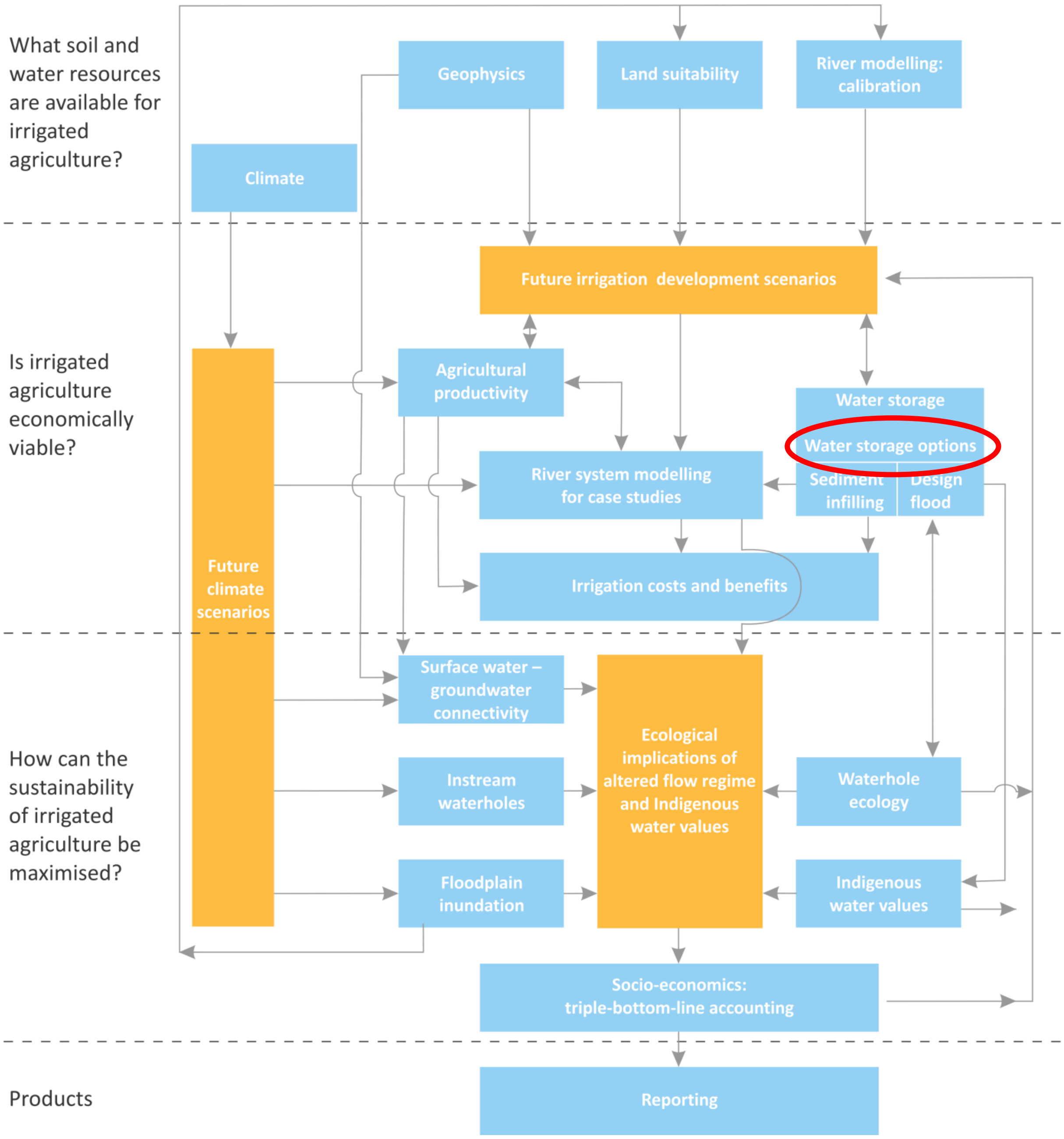
The Assessment is divided into 12 scientific activities, each contributing to a cohesive picture of regional development opportunities, costs and benefits. Preface Figure 1 illustrates the high-level linkages between the 12 activities and the general flow of information in the Assessment. Clicking on an 'activity box' links to the relevant technical report.

The Assessment is designed to inform consideration of development, not to enable particular development activities. As such, the Assessment informs – but does not seek to replace – existing planning processes. Importantly, the Assessment does not assume a given regulatory environment. As regulations can change, this will enable the results to be applied to the widest range of uses for the longest possible time frame. Similarly, the Assessment does not assume a static future, but evaluates three distinct scenarios:

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

As the primary interest was in evaluating the scale of the opportunity for irrigated agriculture development under the current climate, the future climate scenario (Scenario C) was secondary in importance to scenarios A and B. This balance is reflected in the allocation of resources throughout the Assessment.

The approaches and techniques used in the Assessment have been designed to enable application elsewhere in northern Australia.



Preface Figure 1 Schematic diagram illustrating high-level linkages between the 12 activities (blue boxes)

This report is a technical report. The red oval in Preface Figure 1 indicates the activity (or activities) that contributed to this report.

The orange boxes indicate information used or produced by several activities. The red oval indicates the activity (or activities) that contributed to this technical report. Click on a box associated with an activity for a link to its technical report (or click on 'Technical reports' on <http://www.csiro.au/FGARA> for a list of links to all technical reports). Note that the Water storage activity has multiple technical reports – in this case the separate reports are listed under the activity title. Note also that these reports will be published throughout 2013, and hyperlinks to currently unpublished reports will produce an 'invalid publication' error in the CSIRO Publication Repository.

Executive summary

Overview

Current allocations of water in the Flinders and Gilbert catchments are low, relative to their median annual streamflow (i.e. ≤ 2%). The recent release of water in the two catchments in 2013 was followed by calls for a review of the Gulf Water Resource Plan. However, further incremental releases of water for consumptive use may preclude the development of large water storages in the future. Consequently the primary purpose of this study is to provide a comprehensive overview of the different surface water storage options in the Flinders and Gilbert catchments, to help enable decision makers take a long term view of water resource development and to help inform future allocation decisions.

The construction of large instream dams in the Flinders catchment would be expensive (i.e. greater than $6000/ML of water supplied in 85% of years, excluding water distribution costs and losses) and no locations in the Flinders catchment were considered to be particularly suitable for development. The better large dams in the Flinders catchment have an equivalent annual unit cost per ML of water supply in 85% of years of more than $430, excluding operation and maintenance costs, water distribution costs and losses. This is nearly twice the equivalent annual unit cost per ML of effective offstream storage (i.e. after accounting for evaporation and seepage losses from the offstream storage), storing water for 12 months of the year. Consequently offstream storages are the most promising water storage option in the Flinders catchment.

The construction of the more promising large instream dams in the Gilbert catchment is estimated to cost between $1500/ML and $2000/ML of water supplied in 85% of years. These dams have an equivalent annual unit cost per ML of water supplied in 85% of years of between $100 and $140, which is considerably less than the equivalent annual unit cost per ML of effective offstream storage (i.e. after accounting for evaporation and seepage losses from the offstream storage) of at least $140 and $240, storing water for 4 and 12 months of the year respectively. Furthermore the Gilbert River does not have many locations suitable for offstream storages due to its highly permeable soils and substrata. In select locations the soils adjacent to the Einasleigh River may be suitable for offstream storages.

The investigation of a potential 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.

Instream water storages

This report documents the results of an assessment of 22 potential dam locations, 15 in the Flinders catchment and 7 in the Gilbert catchment. One of the potential dam locations in the Gilbert catchment had not previously been investigated (i.e. Dagworth). The remaining 21 potential dam locations had been investigated and documented in some form prior to the Assessment. The extent of prior investigations ranged from vague and isolated references to potential locations (e.g. Mount Alder and Mount Noble) to detailed hydrological and geotechnical investigations (e.g. Cave Hill and Glendower). 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 were never officially published or only exist as hardcopy documents in the Queensland State Government or SunWater archives.

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. 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 engineering geologist as part of the Assessment, but no additional geotechnical investigations were undertaken. Geotechnical investigations are expensive and time consuming and were beyond the scope of this regional scale study.

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 water storages. The DamSite model was used to assess over 100,000 potential dam sites in each catchment. In many cases the model confirmed the relative potential of known potential dam locations.

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 permeabilty 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 was Dagworth, a previously undocumented potential site on the middle reaches of the Einasleigh River in the Gilbert Catchment.

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 Flinders and Gilbert catchment are provided in Preface Table 1 and Preface Table 2 respectively. It should be noted that at some of the locations, up to three different sites were investigated. Only the most favourable site at each location is reported in this document. While the Assessment did investigate the suitability of soils for irrigation that aspect is reported in the companion technical report on land suitability (Bartley et al. 2013).

Potential dam sites in the Flinders catchment

One of the primary limitations to siting large dams in the Flinders catchment is that topographically suitable areas are limited to the relatively small headwater catchments. Most of the Flinders catchment is either underlain by the gently rolling downs of the Great Artesian Basin or the flat mid to lower Flinders River coastal floodplain, both of which present few opportunities for instream dams. In most cases embankments would have to be excessively long to provide adequate storage capacity, and the construction and operation of a spillway to cope with the large flood events would entail significant costs and risk. The best structural unit in the Flinders catchment in which to locate dams is the Mt Isa Inlier, located in the south-west portion of the catchment. Here the topographic relief is adequate and the rock non-erodible and of high strength. The primarily limitations are that the catchment areas are small to moderate in size (i.e. < 6000 km^2) and mean annual rainfall and hence runoff is low (i.e. < 450 mm/yr annual rainfall). In the eastern portion of the catchment other topographically favourable locations for large dams exist, but at many of these locations geological limitations are likely to pose moderate to serious difficulties for dam construction and the catchment areas are small (i.e. < 2000 km^2).

Fifteen potential dam locations in the Flinders catchment were reviewed. The most favourable site at each location is summarised in Preface Table 1. Three potential dam sites in the Flinders catchment were selected for further analysis on the basis that each was initially deemed to be the most promising in each of three distinct geographical areas. The selected sites were Cave Hill, O’Connell Creek and Porcupine Creek. It should be noted, however, that none of these three preferred options was considered to stand out as particularly well suited for development.

The investigations of the three short-listed options sought to further assess the 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 1 Potential dams assessed in the Flinders catchment

At some locations, up to three alternative sites were assessed. For these locations, the most suitable alternative site is reported

DAM ID	DAM NAME	DAM TYPE*	CATCHMENT AREA (km^2)	SPILLWAY HEIGHT** (m)	FULL SUPPLY LEVEL (mEGM96)	CAPACITY (GL)	ANNUAL WATER YIELD*** (GL)	CAPITAL COST## ($ million)	UNIT COST### ($/ML)	EQUIVALENT ANNUAL UNIT COST#### ($ per year per ML)
1	Alston Vale	RCC	1,132	30	311	241	12	$275 ☐	$23,510	$1,647
2	Black Fort	EB#	4,249	16	243	43	20	$225 ☐	$11,170	$782
3	Cameron Creek	RCC	494	22	225	190	7.7	$325 ☐	$42,230	$2,959
4	Cave Hill	EB	5,264	16	224	248	40	$249 ◘	$6,170	$432
5	Chinaman Creek Dam	CC	167	14	190	2.75	NA	NA	NA	NA
6	Corella Dam	EB	335	20	302	20	3.7	$225 ◘	$60,020	$4,206
7	Corella River downstream	RCC	642	22	262	101	9.1	$225 ☐	$24,850	$1,741
8	Flinders 856 km	RCC	1,694	32	500	89	39	$275 ☐	$7,110	$498
9	Glendower	RCC	1,912	32	427	309	57	$375 ☐	$6,580	$461
10	Mt Beckford	EB	2,065	21	364	245	45	$450 ☐	$9,990	$700
11	Mt Oxley	RCC	690	34	593	62	22	$225 ☐	$10,300	$721
12	O'Connell Creek offstream	EB	1,508	9	201	127	34^^	$229^ ◘	$6,760	$474
13	Porcupine Creek	RCC	1,051	35	411	31	11	$179 ◘	$15,610	$1,093
14	Richmond Dam	EB	17,724	11	203	200	30	$375 ☐	$12,410	$869
15	White Mountains	RCC#	1,085	37	569	111	34	$225 ☐	$6,720	$470

* Conventional concrete (CC), embankment dam (EB), roller compacted concrete dam (RCC).

** The height of the dam abutments 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.

details of original dam proposal could not be located. Dam type listed is considered most likely based on available information.

◘ indicates preliminary cost estimate is likely to be –10% to +30%. ☐ indicates preliminary cost estimate is likely to be –10% to +50%. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher. Operation and maintenance costs are typically about 0.4% of the capital cost. However, O'Connell Creek offstream storage would cost about 1% of the capital cost per year due to operation and maintenance of the diversion weir and erodibility of the berm and batter slopes of the diversion channel.

This is the unit cost of annual water supply and is calculated as the capital cost divided by the water yield at 85% annual time reliability.

Assuming a 7% real discount rate and a dam life of 100 years. Capital cost only. Does not include operation and maintenance costs.

^This includes the cost of the diversion weir and diversion channel as well as the EB dam across O'Connell Creek. Operation and maintenance costs of the O'Connell Creek offstream storage would be about 1% of the capital cost per year due to operation and maintenance of the diversion weir and erodibility of the berm and batter slopes of the diversion channel.

^^This analysis did not assume a threshold flow requirement above which water can be diverted from the Flinders River nor did it take into consideration the hydraulic connection between the river and the O'Connell Creek offstream storage.

Short-listed options

Cave Hill

Cave Hill is the most promising dam location in the Cloncurry area. The preferred site can supply about 40 GL of water in 85% of years. However, the location is not topographically favourable for a dam and for every GL of water released from the dam, 1.2 GL of water would be lost to evaporation. Furthermore there are considerable geological uncertainties that would need to be investigated. The dam's reservoir inundates parts of two properties and a large area of regional ecosystems 'of concern'.

Two potential dam sites were previously identified at the Cave Hill location: a downstream site and an upstream site. A variant of the Cave Hill downstream site was selected for further investigation in the Assessment because it had one of the largest yields of potential dams in the Flinders catchment, was relatively close to the town of Cloncurry and has soils available that are moderately suitable for irrigation. The Cave Hill upstream site was disregarded because of the excessive length of the dam axis.

Under the original proposal, the downstream dam axis was underlain by faults intruded by hydrothermal quartz containing voids infilled with alluvium. The voids are likely to be numerous and extremely variable in size. In one borehole along the original proposed axis, competent rock was not intersected between the base of the alluvium at a depth of 12 m and the end of the borehole at 35 m. For the purposes of the Assessment the dam axis was realigned to avoid the known faults. However, no geological investigations have been undertaken beneath the new Cave Hill dam axis proposed by the Assessment. Herein the variant of Cave Hill downstream site will be simply referred to as the Cave Hill dam.

It is now proposed that the dam comprise a zoned earth and rock fill embankment located 100 m upstream of the original axis with a slurry trench cut off through the river bed sands rather than the clay blanket as originally proposed. A separate saddle dam approximately 900 m long and 5 m maximum height would be required on the left bank some 6.5 km west of the river to contain flood rises in the reservoir. The saddle dam would be an earth fill embankment with an erodible downstream zone. The saddle dam required on the right bank side would also be an earth and rockfill embankment approximately 720 m long with a maximum height of 16 m.

The capital cost of the dam is estimated to be $249 million (with estimates ranging between $225 million and $325 million), not including the cost of any downstream distribution works. Annual operating and maintenance costs are likely to be relatively low for the type of dam proposed. It is emphasised that the viability of this proposal depends on detailed foundation drilling, demonstrating that the hydrothermal quartz outcrop exposed on the right abutment can be avoided by the axis relocation now proposed.

O'Connell Creek

The O'Connell Creek offstream storage and associated diversion weir on the Flinders River is the most promising large water storage scheme in the Richmond area. The major limitation of the site is that it is very flat, resulting in a very shallow storage. Hence, although the reservoir can hold 127 GL at FSL, it can only supply 34 GL in 85% of years under a generous set of assumptions (see below). The annual operating costs for the storage and diversion scheme are likely to be high compared to other water storage developments in the Flinders catchment. The diversion weir would impinge upon the known range of barramundi and the predicted range of freshwater sawfish, and most of the reservoir created by the water storage and diversion weir would inundate areas of regional community ecosystems that are likely to be 'of concern'.

The O'Connell Creek offstream storage was selected over the nearby potential Richmond Dam on the Flinders River because of major uncertainties with the structure and impacts of that dam. These include the risk of storage sedimentation, increased risk of flooding at Richmond, and the risk of scour damage during periods of spillway discharge.

The O'Connell Creek proposal involves a diversion weir downstream of Richmond, which diverts water into a 55 m wide diversion channel running between the Flinders River and the nearby O'Connell Creek. The O'Connell Creek offstream storage would consist of a 4 km long earthfill embankment dam located approximately 17 km north-west of Richmond. No geological investigations have been carried out at the site. An airborne electromagnetic survey indicates a possible anticlinal structure and fault underlying the creek and left abutment approximately 4 km downstream of the dam axis. Future investigations should target this area to assess shear strength properties of the underlying rock. Based on investigations at the Flinders River dam site to the north of the site and a site inspection as part of the Assessment, the right abutment is an alluvial terrace of the Flinders River and the left abutment is residual clay overlying mudstone. Subject to detailed surveys and analysis of flood effects, work may be required to protect the racecourse and airport area from flooding and a portion of the Great Northern Railway may need to be raised.

The capital cost of the O'Connell Creek offstream storage (including the diversion weir and channel) is estimated at approximately $229 million, with estimates ranging between $200 million and $300 million. Annual operating costs for the scheme are likely to be high compared with many other water storage developments, because of the exposure of a gated diversion weir to long periods of flood flows in the Flinders River, the need to closely control operation of the diversion weir and diversion channel control gates, and likely high erodibility of the berm and batter slopes along the diversion channel and in any proposed irrigation area. Annual operating costs are likely to be of the order of $2.30 million for the offstream storage scheme.

Porcupine Creek

The potential Porcupine Creek dam was short-listed because it was initially deemed to be the most geologically suitable of the potential dam sites in the upper Flinders. The other sites in the upper Flinders were assessed as being either geologically unsuitable or too far from arable land. The major limitation of the site is the relatively small storage volume and water yield. On the basis of the yield to cost ratio, it is unlikely that this site would be viable. The reservoir would inundate a small area of regional ecosystem 'of concern' and the dam is unlikely to impinge on the distribution of any important fish species.

The Porcupine Creek potential dam site is immediately downstream of the Porcupine Gorge National Park and adjacent to the Kennedy Development Road. This site would be suitable for a roller compacted concrete dam with a central overflow crest 35 m above bed level, with RCC abutments extending to the top of the bank. A short earth embankment saddle dam would be required on the right bank to contain flood rises in the reservoir. In the area of the potential dam site, Porcupine Creek has eroded a gorge through a basalt plateau and the underlying sedimentary rocks of the Great Artesian Basin. No site geological investigations have been undertaken. A site inspection as part of the Assessment identified a layer of gravel marking the contact between the basalt and underlying sedimentary rocks. This unconformity presents a major issue for both stability and reservoir leakage. It is proposed that potential seepage and piping through a right bank gravel layer would be controlled by a concrete slab anchored to the abutment extending upstream to blanket the gravel layer, or by other suitable treatment. If further investigations were to conclude that clay material in the layer is dispersive, additional treatment such as a downstream filter blanket would be necessary. The storage would extend into the downstream section of the Porcupine Gorge National Park but would not be seen from the park lookout area upstream. Four cultural heritage sites listed in the Queensland Department of Aboriginal and Torres Strait Islander and Multicultural Affairs database would be affected.

The capital cost of the dam is estimated at about $179 million, with estimates ranging between $160 million and $230 million. There would be additional costs if a downstream regulating weir was required. Annual operating and maintenance costs for the dam should be relatively low, given the type of dam proposed and good access to Hughenden.

Potential dam sites in the Gilbert catchment

Potential dam sites in the Gilbert catchment occur in erosion resistant units of the Etheridge Province (a province is an area in which geological history has been the same), the Kennedy Province, and where resistant granite intrusions occur.

Rock in the Etheridge Province mostly consists of meta-sedimentary types. Generally the topography in this province is not favourable for dam construction except where there are erosion resistant units or where there are resistant granitic intrusions. Rocks of the Kennedy Province include both granite and ignimbrite. Ignimbrite is a strong rock formed from the welding and later consolidation of an ash flow tuff. The best sites occur where the rivers have eroded through ignimbrite. It is resistant to weathering and erosion, and river valleys tend to be relatively narrow and the depth of unconsolidated alluvium relatively shallow.

There are two major basalt provinces in the Gilbert catchment, the Chudleigh Basalt Province and the McBride Basalt Province. Lava flows from the Chudleigh Basalt Province have affected the Copperfield River and the upper reaches of the Einasleigh River. Basalt has flowed down the former river valleys and floodplains forming lava fields and, in some cases, blocking former river channels. The most northern part of the flow is about 24 km north of Einasleigh. The Undara basalt flow of the McBride province has affected the middle reaches of the Einasleigh River downstream of its confluence with Junction Creek to their confluence with Parallel Creek – a distance of about 60 km. Basalt flows cause problems for dam foundations as they can overlie alluvial material which can act as leakage paths underneath or around the dam. Remedial measures are generally expensive and can require extensive excavation of basalt and alluvial material, and cement grouting.

Seven potential dam locations were reviewed. Six of these had been previously identified, although the only reference to two of the sites was a location name (i.e. Mount Alder and Mount Noble). Prior to the Assessment the fewer potential locations identified in the Gilbert catchment than the Flinders catchment is probably in part because the Gilbert catchment is more remote than the Flinders catchment and the Flinders catchment has had a long history of champions promoting development. The favoured site at each of the seven locations in the Gilbert catchment is summarised in Preface Table 2. Three potential dam sites in the Gilbert catchment were selected for further analysis on the basis that each was initially deemed to be the most likely site to proceed in three distinct geographical areas. The selected sites were potential dams at Dagworth and Green Hills and the third site entailed raising the existing Kidston Dam (officially known as Copperfield River Gorge Dam).

The investigations of the three 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 dams assessed in the Gilbert catchment.

DAM ID	DAM NAME	DAM TYPE*	CATCHMENT AREA (km²)	SPILLWAY HEIGHT** (m)	FULL SUPPLY LEVEL (mEGM96)	CAPACITY (GL)	ANNUAL WATER YIELD*** (GL)	CAPITAL COST# ($ million)	UNIT COST## ($/ML)	EQUIVALENT ANNUAL UNIT COST### ($ per year per ML)
1	Bundock Creek	EB/ RCC	205	14	659	30	8.8	$225☐	$25,590	$ 1794
2	Dagworth	RCC	15,351	30	227	498	326	$474 ◘	$1450	$102
3	Green Hills	RCC	8,310	20	253	227	172	$335 ◘	$1950	$137
4	Raising Kidston Dam	CC	1,244	40	588	25^	17^	$34 ■	$1990	$139
5	Mount Alder	RCC	8,641	20	425	31	37	$275 ☐	$7510	$526
6	Mount Noble	RCC	12,383	20	337	103	113	$375 ☐	$3322	$233
7	North Head	EB/ RCC	4,680	30	344	136	108	$325 ☐	$3013	$211

* Conventional concrete (CC), embankment dam (EB), roller compacted concrete dam (RCC). The existing Kidston Dam is a RCC dam but it would be raised using CC.
** The height of the dam abutments 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.

■ cost estimate based on schedule of quantities estimated by McIntyre and Associates (1998). This includes raising of the dam and diversion infrastructure. ◘ indicates preliminary cost estimate is likely to be –10% to +30%. ☐ indicates preliminary cost estimate is likely to be –10% to +50%. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher. Operation and maintenance costs are typically about 0.4% of the capital cost.
This is the unit cost of annual water supply and is calculated as the capital cost divided by the water yield at 85% annual time reliability.
Assuming a 7% real discount rate and a dam life of 100 years. Capital cost only. Does not include operation and maintenance costs.
^ Existing Kidston Dam capacity is 20 GL and annual water yield at 85% time reliability is 15 GL.

Dagworth

The Dagworth dam site appears to be geologically favourable and has the largest storage volume and yield of all the potential dam sites investigated in the Gilbert catchment. Despite being the most downstream of the potential dam sites on the Einasleigh River, the site is still approximately 70 km upstream of large areas of moderately suitable soil. The reservoir created by the dam would inundate a large area of regional ecosystems ‘of concern’ and the dam wall would most likely impede the movement of barramundi and freshwater sawfish.

Two potential dam sites situated in similar geological conditions were identified using the DamSite model on the Dagworth property along the Einasleigh River. Following a site inspection and a preliminary assessment of both sites, the upstream Dagworth dam site was short-listed because it had smaller saddle dam requirements. The potential dam site commands a large catchment area (about 15,000 km²) and the geology of the site is favourable, being located in extremely high strength dacitic ignimbrite. A concrete gravity dam with central overflow spillway 30 m above the river bed would be possible, with the main dam wall of RCC construction. On the right bank, an earth and rock fill embankment saddle dam approximately 650 m long and 22 m maximum height would be required. The crest level of the saddle dam embankment would be set to contain the 1 in 1000 year Annual Exceedance Probability (AEP) flood and, in the event of more extreme flood events, erode away to form an auxiliary spillway. If this proposal were to be considered further, the impact of erosion of the large volume of fill from the saddle dam in the event of floods of high magnitude would need to be assessed in detail, as would the potential impact of the increase in flood discharge from the dam in such an event. The capital cost of the dam is estimated to be $474 million, not including the cost of any downstream distribution works. Annual operating and maintenance costs are likely to be relatively low for the type of dam suggested, although remoteness from service centres may increase some costs.

Green Hills

The Green Hills upstream site is the most suitable dam site on the Gilbert River. The site is geologically favourable and the dam has a relatively high yield (172 GL). The site is also close to moderately suitable soil. The reservoir created by the dam would inundate a large area of regional ecosystem 'of concern' and the dam wall would most likely impede the movement of barramundi and freshwater sawfish.

Two sites approximately 5 km apart had previously been identified on the Gilbert River near the Green Hills station, though the downstream site had received most attention. Following a site inspection and an assessment of both sites, the upstream site was selected for further investigation because of the large, previously unidentified saddle dam requirements at the downstream site.

The potential Green Hills upstream dam site commands a large catchment (about 8300 km^2) and it is close to moderately suitable alluvial soils adjacent to the Gilbert River. Limited surface mapping and seismic traverses of the upstream (and downstream) site had previously been undertaken. The site geology is favourable, with slightly weathered high-strength ignimbrite outcropping on both abutments. The dam would consist of a concrete gravity dam of roller compacted concrete construction with a central overflow spillway 20 m above the river bed. Four saddle dams would be required to contain the storage, particularly during flood events (flood design of the Green Hills dam sites was not undertaken in previous studies). The crest level of saddle dam number two would be set at a level to contain the 1 in 1000 year Annual Exceedance Probability (AEP) peak flood level and would be expected to fail in the event of more extreme floods to create an auxiliary spillway. Crest level of saddle dam number three would be 0.5 m higher and would also be expected to fail in the event of a more extreme flood event, again to increase the auxiliary spillway discharge capacity. The viability of this arrangement will need to be confirmed by further analyses should this proposal be advanced further. A dam wall higher than 20 m would result in excessively large saddle dams.

The capital cost of the dam is estimated to be $335 million, not including the cost of any downstream distribution works. Annual operating and maintenance costs are likely to be relatively low for the type of dam proposed, although the site is remote from major service centres.

Raising Kidston Dam

Kidston Dam (officially known as Copperfield River Gorge Dam) is an existing dam located in the upper reaches of the Gilbert catchment. There is currently potential to release 15 GL of water from the dam in 85% of years. Raising the dam wall by 2 m could supply 17 GL at the dam wall in 85% of years. A limitation of the dam is that it is about 70 km upstream from the town of Einasleigh, the nearest large area of moderately suitable soils. This is likely to result in large transmission losses between the dam and Einasleigh. As this is an existing reservoir, raising the dam wall carries low risk because the geology is known and there would be fewer additional ecological or social impacts.

The Kidston Dam was the first RCC structure built in Australia. It is 40 m in height above its lowest foundation level and a 13 m high fuse plug embankment secondary spillway is set to discharge to an unlined gully through the right abutment when headwater levels reach 0.5 m of the dam abutments. The dam was designed to be constructed to a very tight time frame and to provide a water supply to a mine whose operational life was expected to be only 15 to 20 years. However, SunWater (2005) concluded that the dam foundations and the main dam wall are of an adequate standard to ensure the dam's stability over the long term and are suitable to support a 2 m raising of the wall.

The potential to raise the existing Kidston Dam by 2 m was selected as an option for further investigation, on the basis that it is an existing reservoir and hence likely to be one of the more economically viable water supply options. The most appropriate form of raising is considered to be by placing conventional mass concrete on the downstream face of the dam to raise the spillway crest by 2 m and the abutment sections by a similar amount. In addition to the major works, a number of deficiencies in the existing works (resulting from the low cost approach adopted by the original developers) would need to be addressed. Unfortunately, raising the main dam wall would still result in a relatively small total storage volume.

The capital cost for a 2 m raising of the dam and irrigation infrastructure is estimated to be $34 million. Annual operating and maintenance costs for the dam should be relatively low given the type of raising suggested. No allowance has been made in the dam estimate for the cost of a fish transfer facility on the basis that the existing barrier has been in place for nearly 30 years and as a result there has been no movement of native fish from downstream of the dam into the reservoir during that time. If a fish transfer facility were required, the capital cost would increase by at least $5 million.

Offstream storages in the Flinders and Gilbert catchments

This report provides a broad scale assessment of the suitability of offstream water storage locations in the Flinders and Gilbert catchments. It does not attempt to produce individual engineering water harvesting infrastructure designs for individual producers. Nor does this report seek to provide instruction on the design and construction of offstream water storages. Numerous other publications and on-line tools already provide detailed information on nearly all facets of offstream storage developments.

A desktop assessment of the suitability of offstream storages in the Flinders and Gilbert catchments was undertaken based on available data from the top 1.5 m of the soil profile. These data were sourced from the companion technical report on land suitability (Bartley et al. 2013). Hence this suitability assessment does not give consideration to the nature of subsurface material below 1.5 m depth, with the exception of general information from broad scale geological mapping. The soils of the Flinders catchment in the vicinity of soils suitable for irrigation appear to be more suitable for the siting of offstream storages than the soils of the Gilbert catchment, which tend to have a sandy texture. In large parts of the Finders catchment, predominantly on the Mitchell Grass plains, there is no runoff in at least 20% of years. In the Gilbert catchment the soils adjacent to the Gilbert River and to a lesser extent along the Einasleigh River have a high sand content and are generally not geologically favourable for siting offstream storages.

Only one prior study in the catchments documented an assessment of ring tank storage. That study investigated 8 large 8000 ML storages near Richmond as an alternative to the O'Connell Creek offstream storage. A review of the cost of these storages estimated each to be about $10m, about one third of the cost of estimates provided in the original study. Several studies providing cost estimates for offstream storages elsewhere were reviewed.

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.

In a companion technical report on sediment yields, Tomkins (2013) collated historical sediment yield data from 10 studies across northern Australia, including a study from the Flinders River at Glendower. A non-linear (power) function was fitted to the data to derive the relationship between sediment yield and catchment area. Discharge was not considered as a predicative variable since few of the studies provided details on mean annual discharge. The relationship derived by Tomkins (2013) was found to estimate sediment yield values slightly lower than global relationships, which was not unexpected given the antiquity of the landscape (i.e. it is flat and slowly eroding under 'natural' conditions).

Eighty-two percent of the potential dams examined in the Assessment are estimated to have between 0.3% and 7% sediment infilling after 30 years and between 1% and 24% sediment infilling after 100 years. These are predicted to be the most likely percentages, although infilling under the worst case scenario could be as high as 0.9 to 22% after 30 years and 3 to 72% after 100 years for 82% of dams, with four dams at or close to 100% after 100 years. The most likely median time to complete sediment infilling (100%) is estimated at around 780 years. Under the worst case, the median time is around 375 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 and downstream impacts on river channels and assessment of estuarine and coastal geomorphology.

Ecological considerations

The water impounded by a dam inundates an area of land, drowning not only instream habitat but surrounding flora and fauna communities. For instream ecology, the dam wall acts as a barrier to movements of plants, animals and energy, potentially disrupting connectivity of populations and ecological processes. There are thousands of studies linking water flow with nearly all the various elements of instream ecology in freshwater systems. Dams also create a large, deep lake, a habitat type that is in stark contrast to the usually shallow and often flowing habitats it replaces. This lake-like environment favours some species over others and will function completely differently to natural rivers and streams.

The lake-like environment of an impoundment is often used by sports anglers to augment natural fish populations, through artificial stocking. Whether fish stocking is a benefit of dam construction is a matter of point-of-view. Stocked fisheries provide a welcome source of recreation and food for fishers, and potentially an economic benefit to local businesses, but they have also created a variety of ecological issues. Numerous reports of disruption of river ecosystems highlight the need for careful study and regulatory management of fisheries. Impounded waters have often been subject to unauthorised stocking of native fish and releases of exotic flora and fauna.

A desktop assessment of potential environmental issues associated with potential dam sites in the Flinders and Gilbert catchments was undertaken. The dearth of environmental information available for the two catchments limited the level of detail that could be achieved. 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 much of the Assessment area, 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).

Fifty fish species are known from the Flinders catchment (Waltham et al. 2013). The locations of potential dam sites on the Flinders River upstream of Richmond, and the Cloncurry River upstream of Cloncurry, generally have less than <10 species present, though a more intensive survey may raise that figure slightly. With the exception of a dam on the Flinders River at Richmond and a diversion weir associated with O'Connell Creek offstream storage, also near Richmond, none of the potential dam sites in the Flinders catchment are likely to significantly impinge upon the known or expected habitat of Barramundi, freshwater whipray and freshwater sawfish.

A total of 42 fish species are known from the Gilbert catchment. The decline in numbers of fish species with increasing distance from the ocean, which is so widely recognised in other catchments, is not clear here. This is probably due to a lack of survey data in the lower reaches, where the highest diversity is to be expected. Available records for barramundi, freshwater sawfish and the freshwater whipray are scant, although both barramundi and sawfish are likely to occur further upstream than the currently available records suggest, and thus intersect with some potential dam sites. In the Gilbert catchment, freshwater sawfish are likely to be able to penetrate upstream of the Green Hills site on the Gilbert River and possibly as far as, or at least near to, the Mt. Noble site on the Einasleigh River.

The majority of potential dam sites in the Flinders and Gilbert catchments contain some regional ecosystems considered to be either 'endangered' or 'of concern'. If any potential dam site is considered for further investigation, the vegetation and fauna communities present would need to be investigated much more thoroughly.

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 Flinders and Gilbert 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 clearly show that Indigenous people located their campsites and subsistence activities along major watercourses and drainage lines. Archaeological sites in parts of the catchment area potentially date to the Pleistocene. The cultural heritage value of these landforms and their immediate surrounds is therefore assumed to be moderate to very high.

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Part 1 Introduction and methods

1 Introduction

Civilisations through time have depended heavily on river systems for their livelihood and many have sought to alter river flows for agricultural purposes. Earliest evidence of river engineering include the ruins of irrigation canals over eight thousand years old in Mesopotamia, while the remains of water storage dams found in Jordan, Egypt and other parts of the Middle East date back to at least 3000 BC (WCD 2000). In Australia there is evidence that Indigenous peoples engineered structures to divert river flows prior to European settlement. Examples in the Northern Territory are seen in the Roper catchment where diversions probably served to sustain wetlands so as to enhance food gathering opportunities (Barber and Jackson 2012), and in the Indigenous dam building documented by early settlers in the Flinders catchment (see companion technical report on Indigenous Water Values; Barber et al. 2013).

After European settlement, the first large dam (> 10m wall height) in Australia was Lake Parramatta on Hunts Creek (NSW), constructed in 1857 (ANCOLD 2010). However, dam construction in Australia and Queensland did not commence in earnest until the mid-1950s (Figure 1.1). Today the number of large dams on the ANCOLD register is over 560. Collectively these dams generated about 6.2% of Australia's electricity (World Bank http://data.worldbank.org/indicator/EG.ELC.HYRO.ZS) and meet 75% of Australia's ~25,000 GL annual water use. All bar three of Australia's dams with a storage volume greater than 500 GL are located south of the Tropic of Capricorn and are close to Australia's main population centres and irrigation regions (Figure 1.2).

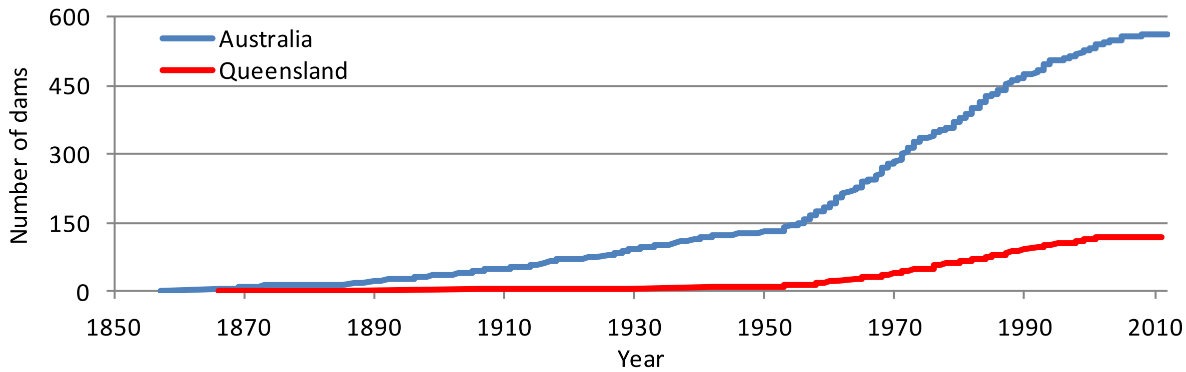


Figure 1.1 Cumulative number of large dams (>10m wall height) in Australia and Queensland over time since European settlement

Clearly dams have significantly influenced Australia's rural development. Particularly in southern parts of Australia, large dams have been an effective means of providing reliable water supplies, in a dry and variable climate. Without the elaborate series of dams in the catchments, most of the irrigated land in the Murray Darling Basin, Australia's major food bowl, could not be watered. However, dams have proved costly in terms of capital expenditure and maintenance, and in degradation of land and other natural resources. Further, dams have resulted in flows being regulated in many of Australia's rivers and complex and often unpredictable environmental and social impacts have often occurred.

The large, often public, capital expenditure requirements and environmental and social impacts have led to some sectors of the public questioning whether dams are an appropriate pathway for development. The change in community attitudes and values regarding dams and the environment in general is reflected in Figure 1.1, which shows that the number of dams constructed in Australia and Queensland started to plateau in the mid-1990s, despite the backdrop of the Millennium drought from 1996 to 2008 in south-eastern Australia. A similar trend has occurred in other developed countries (WCD 2000) - where there has been a general move away from planning and construction of large water resource systems consisting of large dams and associated works, towards managing and operating current systems more efficiently.

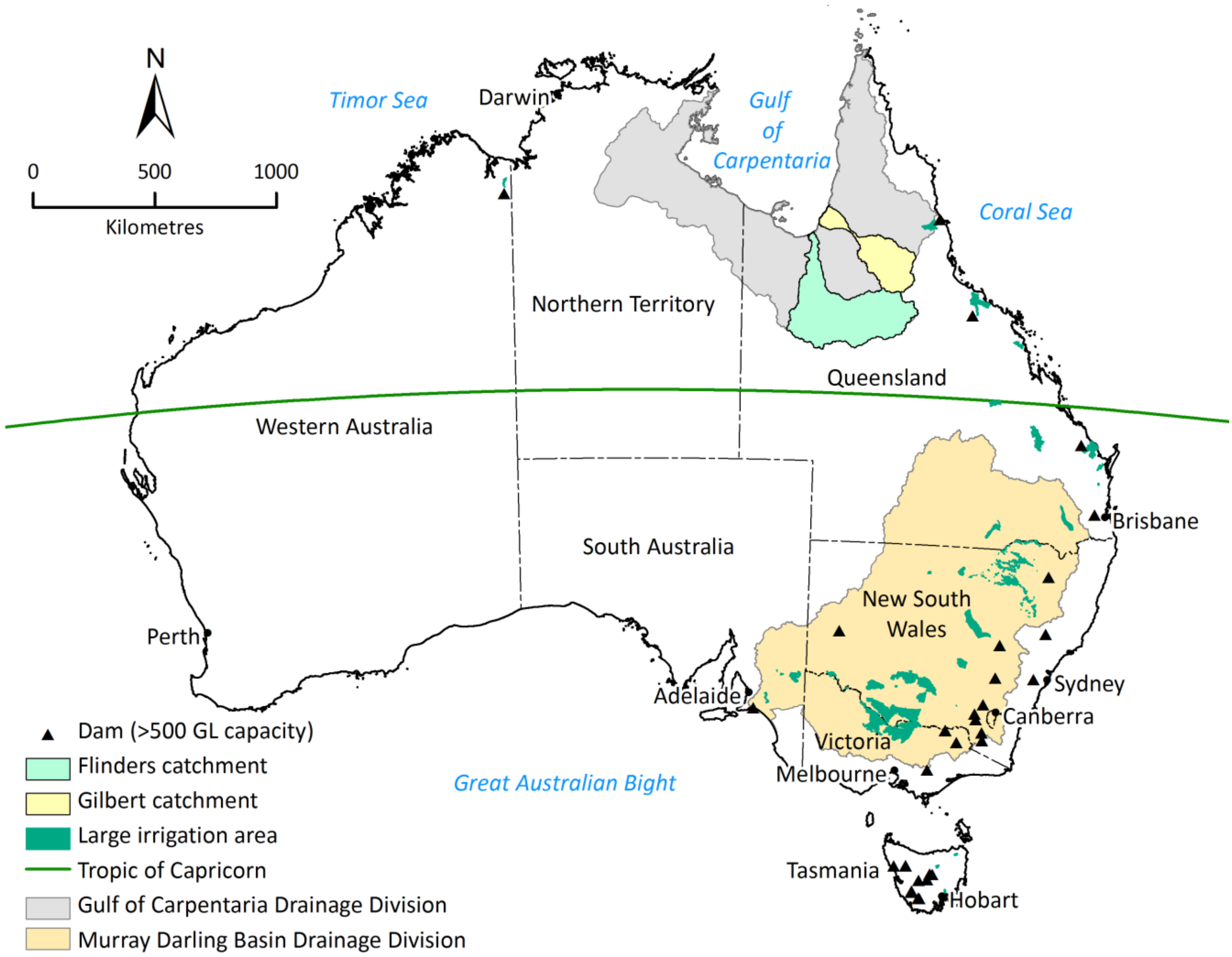


Figure 1.2 Major dams (greater than 500 GL capacity), large irrigation areas and selected drainage divisions across Australia

The Flinders and Gilbert catchments of the Flinders and Gilbert Agricultural Resource Assessment are also shown

In 1994, the Council of Australian Governments released a Communique setting out a framework for water reform in Australia. These directions were reinforced in 2004 when the National Water Initiative (NWI 2004) was released. One of the central tenants of the reforms was a users pay principle, where the cost of providing and supplying water was to be recovered by the sale of water, with any subsidies to be transparent. Prior to the NWI, with the exception of tailing and water supply dams associated with mining, the majority of large dams in Australia have been publically funded by state or local governments with, on occasions, support from the Commonwealth Government. However, even after the NWI, public investment in water infrastructure continued (e.g. desalinisation plants). Consequently some sectors of the public have generally come to take the view: 'Governments fund roads, rail, ports and even desalinisation: so why not fund water storage?'.

The most recent large dams constructed in Queensland were Paradise Dam, completed in 2005, and Wyaralong Dam, completed in 2011. These were both roller compacted concrete gravity dams (see Section 1.2) with heights and lengths of 37 metres and 920 metres and 48 meters and 490 meters respectively. Paradise Dam cost $290 million indexed to 2011 $'s and the final cost of Wyaralong Dam was $348 million. Both dams were developed by special purpose companies established and funded by Queensland state government. In the case of Paradise Dam, it was intended that there would be substantial cost recovery through the sale of water allocations, mainly to irrigators in the Bundaberg area, whereas for Wyaralong Dam which was built for urban water supply, the cost will ultimately be recovered from water users in south east Queensland.

The change in community values regarding the environment is reflected in part by a more involved process for environmental approval and community consultation, which can today comprise a large part of the cost of developing a proposal and the time to reach a commitment to start construction. A recent example in Queensland was the Traveston Dam in the Mary River catchment that was proposed by the state government in response to the water supply crisis in south east Queensland during the Millennium drought. After extensive engineering and environmental assessments, the proposal received environmental approval under state legislation but was abandoned when the proposal was rejected under Commonwealth legislation. Major costs were incurred apart from the substantial study costs, as most of the land required for the storage area had been pre-purchased because of the perceived urgency of the project.

Dams in the Flinders and Gilbert catchments

Flow in rivers in northern Australia is highly seasonal compared to that in southern Australia and other areas of the world of the same climate types (Petheram et al. 2008). In the Flinders and Gilbert catchments for example, 95% and 98% of the runoff occurs during the months of November to April respectively (Lerat et al. 2013). This means that in the absence of groundwater, supplementary or fully irrigated crops require some form of water storage (either offstream or instream).

The predominant landuse in the Flinders and Gilbert catchments has been extensive grazing since first European settlement in the 1860's. However, there has been persistent interest in irrigated agriculture in the region since at least the 1970's, and studies have been conducted into 15 potential storage sites in the Flinders catchment and 6 potential sites in the Gilbert catchment. These studies were undertaken by a range of organisations, at different periods of time and to different degrees of detail. These factors make it very difficult to compare the outcomes of one study with another. Furthermore many of the reports were not published, or only exist as hardcopy reports in the Queensland State Government or SunWater archives.

Report objectives

The objectives of this report were to:

- Review all previous studies (published and unpublished) on water storages in the Flinders and Gilbert catchments.
- Identify and assess all other potential storage locations within the two catchments using the DamSite model.
- Identify the most promising surface water storage options in each catchment, and for three storages in each catchment provide a revised cost estimate based on the available data, reflecting current prices.
- Represent the results in a consistent tabulated format that facilitates site comparisons.
- Provide a regional scale perspective of the best opportunities for offstream storage.

As part of this study, storage volume curves were recomputed using the hydrological corrected Shuttle Radar Terrain Model (SRTM-H) and reservoir yield assessments were reassessed for each dam site using a consistent set of methods across all sites and the latest streamflow and climate datasets. Desktop ecological and cultural heritage assessments were also undertaken. Although the majority of sites were visited and visually inspected by the Assessment's infrastructure planner, engineering geologist, hydrologist and geomorphologist, no new field investigations were undertaken as part of the Assessment.

Site specific field investigations of individual offstream storage sites is beyond the scope of this regional scale investigation. Similarly the Assessment did not set out to identify specific locations for individual offstream storages. Instead the performance of hypothetical offstream storages are discussed and a generalised cost estimate provided.

Report outline

This report is divided into four parts and four appendices.

Part 1, introduction and methods, contains 2 chapters (chapters 1and 2). The first provides introductory material to aspects of large instream dams and offstream dams, key terminology and concepts and the second details the methods undertaken to assess dams in the Flinders and Gilbert catchments.

Part 2, large instream dams, contains two chapters (chapters 3 and 4). The first provides a description of the Flinders catchment and presents summary information for the 15 potential dams assessed in the catchment. Detailed information on the three short-listed dam sites in the Flinders catchment is then presented. The second chapter provides a description of the Gilbert catchment and presents summary information for the 7 potential dams assessed in the catchment. Detailed information on the three short-listed dam sites in the Gilbert catchment is then presented.

Part 3, offstream storages and regulating structures, contains two chapters (chapters 5 and 6), and presents information on offstream storages in the Flinders and Gilbert catchment and general information on regulating structures such as weirs and sand dams.

Part 4, summary comments, contains two chapters (chapters 7 and 8). The first provides a discussion, looking at the results collectively. The second presents the report conclusions.

Appendix A provides a detailed summary of the 12 non-short-listed potential dam sites in the Flinders catchments.

Appendix B provides a detailed summary of the 4 non-short-listed potential dam sites in the Gilbert catchments.

Appendix C provides detailed costings for the short-listed dam sites in the Flinders catchment.

Appendix D provides detailed costings for the short-listed potential dam sites in the Gilbert catchment.

Section outline

The remainder of this introductory chapter is structured so as to give well-informed but non-technical readers some of the background information on surface water storage infrastructure needed to understand subsequent technical sections of the report. First a brief overview of different types of dams and offstream water storage infrastructure is provided. Next the broad steps in the investigation of a dam site are described. This provides the context for the additional work needed in order to 'prove up' a potential dam site subsequent to this report. Section 1.4 provides a broad overview of the social and ecological impacts of dams, and is followed by an overview of existing dams in the Flinders and Gilbert catchments. This is followed by a section providing an overview of existing dams in the Flinders and Gilbert catchments. Finally Section 1.6 presents an overview of the 1 Second Shuttle Radar Terrain Model (SRTM). Reliable, high resolution elevation data are fundamental to dam design and costing and evaluating storage capacities. The SRTM was the primary elevation dataset used in this report and hence it is important that readers understand its limitations and where and how these may result in uncertainty in subsequent analyses that utilise this dataset.

1.1 Key terminology and concepts

1.1.1 WATER YIELD

Yield is the amount of water that can be released in a controlled manner from a reservoir system. Yield values are accompanied by a reliability value; where for all other factors held constant increasing the reliability decreases the yield. Other terms that are used synonymously with yield are release, draft and regulation.

1.1.2 WATER YEAR AND WET AND DRY SEASONS

The Gulf region experiences a highly seasonal climate, with the majority of rain falling between December and March. Unless specified otherwise the wet season is defined as being the six-month period from

1 November to 30 April and the dry season is the six-month period from 1 May to 31 October. All results in the Assessment are reported over the 'water year', defined as the period 1 July to 30 June and which allows each individual wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons). This is the best option for reporting climate statistics in northern Australia and from a hydrological and agricultural assessment viewpoint.

1.1.3 SCENARIO DEFINITIONS

The Assessment, considered three different scenarios of climate and surface water, groundwater and economic development, as used in the *Northern Australia Sustainable Yields Project* (CSIRO, 2009a, b, c):

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

As the primary interest was in evaluating the scale of the opportunity for irrigated agriculture development under the current climate, the future climate scenario (Scenario C) was secondary in importance to scenarios A and B. This balance is reflected in the allocation of resources throughout the Assessment.

Scenario A

Scenario A included historical climate and current development. The historical climate data were of 121 years (water years from 1 July 1890 to 30 June 2011) of observed climate (rainfall, temperature and potential evaporation for water years). All results presented in this report are reported over this period unless specified otherwise. Current development is the current level of surface water, groundwater and economic development that was defined as that of 1 July 2013. The Assessment assumes that all current entitlements are being fully used. Scenario A was used as the baseline against which assessments of relative change were made. Historical tidal data were used to specify downstream boundary conditions for flood modelling undertaken by the Assessment.

Scenario B

Scenario B included historical climate and future irrigation development, undertaken by the Assessment through discussion with stakeholders. Scenario B used the same historical climate data as Scenario A. Future irrigation development is described by each case study storyline, and river inflow and agricultural productivity were modified accordingly.

Scenario C

Scenario C included future climate and current development. It was based on a 121-year climate data sequence scaled for ~2060 conditions. These climate data were derived from a range of global climate model (GCM) projections for a 2 °C global temperature rise scenario which encompassed different GCMs for this single global warming scenario – the projections were then used to modify the observed historical daily climate sequences. The current level of surface water, groundwater and economic development were assumed. Tidal level data were manipulated to reflect a ~2060 sea-level rise (i.e. the median date at which the GCMs reach a 2 °C global temperature rise).

1.2 Types of water storages

1.2.1 DAMS

Dams are usually constructed from earth, rock or concrete materials, as a barrier wall across a river so as to store water in the reservoir created. They need to be able to safely discharge the largest flood flows likely to enter the reservoir and the structure has to be designed so that the dam meets its purpose, generally at least for 100 years.

Embankment dams

Embankment dams (EB) are usually the most economical, provided that suitable construction materials can be found locally, and are best suited to smaller catchment areas where the spillway capacity requirement is small, such as at the Belmore Creek (Norman catchment) and Corella (Flinders catchment) Dams. In the case of Belmore Creek Dam, a central earth core within the embankment is the water tight barrier to prevent water percolating through the rock fill (Figure 1.3), whereas at Corella Dam, the seepage barrier is a thin reinforced concrete slab placed on the upstream face of the rock fill (Figure 1.4).

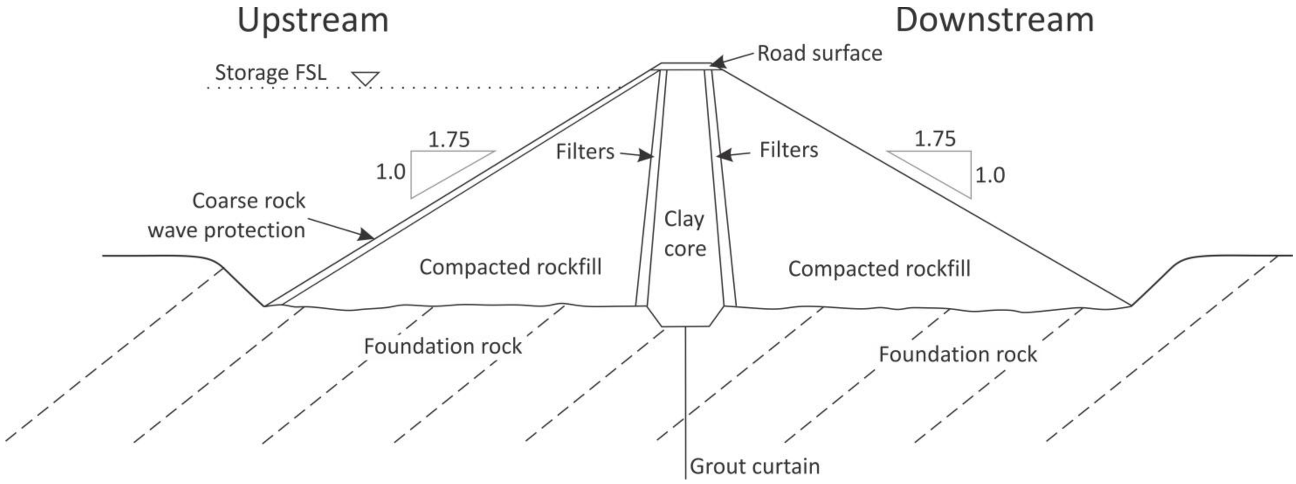


Figure 1.3 Schematic cross-section diagram of an embankment dam

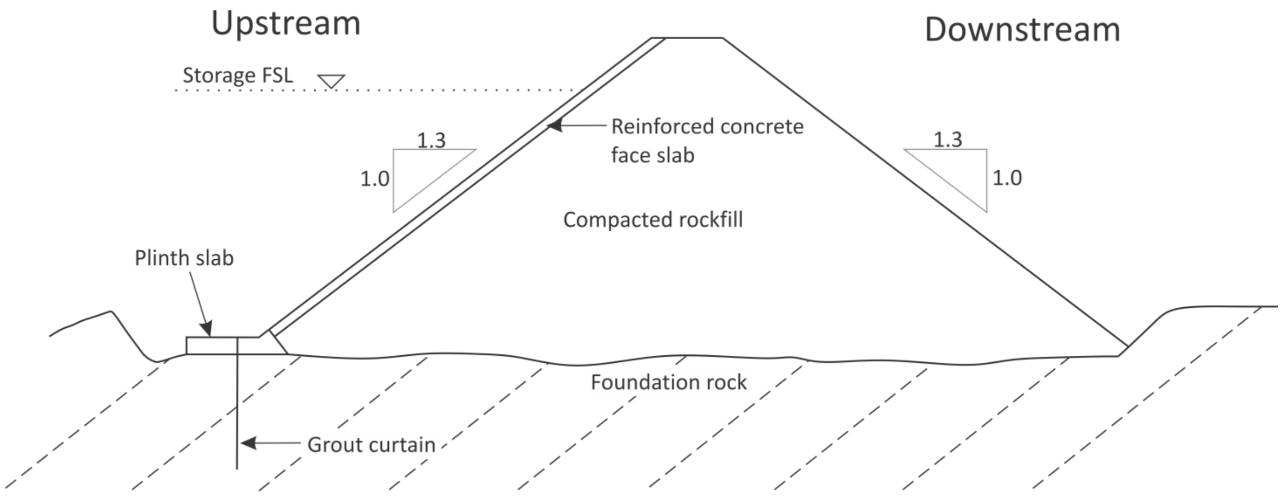


Figure 1.4 Schematic cross-section diagram of a concrete faced rockfill dam.

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

Concrete gravity dams

Where a large capacity spillway is needed to discharge flood inflows, a concrete gravity dam with a central overflow spillway is generally the most suitable type. Traditionally, concrete gravity dams were constructed by placing conventional concrete (CC) in formed 'lifts'. Kidston Dam in the Gilbert catchment, however, was the first dam in Australia where the roller compacted concrete (RCC) was used with the low cement concrete placed in continuous thin layers from bank to bank and compacted with vibrating rollers. This approach allows quite large dams to be constructed in a far shorter time frame than required for conventional concrete construction.

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

1.2.2 WEIRS

Weirs differ from dams in that they are lower barriers located entirely within stream banks and are totally overtopped during flood events. As a rule of thumb, however, weirs are constructed to half the bank height.

Downstream regulating weirs allow for more efficient releases from the storages and for some additional yield from the weir storage itself, thereby reducing the transmission losses normally involved in supplemented river systems.

Broadly speaking, there are two types of weir structures: concrete gravity weirs and sheet piling weirs. These are discussed below. For each type of weir, rock filled mattresses are often used on the stream banks, extending downstream of the weir to protect erodible areas from flood erosion. A brief discussion on sand dams is also provided.

Weirs, sand dams and diversion structures obstruct the movement of fish in a similar way to dams.

Concrete gravity type weirs

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

Sheet piling weirs

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

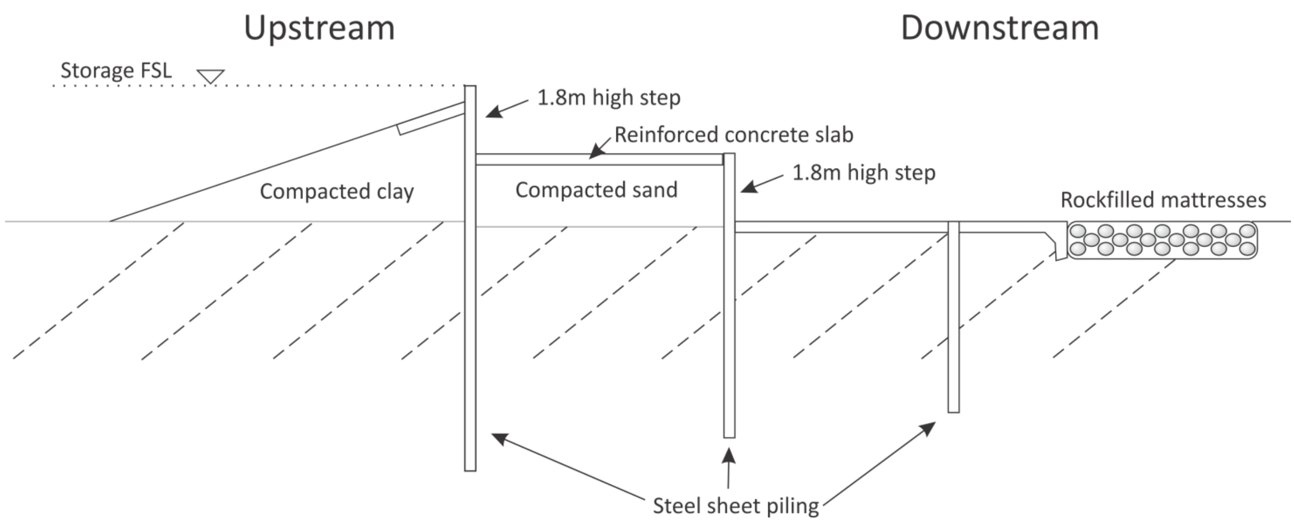


Figure 1.5 Schematic cross-section diagram of sheet piling weir

For each type of weir, rock filled mattresses are often used on the stream banks, and extending downstream of the weir to protect erodible areas from floods.

Sand dams

Sand dams are low embankments built of sand. They are constructed to form a pool sufficiently deep from which to pump water (i.e. typically greater than 4-m depth required) and are widely used in the Burdekin River near Ayr, where the river is too wide to construct a weir. Sand dams are constructed at the start of each dry season during periods of low or no flow when heavy earth moving machinery can access the bed of the river. Typically sand dams take three to four large excavators about two to three weeks to construct and no further maintenance is required until they need to be reconstructed again after the wet season. Bulldozers can construct a sand dam quicker than a team of excavators but have greater access difficulties. Because sand dams only need to form a pool of sufficient size and depth from which to pump water, they usually only partially span a river and are typically constructed immediately downstream of large, naturally formed waterholes.

The cost of 12 weeks of hire for a 20-tonne excavator and float (i.e. transportation) is approximately $75,000. Although sand dams are cheap to construct relative to a concrete or sheet piling weir, they require annual rebuilding and have much larger seepage losses beneath and through the dam wall. No studies have been located that quantify losses from sand dams.

1.2.3 OFFSTREAM WATER STORAGES

Offstream water storage facilities can take the form of gully and hillside dams, ring tanks, turkey nest tanks and excavated tanks (described in more detail in Table 1.1). However, technically the term offstream water storage as applied to gully or hillside dams, which intercept small drainage lines, is a misnomer. Weirs can also be used in conjunction with offstream water storages, where the weir is used to raise the upstream water level to allow diversion into an offstream storage or the creation of a pumping pool. The most suitable type of offstream water storage depends on a number of factors, including topography, availability of suitable soils, excavation costs and source of water (i.e. groundwater or surface water pumping, flood harvesting).

Table 1.1 Types of offstream water storages. Adapted from(Lewis (2002)

TYPE OF ON FARM DAM	DESCRIPTION	STORAGE TO EXCAVATION RATIO
Gully dam	Earth embankment built across a drainage line. Dams are normally built from material located in the storage area upstream of dam site. Gully dams can also be used in conjunction with offstream water storages, where the weir is used to raise the upstream water level to allow diversion into offstream storage or the creation of a pumping pool.	10:1 (favourable conditions)
Hillside dam	An earth dam located on a hillside or slope and not in a defined depression or drainage line	5:1 (on flatter terrain) 1:1 (on steeper slopes)
Ring tank	A storage confined entirely within a continuous embankment built from material obtained within the storage basin	1.5:1 (small tank) 4.5:1 (large tank)
Turkey nest tanks	A storage confined entirely within a continuous embankment but built from material borrowed from outside the storage area. All water is therefore held above ground level	Usually smaller than ring tanks and lower storage to excavation ratio
Excavated tanks	Restricted to flat sites and comprise excavations below the natural surface. Excavated material is wasted. Generally limited to stock and domestic use and irrigation of high value crops.	Low storage to excavation ratio

1.3 Stages of investigation in the design, costing and construction of a dam

The investigation of a potential dam site involves an iterative process of increasingly detailed studies over a period, occasionally as few as 2 or 3 years but often over 10 or more years. Generally, potential dam sites are initially identified from a preliminary consideration of the more significant requirements, including whether:

- the topography favours the creation of a large storage volume by a dam barrier of height and length likely to be economically viable
- the streamflow volumes at the site are sufficiently large for a storage to meet the forecast demand
- the dam site location is in the vicinity of the forecast demand for water.

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

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

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

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

1.4 Environmental and other considerations for dams

1.4.1 SEDIMENTATION CONSIDERATIONS

The impacts of dams on sediment transport in rivers are widely reported across the globe (e.g. Vorosmarty et al., 2003; Syvitski et al., 2005). Dam walls act as barriers to sediment transport, trapping around 100 % of bed load material (i.e. sand and gravel) and up to 100 % of suspended sediment (i.e. clay, silt and fine sand). There are often downstream changes as well, including sediment starvation, which can trigger channel bed incision and bank erosion.

Sedimentation within dams is potentially a major problem for water storage capacity, since infilling progressively reduces the volume available for active water storage. Vorosmarty *et al.* (2003) estimates that most dams trap > 50 % of the sediment load and on average this results in the trapping of 25 to 30 % of the global sediment flux. Some dams have a predicted lifespan of only decades before completely infilling. For example, the World Commission on Dams (2000) shows data where 5 of the 47 dams surveyed had a loss of active storage capacity of > 60 %, and one of these had lost 80 % of capacity in just over 25 years. Extreme sedimentation has also been shown to have affected some smaller dams in Australia (Chanson, 1998).

Prior to construction of Lake Argyle (the largest reservoir of water in northern Australia and the second largest in Australia) the Ord River had such high sediment loads (29 million tonnes per annum) that an area of 10,000 km^2 of degraded land (20% of the catchment area) was purchased to protect it from ranching, and was revegetated at high expense, to ensure that the storage capacity would remain viable (see Payne et al 2004).

Other impacts of sediments in dams include abrasion of outlets and turbines, and poor water quality especially where sediment re-suspension occurs and/or where sediments are carrying considerable nutrients. In some instances, the pattern of dam sedimentation is also problematic. The majority of sediments, particularly coarse bed load sediments, are deposited in the backwater (upstream) areas of reservoirs due to a rapid decline in flow velocity from riverine to lake conditions (Outhet, 1991). Depending on dam levels during flow events, the build up of sediments in the back-water can cause back-flooding beyond the flood limit originally determined for the reservoir.

1.4.2 RESERVOIR DYNAMICS AND WATER QUALITY

Water quality is an important aspect of reservoir dynamics because it impacts upon the utility of the reservoir to satisfy its design objectives. The principal water quality issues associated with reservoirs are: algal blooms (especially potentially toxic blue-green algal blooms), low dissolved oxygen, high concentrations of dissolved metals (principally Fe and Mn), and greenhouse gas emissions. The presence of blue-green algal toxins impacts on the suitability of the water for domestic consumption, contact recreation, and for spray irrigation where inhalation by humans may occur. High concentrations of dissolved Fe and Mn, typically associated with low dissolved oxygen, increase water treatment costs and consumer complaints. Furthermore, depleted dissolved oxygen reduces the habitat available to fish, yabbies and other oxygen-dependent aquatic animals. In addition to these factors, the presence of a reservoir changes the net greenhouse gas (GHG) emissions of the landscape compared to pre-inundation conditions: an effect that ranges from relatively small net increase (e.g. Figure 1.6) in boreal Canada ; Teodoru et al. 2012) to substantial increases in southeast Queensland where reservoir emissions are estimated to contribute about 1/3 of the total GHG footprint of the urban water system (Hall et al. 2011).

All of these water quality impacts depend directly on the stratification dynamics of a reservoir. A stratified reservoir consists of an actively well-mixed surface layer, a thermocline where the temperature decreases sharply, and a hypolimnion (the bottom coldest region of the reservoir) (. When a water column becomes stratified, i.e. the top is less dense (warmer and/or fresher) than the bottom (colder/saltier), vertical transport of heat and chemicals (e.g. dissolved oxygen) often slows down to rates not much greater (≤ 10 times) than the rate of molecular diffusion (e.g. Chaffey Dam, NSW; Sherman et al. 2000).

Seasonal stratification follows a very predictable pattern. Beginning in winter, the water column of a reservoir will become well-mixed and have a temperature that reflects the ambient winter air temperature. Commencing in spring, typically late September, the days become longer and warmer and the surface of the water column begins to warm more quickly than deeper waters. As time progresses, the upper water column continues to warm, with the surface mixed layer temperature close to the average air temperature, while the bottom of the water column warms much more slowly because the vertical transport of heat from above is quite slow.

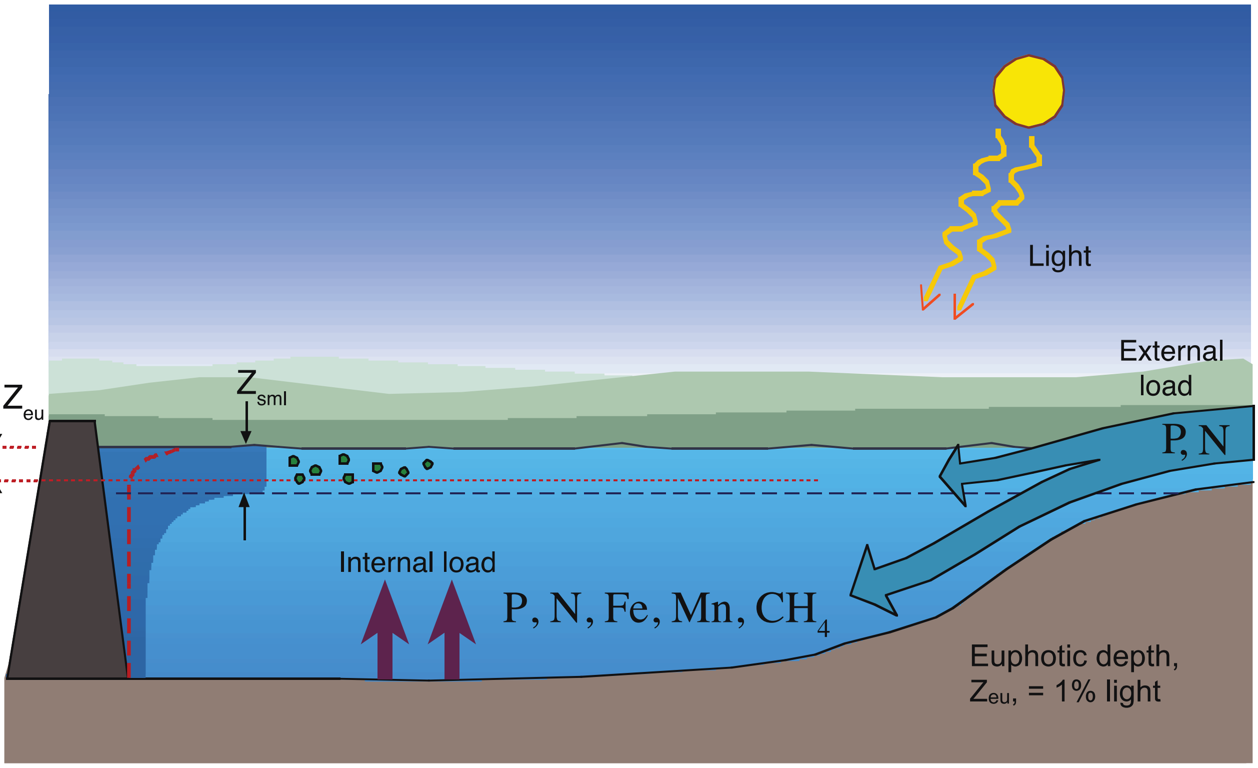


Figure 1.6 Reservoir system concept diagram.
Thermal stratification is denoted by dark blue shading, light penetration (red dashed line), SML depth (black dashed line), euphotic depth (Zeu, red dotted line). Internal loads of phosphorus, nitrogen, iron, manganese and methane commence following the onset of anoxic conditions in the deeper water. External loads enter the reservoir at a depth determined by the inflow density and that of the receiving water.

The presence of a temperature gradient in the water column impacts on the path followed by river inflows, i.e. inflows warmer than the surface mixing layer (SML) will flow over the top of a reservoir; inflows colder than the deep water will flow along the bottom of the reservoir; and intermediate temperature inflows will form an intrusion that moves through the reservoir at a level where the reservoir and inflow densities are similar. The Sydney Cryptosporidium event was the direct result of an intrusive flow 'short-circuiting' the reservoir, i.e. the inflowing water passed through the reservoir rather than mixing into it. Thermal stratification can also lead to cold water pollution downstream of the dam if water is released from the deeper regions of the reservoir.

Blue-green algal blooms require light and nutrients. The most common species of blue-green algae possess gas spaces that allow them to float and remain within the SML, while algal species that sink will descend out of the SML. Blue green algal blooms in Australia are not observed when the SML depth, Z_{sml} is more than three times the euphotic depth, Z_{eu}, because they do not receive sufficient light to support a growing population. The euphotic depth is the depth below the water surface where the down-welling photosynthetically active radiation (i.e. light with wavelengths 400-700 nm) has decreased to 1% of the value at the water surface. In most Australian reservoirs, Zsml:Zeu < 2 and light will not be a limiting factor for buoyant blue green algal growth under most conditions. In both reservoirs and river weir pools when Zsml:Zeu < 3, blue green algal populations have been observed to grow at their light-limited rate, roughly doubling every two days, until the available phosphorus has been exhausted (Sherman et al. 1998,2000;

Bormans et al. 2004). Practical experience has shown that it takes about two weeks of persistent stratification with Zsml:Zeu < 3 for a blue green algal population to reach troublesome levels.

The amount of light experienced by algae in the water column depends on the SML depth which, in turn, is controlled by the balance between the stabilising effects of light absorption and the destabilising effects of surface heat losses (conduction and evaporation) and wind stirring. As a general rule, the daily SML depth is greatest just before sunrise due to convective mixing driven by surface heat losses at night. It is very common in Australia to have wind during the daytime and calm at night, with the stabilising contribution of solar radiation offsetting the destabilising contribution of wind stirring.

A very important impact of stratified conditions is that the downwards flux of oxygen from the surface is generally less than the oxygen consumed by organisms in the lower water column and sediments and it is not uncommon for dissolved oxygen to become completely depleted below the bottom of thermocline by late October. Oxygen depletion is frequently accompanied by an accumulation in the deeper waters of dissolved bioavailable nutrients, especially phosphorus, and dissolved methane which have been released from the sediments. Often, dissolved oxygen falls to close to zero below the bottom of the thermocline and conditions remain anoxic from late October until winter mixing occurs sometime between late May and early July.

Throughout the entire stratified period, nutrients and methane are released from the sediments and accumulate in the deeper region of the reservoir. If water is released from below the thermocline, the dissolved methane will be immediately outgassed a short distance downstream of the dam wall. When the water column finally mixes in winter, the accumulated nutrients are redistributed throughout the water column and support the development of a larger algal population during the following year than would have been the case had oxygen concentrations been higher (Sherman et al. 2000). Concurrently, a proportion of the accumulated dissolved methane is outgassed to the atmosphere and the remainder is oxidised by bacteria within the water column (Schubert et al. 2010).

1.4.3 CONSIDERATIONS IN ASSESSING ECOLOGICAL RESPONSES TO DAMS

Numerous studies have linked water flow with nearly all elements of instream ecology in freshwater systems. The basic guiding principles connecting streamflow to ecology were summarised by Bunn and Arthington (2002) as follows:

Principle 1: Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition

Principle 2: Aquatic species have evolved life history strategies primarily in direct response to the natural flow regime

Principle 3: Maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species

Principle 4: Invasion and success of exotic and introduced species is facilitated by the alteration of flow regimes.

The extent to which a dam or impoundment alters streamflow depends on a number of factors, such as the size of the dam relative to the streamflow of the river and the way in which water is to be used from that dam. Typically, dams reduce the volume of water in downstream reaches. This occurs where water is withheld for other uses or delivered to other areas (e.g. piped to cities). However, in dams where the water is delivered downstream for irrigation using the river as the conduit, the water stored in the reservoir during the wet season is typically released during the dry season. This occurs for example, in the Burdekin River, where water trapped by the Burdekin Falls Dam during the wet season is released through the remainder of the year, resulting in higher than natural flows during the dry season. The loss of the wet-dry seasonality that typifies the ecology and ecological processes of northern Australian rivers can cause as many changes in natural instream ecology as reductions of water.

While the amount and pattern in which water is stored and released from dams is the primary determinant on the type of ecological change, this report is more focused on the impacts of the dam itself. The downstream ecological changes as a result of perturbations to flow below dams will be considered in the companion report on aquatic ecology (Waltham et al. 2013).

The water impounded by a dam inundates an area of land, drowning not only instream habitat but surrounding terrestrial vegetation and fauna communities. Natural riverine corridors generally support high ecological diversity in Australian landscapes. For instream ecology, the dam wall acts as a barrier to movements of plants, animals and energy, disrupting connectivity of populations and ecological processes. Also, a dam creates a large, deep lake, a habitat type that is in stark contrast to the usually shallow and sometimes flowing habitats it replaces. This lake-like environment will favour some species over others and will function completely differently to natural rivers and streams.

The lake-like environment of an impoundment is often used by sports anglers to augment natural fish populations through artificial stocking. Fish stocking is common in impoundments in Queensland (Hollaway and Hamlyn 2001; Moore 2007). Such activity is regulated by Qld Fisheries authorities under the Fisheries Act (1994) and the Fisheries (Freshwater) Management Plan (1999). Certain stockings of native fish and crustaceans are permitted into farm dams and similar waters (for instance barramundi have been stocked into the house dam at Silver Hills station (Hogan and Vallance 2005)), but any stocking into public waters such as rivers or impoundments requires a permit. Several sites in the Flinders catchment (Lake Corella, Chinaman Creek Dam and Lake Fred Tritton) are currently stocked to create a recreational fishery. No such stocking currently occurs in the Gilbert catchment, although it has been proposed for the Kidston Dam by local residents and Barlow (1987). Whether fish stocking is a benefit of dam construction is a matter of debate and point-of-view. Stocked fisheries provide a welcome source of recreation and food for fishers, and sometimes an economic benefit to local businesses, but they have also created a variety of ecological impacts (see Burrows 2004, Pusey et al. 2006 for north Queensland examples), which highlight the need for careful regulatory management. Impounded waters may also be subject to unauthorised fish stocking of native fish. Examples include the stocking of sooty grunter into Chinaman Creek Dam in 1997 (Pearce et al. 2001) and the numerous fish species released into Tinaroo Dam (Burrows 2004) on the nearby Atherton Tablelands. Exotic flora and fauna have also been released into impoundments, such as African tilapia species being released into the town weirs on the Wild River upstream of Herberton (Burrows et al. 2008).

1.4.4 INDIGENOUS CULTURAL HERITAGE CONSIDERATIONS

Introduction

Archaeological evidence of the Indigenous occupation of the Flinders and Gilbert catchment areas dates back to the late Pleistocene or early Holocene period, about 11,000 years ago, and there is some indication of even earlier occupation prior to the Last Glacial Maximum, that is, before c. 23,000 years ago (Morwood 1990). Indigenous people still comprise a significant proportion of the current population of the region (for instance approximately 12% of the population in the Flinders catchment; Jackson et al 2013).

Thousands of years of occupation have left a wealth of traces of archaeological evidence, and there is the potential to yield further information regarding earlier cultures and societies and their adaptations to various past environments and climates. Pre-contact Indigenous occupation of the area is known to have had strong associations with sources of permanent and semi-permanent water, resulting in a concentration of archaeological sites in riverine areas (Hatte 1998; Lovell 1995; Gorecki and Grant). As instream dams are located on major watercourses, they are highly likely to impact upon Indigenous heritage and archaeological sites. In addition, many non-archaeological sites of cultural significance to Indigenous people are associated with water sources and other landform features. For example, particular water bodies in Australia are often associated with conception sites and/or creation stories. However, the term cultural heritage is not just about the past and heritage ‘value’ is not solely about scientific values (i.e. archaeological significance), it encompasses contemporary social values as well as aesthetic and spiritual values related to strongly held concepts of ‘dreaming’ and ‘country’ among Indigenous people.

Any final decisions on the building of dams or infrastructure for irrigation development should incorporate the results of an assessment of the implications of the change in use of water and riverine landscapes for cultural heritage sites, and the values held by local people – past, present and future.

Understanding Indigenous cultural heritage values

The term 'value' is often used interchangeably with 'significance' in heritage studies. However this can be confusing in Australia where there is a a multi-tiered heritage regulatory system based on thresholds of local, state, and national significance. It is more useful to consider values in terms of exploring a more nuanced understanding of the nature of significance. A place can have a range of values yet not meet the (official) thresholds for local significance, or it may reflect the same range of values but in such a way that it is declared of National significance. Places may have value to different or multiple groups in society. Indigenous cultural places may have value in terms of the scientific information they may yield, or in terms of their iconic importance to the Australian people at large, or to a specific Indigenous group for their spiritual value. Some places may have contemporary social value to the Indigenous community as places of memory, contemporary resource use or continuing cultural practice.

The Burra Charter defines cultural significance as meaning:"… aesthetic, historic, scientific, social or spiritual value for past, present or future generations" (Australia ICOMOS 1999, p. 2). This preliminary overview can only summarise the likely nature of the cultural heritage values of the case study areas. Much additional work, including field studies with Indigenous Traditional Owners and those with historical connections to case study areas, is required to gain an adequate understanding of the likely impacts of the water storage options on Indigenous cultural heritage. Identifying intangible heritage values and understanding how these may or may not be affected requires gaining a better understanding of how Indigenous people in this region value land and landscape; and involving communities in identifying strong and special associations with place.

In contrast, most reported investigations into Indigenous cultural heritage in the area have focussed on archaeological evidence of Indigenous life in the period preceding European settlement and in the immediate 'contact' period. Places or objects that contain such evidence are protected under Queensland legislation (see section 3.2) and it is in this statutory context that most such places have been identified, i.e. as part of the assessment of potential impacts relating to development proposals. In the main, these studies do not document contemporary indigenous values except where these relate to sites, or Indigenous objects. However, it is known that Indigenous people are likely to have a variety of contemporary interests in rivers, lagoons and springs, including their protection as ongoing sources of food and perhaps medicinal plants, and places important for continuing cultural practices such as fishing, recreation and trans generational teaching (see also Stoeckl et al 2006; Jackson et al 2013). Any detailed assessment of the impact of the proposed water storage options will require both systematic field survey to identify Indigenous cultural heritage protected under Queensland legislation and comprehensive consultation with Indigenous people about the archaeological sites and to identify places of contemporary significance. The consideration of wild resource 'use values' for Indigenous people should be included in such a study (see for example English 2002).

Statutory protection

The principal statutory protection for cultural heritage in Queensland is provided by the *Aboriginal Cultural Heritage Act 2003*. This Act defines Cultural Heritage as:

- a significant Indigenous area in Queensland; or
- a significant Indigenous object; or,
- evidence, of archaeological or historic significance, of Indigenous occupation of an area of Queensland (Section 8).

The Act is administered by the Cultural Heritage Unit of the Queensland Department of Aboriginal and Torres Strait Islander and Multicultural Affairs (DATSIMA).

The Act contains a general Duty of Care to take all reasonable and practical steps to be aware of, and to avoid harming, Indigenous cultural heritage. Section 23(1) requires that a person must exercise due diligence and reasonable precaution before undertaking an activity that may harm Indigenous heritage. Everyone has a responsibility to exercise Duty of Care. Duty of Care Guidelines attached to the Act set out key indicators of compliance which include, but are not limited to, the following:-

- proof of consultation with the registered Native Title Applicants
- cultural heritage studies undertaken in association with the registered Native Title Applicants
- searches of cultural heritage information contained in the cultural heritage register and database held by the Cultural Heritage Unit within DATSIMA
- a Cultural Heritage Management Plan (CHMP) or other agreement with the registered Native Title Applicants.

When an Environmental Impact Statement (EIS) is undertaken, a CHMP is mandatory if the project requires some form of permit, approval or licence. This means that high impact developments will be aallowed to proceed only when an effective CHMP (containing the results of a cultural heritage study) has been agreed between the proponent and Native Title Party/ies, and the CHMP is registered with the State.

Where the legislation does not automatically require a mandatory cultural heritage management plan, the legislation allows for the development of voluntary CHMP's or Cultural Heritage Management Agreements (CHMA's) as a measure to encourage industry to adopt best practice.

An Indigenous Cultural Heritage Body is a corporation that has been approved by the Minister of DATSIMA as an approved cultural heritage body for an area. The cultural heritage body is the initial contact point for cultural heritage issues within a Native Title area and it usually represents the registered Native Title claimant group for that area. The function of this body is to identify the Native Title Parties for an area. A cultural heritage body must have the written support of a significant proportion of the Native Title Applicants of an area.

Indigenous cultural heritage in the Flinders and Gilbert catchments

The cultural heritage potential willdiffer according to the various landforms and environmental zones and the degree of both previous and recent human disturbance. Some areas might have a moderate to high level of cultural heritage potential (such as elevated river banks and rocky outcrops and escarpments), while others will have lower levels of cultural heritage potential (e.g.: low-lying, flood prone areas and heavily disturbed areas where there has been extensive surface and subsurface ground disturbance due to farming, land clearing).

However, in general, previous archaeological investigations in the broader study regions (Hatte 1989; Gorecki & Grant 1994; Grant 1992; Salmon 1992) have consistently confirmed that major watercourses and their tributaries tend to be highly sensitive environments from a cultural heritage viewpoint. These studies clearly show that in the past Indigenous people located their campsites and subsistence activities along major watercourses and drainage lines. The cultural heritage potential of these landforms and their immediate surrounds is therefore assessed as moderate to high.

Sizeable watercourses, especially those with semi-permanent water, have been found to contain archaeological evidence for ephemeral 'dinnertime camps', but also more complex Indigenous base camps. Low-density stone artefact scatters, isolated artefacts and hearths are likely to be relatively common on the elevated banks and terraces of watercourses in the areas upstream of the potential dam sites. Overall, the potential for watercourses to retain intact archaeological sites and evidence may depend upon the degree of previous disturbance and degradation along elevated banks and terraces.

Potential dams that inundate large areas of land can be assessed as a high impact development, resulting in major transformation of the existing landscape. The size, scale and location of likely potential dams mean that they have the potential to impact upon cultural heritage sites and values. To assess contemporary cultural values further consultation with Indigenous people is required. Post-contact sites relating to the recent European past may also be an issue. The value of such places including places of memory and lived experience may involve traditional owners but may also include Indigenous people with recent historic links because of forced removals and their involvement in the pastoral industry.

1.5 An overview of existing dams in the Flinders, Gilbert and Norman catchments

The Gilbert and Flinders catchments exhibit high topographic and geological diversity such that no one type of dam has been proposed as the most suitable, of the numerous potential dam sites investigated over the years. Although all the large dams constructed to date in the Flinders, Gilbert and nearby Norman catchments have been founded on rock that is only slightly weathered and has good strength characteristics, each one is of a different type, as shown in Table 1.2.

Table 1.2 Constructed dams in the Flinders, Gilbert and Norman catchments

NAME OF DAM	NEAREST TOWN	ORIGINAL OWNER	YEAR CONSTRUCTED	HEIGHT ABOVE BED LEVEL (m)	STORAGE CAPACITY AT FSL (GL)	TYPE OF DAM
Corella Dam (Flinders)	Mt Isa	Mary Kathleen Uranium Ltd	1959	22.9	15.3	Embankment -concrete faced rock fill.
Kidston Dam (officially known as Copperfield River Gorge Dam) (Glbert)	Kidston	Kidston Gold Mines Ltd	1984	38	20.4	Concrete gravity – roller compacted concrete.
Chinaman Creek Dam (Flinders)	Cloncurry	Cloncurry Shire Council	1993	13.7	2.8	Concrete gravity – conventional concrete.
Belmore Creek Dam (Norman)	Croydon	Croydon Shire Council	1994	15.0	5.8	Embankment - earth and rock fill.

Source: ANCOLD Register of Large Dams

Figure 1.7 Downstream face of Kidston Dam on Copperfield River, Gilbert Catchment

1.6 Deriving dam axis elevation profiles and reservoir volumes

1.6.1 BACKGROUND

Elevation data are fundamental to assessing dam design and evaluating water storage capacities. For the Flinders and Gilbert catchments the national 1 second hydrological digital elevation model (DEM-H), derived from the Shuttle Radar Topographic Mission (SRTM) data (Gallant et al, 2011), is the finest resolution digital elevation dataset available. This dataset covers the entire continent, and over most of Australia, and particularly northern Australia, constitutes the best available data. In using any elevation dataset it is important to understand the strengths and weaknesses, so a brief discussion of the DEM-H is provided below.

The SRTM data and processing to form the national 1 second DEM-H

The SRTM data were acquired by NASA over 10 days in February 2000, and after a substantial processing effort, was released in 2005. While the SRTM dataset is remarkably accurate it has several characteristics that make its immediate application for hydrology difficult. It contains voids (areas without data), striping due to uncorrected instrument artefacts, and considerable noise and offsets due to radar reflection by trees. The combination of resolution, noise and tree effects means that most watercourses in Australia are not represented, although the largest watercourses in the Flinders and Gilbert catchments are visible in the SRTM data. Further limiting the utility of the data was the reduced resolution of the publicly released data: although it was processed to 1 second resolution (about 30 m), the products were released at a degraded 3 second resolution (about 90 m).

In 2007 CSIRO acquired the 1 second dataset and over a period of 4 years, in partnership with Geoscience Australia, the Bureau of Meteorology and the Australian National University, filled the voids, removed the striping and vegetation offsets and smoothed the noise, using a series of novel algorithms (Gallant et al. 2011). Drainage lines were then enforced in the smoothed product (DEM-S) using the ANUDEM software and the national 1:250k stream network (modified to reduce conflicts with the finer scale DEM data). To date, Australia is the only country that has an SRTM-based product of this quality and the only country outside the USA to have publicly released SRTM-based data at 1 second resolution.

Limitations of the SRTM

The SRTM-derived DEMs have a number of limitations, even with the significant improvement. Voids (mostly due to water surface or very steep terrain) were infilled using the 9 second DEM, which lacks detail, but this only affects small areas of Australia, and virtually none of the Flinders and Gilbert catchments. The removal of tree offsets was ineffective in some areas, although there were only minor vegetation effects in the Flinders and Gilbert catchments. There is also a vertical datum difference between SRTM, which is based on the EGM96 geoid, and the Australian height datum (AHD); the difference is poorly defined due to the lack of a well-defined AHD surface across the continent, but is generally less than 1 m.

The vertical accuracy of the SRTM data was assessed by Rodriguez et al (2006) and for Australia 90% of reference heights were found to be within 6 m of the correct height. Some of this error is due to the offsets induced by trees, so the Australian processed products (e.g. DEM-H and DEM-S) are expected to be slightly better than this. Relative error (the error in height difference between two nearby points) is typically better than the absolute error.

The greatest limitation for the application of evaluating potential dam sites is the limited ability to accurately resolve the shape of small steep features such as those forming the restrictions that create good sites for dams. The SRTM instrument itself could resolve features on the order of 50-60 m, but some of the subsequent processing smoothed or removed some of the remaining detail. The evaluation in the following section illustrates the ability of the SRTM-based DEM-H to capture the topographic features relevant to dam sites.

1.6.2 PERFORMANCE OF SHUTTLE RADAR TERRAIN MODEL AT ASSESSING RESERVOIR VOLUME AND DAM AXIS CROSS-SECTIONS

In assessing a water storage proposal, elevation data are used to: i) compute the upstream catchment area; ii) compute the storage volume; and iii) develop cross-sections and contour maps in the vicinity of the dam site to assist in the design and construction of the dam wall and saddle dams. The SRTM is excellent for computing catchment areas. The limitations of using the SRTM to compute storage volumes and develop cross-sections perpendicular to a river are discussed below.

Computation of storage volumes

Experience with the SRTM-derived digital elevation model (DEM) leads us to believe that the errors for larger storages will be small compared to storage volume. This is confirmed by the example analysis in Figure 1.8 showing the comparison of storage areas and volumes derived from DEM-H and a more accurate survey: differences are negligible for dam heights more than about 7 m.

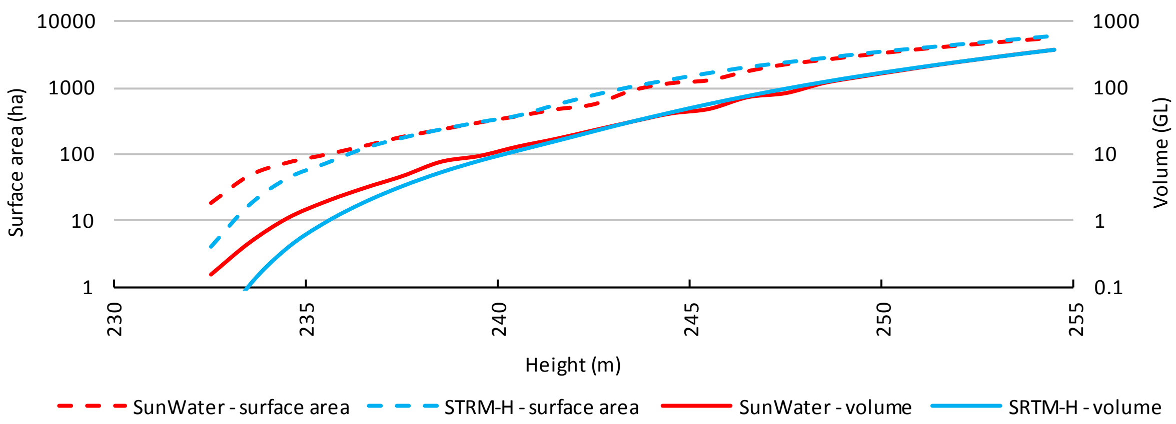


Figure 1.8 Comparison of SRTM-H and photogrammetry survey for the Green Hills dam site (Gilbert catchment) for a range of heights

Cross-sections perpendicular to a river

The ability of DEM-H to capture the detailed topographic structure around a potential dam site is rather more limited than its ability to characterise the catchment area and storage volume. Figure 1.9 shows a topographic cross-section at a potential dam site based on DEM-H and a more accurate laser altimeter. While the SRTM-based DEM-H captures the overall topographic structure very well, it is unable to resolve the fine-scale topographic variations around the channel (at 3800 to 4000 m distance along the profile), missing both narrow peaks and narrow channels. This could lead to erroneous dam cost estimates, although in this case the channel is very small.

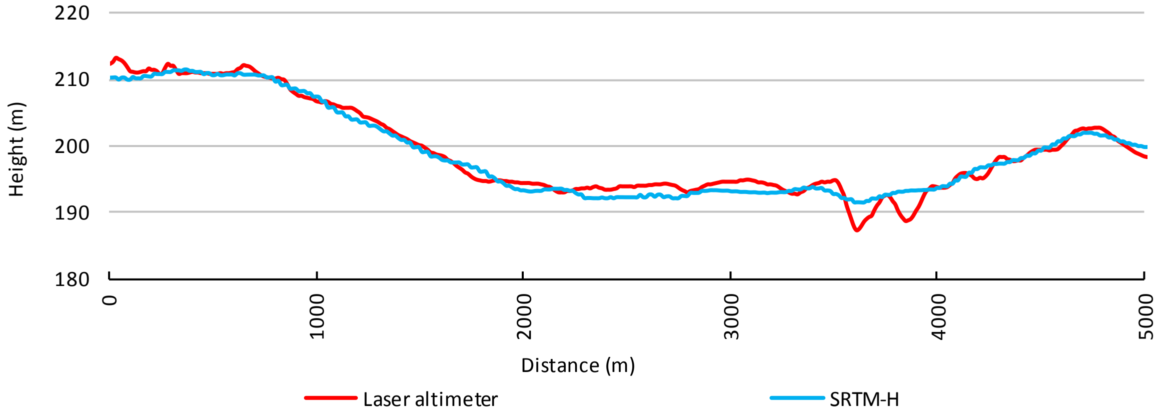


Figure 1.9 Comparison of SRTM-H and laser altimeter on flat terrain with slopes mostly less than 1 degree. (O'Connell Creek offstream storage on O'Connell Creek, Flinders catchment)

Figure 1.10 compares the SRTM-derived DEM-H at 30 m resolution to a high resolution DEM at 2.5 m (developed using 'structure from motion' method described in Section 2.3.1) at one of the potential dam sites. Note that some of the detail in the photogrammetric DEM profile is due to trees, notably the section between about 1380 to 1480 m.

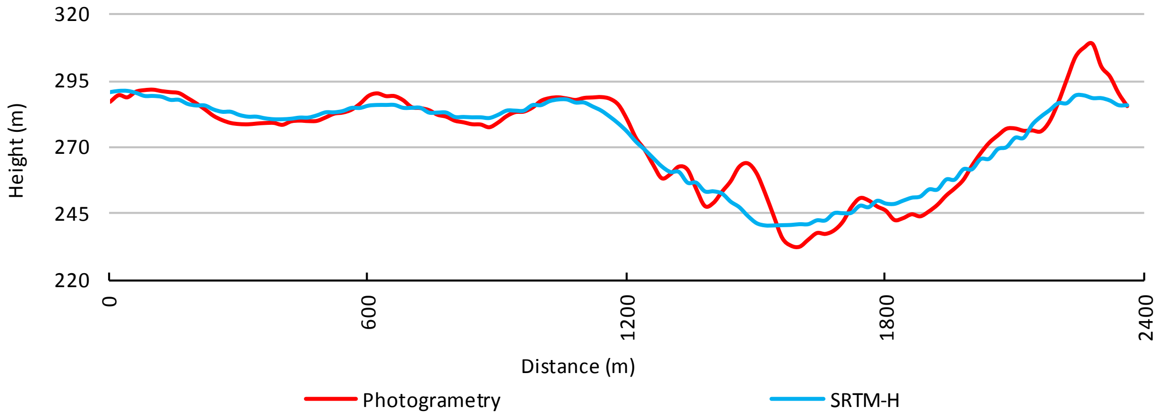


Figure 1.10 Comparison of SRTM and photo DEM in moderate relief terrain with slopes up to 15 degrees. (Corella River damsite, Corella River, Flinders catchment)

Figure 1.11 illustrates a comparison between the SRTM-H and a cross-section surveyed using Real Time Kinematic (RTK) survey equipment at a potential dam site with a shear face. It can be seen that the SRTM-H is unable to adequately resolve the very steep topography at 400m.

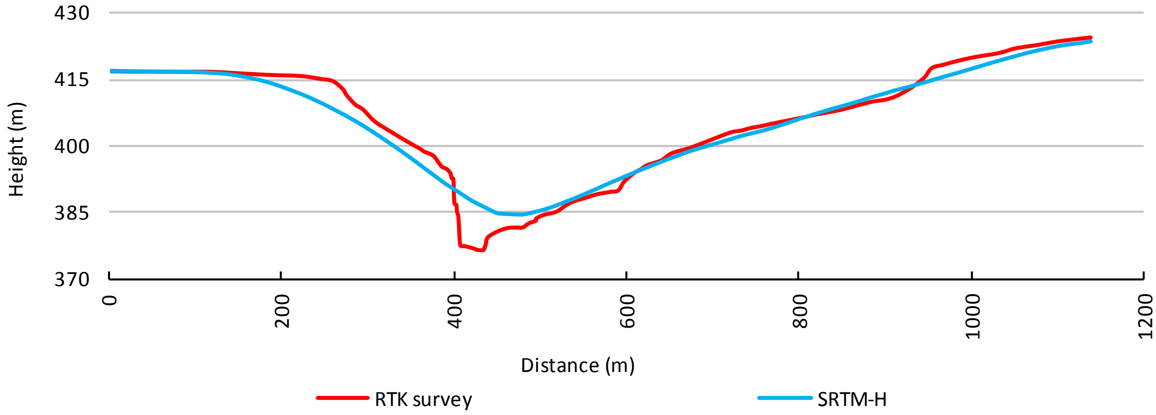


Figure 1.11 Comparison of SRTM and surveyed cross-section in steep terrain with slopes up to 90 degrees. (Porcupine Creek damsite, Porcupine Creek, Flinders catchment)

2 Methods for assessing large dams

This section describes the methods used to evaluate the existing and potential large (instream) dam sites in the Flinders and Gilbert catchments. The methods used to assess the suitability of offstream storages is discussed in Section 5.1.

The first phase of the investigation into large dams involved i) identifying all large dam proposals that had been the subject of earlier or current investigations; and ii) running the DamSite model to ensure no potential dam options had been overlooked (Section). These two activities were undertaken concurrently and are described in Section 2.1.

Based on the review of existing reports and the DamSite model results a list of potential dam sites to investigate in more detail was established. Section 2.2 lists the potential dam sites investigated and provides a summary of the methods used for more than 20 parameters against which each potential dam site was assessed.

Section 2.3 provides detailed methods for selected parameters outlined in Section 2.2. The more detailed methods are on the topics listed below:

- Developing a DEM using the structure from motion method (Section 2.3.1)
- Reservoir yield analysis using the behaviour analysis model (Section 2.3.2)
- Computing design flood discharge (Section 2.3.3)
- Computing evaporation from an open water body (Section 2.3.4)
- Assessing the risk of reservoir sedimentation (Section 2.3.5)
- Water quality and stratification considerations (Section 2.3.6)
- Environmental assessment (Section 2.3.7)
- Indigenous cultural heritage assessment (Section 2.3.8)
- Estimating dam cost (Section 2.3.9).

The method by which three potential dam sites in each catchment were short-listed is outlined in Section 2.4.

2.1 Identification of potential dam sites in the Flinders and Gilbert catchments

2.1.1 REVIEW OF AVAILABLE REPORTS

A large number of potential water storage options in the Flinders and Gilbert catchments have been investigated over a period of more than 40 years, both by State water resources agencies and various consultants engaged by state and local governments and private interests. To date only a few large water storages have been constructed in the Assessment area (see Section 1.5).

A comprehensive review was undertaken of all available reports likely to include relevant information on past water storage studies. Reports were accessed from state agency libraries including the SunWater Corporation library. This process was undertaken by an expert with extensive dam planning, design and construction experience and by an engineering geologist with major dam investigation and review experience.

During the review of existing reports and reassessment of potential dam sties it became particularly evident that previous investigations varied considerably in scope and in rigour. Only the more recent studies included for example, consideration of the social, environmental and cultural issues involved in major water storage developments, or included any allowance in cost estimates for the compensation or management costs involved in dealing with such issues. For some options (e.g. Glendower and Cave Hill dam sites in the Flinders catchment), geological conditions and the availability of construction materials had been investigated by site mapping, seismic traverses, drilling, and by trenching and laboratory testing of materials. In other options, geological conditions were assessed by site inspection only, if at all (e.g. Mount Noble and Mount Alder in the Gilbert catchment).

For the majority of the water storage options, it is clear that the technical data available and assessments made at the time involved uncertainties as to adequacy and accuracy. For example, the reliability of survey datums is uncertain, where old surveys based on a state datum were converted incorrectly to the more recent Australian Height Datum network. Any such inaccuracies have implications not just for topographic data but also for the estimation of storage volumes and surface areas. It is only for the more recent studies, such as for the Green Hills dam options on the Gilbert River where the topographic and storage characteristics were derived from a digital terrain model developed from recent photogrammetry, that the topographic and storage data could be regarded as accurate. However, in the case of Green Hills the photogrammetry did not have sufficient extent to identify a very large saddle dam required at the downstream dam site.

A further issue that required consideration is that dam engineering standards have developed considerably since many of the past investigations were undertaken. In the mid 1980's for example, the Bureau of Meteorology adopted new approaches to the prediction of extreme precipitation so that estimates of Probable Maximum Flood are now considerably higher than the estimates prepared at the time of many of the above studies. Given the state's policies regarding the adequacy of dam spillways, the spillway capacity for many of the options will need to be substantially greater than that estimated previously which will of course, significantly increase costs. In the case of the Burdekin Falls dam the spillway capacity was originally assessed as being 64,600 m^3/s. Based on the new methods for computing Probably Maximum Precipitation (PMP) the required spillway capacity was revised as being 112,200 m^3/s (SunWater 2009).

In undertaking the review, data for each site were compiled using a common framework (see Section 2.2) thus facilitating comparisons between dam proposals. The ultimate purpose of the review was to identify water storage options worthy of further investigation within the context of the Assessment. The review summaries were augmented with information gathered from site inspections during November 2012 and in January 2013 (Table 2.1 and Table 2.2). This was further augmented with more recent geological and topographic mapping (i.e. using the SRTM-H, which in the majority of cases, was superior to the historical topographic mapping), desktop ecological and cultural assessments and new hydrological modelling using recent climate and streamflow input data over a consistent assessment time period and using a consistent set of methods. The specific methods used to assess each potential dam site are described in Section 2.2.

Table 2.1 Potential dams assessed in Flinders catchment

Note that at some of the locations up to three alternative sites were assessed. All parameters are with respect to the proposed structural arrangement. Site visit indicates whether site was visited as part of the Assessment. Past visit indicates whether site had been visited prior to the Assessment by one of the members of the Assessment team

DAM ID	NAME	SPILLWAY HEIGHT (m)	DAM TYPE*	CAPACITY FSL (GL)	SURFACE AREA AT FSL (Ha)	AVE. DEPTH^ (m)	CATCHMENT AREA (km^2)	VOL TO AREA RATIO^^	SITE VISIT	PAST VISIT
1	Alston Vale	30	RCC	241	2367	10.2	1132	0.21	✓	×
2	Black Fort	16	EB**	43	1117	3.8	4249	0.01	✓#	✓
3	Cameron Creek	24	RCC	190	2539	7.5	494	0.39	✓	×
4	Cave Hill	16	EB	248	5044	4.9	5264	0.05	✓	✓
5	Chinaman Creek Dam	14	CC	2.75	125	2.2	167	0.02	✓	✓
6	Corella Dam	20	EB	20	332	6.2	335	0.06	✓	✓
7	Corella River	24	RCC	101	1499	6.7	642	0.16	✓	×
8	Flinders 856 km	34	RCC	89	813	10.9	1694	0.05	×	×
9	Glendower	34	RCC	309	2567	12.0	1912	0.16	×	✓
10	Mt Beckford	23	EB	245	2826	8.7	2065	0.12	✓	×
11	Mt Oxley	36	RCC	62	474	13.1	690	0.09	×	×
12	O'Connell Creek offstream	9	EB	127	3352	3.8	1508	0.08	✓	✓
13	Porcupine Creek	35	RCC	31	308	10.0	1051	0.03	✓	×
14	Richmond Dam	13	EB	200	5732	3.5	17,724	0.01	✓	✓
15	White Mountains	37	RCC**	111	1049	10.5	1085	0.10	×	×

* Conventional concrete (CC), embankment dam (EB), roller compacted concrete dam (RCC).
** Details of original dam proposal could not be located. Dam type listed is considered most likely based on available information.
^ This is the ratio of the capacity of the reservoir to the surface area of the reservoir at FSL.
^^ This is the ratio of the capacity of the reservoir at FSL to the catchment area of the dam.
# Air reconnaissance only.

Table 2.2 Potential dams assessed in the Gilbert catchment
Note that at some of the locations up to three alternative sites were assessed. All parameters are with respect to the proposed structural arrangement. Site visit indicates whether site was visited as part of the Assessment. Past visit indicates whether site had been visited prior to the Assessment by one of the members of the Assessment team

NAME	SPILLWAY HEIGHT (m)	DAM TYPE*	CAPACITY FSL (GL)	SURFACE AREA AT FSL (Ha)	AVE. DEPTH^ (m)	CATCHMENT AREA (km^2)	VOL TO AREA RATIO^^	SITE VISIT	PAST VISIT
Bundock Creek	14	EB/ RCC	30	808	3.7	205	0.15	✗	✓
Dagworth	30	RCC	498	5885	8.5	15,351	0.03	✓	✗
Green Hills	21	RCC	227	4151	5.5	8,310	0.03	✓	✓
Raising Kidston Dam	40	CC**	25	257	9.7	1,244	0.02	✓	✓
Mt Alder	20	RCC	31	614	5.0	8,641	0.01	✓	✗
Mt Noble	22	RCC	103	2012	5.1	12,383	0.01	✓	✗
North Head	32	EB/ RCC	136	1610	8.5	4,680	0.03	✗	✓

* Conventional concrete (CC), embankment dam (EB), roller compacted concrete dam (RCC).
** The existing Kidston Dam is a RCC dam but it would be raised using CC.
^ This is the ratio of the capacity of the reservoir to the surface area of the reservoir at FSL.
^^ This is the ratio of the capacity of the reservoir at FSL to the catchment area of the dam.
# Air reconnaissance only.

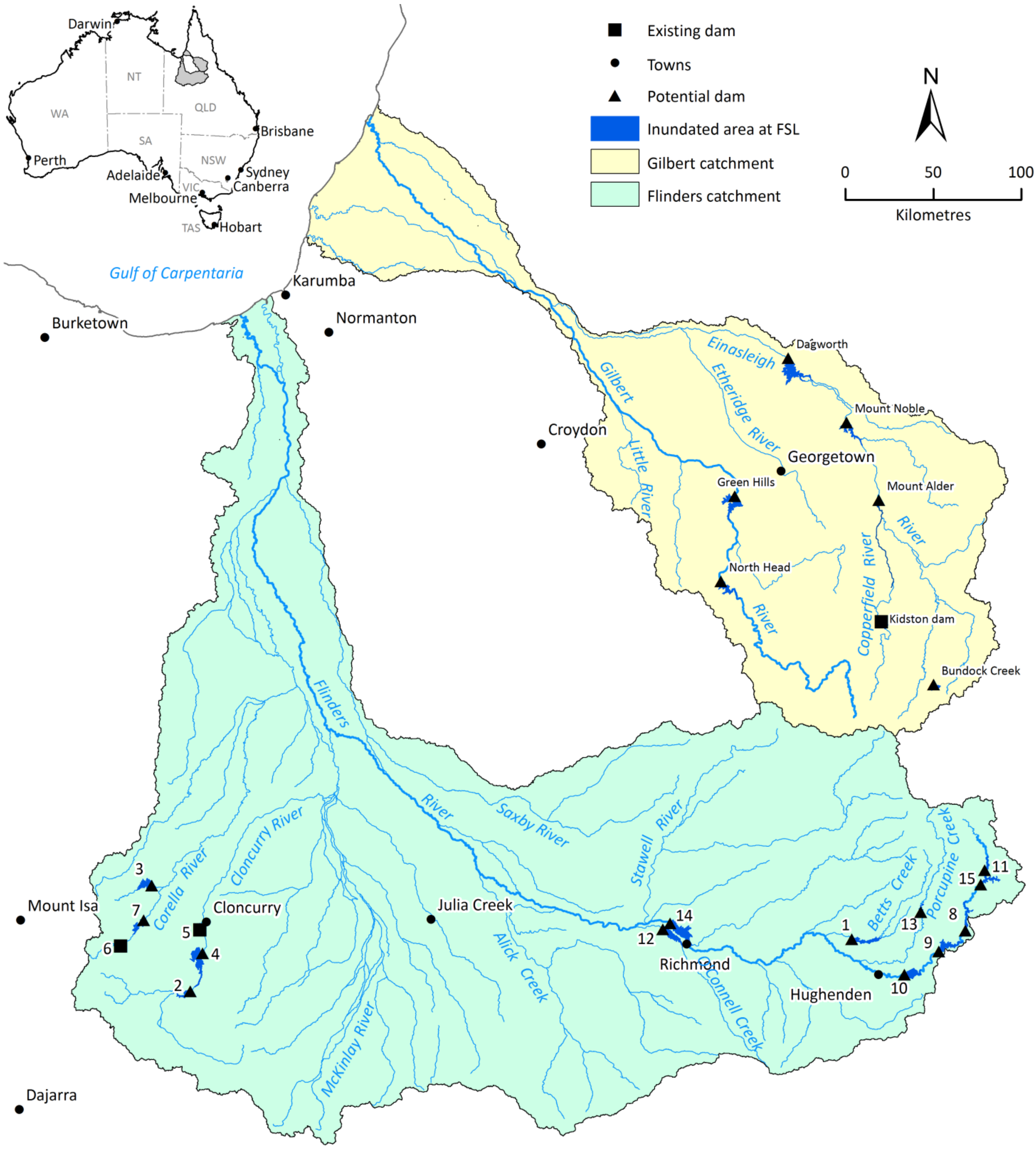


Figure 2.1 Existing and potential dam sites assessed in the Flinders and Gilbert catchments
Numbers in Flinders catchment correspond to Dam ID in Table 2.1.

2.1.2 DAMSITE MODEL ANALYSIS

Topographically a reservoir site with high potential can be defined as having a deep narrow valley for a dam site impounding a suitably voluminous valley for storage. The attractiveness of a narrow dam site is the relatively low cost incurred to construct the dam and therefore the qualitative topographic description ‘deep narrow valley’ can be expressed as a single cost term based on the geometry of the dam. The volume of the valley only describes the ability to hold water but to have high potential a site also needs to have sufficient inflow and reliability of flow to utilise the storage volume and produce a high (water) yield. Water yield is generally the goal of a new dam and is therefore a suitable term for summarising a range of topographic and hydrologic parameters, and yield per unit cost is a valuable single term for comparing sites.

This section describes the DamSite model, a series of algorithms that searches across a DEM and automatically locates favourable locations in the landscape for possible water storage sites.

Spatial analysis to quantify dams and impoundments

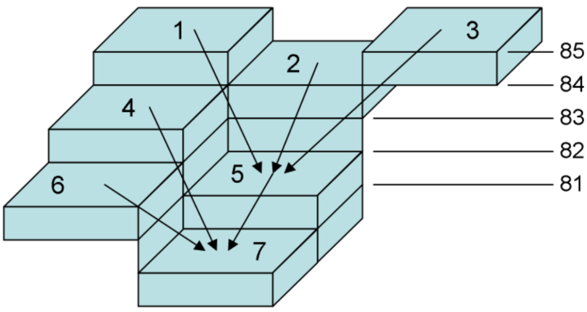
To simplify the analysis, in the DamSite model dam walls are assumed to be built along catchment boundaries of valleys rather than as straight lines across valleys. This will be a reasonable approximation in steeper terrain where the catchment boundary is typically nearly perpendicular to a river channel, but is likely to be a poorer approximation in flatter terrain; the dam width and hence cost will be over-estimated in those areas.

The geometric parameters are derived from a DEM and its corresponding single direction (D8) flow network. Flats and depressions must be treated so that there are no interruptions to the flow network. The method rounds DEM elevations to integers so that discrete heights can be counted.

The volume and area of an impoundment contained by a dam along the catchment boundary is represented by a table of heights and corresponding areas (represented by a count of DEM cells). A table is computed for every cell in the DEM starting at the cells with no inflows (tops of hills and ridges), and building tables for each downstream cell by combining the tables from cells that flow into it. Figure 2.2 shows a schematic of several cells, the flow paths between them and the resulting tables of heights and cell counts for each cell.

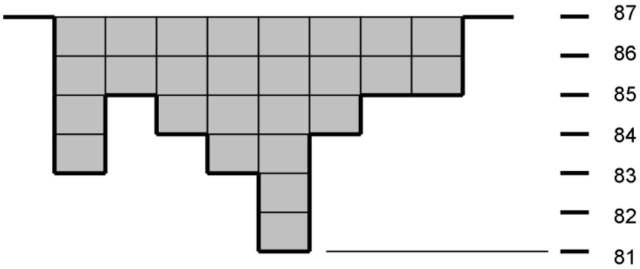
Given the height-count table for a cell, the area of impoundment (in m^2) for a given water surface elevation is simply the sum of cell counts with heights less than or equal to the water surface elevation, multiplied by cell area. The volume (in m^3) is the sum of areas for heights less than or equal to the water surface height (using an elevation increment of 1 metre). The table thus captures the depth-area-storage relationship at each DEM cell.

The dam width and height can be represented by a height-count table similar to that used for storage area and volume. Figure 2.3 shows a schematic of a dam face, including a saddle dam with a base at 83 m elevation.



Cell	Height	Count
1	85	1
2	84	1
3	85	1
4	84	1
5	82	1
	84	1
	85	2
6	83	1
7	81	1
	82	1
	83	1
	84	2
	85	2

Figure 2.2 The construction of the height-count table for a small set of cells connected by flow paths. The table for each cell is constructed by combining the tables of each contributing cell.



Height	Count	Cum
81	1	1
82	0	1
83	2	3
84	2	5
85	3	8
86	0	8

Figure 2.3 Counts of cells for 1 metre increments of height of dam wall. The dam width is the cumulative count of cells with increasing height.

From the dam wall height-count table, the width of a dam (in meters) of a given height is the sum of the cell counts with heights less than or equal to the dam top elevation, multiplied by cell size, noting that the width includes that of saddle dams not connected to the main dam wall. The face area of the dam (in m^2) for a given height (again including saddle dams) is the sum of dam widths less than or equal to the dam height (using an elevation increment of 1m).

The dam wall analysis extends to encompass the entire catchment boundary for each cell: in practice dams are not constructed to surround an entire catchment but the inclusion of the entire catchment boundary ensures that all saddle dams are included in the analysis. Attempts to limit the analysis to realistic dam widths did reduce the computation time but frequently missed saddle dams that were in some cases much longer than the "main" dam located on the channel being dammed, leading to mis-identification of sites as suitable locations for dams.

Computation of reservoir yield for large instream storages

The storage volumes computed above were used in a preliminary reservoir storage yield-reliability technique, referred to as the Gould-Dincer approach (Equation 1).

This approach has been recommended for use as a preliminary reservoir storage-yield-reliability technique by Gould (1964), Teoh and McMahon (1982), McMahon and Adeloye (2005) and most recently, by McMahon et al. (2007a). It is, however, only appropriate for application to carry-over storages. When the storage is within-year (i.e. the storage fills every year) the Gould-Dincer yield results become erroneous, and in some cases negative in value. To address this issue, at each storage location an estimate of reservoir yield was also computed assuming the storage was within-year. Existing methods in the literature for adjusting carry-over estimates of reservoir yield to account for within-year storage (Adeloye e t al. 2003) were found to be unsuitable. Hence a new method for computing within-year reservoir yield to be used in conjunction with the Gould-Dincer approach was devised. This is described below.

At each storage location and for each incremental dam wall height, the larger of the carry-over and within-year yield estimates was adopted.

Gould-Dincer Gamma approach for estimating carry-over storage yield

The Gould-Dincer approach can deal with Normal, Log-normal or Gamma distributed flows. Petheram et al. (2008) observed annual streamflow series across northern Australia to be Gamma distributed so the Gamma version of the Gould-Dincer approach is adopted here and shown in Equation 1.

$$D = \mu - \frac{\sigma^2}{S\gamma^2}\left(\frac{1-\rho^3}{\left(1-\rho^2\right)^{1.5}}\right)^{-2}\left[\left\{1+\frac{\gamma z_\delta}{6}\left(\frac{1-\rho^3}{\left(1-\rho^2\right)^{1.5}}\right)-\frac{\gamma^2}{36}\left(\frac{1-\rho^3}{\left(1-\rho^2\right)^{1.5}}\right)^2\right\}^3-1\right]^2\left(\frac{1+\rho}{1-\rho}\right) \quad (1)$$

The Gould-Dincer Gamma approach computes yield, draft or demand (D) using the annual streamflow characteristics: mean annual flow (μ), standard deviation of annual flow (σ), coefficient of skewness (ϒ) and lag-one serial correlations coefficient (ρ). The catchment averaged μ from the upstream contributing area of each hypothetical storage location was computed from the long term mean annual runoff grids produced by the Northern Australia Sustainable Yields Project (Petheram et al., 2009). The σ value was computed from the relationship between the coefficient of variation of annual flow (Cv) and μ for rivers in northern Australia provided by Petheram et al. (2008). Because the Gould-Dincer-Gamma approach is relatively insensitive to ϒ and ρ, median values for rivers in northern Australia provided by Petheram et al. (2008) were used. In Equation 1 z_{δ} is the standardized Normal variate at δ probability. To compute a preliminary estimate of yield we adopted δ = 0.20, i.e. equivalent to 80% annual time reliability.

The Gould-Dincer Gamma approach outlined above was used to compute the yield for every hypothetical storage location and dam height computed in Section 2.1. Although the Gould-Dincer Gamma approach is considered to provide an approximation to the yield (i.e. as computed by more computationally intensive methods like the behaviour analysis model), it is considered adequate for this application where its use is limited to relative comparisons between hypothetical storages.

Computation of within-year storage yield

The basis of this simple approach was the generation of a grid of the annual runoff percentiles equivalent to the reliability used in the Gould-Dincer Gamma approach described above (i.e. 80% exceedance runoff in this case). At each storage location 80% exceedance streamflow was computed by multiplying the catchment averaged 80% exceedance runoff by the catchment area. For each dam height the smaller of i) the storage volume; and ii) the 80% exceedance streamflow was adopted. This value was then adjusted for evaporation during the dry season months March to August (E_{Dry}), computed using Equation 2. This time period was adopted on the basis that within-year storages are most likely to be used to irrigate short season crops planted at the end of the wet season when the soil water is at its highest, rather than plant perennial crops or double crop and have to store water to the end of the dry season when evaporation rates are at their highest.

$$E_{Dry} = \sum_{March}^{Aug} E \times 0.7 \times A \qquad (2)$$

Where E is the daily evaporation computed using Morton's wet areal potential and A is the reservoir surface area at FSL.

Ranking dams at and between location/s

To select the 'best' dam in each DEM cell it was necessary to identify dams that are economically efficient to construct for the amount of water they supply. To do this at each DEM cell, dam cost and reservoir yield was modelled for each 1 meter height increment and the cost (millions of dollars) for each increment in dam size (including saddle dams) was estimated using Equation 4. This equation was derived using (CPI adjusted) dam capital cost and readily available dam attribute data (e.g. dam height and width) for 80 large dams in Australia. These data were sourced from Petheram and McMahon 2012.

$$Cost = EXP(1.5681 * Log(height) + 0.6148 * Log(width) - 5.5466) \qquad (3)$$

where *height* is dam height (metres) and *width* is dam width (metres). The ratio of yield (Gl) to cost ($m), referred to as the unit cost, was then used to find the optimum dam height in each DEM cell. The height and width of dams from the ANCOLD database are plotted in Figure 2.4. These were used to set the maximum height and width of the main dam wall.

In computing the cost the dam height was adjusted to account for freeboard. For dams less than 10 m the dam height used in the cost function was increased by 1 m, for dams between 10 and 20 m the dam height was increased by 2 m and for dams greater than 20 m the dam height was increased by 3 m.

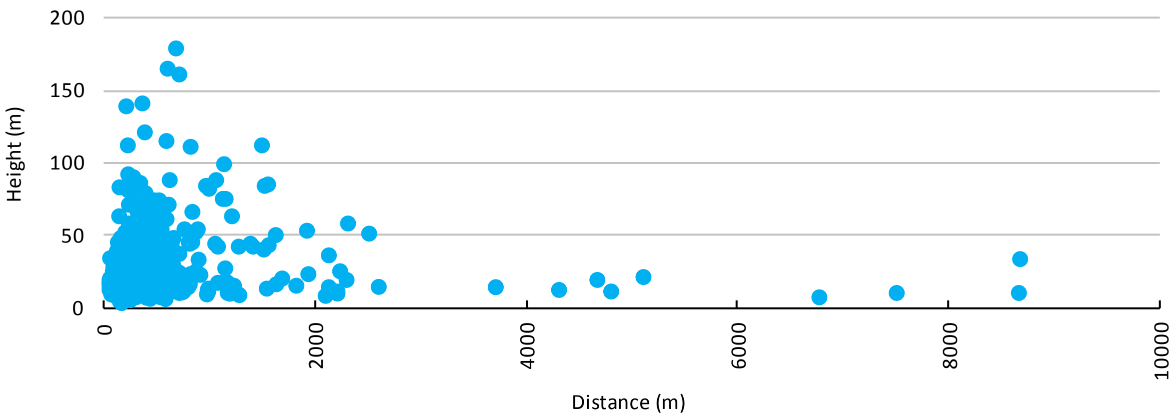


Figure 2.4 Plot of height versus length for 500 of Australia's largest dams (from the ANCOLD 2010 database).

The key output of the DamSite model is a GIS map of topographic and hydrologic dam potential based on the selection criteria applied. This information is valuable for combining with other GIS data for a full assessment of site suitability. High ranking dam locations tend to cluster around topographically favourable areas such as a gorge. To aid visual inspection of the results the 'best' dam locations are limited to local maxima of reservoir yield : cost ratio, spaced no less than 40 cells (about 1.2 km) apart. For each such site, the location, reservoir yield : cost ratio, dam height, dam width, estimated cost, storage, area and base elevation are recorded for further analysis. Decisions on the specific location on a short stretch of channel are best made later, after a site visit.

2.2 Summary of parameters used to assess water storage options

To facilitate comparison of different water storage options, each potential dam site was assessed and reported against the standard set of parameters listed in Table 2.3. The structure of this table is identical to the water storage summary tables presented in the results sections, 3 and 4. This table provides a summary of the methods by which the parameter was investigated. More detailed descriptions are provided in Section 2.3.

Where warranted more detailed descriptions of methods for selected parameters are provided Section 2.3.1 to Section 2.3.9. For some parameters a more comprehensive assessment was undertaken for the six short listed sites.

Table 2.3 Methods used to assess potential dam sites

PARAMETER	DESCRIPTION
Previous investigations	Literature documenting previous dam site investigations were obtained from a variety of sources including state agency libraries and the SunWater Corporation library. Note all distances of dam from the river source were calculated using the topo 250 km stream network and for this reason will vary from previous distances.
Description of proposal	Based on review of past reports. Where no documents were identified this is noted. For the short listed potential dam sites the original proposals were modified to reflect more recent data, methods and contemporary thinking.
Regional geology	The regional geology for each dam site was assessed using the Queensland 1:250, 000 and 1:100,000 geology series, previous dam studies and literature sourced from state agency libraries.
Site geology	The site geology for each dam site was assessed using the Queensland 1:250,000 and 1:100,000 geology series, and most sites were visited by the Assessment geologist see Table 2.1 and Table 2.2.
Reservoir rim stability and leakage potential	These parameters were assessed by overlaying inundated area at FSL on 1:250,000 or 1:100,000 geology data.
Proposed structural arrangement	Based on review of past reports. Where no documents were identified this is noted. For the short-listed potential dam sites new conceptual arrangements were developed, which better reflect contemporary thinking and more recent data.
Availability of construction materials	Based on review of available literature, site visits and proximity to quarry locations.
Catchment area	Catchment areas were derived from SRTM-H. In the majority of cases the SRTM-H data is considered to be superior to historical topographic data for the purposes of deriving catchment areas and computing reservoir volumes.
Flow data	Mean and median flows were computed using observed data from the nearest streamflow gauging station.
Capacity	Dam capacity was derived from SRTM-H, unless stated otherwise. For potential dams the dead storage volume was assumed to be 2% of the reservoir capacity at FSL.
Reservoir yield assessment	A behaviour analysis model was used to assess the reliability of different yields. Four assessments were undertaken at each dam site: 1) under Scenario A (historical daily climate data) for a range of dam wall heights and a perennial crop demand pattern using the baseline river model; 2) under Scenario A using the proposed structural arrangement, the baseline river model and i) a perennial, ii) dry season; and iii) wet season planting crop demand pattern. 3) under Cwet, Cmid and Cdry (i.e. future climate data) for the proposed structural arrangement, baseline river model and a perennial crop demand pattern; and 4) using an ensemble of 50 statistically plausible river models under the proposed structural arrangement using a perennial demand pattern. The performance of each reservoir was reported in terms

PARAMETER	DESCRIPTION
	of the annual time reliability and the volumetric reliability. More detail on these methods is provided in Section 2.3.2.
Open water evaporation	Morton's wet environment areal potential evaporation (APE) (Morton 1983) (see Section 2.3.2) and a stability corrected bulk aerodynamic formulae (Liu et al. 1979) (see Section 2.3.4).
Potential use of supply	Based on review of past studies.
Impacts of inundation to existing property and infrastructure	Based on review of past studies, satellite imagery, GIS overlays and site visit.
Ecological and cultural considerations raised by previous studies	Based on review of past studies.
Estimated rates of reservoir sedimentation	Sedimentation rates were calculated using estimated sediment yields and the FSL dam capacity for each site. Sediment yields were computed from an empirical relationship derived from 10 sediment yield studies across northern Australia. The rates of reservoir sedimentation are presented for 1, 10, 30, 100 and 1000 years, as well as the number of years taken to 100 % infill. Minimum (best case), expected and maximum (worst case) estimates are provided. See Section 2.3.3 for more details.
Water quality and stratification considerations	Used 1-dimensional DLM hydrodynamic reservoir model. Full details on the method are provided in Section 2.3.6.
Environmental considerations	**Barrier to fish movement** Mapped data on the ecological assets and the fish species distribution for both Flinders and Gilbert River catchments were sourced from the companion technical report on aquatic ecology (Waltham et al., 2013). Data on the persistence of dry season pools in both catchments was sourced from the companion technical report on dry season pool (McJannett et al., 2013). Full details on the method are provided in Section 2.3.7. **Ecological implications of inundation** The latest available (2012. V7) regional ecosystem data (Queensland Department of Environment, Heritage and Protection; Herbarium) were used to assess the potential implication of inundation on vegetation communities. No field ecological surveys were undertaken as part of the Assessment.
Cultural heritage considerations	A desktop Indigenous cultural heritage review was undertaken by searching the DATSIMA databases. This was only undertaken for the short listed potential dam sites. See Section 2.3.8 for more information.
Estimated cost	For all potential dam sites that were previously investigated the cost estimate reported in the literature was adjusted for inflation using the Australian Consumer Price Index (CPI), although it was noted throughout that construction costs, particularly in remote areas are likely to have escalated at a higher rate than the CPI, particularly during the recent boom period of mining activity. This is discussed further in Section 2.3.9. For the six dams that were short-listed new cost estimates were computed. This was done by developing conceptual arrangements for each of the storages Cost rates applied for each item of work were derived from earlier estimates for the Green Hills, Connors River dam and Wyaralong Dam. The uncertainty associated with the short listed sites is estimated to be between -10% and +30%. For those dams that were not short-listed, new indicative estimates of dam cost were obtained by simply extrapolating the new cost estimates for the six short listed potential dams based on comparisons of dam dimensions, remoteness and complexity of foundations to the short-listed sites. The uncertainty associated with these estimates is likely to be between -10% and +50%.
Estimated cost / ML of	Estimated capital cost divided by the yield at 85% reliability as computed by the Assessment

PARAMETER	DESCRIPTION
supply	under the proposed structural arrangement.
Potential benefit/cost	Based on reviewed literature.
Summary comment	As provided by Assessment personnel.

2.3 Detailed methods for selected attributes

This section provides more detailed methods for selected parameters presented in Table 2.3.

2.3.1 DEVELOPING DEM FROM STRUCTURE FROM MOTION

To overcome some of the limitations in using the DEM-H to derive dam axis cross-sections that are perpendicular to rivers, a new technique was developed using Structure from Motion (SfM) photogrammetry. This method uses multiple overlapping images to infer three-dimensional structure. Corresponding features in the images are identified and their relative displacements when seen from different viewpoints provide depth information. Freely available software, such as VisualSFM, produces 3D point information from a collection of overlapping images with very little additional information, and it can use GPS data collected along with the images to register and scale the points. The points are then interpolated to produce a DEM.

This new technique for generating digital elevation models was tested at two of the potential dam sites (Corella River downstream and Cave Hill). Images were collected by digital camera and digital video camera from a helicopter circling the sites. At one site, simultaneous GPS recordings were collected. The georeferencing approach was adjusted for trends using the SRTM-based 1 second DEM. The SfM derived DEMs were produced at 0.09 second resolution, about 2.5 m. To illustrate the improvement in resolution the SRTM-H (Figure 2.5) and SfM derived DEM’s (Figure 2.6) are compared for the Corella River potential dam site.

The SfM technique was applied at a third site (Dagworth upstream site), but the results were poor as a consequence of having too few photographs (i.e. < 20) and no accompanying GPS data. In an attempt to overcome the latter issue the unscaled 3D model was scaled and registered using features that could be located in the images and in georeferenced Google Earth imagery. The results from the SfM for this potential dam site were used to inform manual adjustments to the SRTM-H derived cross-section.

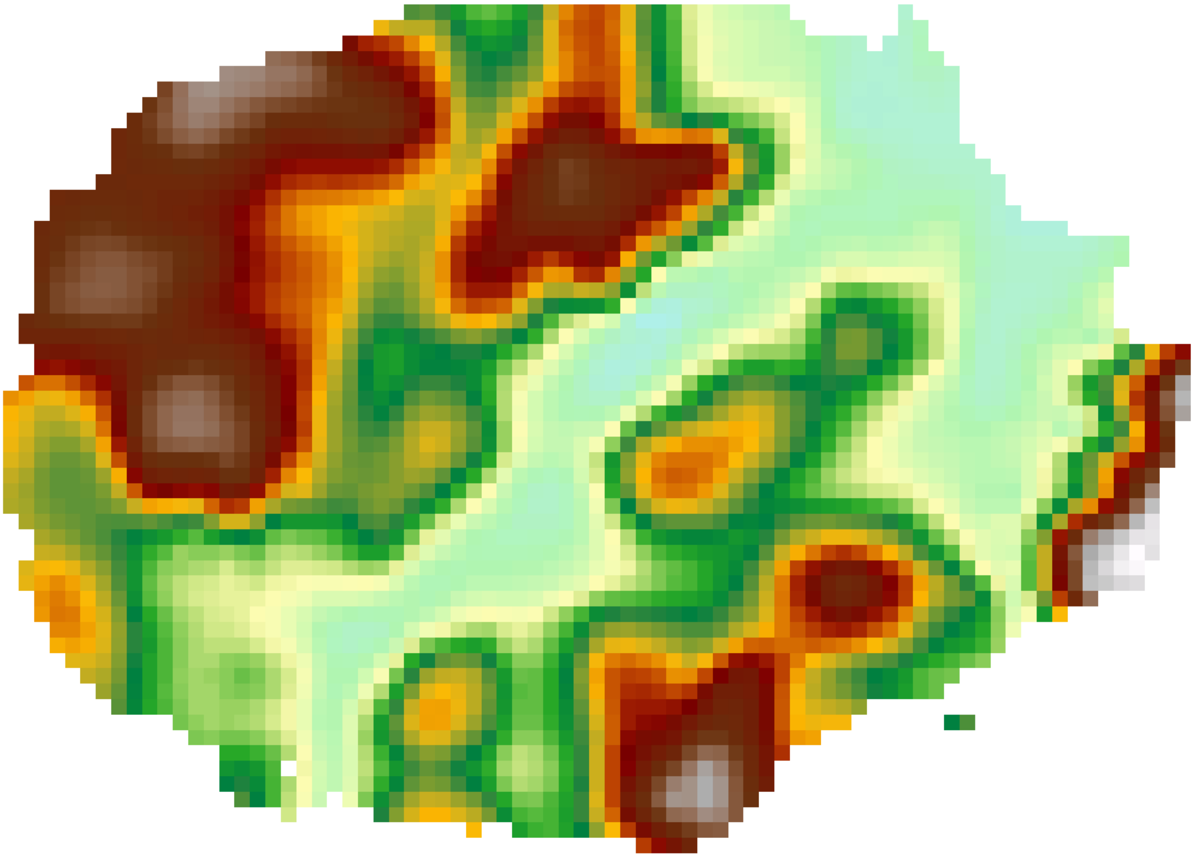


Figure 2.5 SRTM-H 1 second (30 m) DEM at the Corella River site. Width of the image is approximately 2500 m

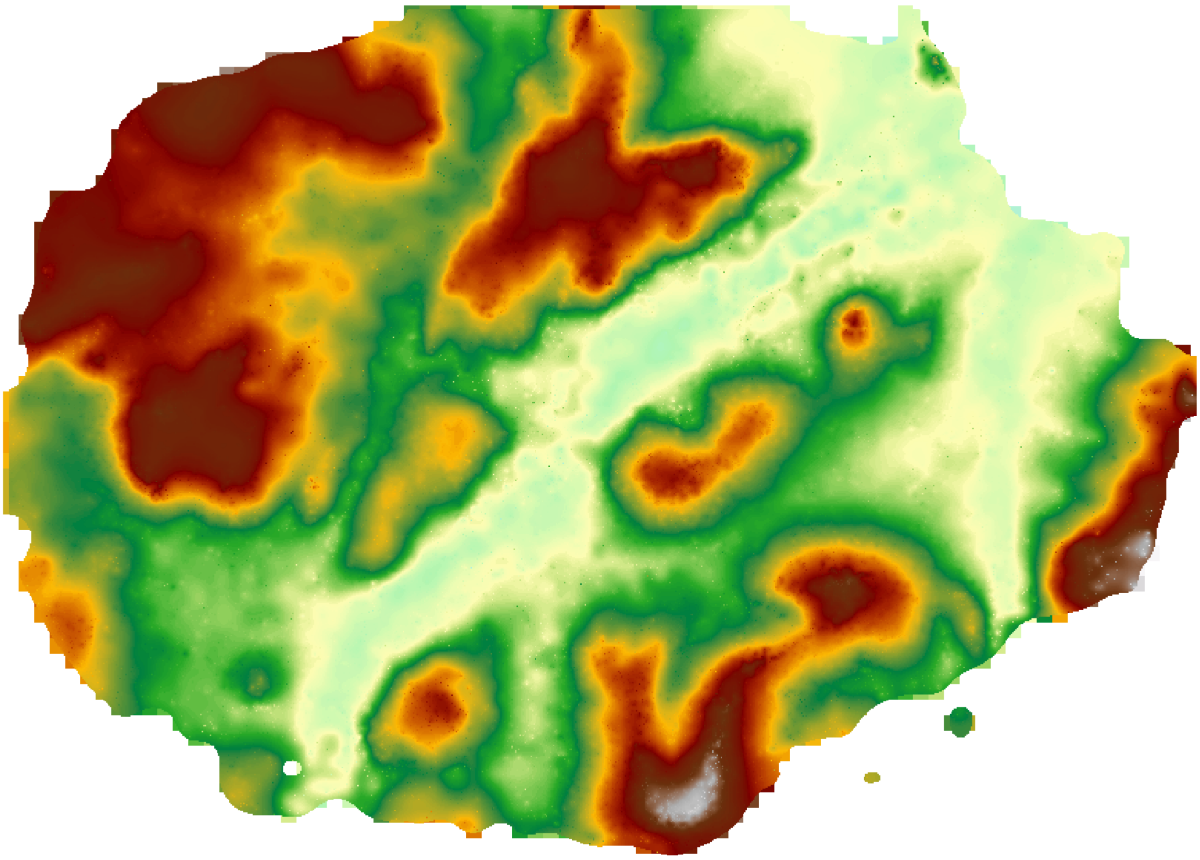


Figure 2.6 SfM derived (2.5 m) DEM at the Corella River site. Width of the image is approximately 2500 m

2.3.2 RESERVOIR YIELD ANALYSIS USING BEHAVIOUR ANLAYSIS MODEL

To assess the reservoir yield of large dams at different reliabilities an assessment was undertaken using a behaviour analysis model. The following section describes the model, the input data and performance metrics. Potential dam inflows used as input to the behaviour analysis model were obtained from the baseline and 50 ensemble Source river system models calibrated as part of the Assessment (see Lerat et al. 2013).

Behaviour analysis model

The water balance of a reservoir must consider inflows, outflows, and evaporation. In general, inflows and outflows consider only surface waters, i.e. river inflows and deliberate releases or spills from a dam. Groundwater interactions, both into and out of a reservoir, are typically neglected for the purposes of water balance modelling, except when they have been identified as a potentially important component of the overall water balance.

A behaviour analysis model was used to compute the annual time and volumetric reliability for each potential dam site selected in Table 2.1 and Table 2.2. The model used in this analysis operates on a daily timestep. A mathematical description of the model is provided by Equation 4 and 5.

$$Z_{t+1} = Z_t + Q_t + A_t \times \left(P_t - E_t - \frac{R_t}{A} \right) - L_t - D_t^{'} \qquad (4)$$

Subject to the constraint $0 \le Z_{t+1} \le S$. Where Z_{t+1} and Z_t are the contents of the storage at the beginning of timestep *t+1* and *t* and S is the volume of the reservoir at FSL. Z and S have units of m^3. Q_t and P_t are the inflow (m^3) and precipitation (m) respectively to the storage during timestep *t*, E_t and L_t are the evaporation (m) and leakage (m^3) respectively from the storage during timestep *t* and A_t is the surface area (m^2) of the storage during timestep *t*. D_t' is the actual water release (m^3) during day *t*. D_t' is equal to the daily D_t when there is sufficient water available in the reservoir; otherwise it will be less than the demand and so a failure (to supply full demand) is said to occur. For each time interval, the total water available is the initial reservoir volume plus the inflow during that interval after adjusting for net evaporation.

When the behaviour analysis is run on a daily timestep the monthly demand is distributed uniformly across each month.

If the water height is below the dead storage height at time *t* then:

$$Z_{t+1} = Z_t + Q_t + A_t \times \left(P_t - E_t - \frac{R_t}{A_t} \right) - L_t \qquad (5)$$

Evaporation was calculated using Morton's wet environment areal (APE) (Morton, 1983) as there was negligible difference between Morton's APE and Morton's Lake evaporation formulations (Morton 1983) in the Assessment area and Morton's APE was readily available. Morton's APE formulation was adopted over other more physically based methods of estimating evaporation (e.g. Penman-Monthieth) because Morton's APE does not require wind speed data, which in Australia only extends back as far as 1975 (McVicar 2011). The appropriateness of using this formulation is examined between 2000 and 2012 using an independent hydrodynamic reservoir simulation model, which uses a stability corrected bulk aerodynamic formulae to compute evaporation (Liu et al. 1979) (see Section 2.3.4).

The behaviour analysis model was repeatedly run using incrementally larger annual demand values (until equal to the mean annual streamflow). The annual demand was disaggregated to a daily demand based on a monthly demand pattern.

Input data

Climate data were sourced from the SILO data spanning 121 years (i.e. Scenario A as described in Section 1.1.3 and the companion technical report on Climate, Petheram and Yang 2013). The behaviour analysis model utilised 121 years of simulated streamflow data (extracted from the Source 'baseline' river system models for the two catchments, developed as part of the Assessment).

To better understand the influence of rating curve uncertainty on model calibration, 50 equally plausible 'observed' streamflow replicates were generated (see Lerat et al. 2013). These replicates were generated using a regression model based on variation in the streamflow gauging measurements. The Source river model was subsequently calibrated to each of the 50 replicates. This innovative approach provides a means of understanding the uncertainty in the model so that modellers can advise whether the model is providing a meaningful answer within the context of the uncertainty that is inherent in the observed streamflow data.

The baseline model run refers to the model calibrated to the original Queensland Government rating curve. It should be noted that there was insufficient time during the Assessment to develop and implement a pragmatic method for assessing the uncertainty in simulated streamflow data as a result of temporally varying uncertainty in rainfall data. The uncertainty analysis in the river system modelling focused on streamflow because this was thought to have the greatest levels of uncertainty.

Generating demand patterns

Reservoir yield was assessed using three constant monthly demand patterns; the first representative of a perennial/full-year crop, the second a crop planted at the end of the wet season (i.e. grows during the dry season) and the third a crop planted at the end of the dry season (i.e. grows during the wet season). The monthly demand patterns were calculated based on the average monthly irrigation application from 121 year APSIM simulations for a bambasti pasture (perennial), dry season sorghum (dry season planting), and wet season sorghum (wet season planting). SILO climate data from Georgetown and Richmond were used as representative climates for the two catchments. The APSIM model was setup to irrigate on a deficit, which essentially meant irrigation was timed perfectly (i.e. no losses). The APSIM model is described in further detail in the companion technical report on Agricultural Productivity (see Webster et al. 2013).

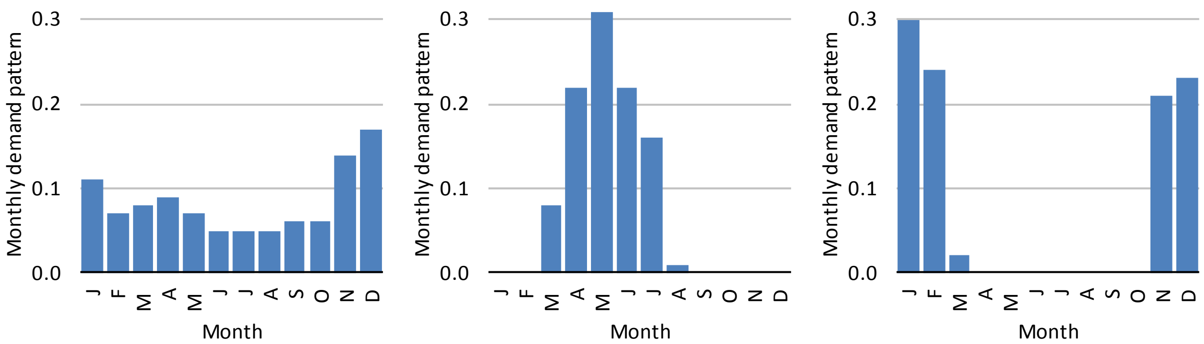


Figure 2.7 Constant monthly demand patterns used in behaviour analysis model for potential dam sites in the Flinders catchment (Richmond climate). From left to right, perennial/rotation demand pattern, dry season planting demand pattern, early wet season planting demand pattern

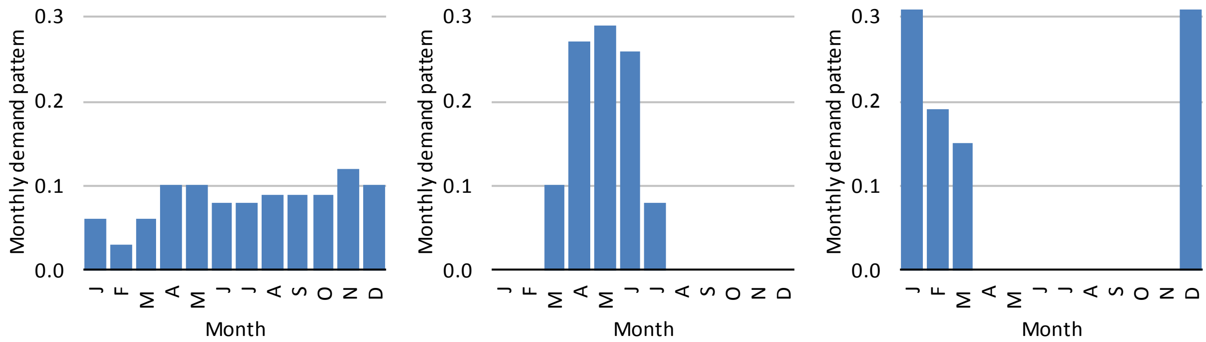


Figure 2.8 Constant monthly demand patterns used in the behaviour analysis model for potential dam sites in the Gilbert catchment (Georgetown climate). From left to right, perennial/rotation demand pattern, dry season planting demand pattern, early wet season planting demand pattern

Reliability metrics

In the Assessment each reservoir was evaluated against three performance criteria, as reported in McMahon and Adeloye (2005); i) time based reliability; ii) volumetric reliability; and iii) resilience. These performance criteria are sensitive to particular aspects of unsatisfactory operation during periods of low reservoir inflows. The inability of a reservoir or system of reservoirs to provide the target demand during a given period is commonly described as a supply failure.

Time based reliability is the probably that a reservoir will be able to meet the demand in any particular interval of time as described in Equation 6:

$$R_t = \frac{N_S}{N} \quad (6)$$

Where R_t is the time based reliability, N_S is the total number of intervals during which the demand was met; and N is the total number of time intervals in the simulation. In the Assessment annual time reliability is reported. Annual time-based reliability is not equal to monthly time-based reliability, unless in any failure year the reservoir has failed in each of the twelve months.

Volumetric reliability is computed as the total quantity of water actually supplied divided by the total quantity of water demanded during the entire simulation period. This is described by Equation 7

$$R_v = 1 - \frac{\sum_{j \in f} \left(D_j - D'_j \right)}{\sum_{j \in f} D_j} \quad (7)$$

Where R_v is the volumetric reliability, *f* is the number of failure periods, D'_j is the actually supply from the reservoir system during the *j*th failure period and D_j is the target demand during the *j*th period and *N* is the number of periods in the simulation. Typically the volumetric reliability is used in conjunction with the time-based reliability, but the time-based reliability may be relaxed if the volumetric reliability is very high or made more stringent if the volumetric reliability is too low.

Resilience is a term used to describe a reservoir performance metric that tries to indicate the speed of recovery of a reservoir following failure. It is described by Equation 8

$$\varphi = \frac{f_s}{f_d} \quad ; 0 < \varphi \le 1 \quad (8)$$

Where φ is resilience, f_s is number of continuous sequences of failure periods and f_d is the total duration of the failures. Obviously it is preferable for a reservoir to recover and return to satisfactory operation. Typically the closer the behaviour of a reservoir to a within-year storage the more rapidly it will recover. The more likely the reservoir behaviour is to be over-year, the more likely it is to lack resilience and take longer to recover following failure (McMahon and Adeloye 2005).

Approach

A series of four hydrological assessments were undertaken and reported for each potential dam site.

The first assessment assumed a constant perennial monthly demand pattern and evaluated reservoir performance for incrementally larger dam wall heights (i.e. FSL). The behaviour analysis model was run on a daily timestep using 121 year streamflow timeseries obtained from the baseline Source river model. The initial storage volume of the reservoir was set to 50% full supply storage volume. This assessment illustrates the relative performance of the reservoir at different FSL and this analysis was in part used in selecting the FSL for the short-listed potential dam sites.

The second assessment evaluated reservoir performance for the selected dam FSL, under a perennial, dry season and wet season constant demand patterns. The behaviour analysis model was run on a daily timestep using 121 year streamflow timeseries from the baseline Source river model. The initial storage volume of the reservoir was set to 50% full supply storage volume. This assessment shows how reservoir performance varies under different monthly demand patterns.

The third assessment evaluated reservoir performance for the selected dam FSL under a perennial constant demand pattern using the baseline streamflow timeseries and the Cwet, Cmid and Cdry baseline streamflow timeseries. The future climate streamflow timeseries were selected by ranking the 15 catchment average (baseline) mean annual runoff generated using empirically scaled daily climate data from the 15 GCM's (i.e. see companion technical report on Climate data, Petheram and Yang 2013). The Cwet, Cmid and Cdry timeseries corresponded to the 10^{th} (i.e. 2^{nd}), 50^{th} (i.e. 8^{th}) and 90^{th} (i.e. 14^{th}) catchment average mean annual runoff values. The GCM's used in the generation of the future streamflow timeseries are described in Table 2.4. This assessment attempts to characterise the uncertainty in reservoir performance as a result of uncertainty in the future climate projections.

The fourth assessment evaluated reservoir performance for the selected dam FSL under a perennial constant monthly demand pattern using an ensemble of 50 river system models (see companion technical report on river modelling, Lerat et al. 2013). The ensemble of river models provides an assessment of the uncertainty in reservoir performance as a result of uncertainty in streamflow data. The initial storage volume of the reservoir was set to 50% full supply storage volume.

Table 2.4 GCM's used in the generation of future streamflow timeseries for the Flinders and Gilbert catchments

CATCHMENT	CWET	CMID	CDRY
Flinders	Meteorology Institute of the University of Bonn, Germany, and Meteorological Research Institute of KMA, Korea (MIUB-ECHO-G)	Geophysical Fluid, Dynamics Lab, United States (GFDL-CM2.0)	NASA/Goddard Institute for Space Studies, United States (GISS-AOM)
Gilbert	Meteorological Research Institute, Japan (MRI-CGM2.2.2)	National Center for Atmospheric Research, United States (NCAR-CCSM3)	Canadian Climate Centre, Canada (CCCMA-GCM3.1 T47)

2.3.3 COMPUTING INFLOW FLOOD HYDROGRAPHS

Prior to the Assessment the only potential dam sites in the Assessment area for which Probably Maximum Flood (PMF) estimates had been computed were Cave Hill and Glendower in the Flinders catchment. Since those PMF estimates were undertaken the method for computing probable maximum precipitation (PMP) has been revised (BOM, 2003a,b), resulting in generally much larger flood volumes. This necessitated some reconsideration of likely PMF values in the Assessment.

Inflow flood hydrographs were computed for PMF, 1:10,000 and 1:1000 Annual Exceedance Probability (AEP) events for three potential dam sites in the Flinders and Gilbert catchments. These sites were the

Dagworth dam site on the Einasleigh River, Green Hills dam site on the Gilbert River, and Cavehill dam site on the Cloncurry River. The design flood discharges were used to assist in the development of conceptual arrangements for potential dams at these locations, including the sizing of spillways and embankments. These dams were selected for this analysis on the basis that they had the largest catchment areas and were likely to experience the greatest flood rise, which would considerable impact on the cost of their construction. Design flood discharges were not computed for the other three short-listed sites (Copperfield River Gorge Dam, O'Connell Creek and Porcupine Gorge) on the basis that (with the available time and resource constraints) the flood rises for these dams were modest relative to the selected sites.

Selection of an approach consistent with the Queensland dam safety guidelines

In Queensland, current dam safety guidelines (DEWS 2012, DNRM 2002) indicate that in areas where life or significant property are at risk, all dams and saddle dams need to be designed to safely discharge the PMF. Using the new methods for computing PMP's released by the BoM in 2003 (BoM 2003) however, construction of the three short-listed dams to safely discharge a PMF is likely to be extremely expensive.

An approach that appears to be consistent with Queensland dam safety guideline on acceptable spillway capacity would be to have primary spillways sized to safely discharge a flood of about 1:10,000 Annual Exceedance Probably (AEP) with erodible saddle dams providing supplementary spillway capacity. It is assumed in each case that the incremental increase in flood impacts resulting from the failure of an erodible saddle dam would be acceptable. For the purposes of the Assessment this approach was adopted for developing the conceptual arrangements of the Cavehill, Dagworth and Green Hills dams and their respective saddle dams.

Inflow flood derivation

To undertake the flood inflow analysis, suitable hydrological models for the potential dam sites were developed using the RORB (runoff-routing) program and calibrated against observed historical streamflow data. As part of this process, simulated flood hydrographs were fitted to observed hydrographs by modifying the two model parameters that control flood routing (the non-linearity exponent, m, and the routing parameter, kc) and the initial loss parameter. The continuing loss values were calculated by using RORB once the other parameters were assigned.

Design rainfall estimates were computed for six different durations using the Probable Maximum Precipitation (PMP) method (BOM 2003a), CRC-FORGE method (Nandakumar et al. 1997) and the method of interpolation between regional estimates of rare rainfalls and PMP (IEAust 1998). To compute the design flood discharges, the RORB models were run with the calibrated routing parameters, recommended initial and continuing loss value for PMF computations (IEAust 1998), storage and spillway configuration information and the aforementioned design rainfall estimates.

For more detail on the methods undertaken for computing inflow flood hydrographs refer to the companion technical report on design flood hydrographs (Lee et al. 2013).

2.3.4 COMPUTING EVAPORATION FROM AN OPEN WATER BODY

As discussed in Section 2.3.2 Morton's APE was used to compute evaporation from the reservoirs in the behaviour analysis model. A second independent approach to assessing the appropriateness of using Morton's APE to compute open water evaporation in the Assessment area was to use the 1-dimensional DLM reservoir simulation model, which uses the stability corrected bulk aerodynamic formulae of Liu et al. (1979) to compute the evaporation rate.

These formulae have advantages over energy-budget methods for the estimation of evaporation in surface waters because they easily accommodate the dynamic changes in heat storage within the water column, are suited for application at the short time steps used in hydrodynamic models and correctly compute evaporation when there is no radiation during a time step. These methods compute evaporation rate per square metre of surface area using the meteorological data and water surface temperature and then applied the rate of evaporation uniformly across the reservoir.

The bulk aerodynamic formula for the estimation of evaporation takes the form of Equation 1.

$$E = \rho\, C_E(U - U_s)(Q_s - Q) \quad (9)$$

where E is the water (evaporation) flux, ρ is the density of air, U is the wind speed, and Q is the specific humidity. U and Q are values at a reference height and just above the water surface (denoted by the subscript 's'). Implicit in this formulation is the assumption that the vertical profiles of wind speed, temperature and humidity follow classic logarithmic scaling. Valuable discussions of the application of bulk aerodynamic formulae in computing turbulent vertical transport of momentum, temperature (sensible heat), and moisture (evaporation/latent heat) are given by Liu et al. (1979) and Fairall et al. (2003) and these are the basis of much of the material presented here. The formulations in Liu et al. (1979) are implemented in the DLM model used to simulate reservoir dynamics in this report as the revisions presented by Fairall et al. (2003) are mainly relevant for high wind speeds (> 10 m s^{-1}) which are not characteristic of inland systems in Australia.

The density of the air, ρ, is computed from the observed temperature and specific humidity (Gill, 1982). The specific humidity in the air just above the water surface, Q_s, is assumed to be saturated with water vapour. The saturation vapour pressure is a function of air temperature and, at the air-water interface, the air temperature is assumed to be equal to the temperature of the water at the interface. The transfer coefficient, C_E, depends on the atmospheric stability and can be computed following Liu et al. (1979). A discussion of this theory is beyond the scope of this report. Detailed laboratory and field experiments have quantified the relationship between evaporation in a turbulent boundary layer above a free water surface and the driving variables: wind speed, air temperature, water surface temperature, and humidity.

Under calm conditions, the bulk formula predicts no evaporation, which clearly cannot happen. In such cases, evaporation is driven by free convection. Under free convection, an unstable density distribution is produced in the air with typically warmer, moister air at the air-water interface compared to conditions above. The density instability drives free convective transport which carries the accumulating moisture upwards away from the water surface. The evaporative flux into still air (i.e. the free convection moisture flux) is computed following relations presented in TVA (1972). These conditions do not occur in the modelling presented here as the daily mean wind speed was never low enough such that the free convective flux exceeded that computed by the bulk formulae.

2.3.5 RISK OF RESERVOIR SEDIMENTATION

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 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 ($y = 55x^{0.86}$), monsoonal Northern Territory moderately undisturbed ($y = 17x^{0.9}$) and the Ord River ($y = 96x^{1.12}$). 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, 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 a preliminary estimates of sediment yields for the dams in the Assessment area.

The predicted sediment yields for the potential dams in the Assessment area were cross-checked with information on catchment sediment supply potential from the Flinders and Gilbert catchments (Tomkins 2013). This was undertaken on the basis that there would be some variability in sediment yields between the sites, based on geology, landforms and discharge. The cross-checking involved an assessment of whether the sediment yields were likely to be an under-estimate, over-estimate or a reasonable approximation. For example, 100 % of the catchments of Chinaman Creek, Corella Dam, Corella River and Cameron River dam sites drain low sediment supply potential geology (i.e. Mount Isa Inlier), so the sediment yields predicted by the power function are thought likely to be an over-estimation. Comparatively, the catchments of Mt Beckford and Richmond dams have < 3 % of their area draining geology with a low sediment supply potential, 45-60 % draining moderate supply potential and 38-47 % draining moderate-high and high supply potential. For these catchments it is thought likely that the power function would provide an under-estimate of sediment yield.

To incorporate the effect of geology on sediment yields, the power function sediment yields were adjusted using the subjective approach indicated in Table 2.5. As a precautionary principal it is thought likely that the adjusted sediment yields err on the side of being conservative.

Table 2.5 Adjustment to sediment yields derived from power function on the basis of expert judgement

EXPERT JUDGEMENT (BASED ON CATCHMENT GEOLOGY)	ADJUSTMENT TO POWER FUNCTION SEDIMENT YIELD
Considerable over-estimate	-40%
Over-estimate	-25%
Slight-over-estimate	-10%
Reasonable	0
Slight under-estimate	+10%
Under-estimate	+25%
Considerable under-estimate	+40%

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.

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.

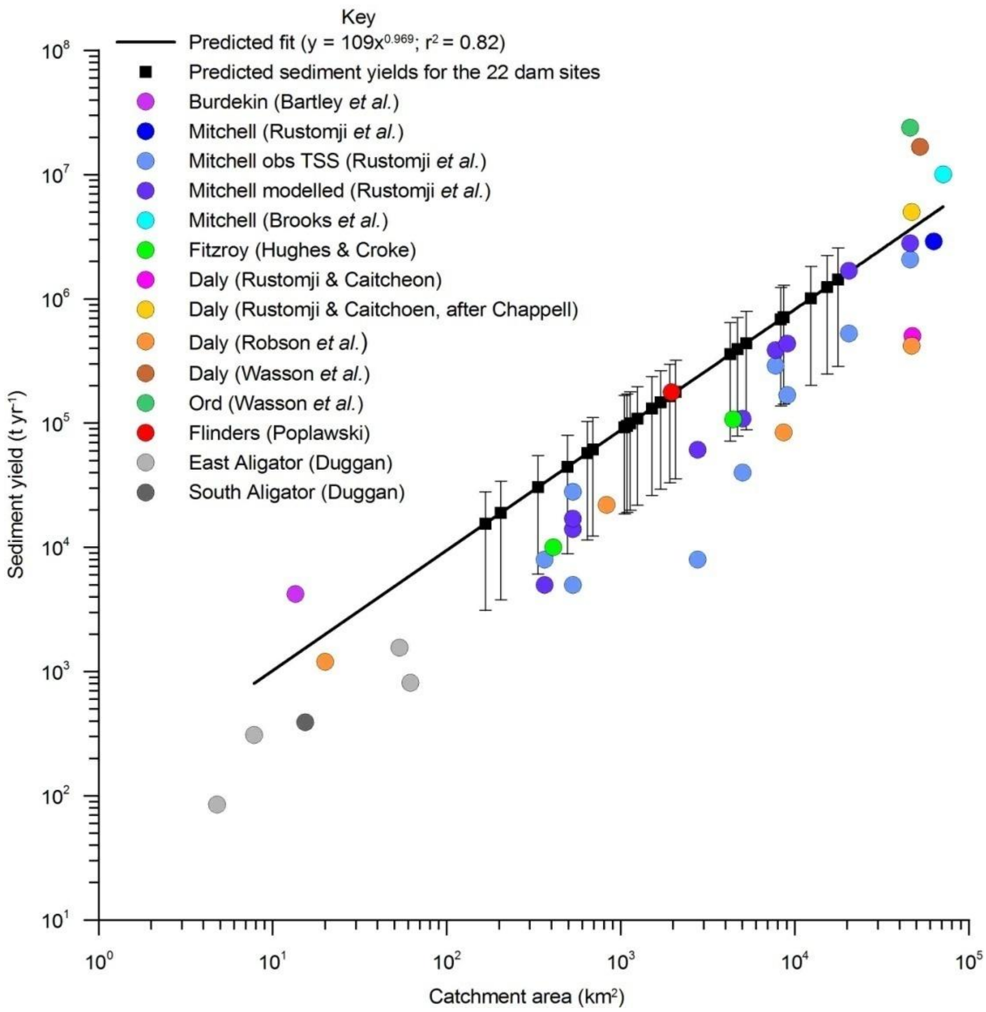


Figure 2.9 Sediment yield data from rivers in northern Australia and predicted sediment yields for the 22 potential dam sites (from companion technical report on sediment yield, Tomkins 2013). The average uncertainty of the predictions (± 79 %) is shown by the error bars

2.3.6 WATER QUALITY AND STRATIFICATION CONSIDERATIONS

The assessment of reservoir stratification dynamics and their water quality implications presented here focuses on the characterisation of the duration of persistent stratification and the depth of the SML. A long duration of stratification implies long periods of low dissolved oxygen concentration and the associated release of nutrients and methane from the sediments. Persistence of shallow SML depths suggests suitable light conditions exist to support algal blooms.

The one-dimensional Lagrangian reservoir model, DLM, was used to perform the theoretical assessment of stratification dynamics and evaporation of the reservoirs. DLM is a one-dimensional, process-based simulation model, that simulates the vertical transport and mixing processes in a lake in order to predict the lake's density (temperature and salinity) structure over time (McCord and Schladow 1998). The hydrodynamic component of DLM is based on DYRESM (Imberger and Patterson 1981). The model represents the reservoir as a Lagrangian vertical array of horizontally well-mixed layers. Mixing is simulated by amalgamating layers. The layers are subsequently divided to maintain spatial resolution within specified bounds. Selective withdrawal is simulated as described by Hocking et al. (1988) and inflow mixing includes entrainment into underflows plus the addition of a parameterisation of entrainment into the plunge zone of inflows absent in other one-dimensional reservoir models (Fleenor 2001). Simulation of the water body proceeds using a variable time step assigned as an integral multiple of 900 seconds to prevent excessive heating or deepening of the surface mixed layer during any single time step.

The model was forced using daily mean meteorological data (shortwave radiation, wind speed, air temperature, relative humidity, cloud cover), inflow volumes and temperatures, and outflow volumes. Turbulent exchange of heat, mass (e.g. evaporation), and momentum across the air-water interface was computed using bulk aerodynamic formulae corrected for atmospheric stability following Liu et al. (1979).

There are very limited field data available for assessment of reservoir model performance. Within the catchments only a single temperature-dissolved oxygen profile was found for Corella Dam (Pearce et al. 2000). The 27 October 2000 temperature ranged from 21.2 - 26.2 °C across a 6 m-deep water column with surface layer thickness of 2 m. The water column was anoxic at the bottom with a steep gradient in concentration beginning at the bottom of the surface layer. This profile was consistent with 1-D DLM model predictions for thermal stratification at the same time of year for this dam given comparable water column depths, which lends some confidence that the 1-D DLM model predictions are representative of expectations in the field. Additional stratification data are available for several storages near Mt Isa (Finlayson et al. 1984) and these storages all exhibit similar strong seasonal stratification, shallow surface layers, and very low dissolved oxygen concentrations at depth, similar to that observed at Corella Dam. In addition some of these storages exhibited rain/inflow-induced mixing during summer; also observed in several of the dam simulations conducted for this report.

2.3.7 ENVIRONMENTAL ASSESSMENT

Although a desktop assessment of potential environmental issues associated with potential dam sites was undertaken, a dearth of environmental information available for the Flinders and Gilbert catchments, limited the level of detail that could be achieved. An assessment of potential impacts was based mainly on fish distribution and passage for which reasonable information exists, inundation of various regional ecosystems that have been mapped in reasonable detail by the Queensland government across much of the Assessment area, and consideration of general environmental issues that commonly arise in dam developments in similar habitats, particularly the Burdekin Falls Dam (Lake Dalrymple) and the Ord River Dam (Lake Argyle).

Fish Distribution and Passage

The distribution of fish species across the Assessment area is not known with precision but enough sites have been surveyed to enable a sufficient understanding of their general distribution patterns, which essentially follow those of fish communities in other catchments in northern Australia. The distribution of fish species in each catchment was gathered by reference to published studies, museum data, and reliable anecdotal information from scientists and knowledgeable locals in the two catchments. These data are presented in more detail in the companion technical report on aquatic ecology (Waltham et al. 2013) but are reported here in relation to the potential dam sites.

Three species stand out as of particular significance, and their distribution was specifically examined in relation to potential dam sites. The first is barramundi (*Lates calcarifer*), an iconic fish species of northern Australia, and one whose distribution is severely curtailed by the construction of dams, unless artificially sustained by stocking of hatchery-reared individuals. The freshwater sawfish (*Pristis pristis)* and freshwater whipray (*Himantura dalyensis*) are two species of high conservation value that would be impacted on by any barriers to their movement. The sawfish is listed on the International Union for Convervation of Nature (IUCN) Red List of Threatened Species and is also listed as vulnerable under the Federal Environment Protection and Biodiversity Conservation (EPBC) Act. As large, benthic species, they are not adept at negotiating physical barriers. In addition, both species utilise brackish/estuarine/coastal waters as part of their life cycle and are thus prone to localised exclusion from reaches where barriers are constructed. As both species are relatively rare, their conservation status and exact upstream distribution is difficult to define. The freshwater whipray tends to prefer brackish waters so is not found as far upstream as the sawfish and is not likely to be found above any of the proposed impoundment sites in the Assessment area.

One of the biggest issues resulting from construction of impoundments is that of fish passage. Fish can be highly mobile, utilising large lengths of river for a variety of purposes. Many Australian freshwater species are derived from marine/estuarine ancestors and thus undertake substantial migrations down to the sea/estuary to breed, barramundi being the most recognisable in this category. Fish that move downstream are denied their return to upstream habitat by barriers such as diversion channels, weirs and dams. In such situations, these species are completely eliminated from habitat upstream of the barrier. Fish passage may be reinstated by engineering structures designed to allow fish to pass upstream, and provision of fish passage is required under the Fisheries Act for all new instream structures. However, such options, besides being costly to construct and maintain, are nearly always inferior to natural fish passage, may not work at all, require regular maintenance, and are even more difficult to achieve for large dams due to the height of the uplift required. It should also be noted that in Australia fish passage has never had to be provided for a fish as large as the freshwater sawfish (up to 6 metres long, and with an unwieldy saw-like rostrum) so this will provide many new challenges should any weir or dam be constructed within the known range of this high conservation value species.

In most catchments there is a natural decline in the number of fish species present, from downstream to upstream reaches. Thus impoundments located further upstream in a catchment will impact upon the movements of lesser numbers of fish species. In addition, impoundments further upstream restrict access to limited lengths of stream above the barrier.

As part of a wider investigation of potential fish passage barriers (mostly road culverts and causeways) across the southern Gulf of Carpentaria, Marsden and Stewart (2005) visited potential fish passage barriers in the lower Flinders catchment. They concluded that the causeway crossings of the Flinders, Bynoe and Little Bynoe rivers along the Burketown-Normanton Road, and of the Flinders River along the Cloncurry-Normanton Road, although allowing fish passage at high flows, would present a barrier to fish movement at lower flows. Burrows and Perna (2006) found that the fish fauna of the Norman River upstream of Glenore Weir was depauperate(i.e. lacking in numbers or variety of species) enough to suggest that it was acting as a fish passage barrier, and because it is located so far downstream on the Norman River it affects a significant length of the river. In the Flinders and Gilbert catchments there are no such major infrastructural barriers low in the catchment (the causeways identified by Marsden and Stewart 2005 notwithstanding). In the Assessment, most potential dam sites are a considerable distance inland, thus reducing their potential impact compared to more downstream potential locations.

Impacts on Regional Ecosystems

The regional ecosystem (RE) communities that may be inundated by each potential reservoir were examined using the Queensland Herbarium's *Regional Ecosystem Description Database (*Queensland Herbarium, 2013). For each potential reservoir this was undertaken by overlaying the outline of the FSL over the RE spatial data layer. To assist interpretation and presentation of the results the regional ecosystem (vegetation) communities were categories as described in Table 2.6.

Table 2.6 Categories of regional ecosystem (vegetation) communities
These biodiversity codes come from the *Vegetation Management Act 1999.*

CATEGORY	DEFINITION	SUBCLASS*
Endangered	Remnant vegetation is less than 10% of its pre-clearing extent across the bioregion; or 10 to 30% of its pre-clearing extent remains and the remnant vegetation is less than 10,000 ha.	Dominant Sub dominant
Of concern	Remnant vegetation is 10 to 30% of its pre-clearing extent across the bioregion; or more than 30% of its pre-clearing extent remains and the remnant extent is less than 10,000 ha.	Dominant Sub dominant
No concern at present, least concern	Remnant vegetation is over 30% of its pre-clearing extent across the bioregion, and the remnant area is greater than 10,000 ha.	Dominant
Non-remnant	Native vegetation	
Plantation	Plantation	
Water	Water	

* 'Dominant' subclass means greater than 50% of polygon contains the regional ecosystem mapping. 'Sub dominant' subclass means that less than 50% of the polygon contains the regional ecosystem mapping.

2.3.8 INDIGENOUS CULTURAL HERITAGE ASSESMENT

As part of the Assessment a desktop Indigenous cultural heritage review was undertaken. This involved:

- Searching the DATSIMA records for listed sites within the project areas;
- Reviewing the DATSIMA site index forms for the relevant listed sites, where permission was granted by the relevant Indigenous Party;
- Searching the DATSIMA records for Cultural Heritage Bodies and/or Indigenous Parties with responsibility for cultural heritage issues within the project areas;
- Undertaking a preliminary review of available reports covering relevant previous Indigenous archaeological work.

In undertaking this review a number of limitations should be noted. The background research was not comprehensive; it involved review of selected archaeological reports. Much of the information was taken from secondary sources (i.e. as indicated by the references). Permission to access the DATSIMA site index forms for the four listed sites within the Porcupine project area was not granted by one of the relevant Indigenous Cultural Heritage Body, Yirendali Operations Pty Limited. Therefore any detailed information in these forms could not be considered. The report addresses pre-contact archaeological heritage only; it does not address non-Indigenous or post-contact Indigenous heritage.

No historical research was undertaken for this preliminary assessment and this should be an essential component of a comprehensive cultural heritage study of the catchment areas. It would be expected that such research would reveal a number of significant cultural places and areas of archaeological potential, such as the location of massacre sites.

2.3.9 ESTIMATING DAM COST

For all potential dam sites that were previously investigated, where a cost estimate was reported in the literature it was adjusted for inflation using the Australian Consumer Price Index (CPI) (Figure 2.10). However, it was noted that construction costs, particularly in remote areas have almost certainly escalated at a higher rate than the CPI, particularly during the recent boom period of mining activity.

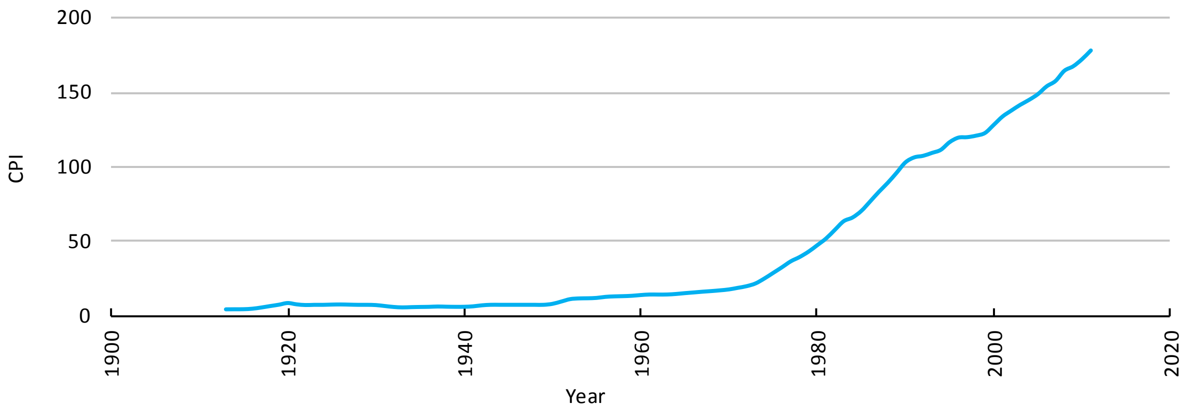


Figure 2.10 Australian consumer price index. Australian CPI values prior to 1948 were derived by developing a relationship with the USA CPI

For the six large dams that were short-listed new cost estimates were calculated. This was undertaken by developing conceptual arrangements for each of the six dams (and their associated saddle dams), and developing a schedule of quantities for the major items of work. For the more complex structures, this involved the estimation of quantities for 50 or more items of work. Cost rates applied for each item were derived from earlier estimates prepared by SunWater for the Green Hills and Connors River dam options and by consultants for other options. Cost data from the recently completed Wyaralong Dam in south east Queensland was also examined. On site and off site overheads were applied at similar rates to those used by SunWater for recent Galillee Basin water supply studies. For raising of the Kidston dam, the schedule of quantities prepared by McIntyre & Associates (1998) was used.

Despite this comprehensive approach, it should be noted that for three of the short-listed dams, Dagworth, Green Hills and O'Connell Creek, geotechnical data was limited to that available from surface inspections and that in all cases further investigations would be necessary to establish a higher level of certainty as to cost. As noted above, the cost of construction in remote areas is likely to be sensitive to the level of construction activity generally and in particular, in the mining sector.

For those dams that were not short-listed, new indicative estimates of dam cost were obtained by simply extrapolating the new cost estimates for the six short listed potential dams based on comparisons of dam dimensions, remoteness and complexity of foundations to the short-listed sites. It should be noted that for a number of the non short-listed potential dam sites, these indicative estimates were based on very little geotechnical information.

2.4 Short listed water storage options

Based on the review of previous dam proposals and the results of the DamSite model, a short-list was compiled of the three water storage options deemed by the authors most likely to proceed within each catchment. Short-listed sites were primarily selected based on topography of the dam axis, geological conditions, proximity to suitable soils and water yield.

For the Flinders catchment these were Cave Hill (downstream site), O'Connell Creek offstream storage and Porcupine Creek. For the Gilbert catchment they were, Dagworth (upstream site), Green Hills (upstream site) and raising the existing Kidston Dam

These six short listed options range from the proposed raising of the Kidston Dam, for which quite comprehensive information is available based on the existing dam development and subsequent studies, to the Dagworth water storage option in the middle reaches of the Einasleigh River, which had not been previously identified or investigatied other than a brief site inspection as part of the Assessment.

It should be noted that the investigations conducted here of the six 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.

For any of these options to advance to construction, far more comprehensive studies as outlined in Section 1.3 would be required. Studies of that level of detail were beyond the scope of this regional scale resource assessment.

Part 2 Large instream dams

3 Flinders catchment

3.1 Study area

3.1.1 OVERVIEW

The Flinders River catchment is located in the Gulf region of north-west Queensland and covers an area of 109,000 km^2. The catchment has a population of approximately 6000 people, about two-thirds of whom reside in four towns: Cloncurry, Hughenden, Richmond and Julia Creek. These towns are located along the Flinders highway, which crosses the southern part of the catchment.

3.1.2 GEOLOGY

There are six major structural units in the Flinders catchment. The oldest units are the Mt Isa Inlier in the west and the Cape River Province in the east. The central part of the catchment is underlain by sedimentary rocks of the Great Artesian and Galilee Basins. Cainozoic basalt flows of the Sturgeon Province outcrop in the upper Flinders River catchment and as far west as Hughenden. A small area of the Georgina Basin occurs in the far southwest of the catchment (Figure 3.1).

Rocks of the Mt Isa Inlier have been subdivided into three broad, north trending provinces – The Western Fold Belt Province, the Kalkadoon-Ewen Province and the Eastern Fold Belt Province. The Eastern Fold Belt Province of Proterozoic age is the most significant for the Flinders catchment. The rocks in this province reveal a complex and repeated history of deposition, deformation and granite batholith emplacement. The most extensively exposed unit in the Eastern Fold Belt Province is the Corella Formation. The unit consists mainly of thinly bedded calcareous meta-sediments, passing into calc-silicate rocks with increasing metamorphic grade. Metamorphic grade can vary significantly over short distances. The main faults have large scale (kilometre) displacements. Some are marked by hydrothermal quartz deposition, forming discontinuous, linear quartz 'blows'. The rocks are resistant to erosion because of their high metamorphic grade and presence of granite intrusions. Accordingly they form terrain of relatively high relief.

The Georgina Basin flanks the western and south-western margins of the Mt Isa Inlier. It contains mainly Early Palaeozoic marine sedimentary rocks. The older rocks are mainly carbonate with minor sandstone and siltstone whereas the younger rocks are dominated by siltstone and sandstone.

The Cape River Province is in the upper Flinders River catchment. It consists of metamorphic rocks, mostly quartzite, schist and gneiss, derived from sandstone and fine-grained sedimentary rocks. Age of the rocks is uncertain ranging from Proterozoic to Early Palaeozoic. The rocks have a complicated structural history with several deformational events recognised. The dominant structural grain trends northwest. The rocks form a dissected terrain with a dendritic drainage pattern influenced by the structural grain. The metamorphic rocks have been intruded by Palaeozoic age granite and overlain by younger sedimentary rocks.

Adjoining Cape River Province are sedimentary rocks of the Galilee Basin. These are also exposed in the deep gorge of Porcupine Creek near Hughenden. The most extensively exposed unit is the Warang Sandstone. Its characteristic blue-white colour, dendritic drainage and dissected outcrop pattern form the spectacular White Mountains area. The Warang Sandstone is an aquifer in the Galilee Basin.

The Great Artesian Basin (GAB) occupies most of the catchment area. Strictly speaking, the GAB is a hydrogeological basin. In the Flinders catchment it includes the Eromanga and Carpentaria geological basins and the upper aquifers of the Galilee Basin. For the sake of simplicity the GAB term will be used throughout this report. The dominant unit, in terms of area, is the Rolling Downs Group. In the Flinders catchment it consists mainly of mudstone and a significant limestone unit – the Toolebuc Formation. The underlying sandstones of the Gilbert River Formation and Blantyre Sandstone are only exposed in Porcupine Creek and Flinders River gorges. The mudstones and limestone underlie the typical rolling downs topography between Hughenden and Julia Creek.

Basalt flows related to the Sturgeon Province erupted between about 1 and 6 million years ago. Basalt flowed down river valleys forming extensive shallow lava plains. New stream courses were then established and erosion along the new valleys led to inversion of relief with the former basalt filled valleys now forming resistant plateaus. The heights of these plateaus decrease with decreasing age of the lava flow. Some of the most recent flows are the Twins Flow (1 Ma) on the west bank of Porcupine Creek, the Torver Flow (2.6 Ma) adjacent to Betts Gorge Creek and the Beckford Flow (3.4 Ma) to the south of and adjacent to the Flinders River at Hughenden.

Broad scale geological considerations in siting dams in the Flinders catchment

In the Flinders, as in all catchments, a prospective dam site requires both a physiographic constriction of the river channel and favourable foundation geology. Favourable foundation conditions include a relatively shallow thickness of unconsolidated materials such as alluvium, and rock which is relatively strong, non-erodible, non-permable and capable of being grouted. The best structural unit in the catchment for locating dam sites is the Mt Isa Inlier. Here there is adequate topographic relief combined with non-erodible rock of high strength. Problems may occur where faults intruded by hydrothermal quartz cross the dam footprint. The hydrothermal quartz often contains voids infilled with soil. These features have potential for piping and would be difficult to treat in a dam foundation.

There are potential sites within the Cape River Province in the upper Flinders River area. Sites with the greatest storage capacity occur where a basalt cap is present.

There are potential sites within sandstones of the Galilee Basin in the upper Flinders River catchment. The sites are topographically favourable and could be suitable for dam construction. However, some of the steeper slopes adjoining major streams show evidence of slope instability (block toppling) and these would require careful assessment. The Warang Sandstone is an aquifer in the GAB so these sites would also have to be assessed for seepage losses.

The gentle rolling downs topography of the Great Artesian Basin presents few opportunities for on-stream dams. Embankments have to be very long to provide adequate storage capacity. Also construction and operation of a spillway to cope with the large flood events would entail a significant risk. Offstream storages appear to be a better option in these areas.

The gorges formed within the basalt plateaus of the Sturgeon Province appear to offer good prospects for development of dams. This applies particularly to Porcupine Creek gorge where the creek has eroded into medium strength rock of the Blantyre Sandstone. However, the contact between the sandstone and the basalt is often marked by a gravel layer. This, together with the high permeability of the basalt itself, requires careful assessment for piping potential and leakage.

Gorges within mudstones of the Rolling Downs Group are problematic for dam construction. This is because the mudstones are often deeply weathered and contain clay seams of low shear strength. Landslides may have formed where there are steep slopes between the resistant caprock and the stream bed. These issues pose difficulties for dam construction, particularly roller compacted concrete dams.

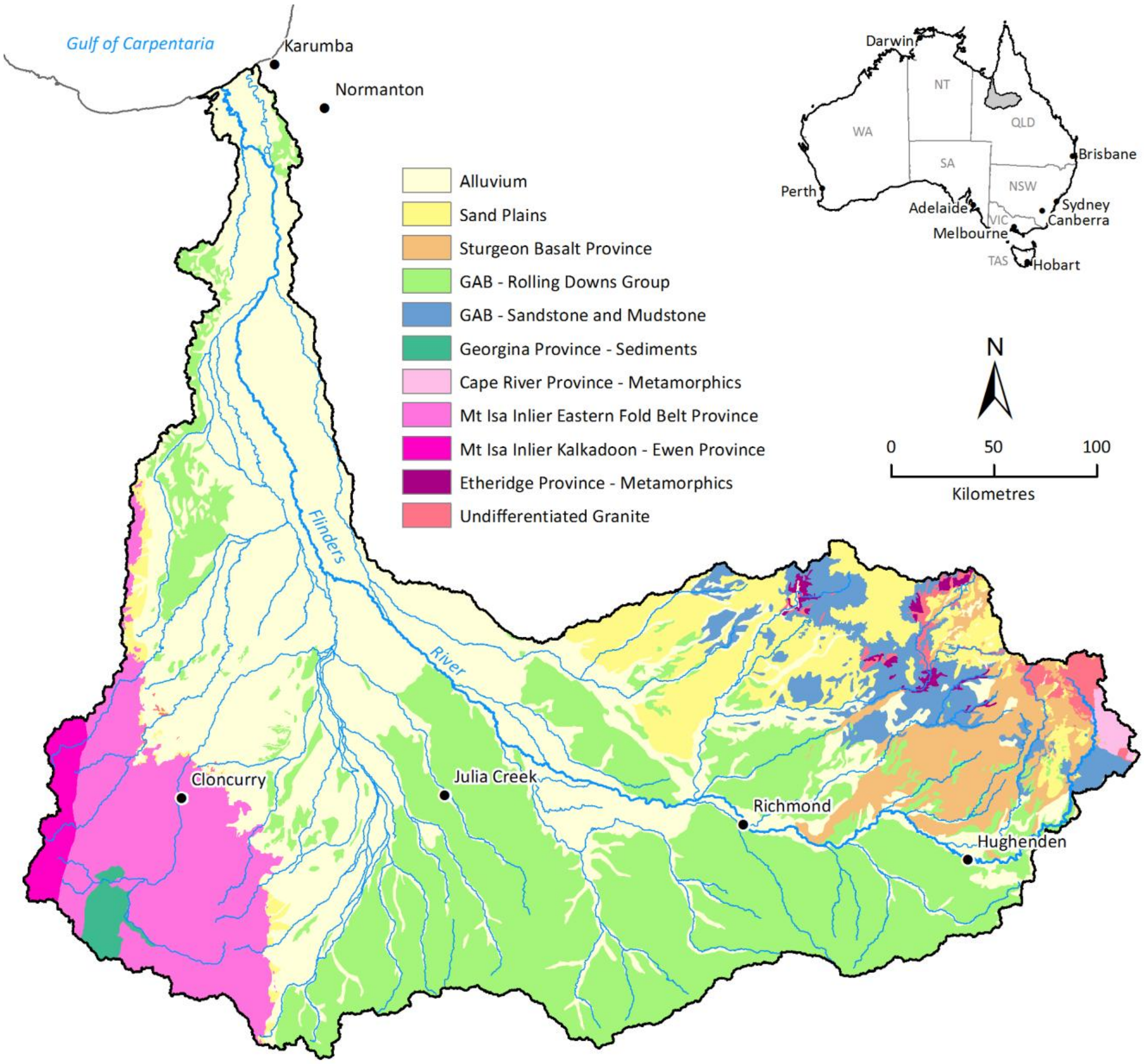


Figure 3.1 Simplified surface geology of the Flinders catchment

3.1.3 CLIMATE

The Flinders catchment has a semi-arid tropical climate. The mean and median annual rainfall spatially averaged across the catchment are 492 mm and 454 mm respectively. However, the historical annual rainfall series for the Flinders catchments shows considerable variation between years (Figure 3.2a). The highest catchment average annual rainfall (1310 mm) occurred in 1974, and was nearly three times the median annual rainfall value. Spatially, mean annual rainfall varies from about 800 mm at the coast to about 350 mm in the south.

The Flinders catchment has a mean annual potential evaporation of 1862 mm. Mean wet and dry season potential evaporation are 1115 mm and 762 mm respectively. The inter-annual variability of potential evaporation (Figure 3.2b) is considerably less than that of rainfall. The majority of the Flinders catchment experiences a mean annual rainfall deficit of greater than 600 mm.

A defining characteristic of the climate of the Flinders catchment is the seasonality of rainfall, with 88% of rainfall occurring during the wet season (November to April inclusive) (Figure 3.3a). The highest median monthly rainfall in the Flinders catchment occurs during the months of January and February (~100 mm). The months with the lowest median rainfall are July and August (~ 0.5 mm).

The climate of the Flinders catchment is described in more detail in a companion technical report by the climate activity (Petheram and Yang 2013).

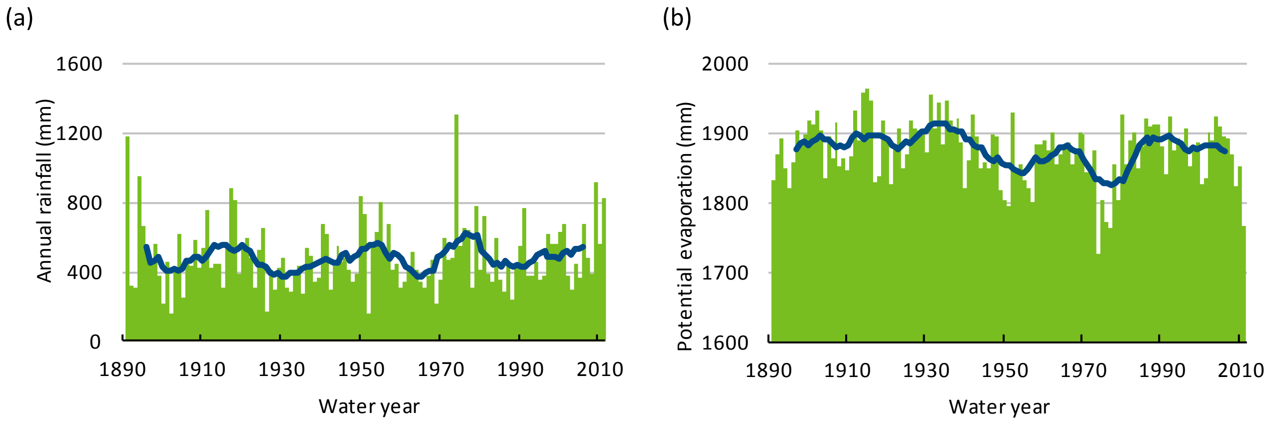


Figure 3.2 Historical annual rainfall and potential evaporation in the Flinders catchment (Petheram and Yang 2013)

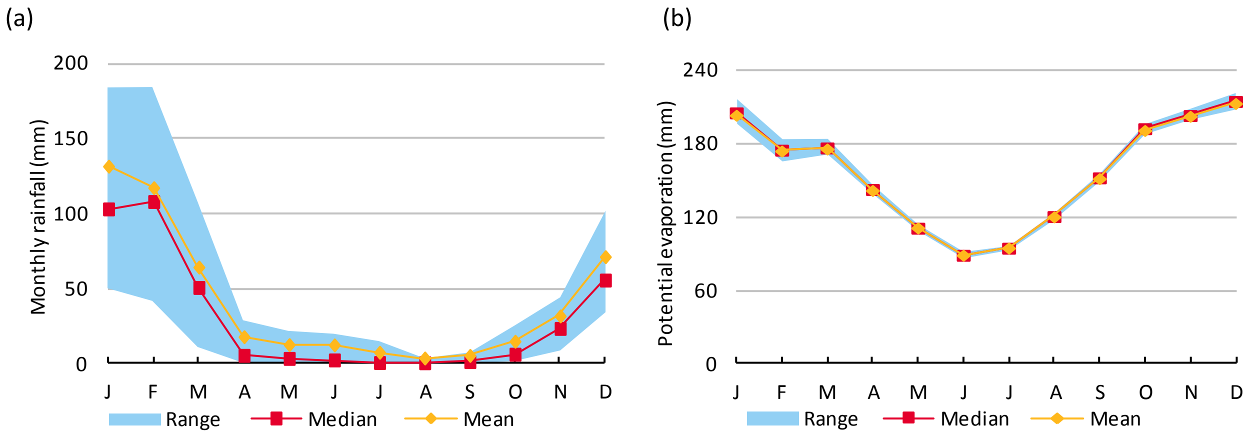


Figure 3.3 Historical monthly rainfall and potential evaporation averaged over the Flinders catchment (A range is the 20th to 80th percentile monthly rainfall) and potential evaporation (Petheram and Yang 2013)

3.1.4 HYDROLOGY

The Flinders River is the main river in the Flinders catchment. It rises in the Great Dividing Range, 100 km north-east of Hughenden. The river flows from north to south, until it reaches Hughenden where it flows across the flat and treeless Mitchell grass plains to the west. After flowing through the town of Richmond, it continues towards the north- west before flowing north and draining into the Gulf of Carpentaria. The Flinders River has five major tributaries. These are the Dutton River, the Stawell River, Alick Creek, the Cloncurry River and the Saxby River (Figure 2.1). The largest tributary is the Cloncurry River, which accounts for half of the catchment area at the confluence between the Cloncurry and Flinders rivers.

Figure 3.4 provides an indication of the quality of the streamflow data in the Flinders catchment. Figure 3.5 shows the simulated annual runoff averaged across the Flinders catchment between 1890 and 2011 and the monthly runoff averaged across the Finders catchment. Figure 3.6 provides an indication of the mean annual flow in different reaches of the Flinders catchment. It should be noted that the mean annual streamflow at the mouth of the Flinders River is twice the median annual streamflow at the same location (Lerat et al. 2013).

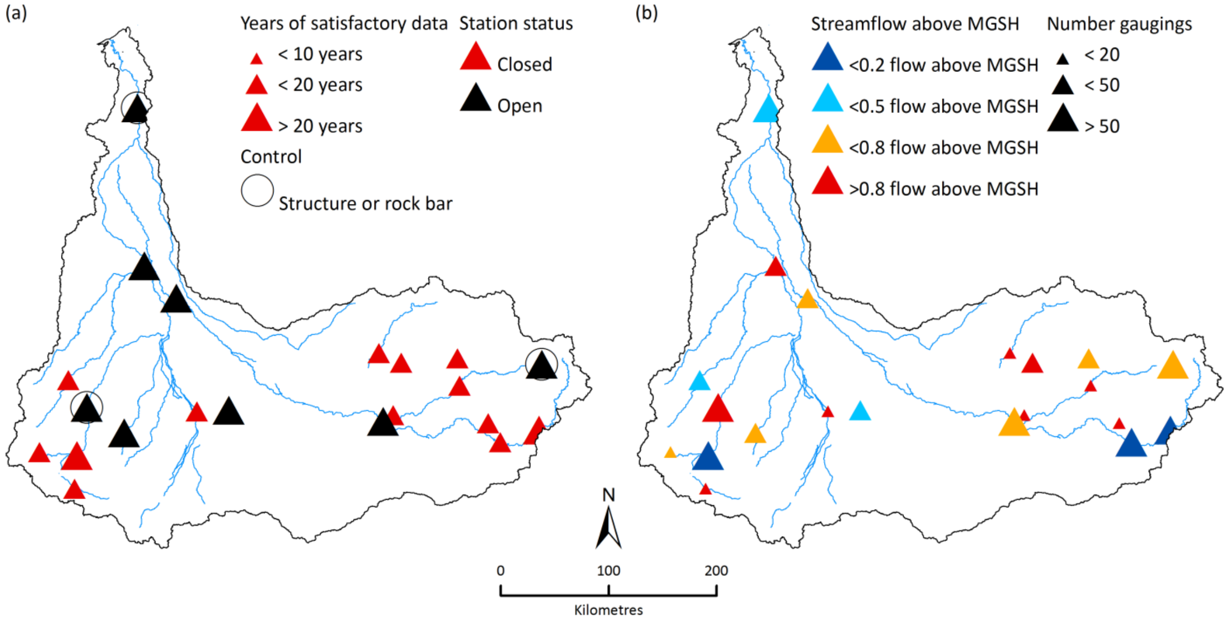


Figure 3.4 Quality of streamflow data in the Flinders catchment (Lerat et al. 2013). (a) The size of the triangle indicates the number of years of satisfactory data and colour of the triangle indicates the station status; (b) the colour of the triangle indicates the proportion of streamflow above maximum gauged stage height (MGSH) and the size of the triangle indicates the number of stage – discharge gauging

Approximately 95% of runoff occurs during the wet season, with the majority of runoff occurring during the months January to March. Figure 3.5 illustrates the large monthly variability in runoff in the Gilbert catchment.

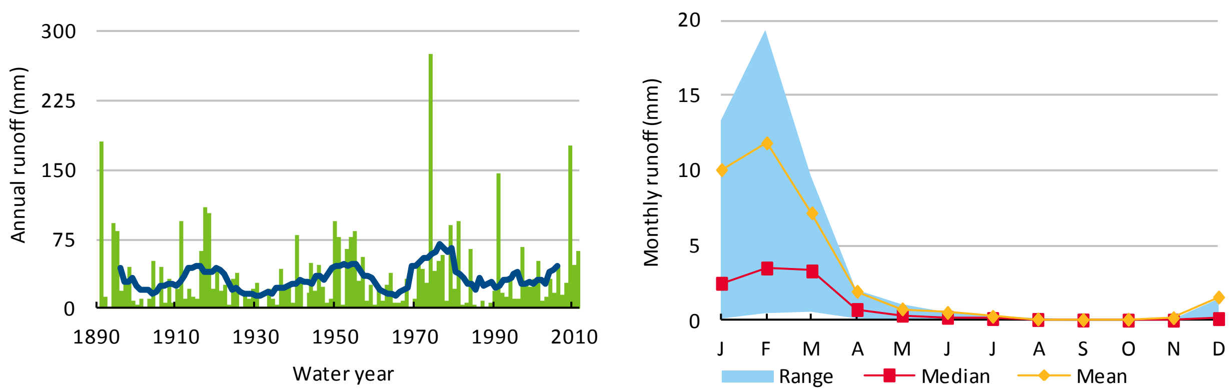


Figure 3.5 Annual runoff averaged across the Flinders catchment under Scenario A (left). Monthly runoff averaged across the Flinders catchment (right) under Scenario A (Lerat et al. 2013)

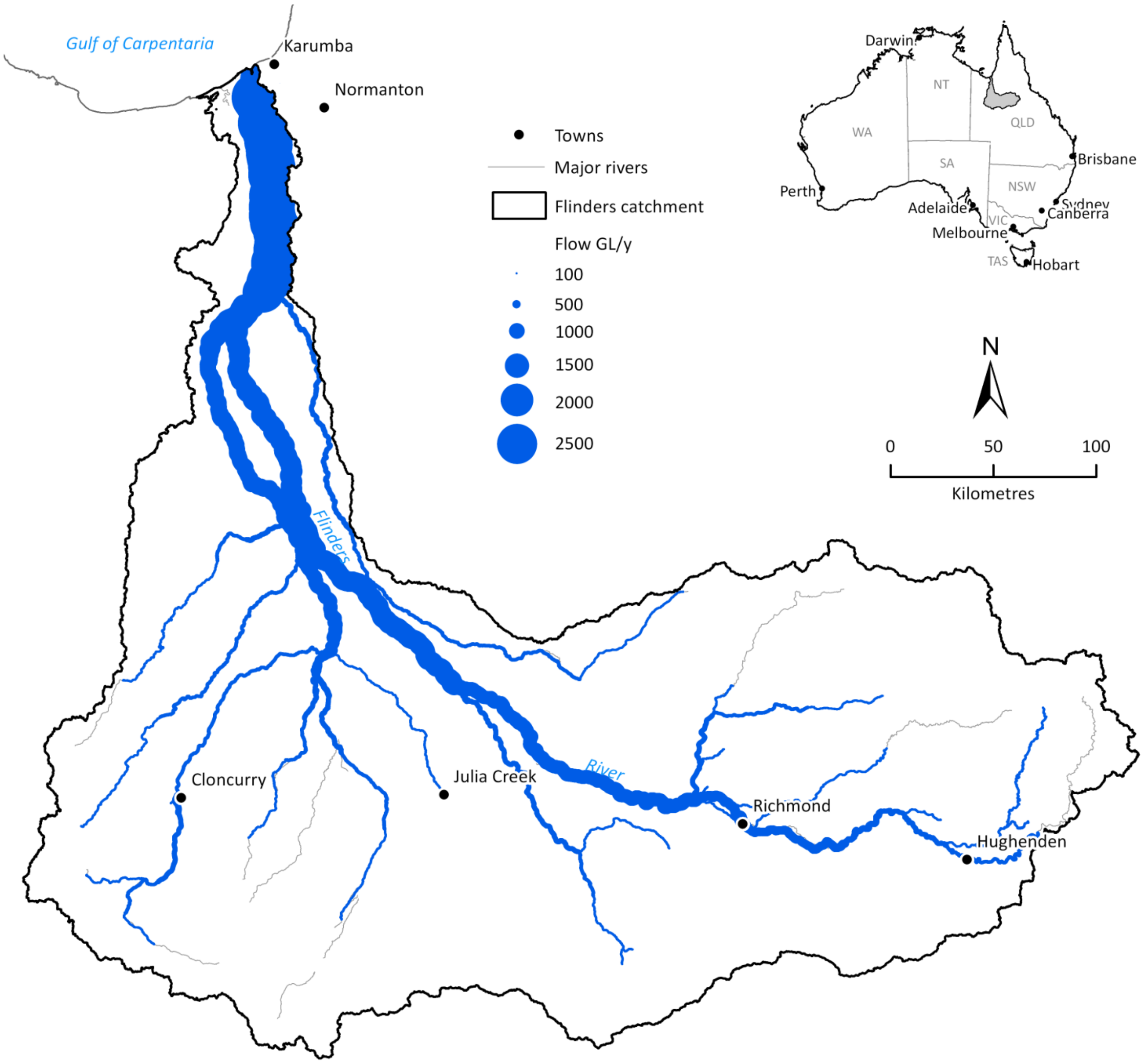


Figure 3.6 Mean annual streamflow in Flinders catchment (companion technical report on river modelling calibration; Lerat et al. 2013)

3.2 Broad analysis of potential dam sites in Flinders catchment

Fifteen potential dam locations were identified from published and unpublished literature accessed from the Queensland Government and SunWater archives. The extent of prior investigations ranged from single reference to potential locations (e.g. Black Fort) to detailed hydrological and geotechnical investigations (e.g. Cave Hill and Glendower). The studies were reviewed and all locations were reassessed using a consistent set of methods, using updated data where available.

3.2.1 DAMSITE MODEL RESULTS

To ensure that no potential dam options had been overlooked, the DamSite model was used to assess over 100,000 potential dam sites in the Flinders catchment. This model uses a series of algorithms that automatically locate and assess favourable locations in the landscape as sites for intermediate to large water storages (Read et al. 2012). A desktop geological suitability of the DamSite model results was undertaken by overlaying the potential dam locations on 1:250,000 geological data.

In the first instance it is instructive to examine the best water storage options in terms of the ratio of reservoir volume at FSL to construction cost i.e. this initial analysis only takes topography into consideration, not hydrology. In Figure 3.7, the dam locations were optimised and then ranked on the basis of storage volume to construction cost, where the construction cost of each dam was based on its dimensions. This figure shows that the part of the Flinders catchment with the most suitable topography for large in-stream dams is around Cloncurry (e.g. upper Cloncurry and Corella rivers). However, some of the more favourable potential dam sites are located on very small drainage lines and are likely to have very low streamflow volumes. If water could be economically pumped into these storages from a larger nearby drainage lines then these potential dam sites could function as a large offstream storage.

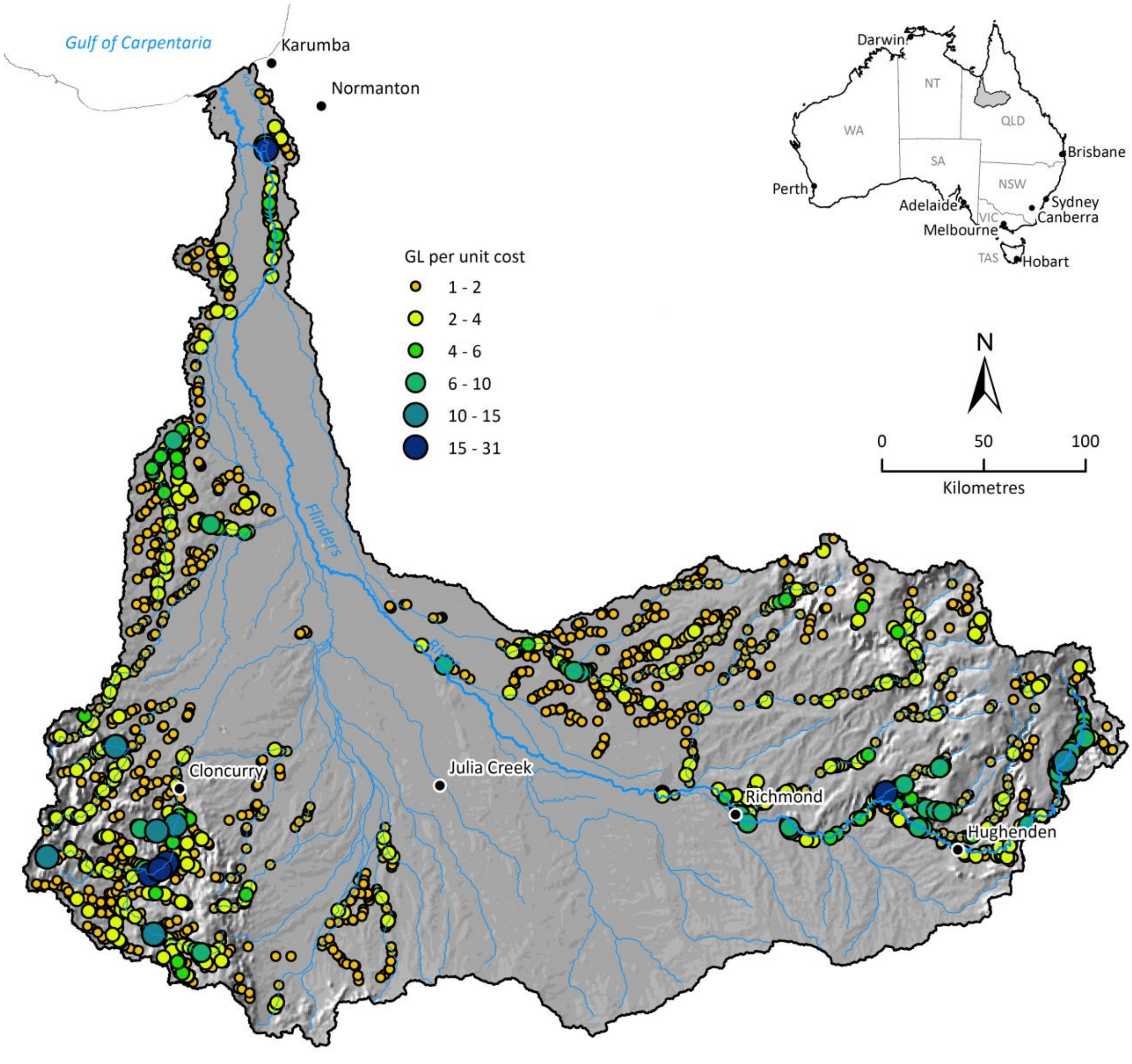


Figure 3.7 Ratio of reservoir volume at FSL to dam cost. Only those potential dams with a GL per unit cost > 1 are shown

To properly assess the potential of a large 'instream' dam the inflows to the dam need to be considered. This was undertaken and the results are presented in Figure 3.8. In this figure the DamSite model results are ranked by water yield at 85% annual time reliability per unit cost. Taking inflows into consideration the majority of potential dam sites in the Flinders catchment have a very low yield per unit cost (i.e. less than 2 GL per unit cost).

Other than the geologically and geographically unfavourable sites identified in the lower reaches of the Flinders catchment (Figure 3.8), no new potential dam sites notably better than those documented in the published and unpublished literature were identified by the DamSite model. In some cases, the model confirmed the relative potential of known dam site locations (e.g. Cave Hill, Black Fort). In other cases it demonstrated that known dam site locations were topographically and hydrologically inferior to other nearby locations (e.g. Mount Beckworth, Alston Vale and Richmond Dam). Due to time and resourcing constraints only those geologically suitable sites located downstream of known potential dam locations and upstream of known arable land were investigated further. In the Flinders catchment, a previously undocumented site, Corella River dam on the Corella River was investigated further. Figure 3.8 illustrates potential dam locations as identified using the DamSite model across the Flinders catchment. Figure 3.9 and Figure 3.10 provide enlarged views of dam sites in key areas of the Flinders catchment.

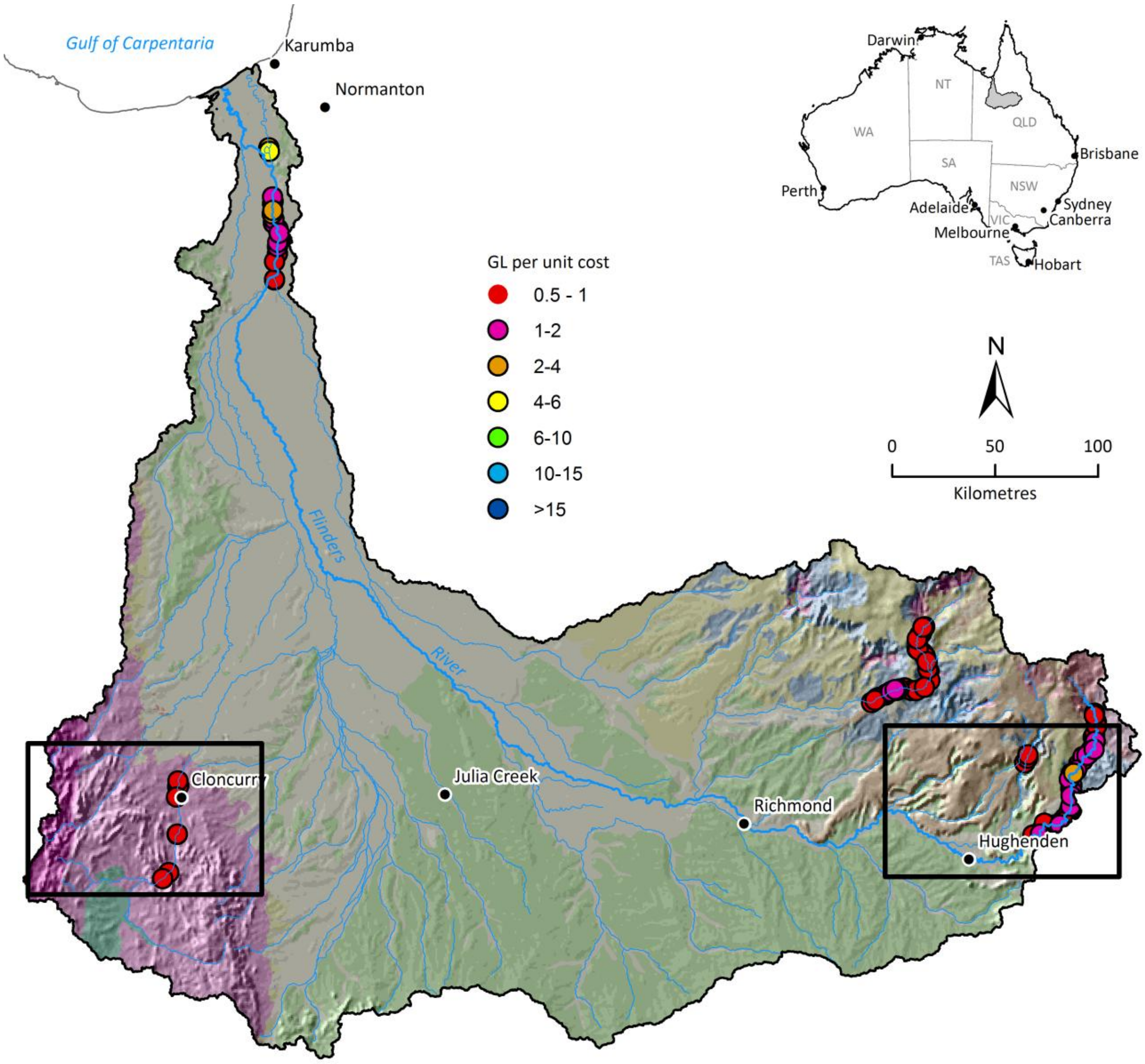


Figure 3.8 DamSite model results for the Flinders catchment. Potential dam sites ranked by the ratio of yield at 85% annual time reliability per unit cost. Only those potential dam sites > 1 GL per unit cost are shown. The transparent shading is the simplified surface geology of the Flinders catchment (Figure 3.1)

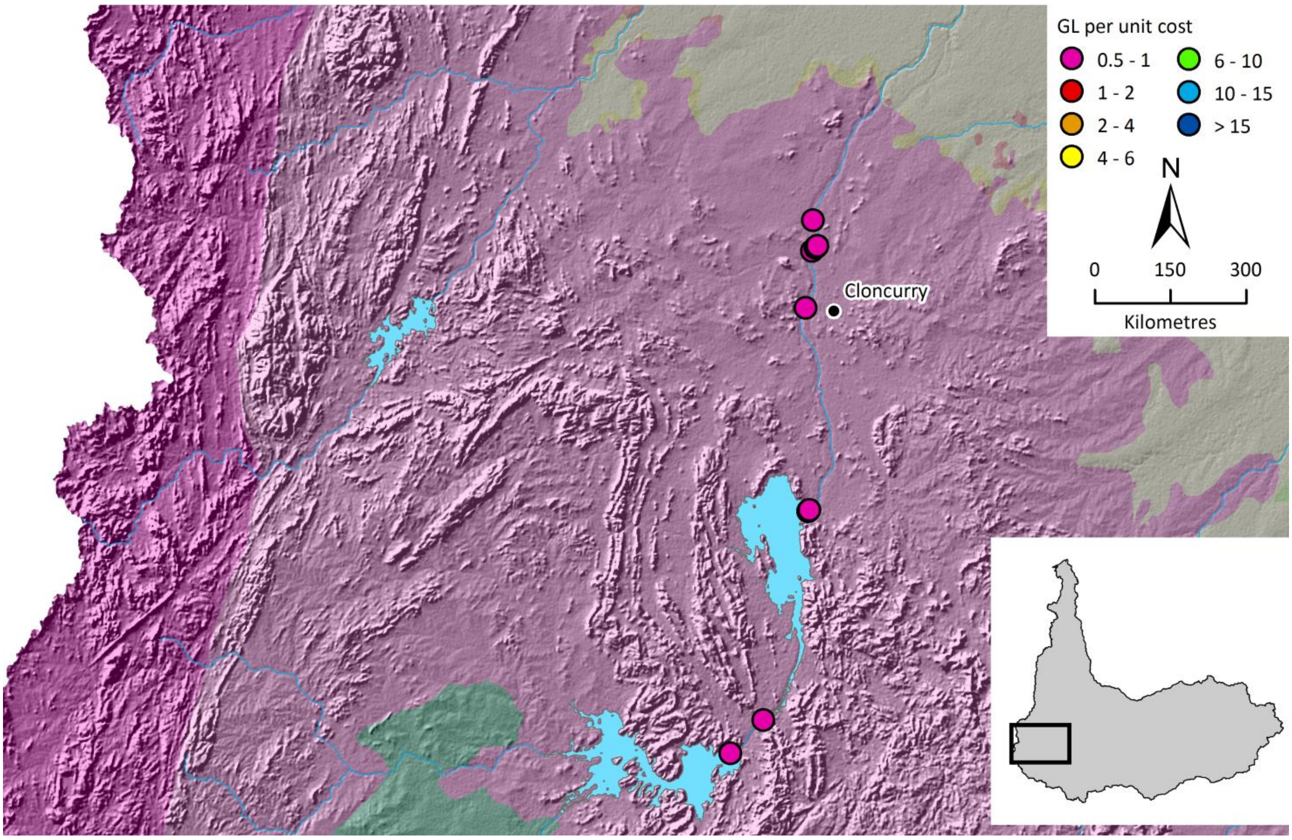


Figure 3.9 DamSite model results for the Cloncurry and Corella rivers in the Flinders catchment. Only those potential dam sites > 1 GL per unit cost are shown. The light blue polygons indicate potential reservoirs.

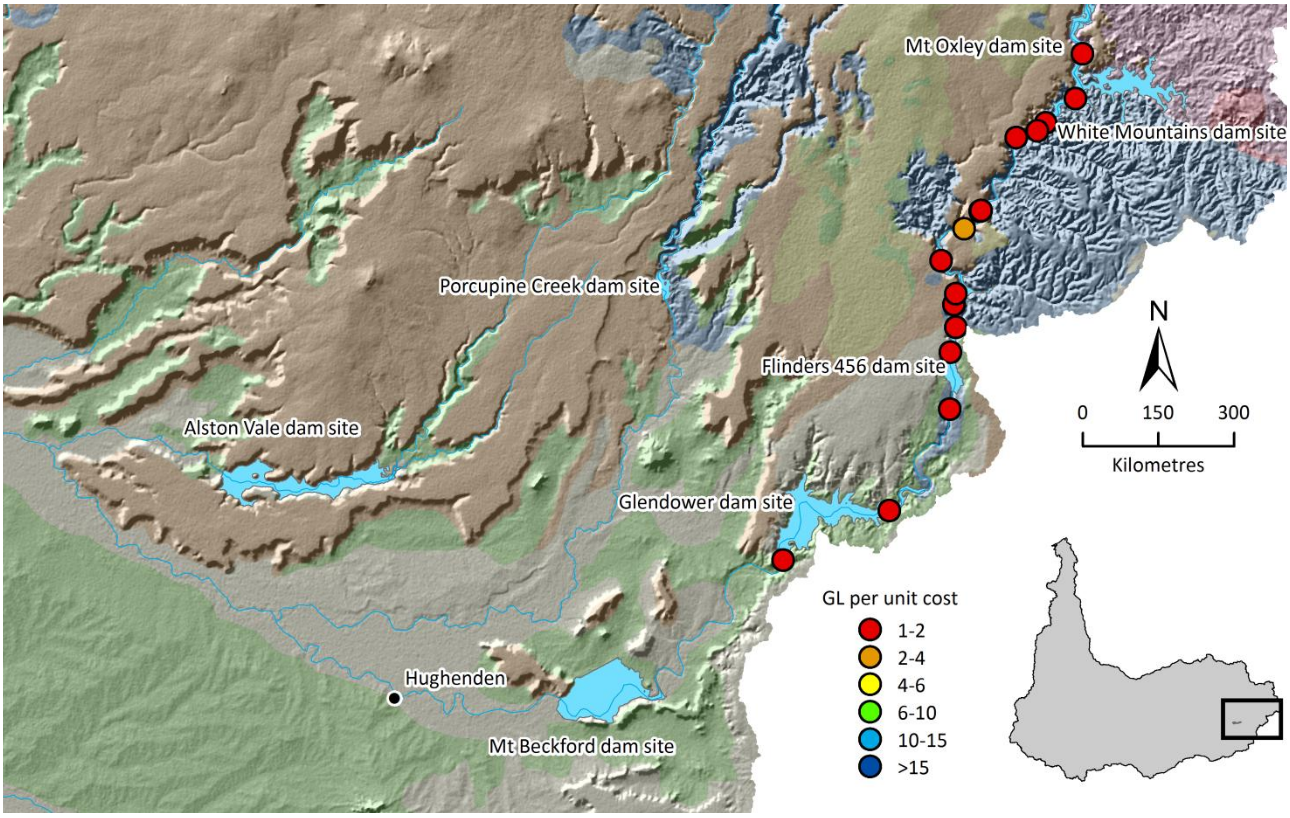


Figure 3.10 DamSite model results for the Flinders River near Hughenden. Only those potential dam sites > 1 GL per unit cost are shown. The light blue polygons indicate potential reservoirs .

In Figure 3.9 the best potential dam site along the Cloncurry River as identified using the DamSite model was the Cave Hill downstream site. The best potential dam site along the Corella River as identified using the DamSite model was the Corella River dam site.

In Figure 3.10 the best potential dam sites along the Flinders River in the vicinity of Hughenden as identified using the DamSite model were along the Flinders River between the potential Glendower dam site and the potential White Mountain dam site.

3.2.2 SUMMARY OF POTENTIAL DAMS ASSESSED IN THE FLINDERS CATCHMENT

Table 3.1 and Table 3.2 provide summaries of potential dams assessed in the Flinders catchment. In presenting this information it should be noted, however, the geological structure at a particular dam site can be very complex, is always unique and requires thorough investigation because of the high financial risks involved. The investigation of a potential dam site generally involves an iterative process of increasingly detailed studies over a period of years, occasionally as few as two or three years but often over ten or more years. For any of the options listed in this report to advance to construction, far more comprehensive studies would be needed than were possible in this regional scale assessment.

An important consideration in assessing a dam for use for irrigation is its proximity to suitable soils. As part of the Assessment 76 crop and irrigation type combinations were assessed, see Bartley et al. (2013) for a full description of the land suitability methods and all land suitability maps. Across the Flinders catchment there is about 8 million ha of land that is classed as moderately suitable under a range of crop and irrigation methods (Bartley et al. 2013). Figure 3.11 maps the existing and potential dam sites assessed in the Flinders catchment together with the land suitability map for wet season sorghum (grain) under spray irrigation. This figure indicates that the potential dams closest to large contiguous areas of land moderately suitable for irrigation are Cave Hill, Cameron Creek, O'Connell Creek and Richmond Dam. Most of the potential dams in the upper Flinders River are a considerable distance upstream of large contiguous areas of land moderately suitable for irrigation.

Three potential dam sites in the Flinders catchment were short-listed and assessed in more detail because each was initially deemed to be one of the more promising sites in each of three distinct geographical areas. The selection of these three sites was based on consideration of topography of the dam axis, geological conditions, proximity to suitable soils and water yield. The short-listed sites are Cave Hill, O'Connell Creek and Porcupine Creek. For these sites, conceptual layouts were developed and preliminary desktop costings undertaken. It should be noted, however, that none of the three short-listed sites in the Flinders catchment is particularly suited to development.

Table 3.1 Potential dams assessed in the Flinders catchment

At some locations, up to three alternative sites were assessed. For these locations, the most suitable alternative site is reported. Dam ID column corresponds to numbers shown on Figure 3.11.

DAM ID	DAM NAME	DAM TYPE*	CATCHMENT AREA (km^2)	SPILLWAY HEIGHT** (m)	FULL SUPPLY LEVEL (mEGM96)	CAPACITY (GL)	ANNUAL WATER YIELD*** (GL)	CAPITAL COST## ($ million)	UNIT COST### ($/ML)	EQUIVALENT ANNUAL UNIT COST#### ($ per year per ML)
1	Alston Vale	RCC	1,132	30	311	241	12	$275 □	$23,510	$1,647
2	Black Fort	EB#	4,249	16	243	43	20	$225 □	$11,170	$782
3	Cameron Creek	RCC	494	22	225	190	7.7	$325 □	$42,230	$2,959
4	Cave Hill	EB	5,264	16	224	248	40	$249 ■	$6,170	$432
5	Chinaman Creek Dam	CC	167	14	190	2.75	NA	NA	NA	NA
6	Corella Dam	EB	335	20	302	20	3.7	$225 ■	$60,020	$4,206
7	Corella River downstream	RCC	642	22	262	101	9.1	$225 □	$24,850	$1,741
8	Flinders 856 km	RCC	1,694	32	500	89	39	$275 □	$7,110	$498
9	Glendower	RCC	1,912	32	427	309	57	$375 □	$6,580	$461
10	Mt Beckford	EB	2,065	21	364	245	45	$450 □	$9,990	$700
11	Mt Oxley	RCC	690	34	593	62	22	$225 □	$10,300	$721
12	O'Connell Creek offstream	EB	1,508	9	201	127	34	$229^ ■	$6,760	$474
13	Porcupine Creek	RCC	1,051	35	411	31	11	$179 ■	$15,610	$1,093
14	Richmond Dam	EB	17,724	11	203	200	30	$375 □	$12,410	$869
15	White Mountains	RCC#	1,085	37	569	111	34	$225 □	$6,720	$470

* Conventional concrete (CC), embankment dam (EB), roller compacted concrete dam (RCC).

** The height of the dam abutments 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.

details of original dam proposal could not be located. Dam type listed is considered most likely based on available information.

■ indicates preliminary cost estimate is likely to be –10% to +30%. □ indicates preliminary cost estimate is likely to be –10% to +50%. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher. Operation and maintenance costs are typically about 0.4% of the capital cost. However, O'Connell Creek offstream storage would cost about 1% of the capital cost per year due to operation and maintenance of the diversion weir and erodibility of the berm and batter slopes of the diversion channel.

This is the unit cost of annual water supply and is calculated as the capital cost divided by the water yield at 85% annual time reliability.

Assuming a 7% real discount rate and a dam life of 100 years. Capital cost only. Does not include operation and maintenance costs.

^This includes the cost of the diversion weir and diversion channel as well as the EB dam across O'Connell Creek. Operation and maintenance costs of the O'Connell Creek offstream storage would be about 1% of the capital cost per year due to operation and maintenance of the diversion weir and erodibility of the berm and batter slopes of the diversion channel.

Table 3.2 Summary comments for potential dams in the Flinders catchment
The companion technical report about water storage options (Petheram et al., 2013) provides a comprehensive review of each of the potential dams listed below.

DAM NAME	COMMENTS
Alston Vale	Weathered mudstone foundations mean a very large mass of concrete would be required to ensure stability of the dam wall. Slopes adjacent to dam wall show recent evidence of landslides.
Black Fort	Reasonable distance upstream of moderately suitable land. As a result the small water yield at the dam wall would be further reduced by river conveyance losses.
Cameron Creek	Small yield, remote and moderate distance upstream of moderately suitable land.
Cave Hill	One of the higher yielding dams in the Flinders catchment and the closest potential dam site to moderately suitable soils near Cloncurry. Further geological investigations required due to the presence of faults in the vicinity of the dam site. Short-listed site. See description below for more detail.
Chinaman Creek Dam	Existing dam. Small catchment area supplemented by water pumped from Cloncurry River. Little opportunity to increase capacity of reservoir.
Corella Dam	Existing embankment dam. Embankment settlement has led to numerous areas of cracking of the face slab, which has worsened as the slab reinforcing mesh has corroded. Rather than repair existing dam the preferred option would be to develop a new RCC dam slightly downstream. Moderate distance upstream of suitable land, small water yield at dam wall would be further reduced by river conveyance loss.
Corella River downstream	Moderate distance upstream of moderately suitable land, small water yield at dam wall would be further reduced by river conveyance losses.
Flinders 856 km	Moderate distance upstream of moderately suitable land. No site or geological inspections have been carried out. Small water yield at dam wall would be further reduced by transmission losses.
Glendower	Moderate distance upstream of moderately suitable land. Geologically unfavourable due to unstable slopes on the left abutment of the dam. Small water yield at dam wall would be further reduced by transmission losses.
Mt Beckford	Long saddle dam requirements. Shallow storage. This proposal has major geological uncertainties and would be expensive. Being close to Hughenden would have recreation value. Would inundate large areas of regional ecosystems 'of concern'.
Mt Oxley	Long distance upstream of moderately suitable land. Large river conveyance losses would further reduce small yield.
O'Connell Creek Offstream	A diversion weir on the Flinders River would divert water into an offstream storage on O'Connell Creek near the town of Richmond. This is the most promising large dam in the Richmond area due to the major uncertainties associated with the Richmond dam (see below). The main limitations with O'Connell Creek are the flat topography and capacity of diversion channel. Short-listed site. See description below.
Porcupine Creek	One of the more geologically suitable potential dam sites in the upper Flinders. Good access from the Kennedy Development Road. The main limitation is the small storage volume and water yield. The reservoir would extend into the Porcupine Gorge National Park. Short-listed site. See description below.
Richmond Dam	Risk of storage sedimentation, increased risk of flooding at Richmond and the risk of scour damage during periods of spillway discharge. Likely to create barrier to movement of barramundi and freshwater sawfish.
White Mountains	Long distance upstream of moderately suitable land. Large river conveyance losses would further reduce small yield.

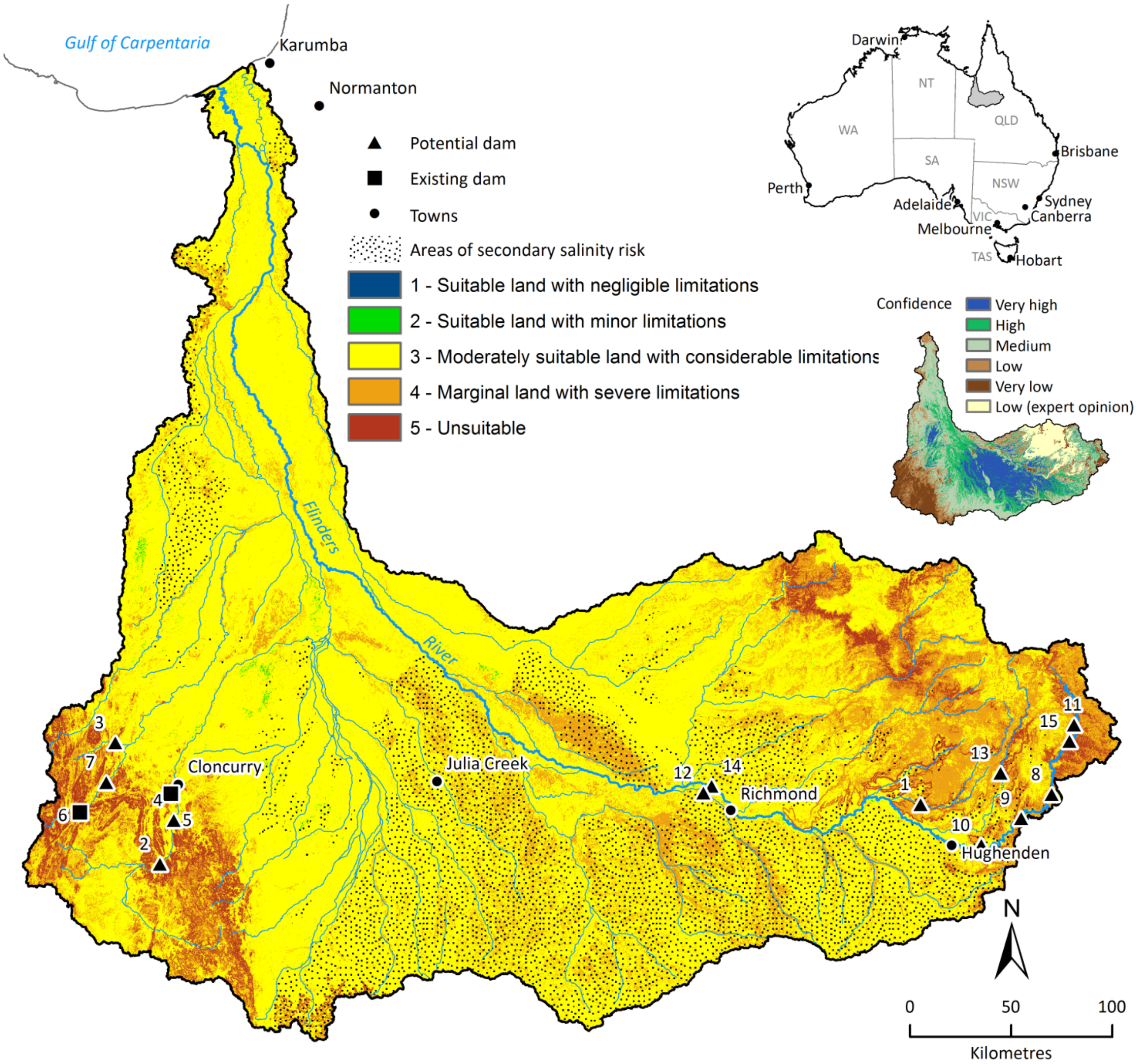


Figure 3.11 Existing and potential dam locations in the Flinders catchment and modelled land suitability for wet season sorghum (grain) under spray irrigation. Confidence map insert is associated with land suitability mapping. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water.

Numbers correspond to Dam ID in Table 3.1. Land suitability data were sourced from the companion technical report on land suitability, Bartley et al. (2013). See Bartley et al. (2013) for a full description of the methods and explanation of the confidence map.

3.3 Broad scale environmental and cultural heritage considerations in the Flinders catchment

3.3.1 INSTREAM CONSIDERATIONS

The Flinders catchment generally has very low relief and the water typically flows relatively slowly, often taking weeks to reach the ocean (with considerable losses occurring along the way). The low flows and flat landscape mean that fish can penetrate further upstream than in catchments with a greater slope. It also means the rivers often break into a series of channels, creating extra aquatic and riparian habitat across the coastal floodplain.

A total of 50 fish species are known to occur within the Flinders catchment (Waltham et al. 2013). Figure 3.12 shows the number of fish species found at each site in various studies. It can be seen that the number of species decreases from the lower to the upper reaches. The locations of potential dam sites on the Flinders River upstream of Richmond, and the Cloncurry River upstream of Cloncurry, generally have less than ten species present, though further, more intensive surveys may lift that figure slightly. Barramundi are known to occur upstream of Richmond (Figure 3.12), indicating that a dam near this location may impact slightly on their distribution. No other potential dam site in the Flinders catchment appears to impinge on the natural distribution of barramundi. Pearce et al. (2001a) noted anecdotal evidence that barramundi have penetrated as up the Cloncurry River as far as the town of Cloncurry, although this is likely to be rare and its range would still be downstream of the most downstream potential dam site on the Cloncurry River (i.e. Cave Hill). It is likely that as a result of artificial stocking of barramundi into Lake Fred Tritton at Richmond, and Chinaman Creek Dam and Lake Corella near Cloncurry (Waltham et al. 2013), the distribution of barramundi in the Flinders catchment has been anthropogenically extended.

None of the potential dam sites in the Flinders catchment impinge upon the known or expected habitat of the freshwater whipray (Figure 3.12). However, potential dam sites near Richmond may also impact upon freshwater sawfish. The most upstream extent of freshwater sawfish on the Flinders River (Figure 3.12) is based on personal communication with north Queensland sawfish expert Stirling Peverell (formerly of Fisheries Queensland) who believes the species could, on occasion, be found as far upstream as Hughenden. Tait (1998a) noted anecdotal reports of freshwater sawfish around Richmond. Freshwater sawfish are typically not readily detected in standard fisheries surveys and need to be specifically targeted in dedicated surveys in order to gain a better understanding of their actual distribution. Because of their size and very distinctive saw-like rostrum, they are readily identified and memorable, so interviews of local people could also help to better elucidate their range.

Large, major permanent waterholes have been mapped as part of this study and in the Flinders catchment. Large permanent waterholes are considered to be key aquatic refugia. Most are located downstream of potential dam sites in the Flinders catchment (Figure 3.13). These waterholes may be affected by alterations to flow regimes from water resource developments, but will not be directly impacted upon by inundations from a dam. The method used to map waterholes is not capable of detecting smaller deep waterholes that may be locally important as refuges, so more detail would need to be obtained on these habitats if any potential dam sites were investigated further.

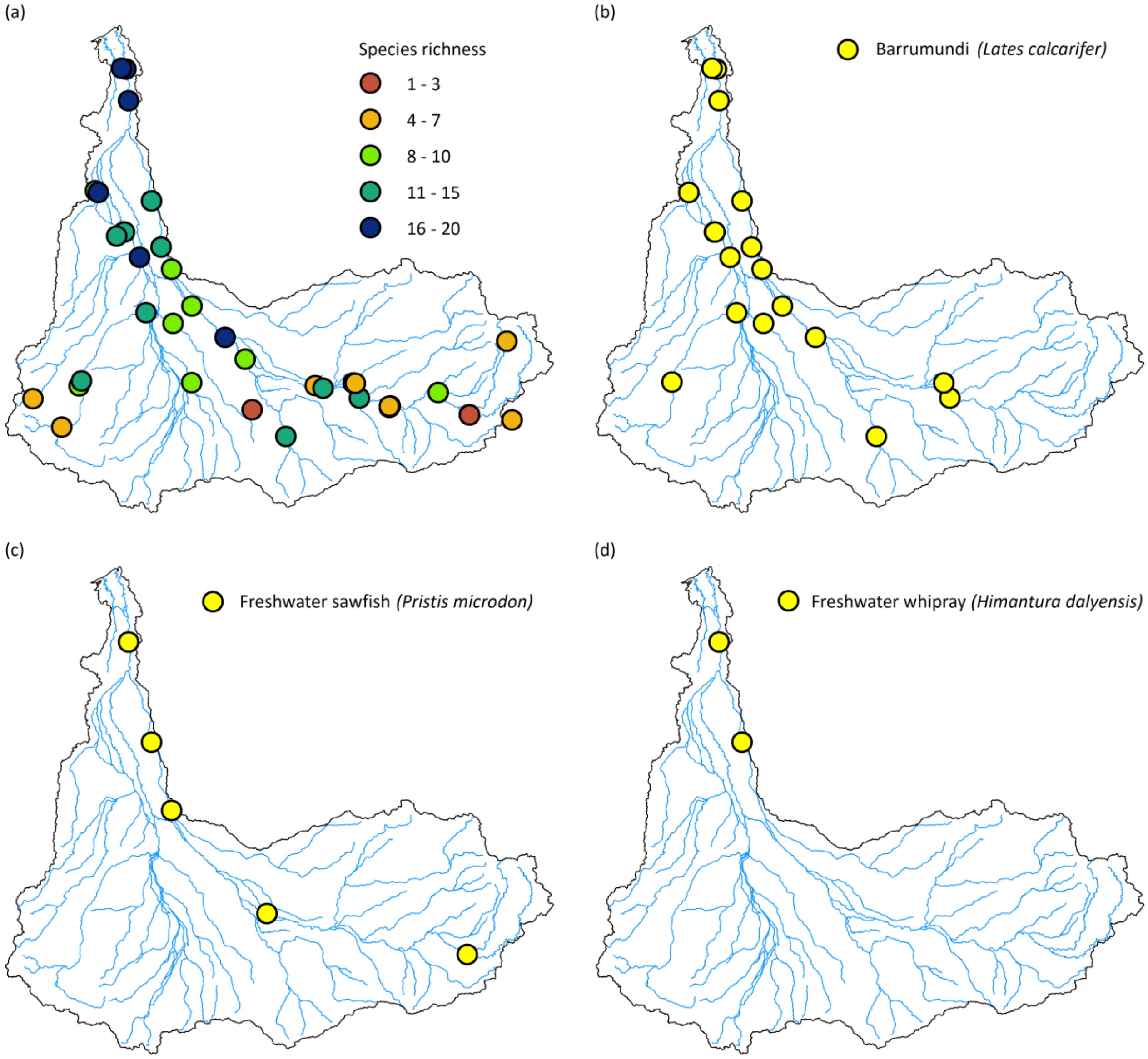


Figure 3.12 Extent of fish surveys in Flinders catchment

(a) Number of species found in fish surveys. (b) Known extent of barramundi distribution (*Lates calcarifer*); photo: <www.anima.net.au>, used with permission. (c) Freshwater sawfish (*Pristis microdon*); photo: S. Peverell, used with permission. (d) Freshwater whipray (*Himantura dalyensis*); photo: B. Pusey, used with permission (figure sourced from companion technical report on aquatic ecosystems, Waltham et al., 2013).

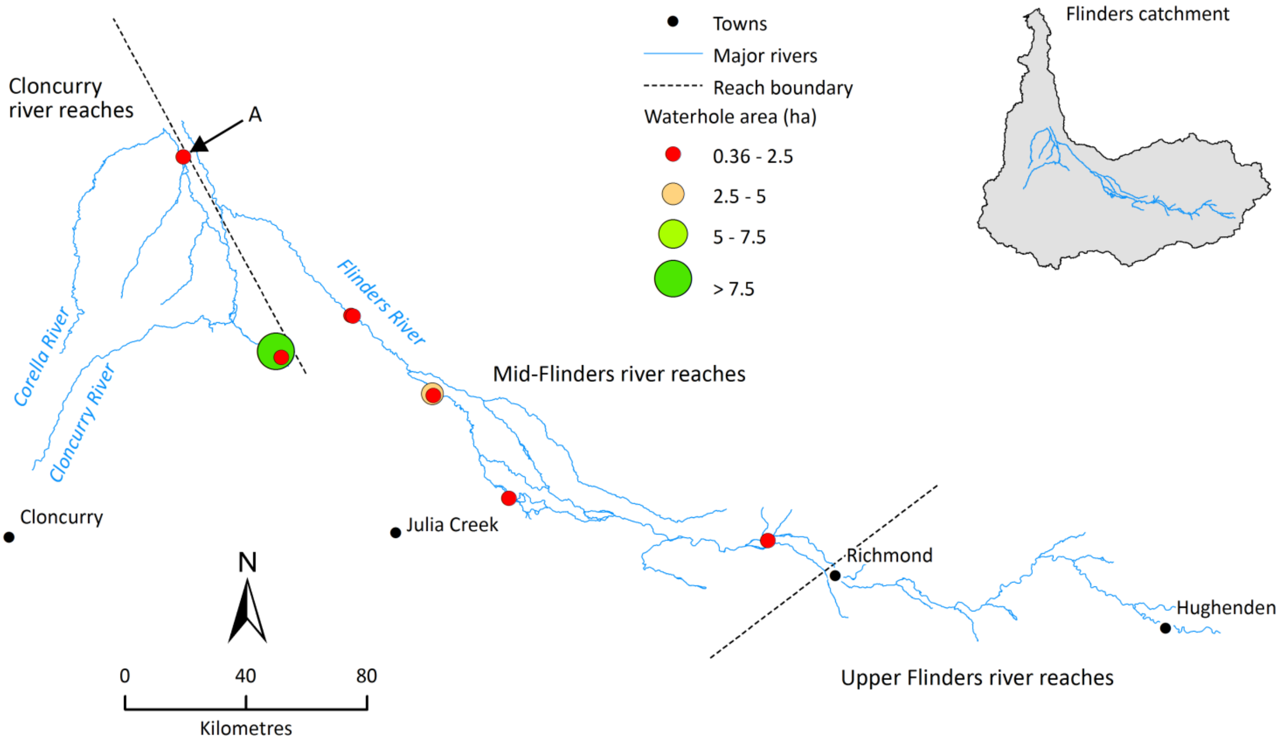


Figure 3.13 Location of key aquatic refugia identified in the Flinders catchment. Inset shows river reaches investigated

Key aquatic refugia are defined as those waterholes which are present for more than 90% of the time. Permanent waterholes less than 0.36 ha were too small to be detected by the satellite imagery. Inset shows the river reaches that were examined. (persistent pool data sourced from companion technical report on dry season pools; McJannet et al., 2013).

3.3.2 REGIONAL ECOSYSTEMS

The regional ecosystem communities that were present at each potential water storage site within the catchment were examined using the Queensland Herbarium's *Regional Ecosystem Description Database (*Queensland Herbarium, 2013) and were categorised as per Table 3.3. In general, most of the Flinders catchment includes 'not of concern' vegetation communities (Figure 3.14), which means that the area of remnant vegetation extends more than 30% of the pre-clearing extent across the catchment. The Assessment examined vegetation communities located within the potential water storage sites, with many found to inundate areas of 'of concern' vegetation (remnant vegetation between 10 and 30% of pre-clearing) particularly in the south-west of the Flinders catchment in the Cloncurry area, along the upper north-east Flinders River and around the townships of Hughenden and Richmond. For potential dam sites in the upper reaches of the Cloncurry and Corella catchments and around Hughenden, these will inundate endangered riparian areas (remnant vegetation less than 10% of pre-clearing extent).

A more detail examination of this mapping is shown for each potential dam site, where the proposed inundation area has been superimposed over the regional ecosystem mapping. If any potential dam site is considered for further investigation, the vegetation and fauna communities present would need to be investigated much more thoroughly, including on ground surveys.

Table 3.3 Categories of regional ecosystem (vegetation) communities
These biodiversity codes come from the *Vegetation Management Act 1999.*

CATEGORY	DEFINITION	SUBCLASS*	AREA (ha)	PERCENTAGE OF CATCHMENT
Endangered	Remnant vegetation is less than 10% of its pre-clearing extent across the bioregion; or 10 to 30% of its pre-clearing extent remains and the remnant vegetation is less than 10,000 ha.	Dominant	45,340	0.4%
		Sub dominant	102,960	0.9%
Of concern	Remnant vegetation is 10 to 30% of its pre-clearing extent across the bioregion; or more than 30% of its pre-clearing extent remains and the remnant extent is less than 10,000 ha.	Dominant	987,550	9%
		Sub dominant	1,287,110	12%
No concern at present, least concern	Remnant vegetation is over 30% of its pre-clearing extent across the bioregion, and the remnant area is greater than 10,000 ha.	Dominant	8,304,520	77%
Non-remnant	Native vegetation		113,662	1%
Plantation	Plantation		80	0.0%
Water	Water		3,890	0.0%

* 'Dominant' subclass means greater than 50% of polygon contains the regional ecosystem mapping. 'Sub dominant' subclass means that less than 50% of the polygon contains the regional ecosystem mapping.

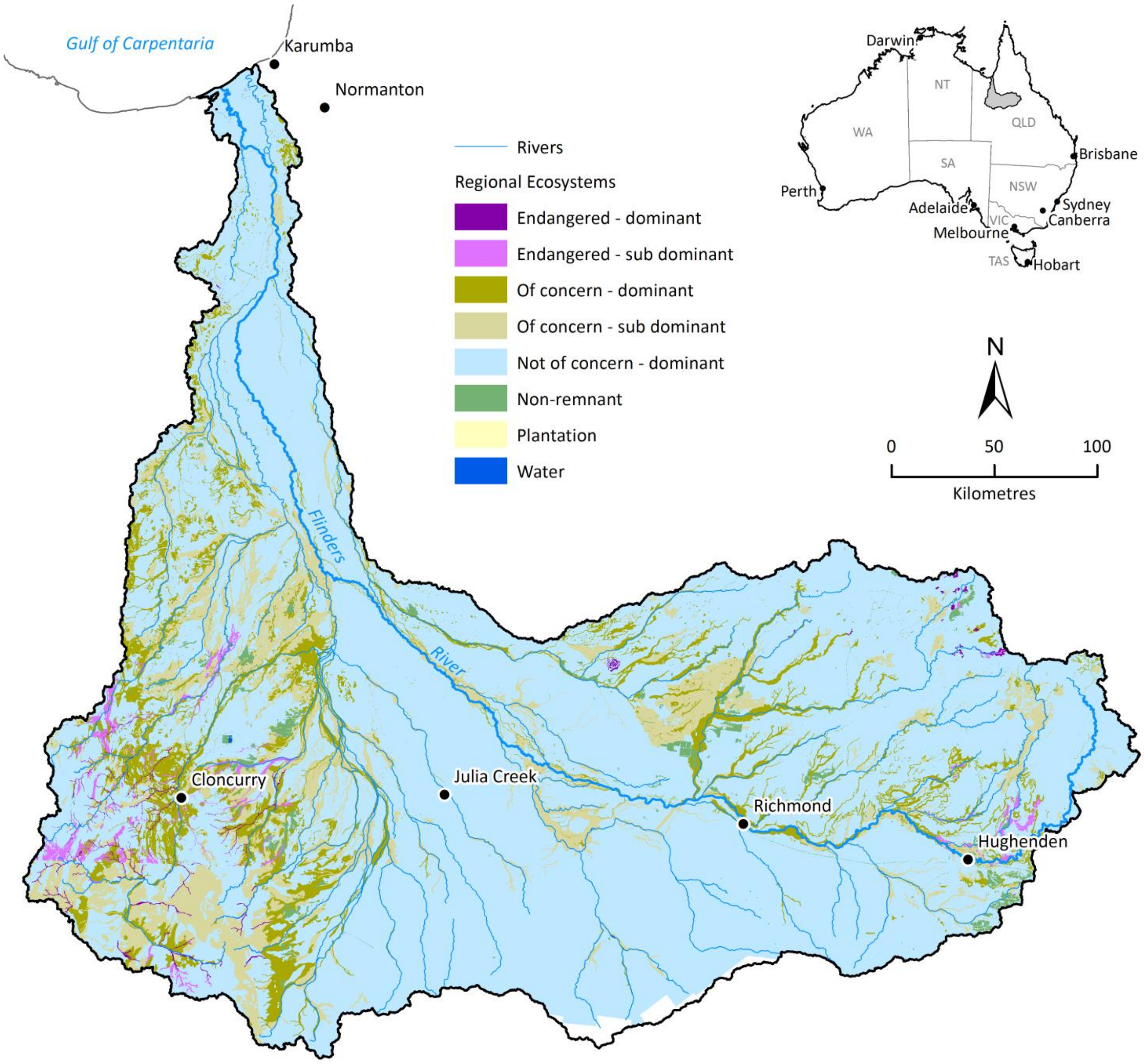


Figure 3.14 Status of regional ecosystem biodiversity status for the Flinders catchment
Definitions and data sourced from Queensland's *Regional Ecosystem Description Database* (Queensland Herbarium, 2013).

3.3.3 INDIGENOUS CULTURAL HERITAGE VALUES

An archaeological investigation of the Indigenous occupation of the north Queensland highlands (Upper Flinders and Gregory Ranges) was undertaken in the 1980s and 1990s (Border & Rowlands 1990). The area includes the headwaters of both the Flinders and Gilbert rivers, but the study was focussed on the upper Flinders River. It was suggested that occupation of the area generally dates back at least 29,000 years. Occupation of the Prairie Creek area, in the vicinity of the potential Porcupine Creek dam, occurred at about 3400 BP, when a change to more intensive use of plant resources (in the form of seed harvest and processing) allowed occupation of this previously marginal country.

The potential Cave Hill dam and O'Connell Creek offstream storage fall on the northern boundary of the Mitchell Grass Downs. A review of the cultural heritage resource of this zone undertaken in 1990 found that there were 102 recorded Indigenous archaeological sites. The low number probably reflects the limited amount of previous investigation (Border and Rowlands 1990). The most common recorded site types were stone quarries, stone artefact scatters, stone arrangements, hearths and scarred trees.

Subsequent archaeological surveys, including a number undertaken for consulting projects, have resulted in the identification of hundreds more archaeological sites in this general area. Surveys of sections of the Flinders River and O'Connell Creek near Richmond in the late 1990s resulted in the recording of 245 sites, with a density ranging up to approximately 4 sites per 100 m (NAC 1997a; 1997b; 1999). Sites consist largely of artefact scatters and hearths, and are generally located close to water sources and on elevated ground (see for example Wallis et al 2004).

Utilisation of the Mitchell Grass Downs is thought to have begun by the late Holocene period (Border and Rowlands 1990). An investigation of hearth sites along the Flinders River, in the Richmond area, included dating seven of these hearths to periods within the last 1,000 years. It was noted that the hearths were single-use features, and that the many present in the locality may represent occupation over a very long period.

3.4 Three short-listed potential dam sites in the Flinders catchment

The three short-listed potential dam sites are described below in alphabetical order.

3.4.1 CAVE HILL DAM SITE ON CLONCURRY RIVER; 393.2 KM

PARAMETER	DESCRIPTION
Previous investigations	QWRC (1987) Cloncurry River Irrigation and Water Supply Project QWRC (1980a) Cloncurry River Basin 915 AMTD 346.8km, 371.1km Flood Hydrolog. QWRC (1980b) Basin 915 Report on Yield Studies for the Cloncurry River at i) Black Fort damsite AMTD 371.1 km; and ii) at Cave Hill damsite AMTD 346.8 km. , Stockill BD (1987) Seismic Refraction Survey, Cave Hill Dam Site, AMTD 346.8- 347.3 km, Cloncurry River GSQ (1978) Report on Preliminary Investigation for Sources of Construction Materials, Cave Hill Damsite.
Description of proposal	The then Queensland Water Resources Commission Dam investigated sites in this area in the 1980s at the request of the Cloncurry Shire Council as potential sources of supply for a possible irrigation and urban water supply project. The studies concluded that the overall economics of the Cave Hill dam site proposal were unattractive and that alternative proposals to improve urban water supplies, subject to further investigation, appeared to be more economical. Since that time, the Cloncurry town water supply was augmented by the Chinaman Creek Dam development in 1993 and recently by an extension of the North West Queensland pipeline from the Ernest Henry mine to Cloncurry. The dam as now proposed at AMTD 393.2 km (previously 346.9 km) and some 18 km south of Cloncurry would therefore be only for irrigation development. The height of the dam spillway was selected to be 16 m above bed level (FSL 224) as this is consistent with the original proposal and any additional height would add considerably to the dam cost as the saddle dam requirements increase considerably. A photograph of the site is shown in Figure 3.15. A location map and map showing the inundated area at FSL are shown in Figure 3.16 and Figure 3.17 respectively.
Regional geology	The main geological units in the reservoir area are metamorphic rocks belonging to the Mt Isa Inlier, Mesozoic sedimentary rocks and alluvium. The metamorphic rocks are of Early Proterozoic age and belong to the Corella Formation and Marimo Slate. They are regionally metamorphosed and folded marine shelf deposited sediments. The original rocks included carbonaceous shales, indicative of deposition in deep troughs, and impure limestones and calcareous siltstones indicative of shallower water. The reservoir area is characterised by northerly trending strike ridges and deformed rock with near vertical slaty cleavage. The first period of deformation resulted in north trending open folds and axial plane cleavage. Further deformation produced northeast trending dextral strike slip faults and breccias. The final stages of the orogeny were marked by intrusion of granite and dolerite. In late Jurassic and Cretaceous times there was sagging of the basement and marine and fluviatile sediments of the Great Artesian Basin were deposited. Uplift in the Cainozoic resulted in erosion of the Mesozoic sediments and these are now preserved as scattered outliers in the reservoir area. Figure 3.18 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams
Site geology	Two dam wall axes at AMTD 346.8 km and 347.3 km were investigated in 1986. These axes were labelled Axis A and C respectively. At Axis A, rocks of the Corella Formation outcrop in a north trending band downstream of the dam axis. The rock consists of marble, scapolitic limestone, quartzite, siltstone, sandstone and calc-silicate breccia. The rock is intensely folded and faulted and it is difficult to trace individual rock units. The rock also shows the effect of metamorphism and metasomatism with development of minerals such as scapolite, coarse calcite and albite.

PARAMETER	DESCRIPTION
	Rocks belonging to the Marimo Slate outcrop at both axes. The main rock types are slate, carbonaceous shale containing pyrite porphyroblasts, quartzite, siltstone and sandstone with minor limestone either as lenses possibly remobilised during deformation. The limestone is partly recrystallised to marble. Hydrothermal quartz and haematite have been emplaced along fault zones. It occurs as discontinuous ovoid masses along the ridges forming the abutments of Axis A. The quartz is cavernous because of incomplete cementation of brecciated rock fragments. The voids are usually less than 200 mm but one large cavity 4 m in size is present on the right abutment. Faults and lineaments have been subdivided into five sets. • North northeast trending (15°). Mapping suggests the sense of displacement is right lateral, probably steeply dipping. These are probably significant in the riverbed area as the set is sub-parallel to the river direction. • Northeast trending (45°). These are steep to vertical with left lateral displacement. • Southeast trending (160°). These are represented by discontinuous hydrothermal quartz. The largest mass occurs along the Corella Formation/Marimo Slate boundary. These faults have a very significant effect on the dam foundation at Axis A. • East southeast trending (105°). These faults are vertical to steep and have a right lateral sense of movement. • East trending (95°). These faults are sub-vertical with a left lateral sense of movement. At Axis A there is up to 15 m of alluvium in the river bed. Boreholes on the right side of the river intersected hydrothermal quartz containing voids infilled with alluvium. Voids are likely to be numerous and extremely variable in size. In one borehole (DD2), competent rock was not intersected between the base of the alluvium at a depth of 12 m and the end of the borehole at a depth of 35 m. At Axis C there is up to 13.5 m of alluvium in the river bed. All boreholes intersected slate, and interbedded siltstone and sandstone. The rock is highly to moderately weathered below the alluvium improving to slightly weathered to fresh with depth. Foundation conditions for a RCC dam are significantly better at Axis C than Axis A although the length of the dam is significantly greater and a significant depth of excavation would be required on the left abutment because of the steeply dipping and toppling nature of the slate rock on this side. It may be possible to avoid the poor foundation conditions at Axis A by shifting the axis location on the right abutment upstream. However there is insufficient foundation information to currently locate this alignment with certainty.
Reservoir rim stability and leakage potential	The rock along the reservoir rim is mostly high strength and highly deformed. It is unlikely to become unstable on filling of the reservoir. The potential for reservoir leakage is low.
Proposed structural arrangement	The proposal as detailed in QWRC (1987) (described as Axis A) involved a 30m high earth and rockfill embankment founded on the river bed alluvium and on the rock exposed on both abutments. A clay blanket (or concrete paving) extending upstream from the embankment sloping earth core was proposed to limit seepage losses through the river bed sands. An unlined chute spillway was located through the left abutment with an erodible fuse plug spillway through a left bank saddle. A 15m high embankment dam was required across a saddle on the right bank. An alternative site, (described as Axis C), 500 m upstream was also considered. The upstream axis offered better geological conditions than Axis A but required an embankment nearly twice as long as that required at Axis A. **Note:** The arrangement as proposed could only be considered viable if significant additional investigations and analyses were undertaken and that the results of this additional work were favourable. There is a significant probability that the costs involved in treating the karstic right abutment and in controlling leakage through the river bed sands would be higher than assumed in the above study. It is now proposed that the dam comprise a zoned earth and rock fill embankment located 100 m upstream of the original Axis A with a slurry trench cut off through the river bed sands

PARAMETER	DESCRIPTION			
	rather than the clay blanket as originally proposed. On the abutments where the embankment is expected to be founded on rock, a grout curtain would be used to control seepage. The dam axis would be aligned and the embankment section as per Figure 3.19. The proposed structural arrangement of the potential Cave Hill dam is shown in Figure 3.20. A separate saddle dam is required on the left bank some 6.5 km west of the river to contain flood rises in the reservoir. It is proposed that the saddle dam, crest level 232m, some 900 m long and 5 m maximum height would be an earth fill embankment with an erodible downstream zone. The crest level would be set slightly above the peak reservoir level for the 1 in 1,000 AEP flood and serve as an auxiliary spillway in the event of more extreme flood events. An uncontrolled service spillway is now proposed to be located through the saddle to the west of the dam where an auxiliary fuse plug spillway was originally proposed. Allowance has been made for a drop structure in the spillway discharge chute with erosion protection to minimise erosion as spillway discharges flow back to the river. The saddle dam required on the right bank side would also be an earth and rockfill embankment approximately 720m long maximum height 16 m again, with a grout curtain to control seepage through the saddle foundations. The saddle embankment crest level, EL 234 has been set to contain the 1 in 100,000 AEP peak reservoir level with the cross river embankment section crest set at EL 235 m. A conduit to provide for stream diversion during construction and for the permanent outlet works would be located on the left abutment side. It is assumed that a fish transfer facility would be required. An allowance has been included for a bi-directional fish lift installed over the embankment. Access to the dam from Cloncurry is assumed to be on the eastern bank of the Cloncurry River with a berm on the downstream slope of the dam embankment providing access to the outlet works and to the right bank area. It is emphasised that the viability of this proposal is dependent on detailed foundation drilling demonstrating that the quartz blow outcrop exposed on the right abutment can be avoided by the axis relocation now proposed.			
Availability of construction materials	Earthfill materials are available from terrace alluvium and fine slope wash adjacent to the Cloncurry River. Concrete aggregate and filter materials are available from channel alluvium in the river. This consists of well to poorly graded sand-gravel mixtures. Chert and sandstone suitable for rockfill and/or concrete aggregate should be available from potential quarry sites within 2 km of the dam site.			
Catchment area	Catchment area at the dam site is 5,264 km^2.			
Flow data	Flow data is available for the Cloncurry River from G.S. 915203B at Cloncurry AMTD 327.6km, catchment area 5,859 km^2. Data is available from 1994 to date. Over this period - Maximum recorded annual flow was 1,986,000 ML Mean annual flow 441,000 ML Median annual flow 230,000 ML Minimum annual flow 11,000 ML Data is also available from an earlier station (G.S. 915203) at Cloncurry commencing in 1969 and from G.S. 915204 at AMTD 371.8 km, that is, 25km upstream of the dam site. Data was collected at this site from October1968 to 1994. The catchment area of this station is 4,240 km^2.			
Storage capacity	248 GL at FSL 224 (Figure 3.21).			
Reservoir yield assessment	40 GL at 85% annual time reliability (Figure 3.22 and Figure 3.23). 34 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 55% Ratio of evaporation to water supplied (at 85% annual time reliability): 1.2 (Figure 3.23)			
Open water evaporation	Mean annual evaporation is estimated to be 6.0 mm d^{-1} using bulk aerodynamic formulae. Mean annual evaporation was estimated to be 5.2 mm d^{-1} using Morton's APE.			
Estimated rates of reservoir		Best case	Expected	Worst case

PARAMETER	DESCRIPTION			
sedimentation	30 years (%)	0.48	3.45	6.86
	100 years (%)	1.61	11.49	22.85
	Years to infill	6217	870	438
Ecological and cultural considerations raised by previous studies	Approx. 23 km of riverine vegetation including paperbark and red gum would be affected and the storage would impact on the habitat of the Cloncurry Parrot It was noted, however, that the creation of a large water body close to Cloncurry would provide a significant recreation and tourism benefit.			
Water quality and stratification considerations	The Cave Hill reservoir is predicted to experience very little persistent thermal stratification due to large summer inflow events, which lead to full mixing of the water column and the introduction of relatively warm inflow water which reduces resistance of this shallow reservoir to mixing due to the much lower temperature difference across the water column. The risk of blue-green algal blooms is low with Zsl:Zeu > 3 at virtually all times on average. The water column is predicted to be generally mixed and dissolved oxygen drawdown is unlikely to be a problem under most circumstances.			
Environmental considerations	Specific data on fish are not available from this site. However, given its location near Chinaman Creek Dam, the fish are likely to be the same, with the possible addition of a few species. The values of the aquatic habitat upstream of the proposed dam wall site are not known. A large proportion of this site covers regional vegetation communities that are likely to be “Of concern’ and some that are “Endangered” (Figure 3.24). *Ecosystem Of Concern* The large riparian vegetation zone is likely to include fringing woodland to open-forest of *Eucalyptus camaldulensis*, *E. tereticornis*, *Melaleuca fluviatilis*, *M. leucadendra*, *Casuarina cunninghamiana, Corymbia tessellaris*. A distinct sub-canopy can occur and contain *Ficus spp., Lophostemon spp.* and *Pleiogynium timorense* as well as juvenile canopy species. The shrub layer varies from light to mid-dense stands of *Ficus opposita*, *Melaleuca spp.* and *Acacia crassicarpa*. Dense ground cover includes *Heteropogon contortus* and *Themeda triandra* as well as a range of other graminoid and forb species.			
Indigenous cultural heritage considerations	There is at present no Indigenous Cultural Heritage body specifically for the potential Cave Hill dam. There are two Indigenous Parties: • Mitakoodi and Maya People (QC96/101 PRC - QUD6106/98) • Kalkadoon People #5 (QC06/2 PRC - QUD15/06) There are three sites listed in the DATSIMA database: BJ00000432 – Artefact scatter BJ00000433 – Artefact scatter BJ00000435 – quarry, artefact scatter No previous archaeological reporting relating specifically to the potential Cave Hill dam have been located. However, the existence of listed sites indicates that some investigation has been undertaken. The presence of these sites and the results of investigations in the catchment more generally indicate that the area is likely to have high archaeological potential. Further investigation, including archaeological survey, would be required to assess the potential Indigenous archaeological impact of works in this area. Any such investigation should be undertaken in consultation with the Indigenous Parties. Should works proceed in this area, it is recommended that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding contemporary use of water sources in the area.			
Estimated cost	The capital cost of the dam is estimated to be $249 million not including the cost of any downstream distribution works (though the range is likely to be $225 m to $325 m). Annual operating and maintenance costs are likely to be relatively low for the type of dam proposed. An annual allowance of 0.4% of capital cost is likely to cover normal costs i.e. $1.0 million. In the event of an extreme event (greater than 1:1,000 AEP) causing erosion of the			

PARAMETER	DESCRIPTION
	left bank saddle dam, significant costs would be involved in reconstructing the saddle dam and in managing any scour damage. In the event of a more extreme event (greater than 1:10,000 AEP) causing erosion of the right bank saddle dam, major costs would be involved in repair and restoration. Previous studies estimated the cost of the dam to be $23.6m in June 1986 prices. Consumer Price Index escalation to 2012 prices suggests a dam cost of $56.8m. Construction costs, particularly in remote areas have almost certainly increased at a higher rate than CPI over this period.
Estimated cost / ML of supply	$6170/ML water supply in 85% of years (does not include transmission/distribution losses or take into account environmental and downstream entitlements).
Potential benefit/cost	Previous studies QWRC (1987) suggested that the urban component of the scheme would have a positive benefit:cost ratio whereas the benefit:cost ratio of the irrigation component, assuming that the irrigation supply was used for forage sorghum production, would be significantly less than one. The analysis conclusion was that the scheme overall would not be economically viable.
Summary comment	Development of the Chinaman Creek Dam and of the pipeline extension from the Ernest Henry Mine ensures that urban water supply demands in Cloncurry will be reliably met for the foreseeable future. The economic viability of a Cave Hill dam based proposal would therefore be solely dependent on irrigated agricultural production.

Figure 3.15 Cave Hill dam site looking upstream

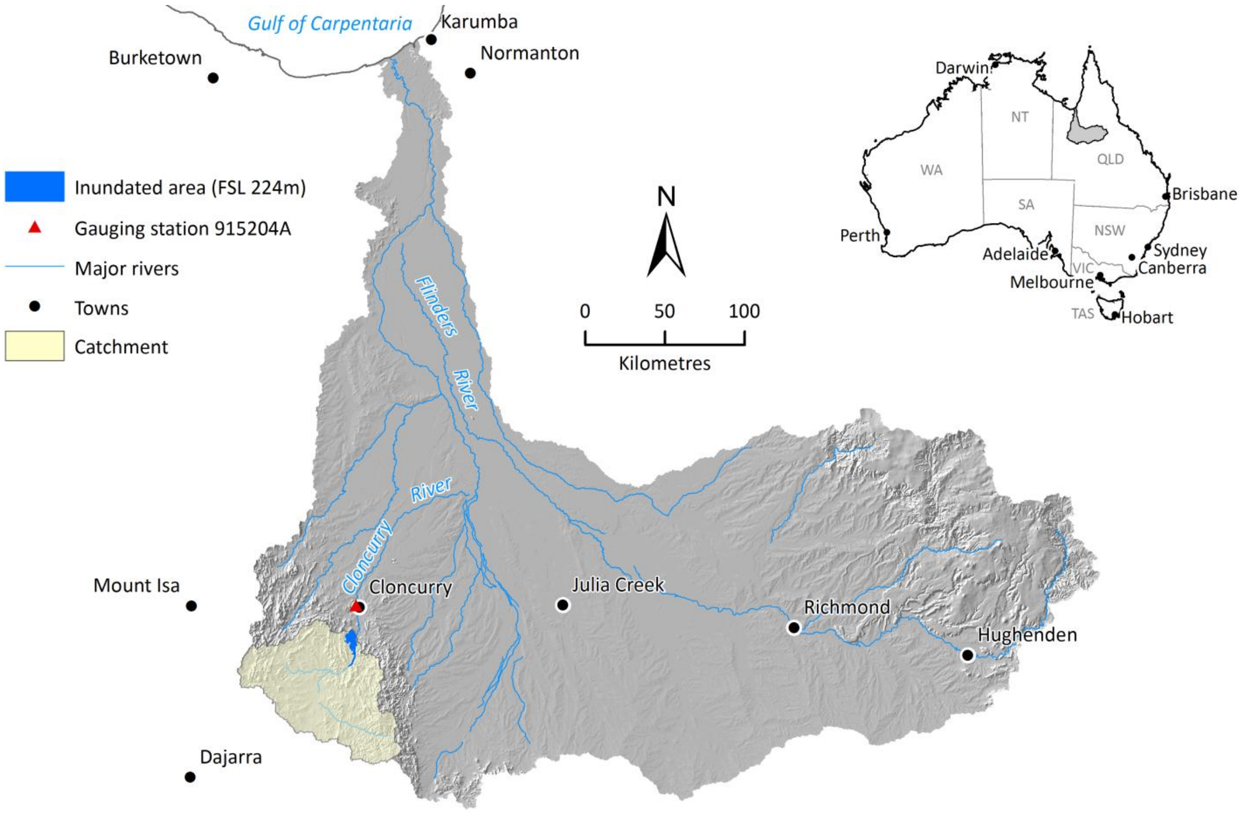


Figure 3.16 Location map of Cave Hill dam, reservoir and catchment area

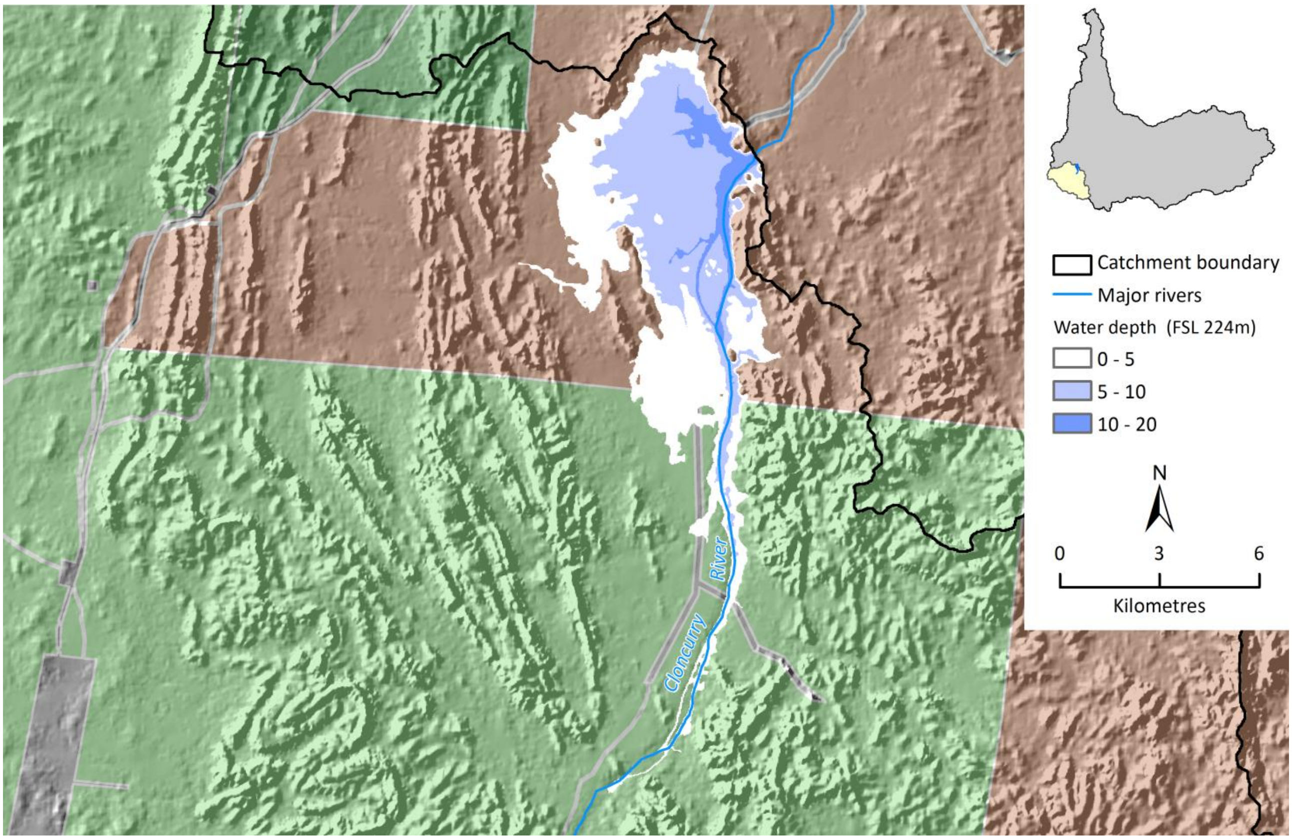


Figure 3.17 Cave Hill dam site depth of inundation and property boundaries (indicated by coloured shading)

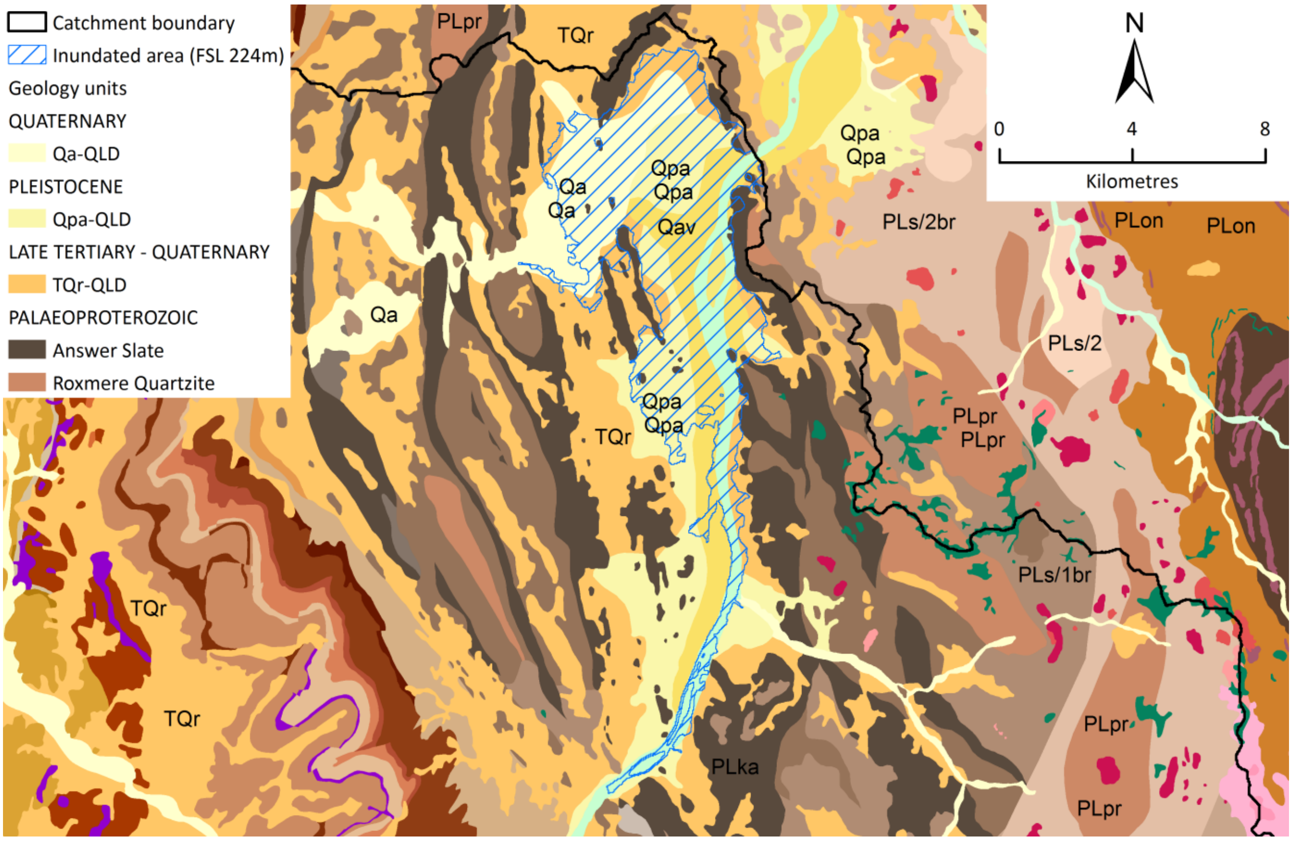


Figure 3.18 Cave Hill dam underlying geology

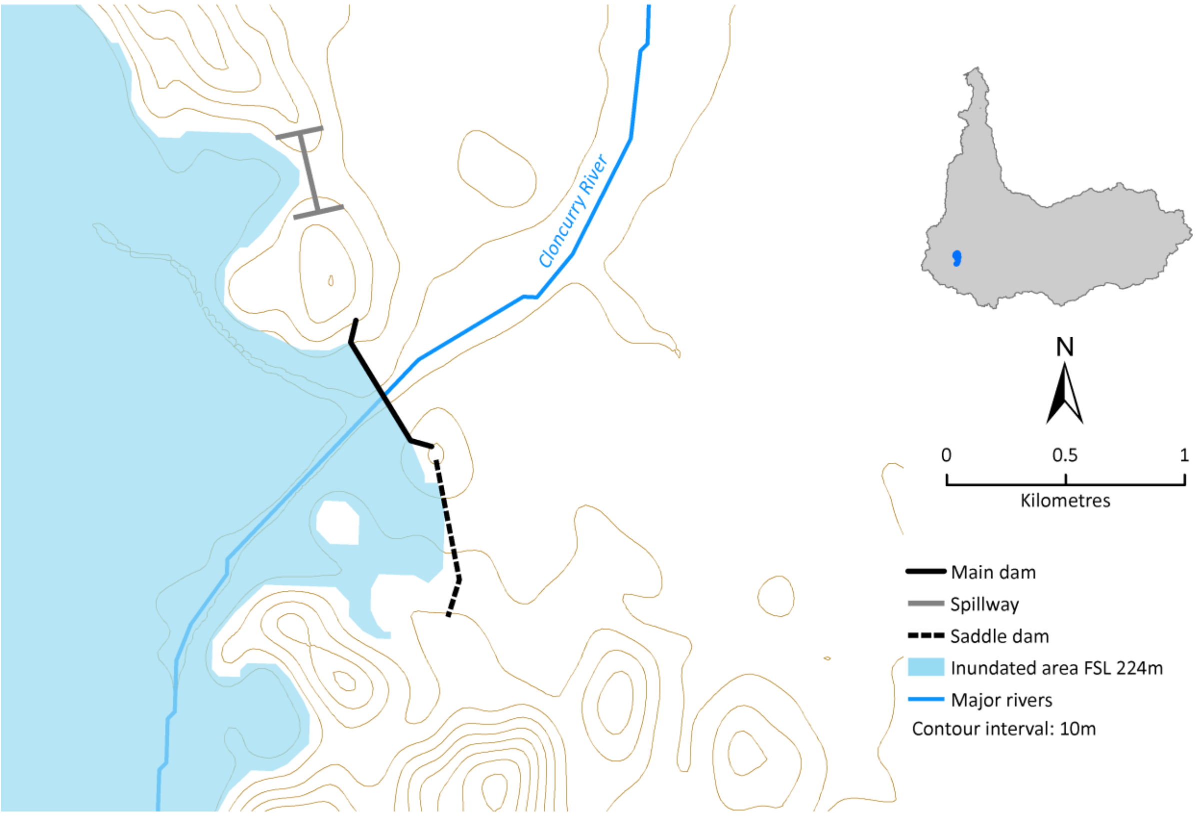


Figure 3.19 Map of proposed structural arrangement for the Cave Hill dam

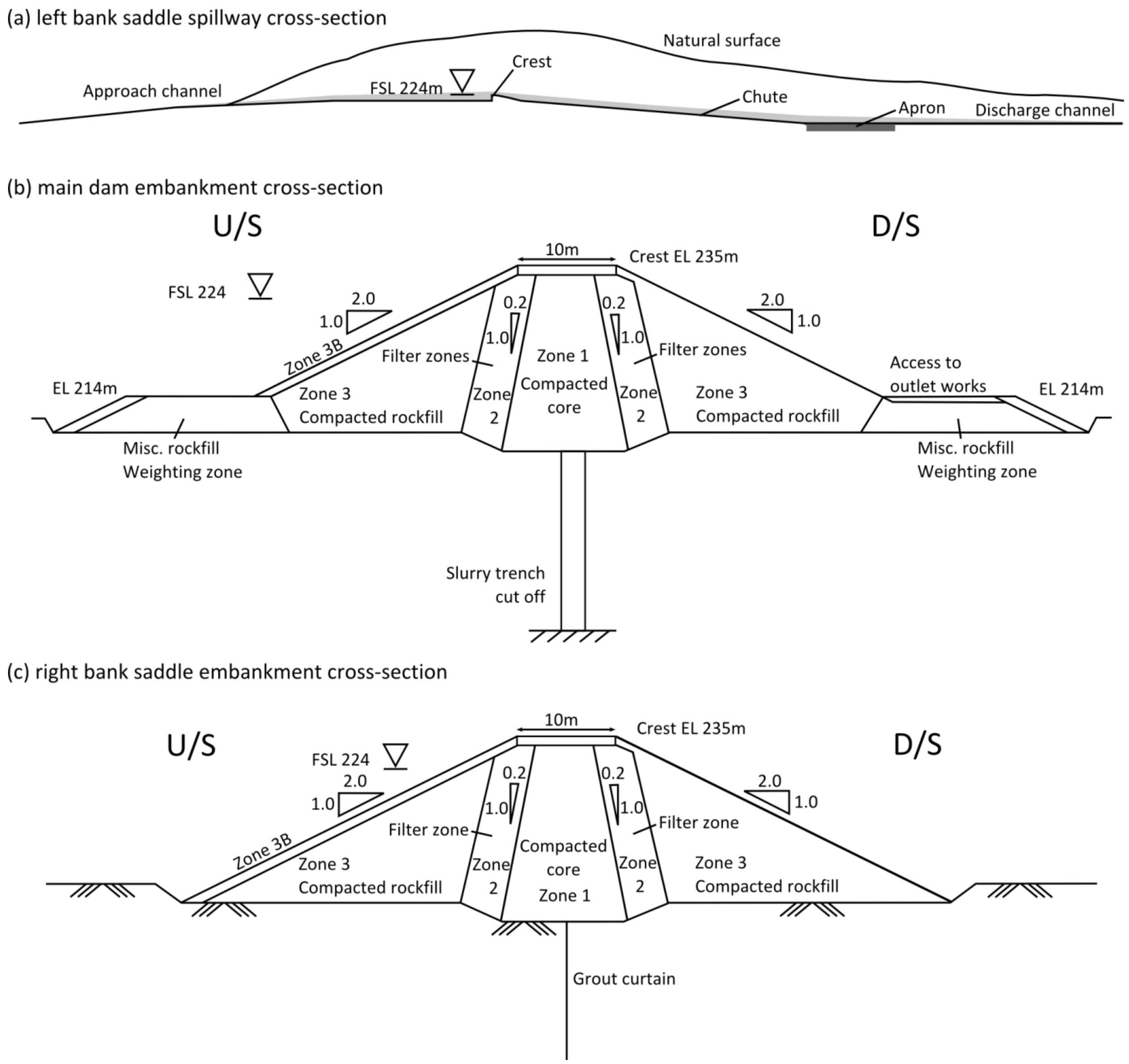


Figure 3.20 Proposed structural arrangement of Cave Hill dam

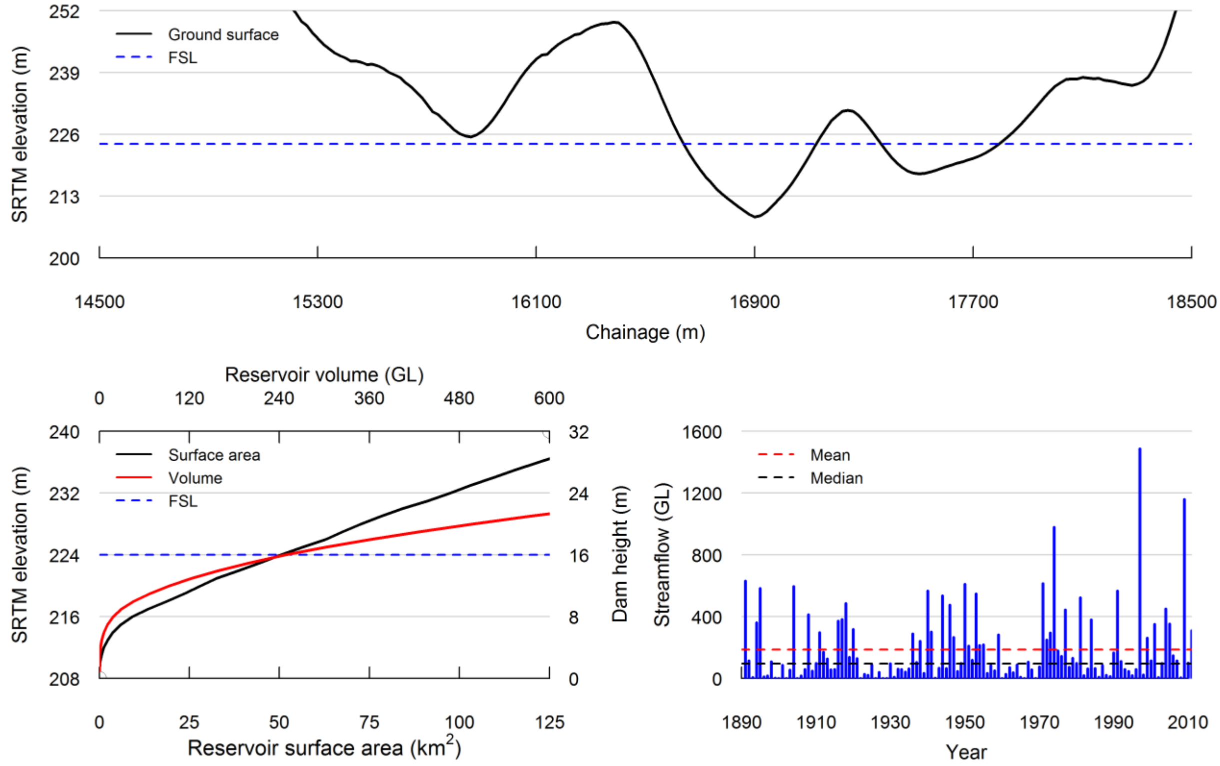


Figure 3.21 Cross-section along main dam axis, volume surface area height relationship and annual streamflow at Cave Hill dam site

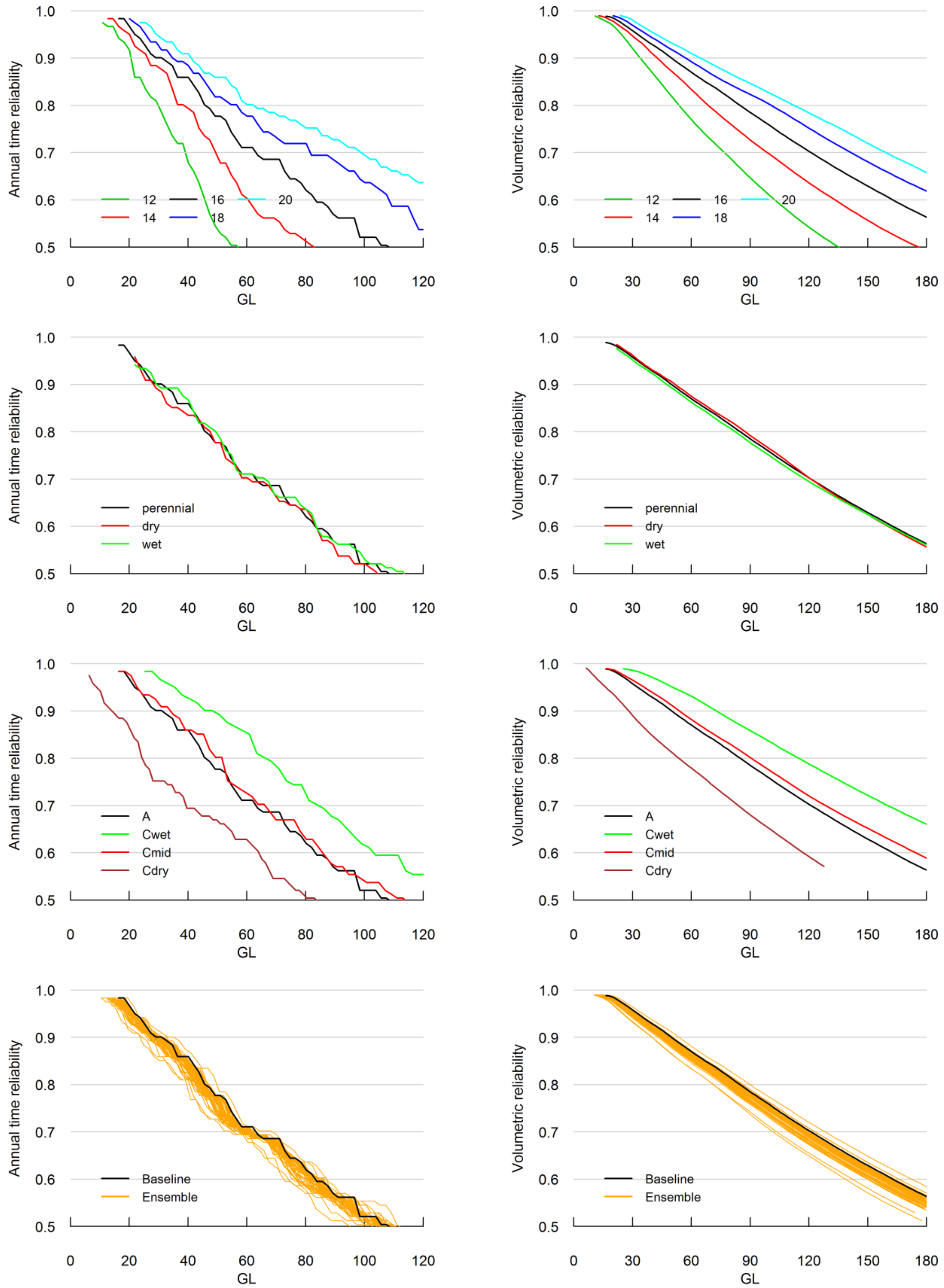


Figure 3.22 Cave Hill dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: Yield-reliability relationship (YRR) for different FSL. Second row: YRR for different demand patterns for 224 m FSL. Third row: YRR under Scenario C for 224 m FSL. Fourth row: YRR for baseline and ensemble model runs for 224 m FSL

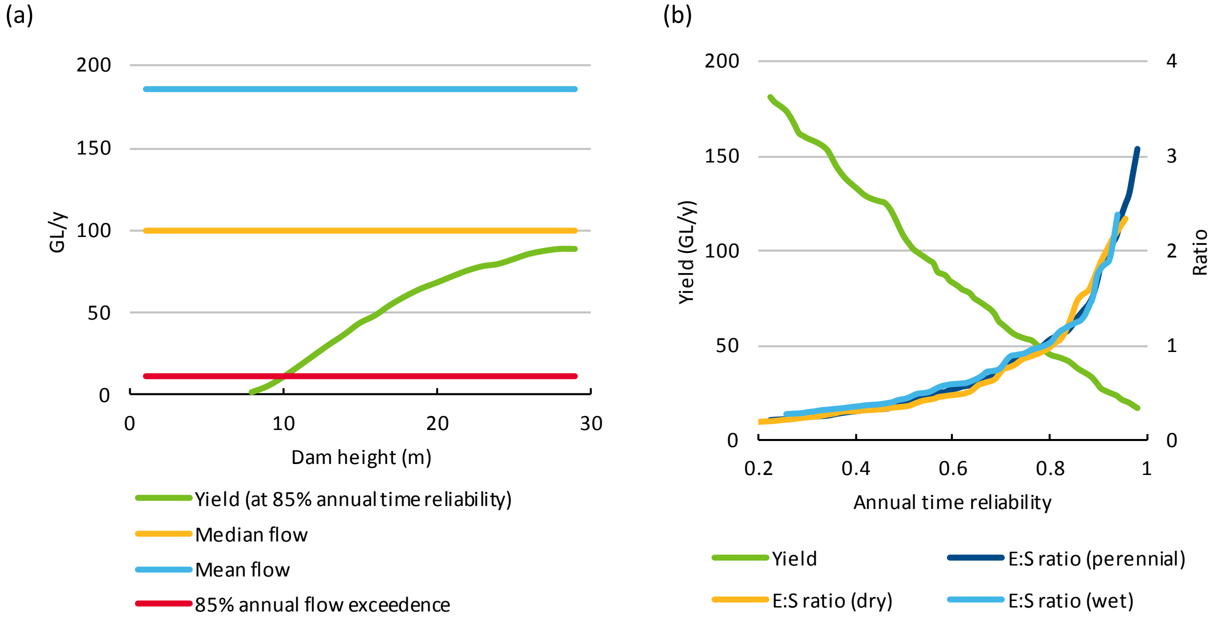


Figure 3.23 (a) Yield at 85% annual time reliability and streamflow at Cave Hill dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Cave Hill dam site for different annual time reliability for the selected dam height of 16 m

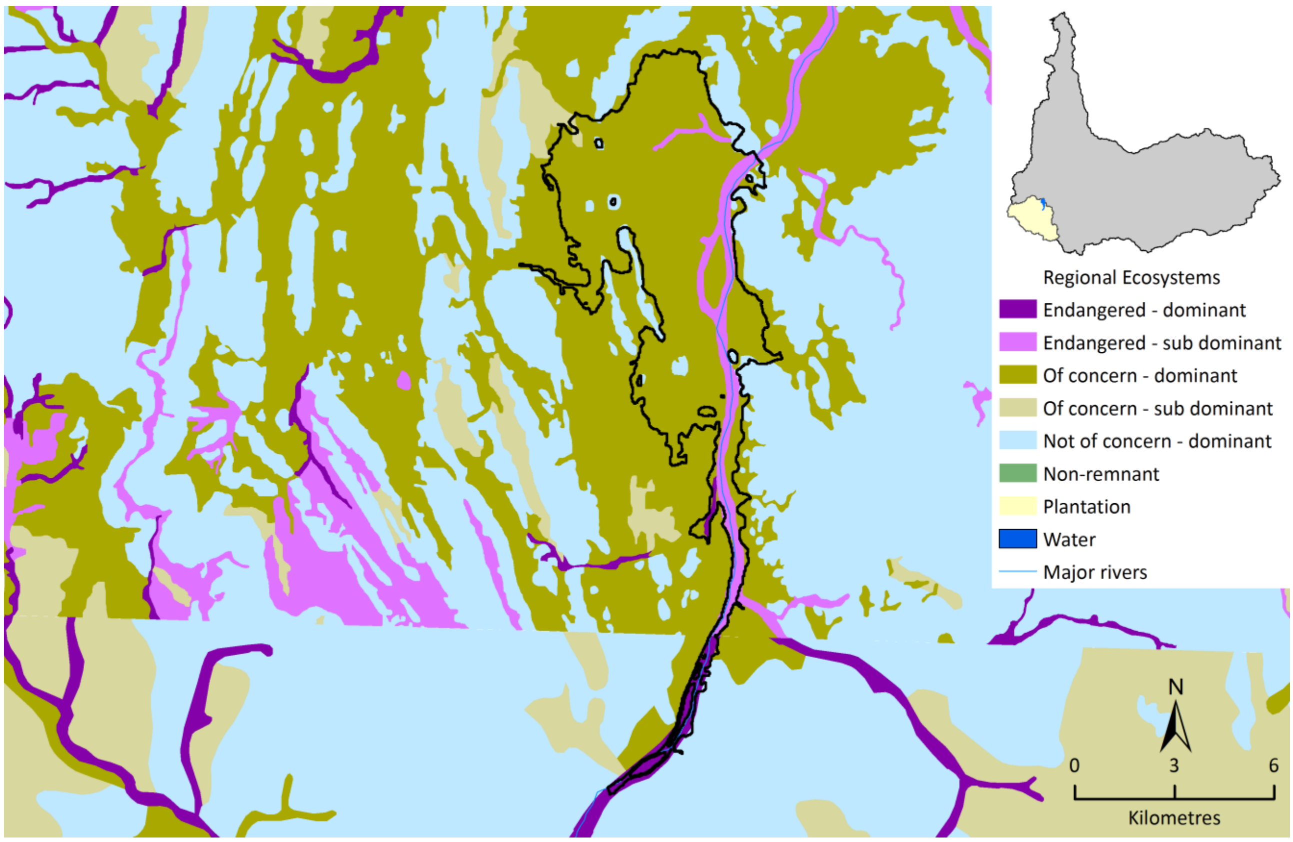


Figure 3.24 Regional ecosystems inundated by the Cave Hill dam reservoir at full supply level

3.4.2 O'CONNELL CREEK OFFSTREAM STORAGE OFF THE FLINDERS RIVER; 19.0 KM

PARAMETER	DESCRIPTION
Previous investigations	Maunsell McIntyre (1999) Flinders River Dam (AMTD 600 km) Pre-Feasibility Report. Maunsell McIntyre (2000) Flinders River Offstream Storage Scheme, Richmond, Pre- Feasibility Report. AECOM (2009) Flinders River offstream Storage Prefeasibility Scheme, AECOM, July 2009. DERM (2009) Review of the AECOM Report on the O'Connell Creek Off Stream Storage Proposal . SunWater (2009) O'Connell Creek Scheme –Notional Irrigation Layout Report.
Description of proposal	The interest in this proposal was primarily for irrigating land extending downstream from the dam on the southern side of the Flinders River. Investigation of the off stream storage (OSS) proposal near Richmond in the Flinders catchment was initiated after studies of the Flinders River (AMTD 600km) dam proposal (Maunsell McIntyre 1999) concluded that the dam would involve very high costs, uncertain foundation conditions and significant risks of sedimentation and increased flooding of the town of Richmond. The off stream storage scheme as originally proposed by consultants to the Richmond Shire Council (Maunsell McIntyre 2000) included a stepped steel sheet piling diversion weir on the river near the downstream outskirts of the town with an inflatable rubber dam on the crest, an open earth diversion channel excavated through the ridge separating the Flinders River from O'Connell Creek and an earth fill embankment creating a storage on O'Connell Creek. The proposed storage was to back up as far as the Great Northern railway bridge over O'Connell Creek. Supply was to be released from the storage to irrigate lands on the south bank of the river towards Maxwelton. A comprehensive review of the offstream storage proposal by the Department of Environment and Natural Resources (DERM 2009) concluded that the cost of the scheme was likely to be significantly higher than as estimated by Maunsell McIntyre (2000) and AECOM (2009). A photograph of the site is shown in Figure 3.25. A location map and map showing the inundated area at FSL are shown in Figure 3.26 and Figure 3.27 respectively.
Regional geology	The site marks the transition from floodplain alluvium associated with the Flinders River to residual clayey soils overlying sedimentary rocks of the Great Artesian Basin. These consist of mudstone, minor siltstone and fine sandstone of the Allaru Mudstone of Early Cretaceous age and platy limestone of the Toolebuc Formation. Figure 3.28 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams
Site geology	No detailed investigations have been carried out at the site. Based on investigations at the Flinders River dam site to the north of the O'Connell Creek offstream storage site and a site inspection, the right abutment is an alluvial terrace and the left abutment is residual clay overlying mudstone. The creek bed is likely to be similar to the left abutment. An airborne ground conductivity survey 4 km downstream of the site indicates a possible anticlinal structure and fault underlying the creek and left abutment. Future investigations should target this area to assess shear strength properties of the underlying rock. The terrace alluvium is likely to be variable consisting of firm to stiff clay and sandy or silty clay with lenses of dense clean sand in the upper 4-5 m and a deeper sand unit overlying rock.
Reservoir rim stability and leakage potential	Slopes on the reservoir rim are very gentle and stability of the reservoir rim is not an issue. The right abutment and right (north) side of the reservoir is an alluvial terrace consisting of clay containing lenses of sand. The leakage potential of the sand lenses into the adjoining Flinders River catchment would require investigation if this proposal is to be considered further. The leakage potential on the left (south) side of the reservoir is low.
Proposed structural arrangement	It should be noted that there has been no investigation of foundation conditions for the dam embankment or for the diversion weir or of ground conditions along the proposed route of the diversion channel. Geotechnical conditions have been inferred from the earlier investigations for the Flinders River dam proposal.

PARAMETER	DESCRIPTION
	For the purposes of this study, the structural arrangement of the works as now proposed is largely as detailed in the DERM (2009) review. The dam axis would be aligned and the embankment section as per Figure 3.29. The proposed structural arrangement of the potential Cave Hill dam is shown in Figure 3.30. **Diversion weir** The diversion weir would be comprised of a weir on the Flinders River near the downstream outskirts of Richmond with vertical lift gates mounted on a low concrete sill. A weir arrangement similar to the Boggabilla Weir on the Dumaresq River is now proposed to minimise sedimentation and flooding risks. The weir would be equipped with a vertical slot fish ladder. **Diversion Channel** An open trapezoidal channel with 150 cu m per s flow capacity (maximum design flow velocity 0.4 m/sec), providing for gravity diversion of river flows from the Flinders River to the O'Connell Creek storage area is now proposed. A channel bed width of 55 m is necessary to limit flow velocities as above. Significant provisions would be needed for drainage and maintenance of the channel berms and batters given the likely erodibility of the soils in the area. A flow control structure equipped with vertical gates would be located towards the Flinders River end of the channel with road access over the structure to provide access to the racecourse and aerodrome areas as well as a deck area to service the gates and hoists. **O'Connell Creek Off stream storage** A 4 km long earthfill embankment dam located some 17 km north west of Richmond with soil/cement or Toolebuc limestone protection of the upstream face. A slurry trench cut off would be used to control seepage in the more permeable zones of the foundation which are expected to be on the right abutment side nearer the Flinders River. O'Connell Creek flood inflows would be discharged via a concrete slab spillway constructed over the embankment. (Similar to the approach used at Chinchilla Weir and Six Mile Creek Dam) The discharge capacity of the spillway and embankment crest level above FSL as specified by the consultants has been assumed to be adequate for the purposes of this assessment. A conduit through the dam would provide for diversion of stream flows during construction and for releases to the irrigation area. Access to the embankment and storage area would be via a 2 lane gravel road branching from the Flinders Highway some 16 km west of Richmond. **Flood protection for infrastructure** Subject to detailed surveys and analysis of flood effects, works may be required to protect the racecourse /airport area and some length of the Great Northern Railway may need to be raised. Given that it has not been possible to examine this issue in detail as part of this study, the allowance made by the consultants adjusted for inflation has been used in this study. **Irrigation area** SunWater (2009) proposed an associated irrigation area, which was assumed to comprise 22 new farm areas totalling 6,600 ha requiring the development of approximately 70km channels, 33 km of drains and some 20 km of service roads. This proposal is subject to there being sufficient supply available supply from the storage.
Availability of construction materials	No investigations for materials have been carried out. However, based on a consideration of the regional geology, earthfill materials are likely to be available in the immediate area. Deposits of silty sand occur at the junction of Stawell River and Alexander Creek about 10 km west of the site. Basalt is available from a deposit about 25 km east of Richmond. Platy limestone and calcareous shale, which have been used as road base, may be available from outcrop of Toolebuc Formation to the north of Flinders River. These materials may be suitable for erosion protection including for wave protection on the O'Connell Creek embankment.
Catchment areas	The catchment area of the Flinders River above the diversion weir site is about 18,600 km^2

<table>
<tr><th>PARAMETER</th><th>DESCRIPTION</th></tr>
<tr><td></td><td>Catchment area of the O’Connell Creek above the dam site is 1,507 km^2</td></tr>
<tr><td>Flow data</td><td>Flinders River: Flows have been recorded at Richmond G.S. 915008A from 1971 to date. Summary flow data over this period is as follows;
Maximum annual flow: 3,167,000 ML
Mean annual flow: 442,000 ML
Median annual flow: 228,000 ML
Minimum annual flow: 0 ML
O’Connell Creek
Based on catchment areas, O’Connell Creek flows at the dam site were assumed by AECOM (2009) to be 7% of the flow in the Flinders River.</td></tr>
<tr><td>Storage capacity</td><td>127 GL at FSL 201 m (Figure 3.31).
This is considerably lower than the estimates made by AECOM (2009) who estimated the storage capacity of the O’Connell Creek OSS at FSL 199 mAHD and 200 mAHD to be 166,000 ML and 192,000 ML respectively. The AECOM (2009) volume computations were based on 4 cross-sectional surveys over the 10 km of the storage. DEM-H data correspond very closely to the surveyed cross-sections reported by AECOM (2009), hence the AECOM (2009) volume estimates are considered to be too large.</td></tr>
<tr><td>Reservoir yield assessment</td><td>34 GL at 85% annual time reliability (Figure 3.32 and Figure 3.33).
32 GL at 95% monthly time reliability.
Note these yield estimates do not assume a threshold flow requirement at the diversion weir nor do they take into consideration the hydraulic connection between the river and the OSS. The only constraint imposed on the diversion of water from the Flinders River was a maximum design flow velocity constraint in the diversion channel.
It should be noted, however, that supply from the OSS is sensitive to threshold flow requirements at the diversion weir prior to diversion to the OSS and to the reliability of supply. These yield estimate are also sensitive to the relative water levels in the river and the OSS. A preliminary analysis taking into consideration the hydraulic connection between the river and the OSS indicated water yields may be as low as 14 GL in 85% of years. However, higher resolution elevation data and site specific stage height to discharge relationships would be required to make an accurate assessment.
Evaporation as percentage of regulated flow (at 85% annual time reliability): 51%
Ratio of evaporation to water supplied (at 85% annual time reliability): 1.1.
Previous yield estimates
Whilst earlier estimates by AECOM indicated yields in the range 50-55 GL/yr the following yields at 85% annual reliability were as assessed by DERM in 2009.
<table>
<tr><th rowspan="2">Threshold flow
(ML/day)</th><th colspan="2">Yield at 85% reliability
(ML/a)</th></tr>
<tr><th>FSL 199 m</th><th>FSL 200 m</th></tr>
<tr><td>117</td><td>27,000</td><td>34,000</td></tr>
<tr><td>1,296</td><td>23,500</td><td>29,000</td></tr>
<tr><td>2,592</td><td>21,500</td><td>24,000</td></tr>
</table></td></tr>
<tr><td>Open water evaporation</td><td>Mean annual evaporation was estimated to be 4.5 mm d^{-1} using a bulk aerodynamic approach. Mean annual evaporation was estimated to be 5.1 mm d^{-1} using Morton’s APE.</td></tr>
<tr><td>Impacts of inundation to existing infrastructure</td><td>AECOM (2009) noted that for the higher FSL particularly, the racecourse and the aerodrome would be subject to flood effects and that more than 1 km length of the Flinders Highway would need to be raised, and possibly, the railway.</td></tr>
<tr><td>Ecological and cultural considerations raised by previous studies</td><td>Issues identified by AECOM (2009) were;
Inundation of vegetation/habitat, particularly the riparian corridor near Richmond,
Possible weed invasion around the periphery of a shallow reservoir during periods of reservoir drawdown,</td></tr>
</table>

<table>
<tr><th>PARAMETER</th><th colspan="4">DESCRIPTION</th></tr>
<tr><td></td><td colspan="4">The need for fish passage at the diversion weir,
Creation of a mosquito habitat and public health risks,
Impacts of extensive agricultural development.
A need for further cultural heritage, indigenous and European, and archaeology surveys was noted.</td></tr>
<tr><td rowspan="4">Estimated rates of reservoir sedimentation</td><td></td><td>Best case</td><td>Expected</td><td>Worst case</td></tr>
<tr><td>30 years (%)</td><td>0.29</td><td>1.83</td><td>4.05</td></tr>
<tr><td>100 years (%)</td><td>0.95</td><td>6.11</td><td>13.50</td></tr>
<tr><td>Years to infill</td><td>10523</td><td>1637</td><td>741</td></tr>
<tr><td>Water quality and stratification considerations</td><td colspan="4">Not assessed.</td></tr>
<tr><td>Environmental considerations</td><td colspan="4">No site-specific data on fish are available from this site but many of the issues are the same as for the nearby Richmond Dam Site visited by Tait (1998a). The O’Connell Creek OSS would create a fish passage barrier on both the Flinders River and O’Connell Creek. These barriers would be within the known range of barramundi and the predicted range of freshwater sawfish, albeit close to their upstream limits.

The area that would be inundated by a potential dam at O’Connell Creek covers a large area of regional vegetation communities that are likely to be “Of Concern” (Figure 3.34).

<u>Ecosystems Of Concern</u>

This site is likely to include Eucalyptus coolabah as a distinct but discontinuous upper canopy layer. E. camaldulensis is conspicuous over sandy or gravelly channels. A lower tree understorey or tall shrub layer may be present in places. The ground layer is variable, composed of grasses and forbs with either predominating, depending on seasonal conditions. Asteraceae spp. particularly abundant following favourable seasons.</td></tr>
<tr><td>Indigenous cultural heritage considerations</td><td colspan="4">At the time of the Assessment there was no Indigenous Cultural Heritage body for the general area. There is one Indigenous Party:
Wanamara People Core Country Claim (QC06/18 PRC - QU460/06)
There are no sites listed in the DATSIMA database.

Previous archaeological investigation of the immediate area has previously been undertaken, and may have extended into the vicinity of the OSS. The results of this work and of investigations in the catchment more generally indicate that the area is likely to have high archaeological potential.

In the late 1990s, an archaeological survey was undertaken of sections of Flinders River and O'Connell Creek, in the vicinity of Richmond (Crothers 1997). As a result of this work, 245 archaeological sites were recorded, the majority being within 200-400 m of permanent or seasonal surface water. The sites are thought to represent camping places, and evidence includes hearths, charcoal, shell and stone artefacts.

A potential dam on the Flinders River, adjacent to the O'Connell OSS, was assessed by Northern Archaeology Consultancies in May 1998. The report describes the area a being rich in Indigenous archaeological resources. A large number of sites have been recorded along the Flinders River and O'Connell Creek, and it was considered that a systematic archaeological survey would result in the recording of many more sites. The following observations and predictions were made:
The highest densities of archaeological sites are likely to be located close to major and relatively permanents sources of water.
A previous study indicated that site density was as high as four sites per 100 m in the riverine zone.
Elevated terrain, raised ridges, high creek banks above the reach of flood levels is likely to contain intact sites.
Most commonly occurring sites are likely to be low-density stone artefact scatters and associated hearth features.
Base camps and small sites representing ephemeral occupation may exist.
Conditions for archaeological site preservation are poor in flood prone parts of the catchment, with a low likelihood of site preservation on the coastal floodplains of the</td></tr>
</table>

PARAMETER	DESCRIPTION
	Flinders River and nearby watercourses. Further investigation, including archaeological survey, would be required to assess the potential Indigenous archaeological impact of works. Any such investigation should be undertaken in consultation with the Indigenous Party. Should works proceed in this area, it is recommended that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding contemporary use of water sources in the case study area.
Estimated cost	The capital cost of the O'Connell Creek OSS including the diversion weir and channel was estimated to be approximately $229 million (with a likely range of $200 m to $300 m). Previously AECOM (2009) and DERM (2009) estimated the cost of the storage scheme to be $117.5m and $239.2m respectively. Based on the 2009 estimate by SunWater (2009) and allowing for cost escalation to 2013, the capital cost of the 7,000 ha irrigation area development was estimated to be about $110 million. Annual operating costs for the O'Connell Creek OSS scheme are likely to be high compared with many other water storage developments given the exposure of a gated diversion weir to long periods of flood flows in the Flinders River, the need to closely control operation of the diversion weir and diversion channel control gates and the likely high erodibility of the berm and batter slopes along the diversion channel and in any irrigation area. Annual operating costs are likely to be of the order of $2.30 million for the off stream storage scheme and a further $1.1 million for the irrigation area.
Estimated cost / ML of supply	$6760/ML of water supplied at the dam wall in 85% of years (does not include transmission/distribution losses or take into account environmental and downstream entitlements). <u>Previous studies</u> At 2011 prices and assuming that a threshold flow of 1,296 ML/day was required, DERM (2009) estimated the cost of water supply at the dam wall at 85% reliability to be be as follows: FSL 199 m $10,255/ML (note the AECOM and DERM FSL have a different datum to those used in the Assessment, which utilised the SRTM). FSL 200 m $ 8,785/ML Including the cost of the irrigation area development, the cost of supply would be as follows; FSL 199 m $14,760/ML FSL 200 m $12,400/ML.
Potential benefit/cost	AECOM (2009) concluded that based on their dam costs and water yields and estimated gross margins for high value crops, the O'Connell Creek OSS scheme warranted further investigation. Substituting the AECOM (2009) dam costs and water yields for those estimated by DERM (2009) or the Assessment, would have a major impact on the profitability of the scheme.
Summary comment	Apart from the water yield assessments, investigations to date been based on minimal information. For example, there has been no subsurface investigations along the diversion channel route or of the OSS embankment foundations. The schedules of quantities and estimates of cost provided by the Assessment therefore involve significant uncertainties.

Figure 3.25 A depiction of the O'Connell Creek offstream storage site looking upstream

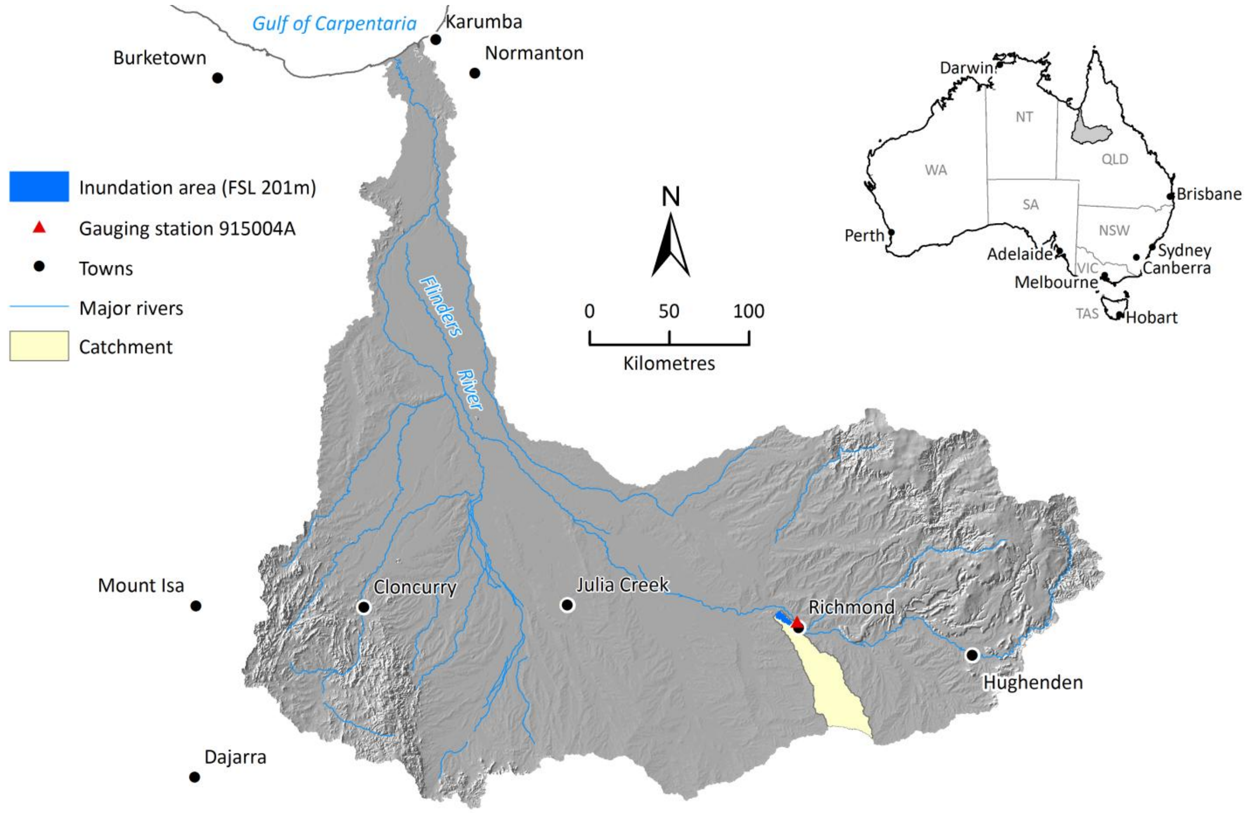


Figure 3.26 Location map of potential O'Connell Creek offstream, reservoir and catchment area

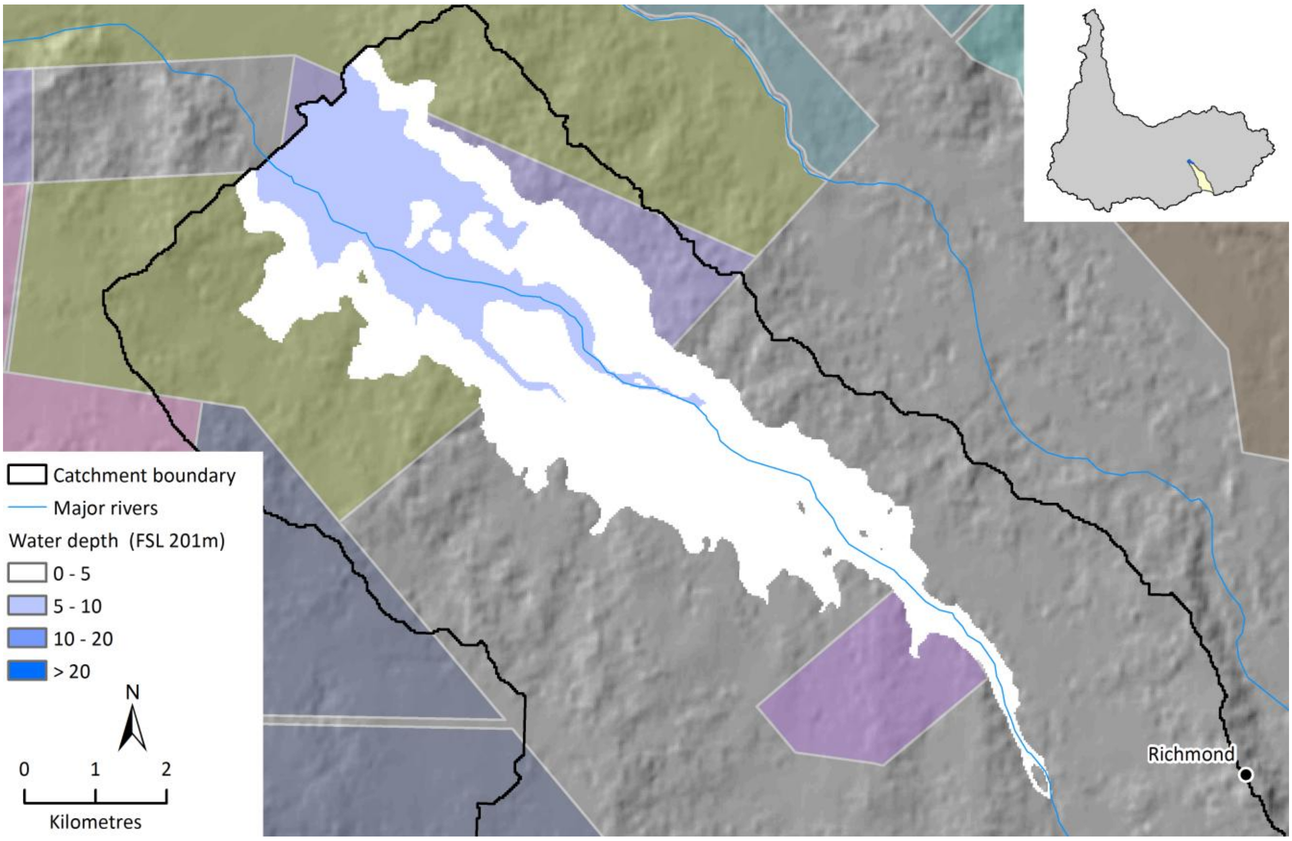


Figure 3.27 Potential O'Connell Creek offstream storage depth of inundation and property boundaries (indicated by coloured shading)

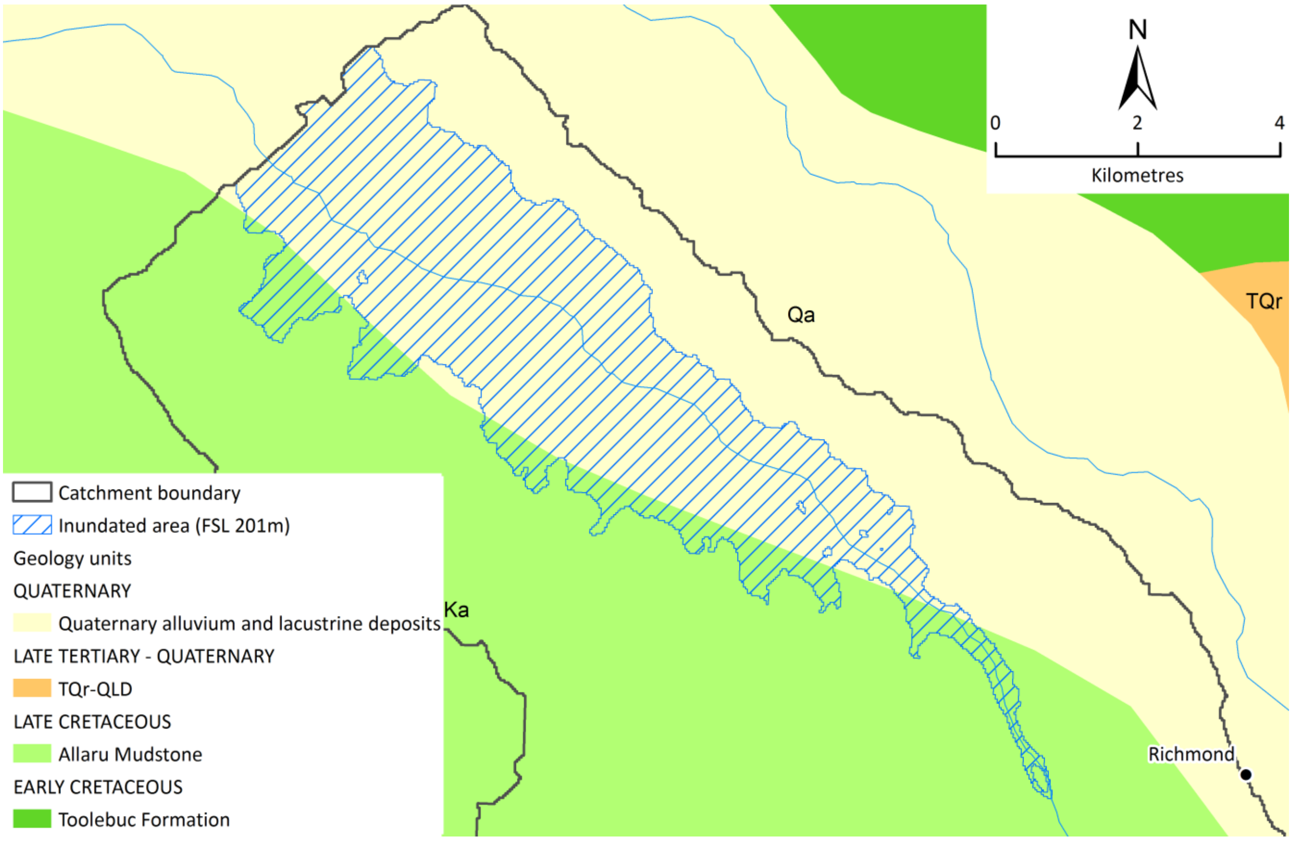


Figure 3.28 Potential O'Connell Creek offstream storage underlying geology

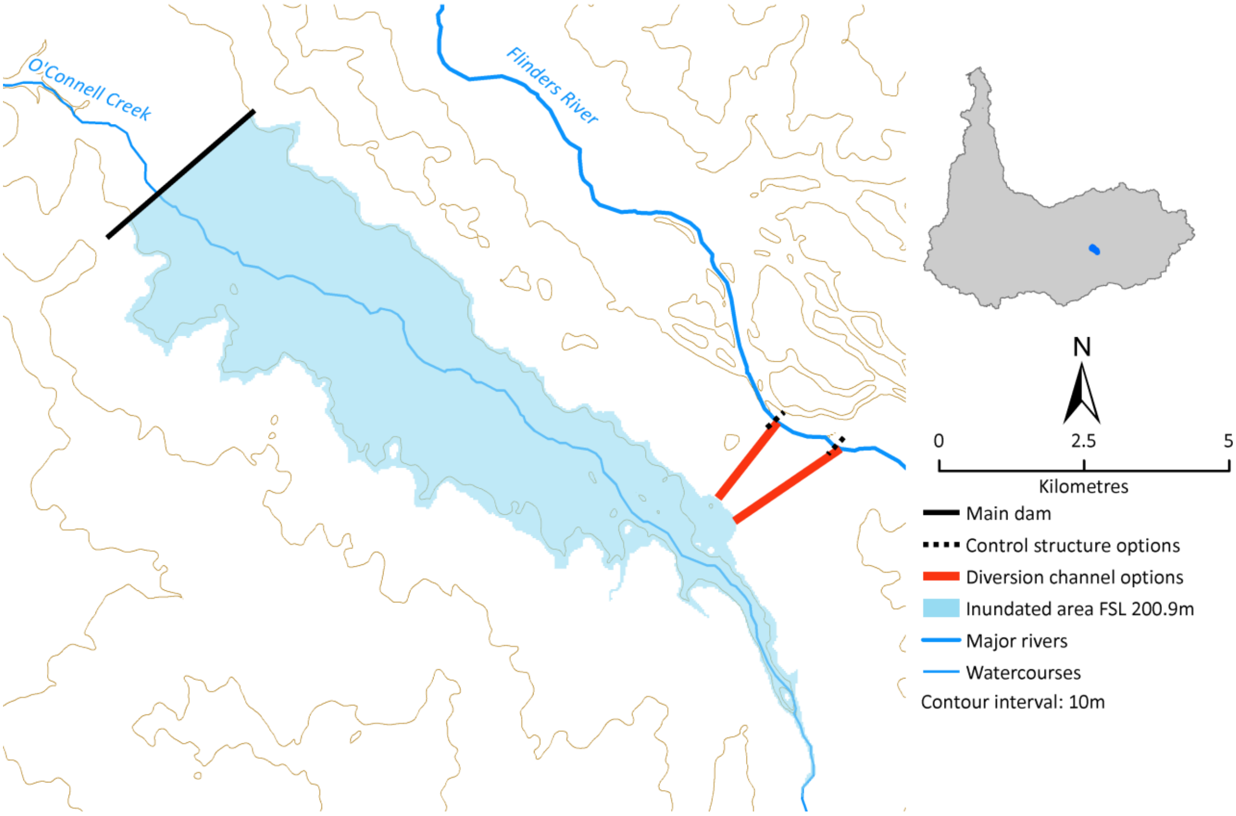


Figure 3.29 Proposed structural arrangement map for the potential O'Connell Creek offstream storage

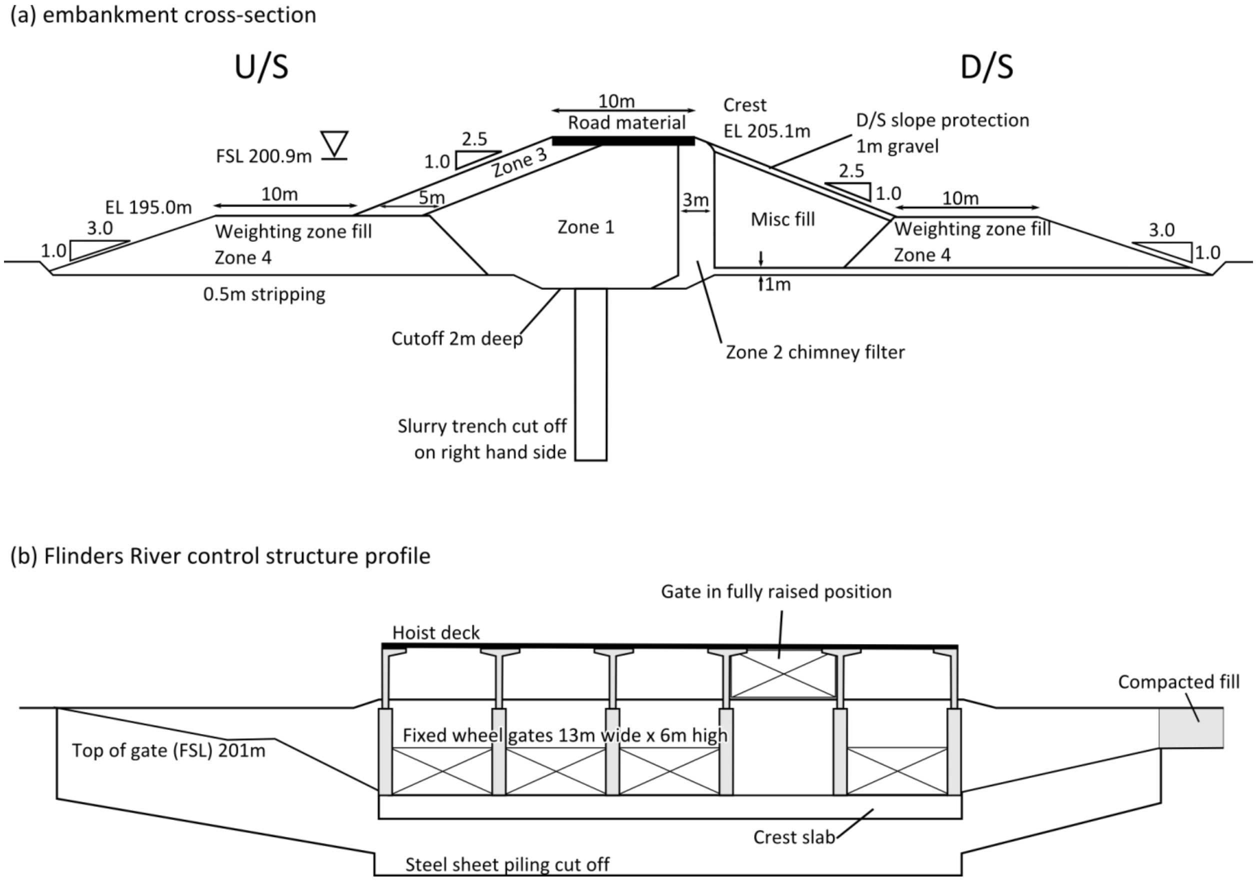


Figure 3.30 Proposed structural arrangement diagrams for the potential O'Connell Creek offstream storage

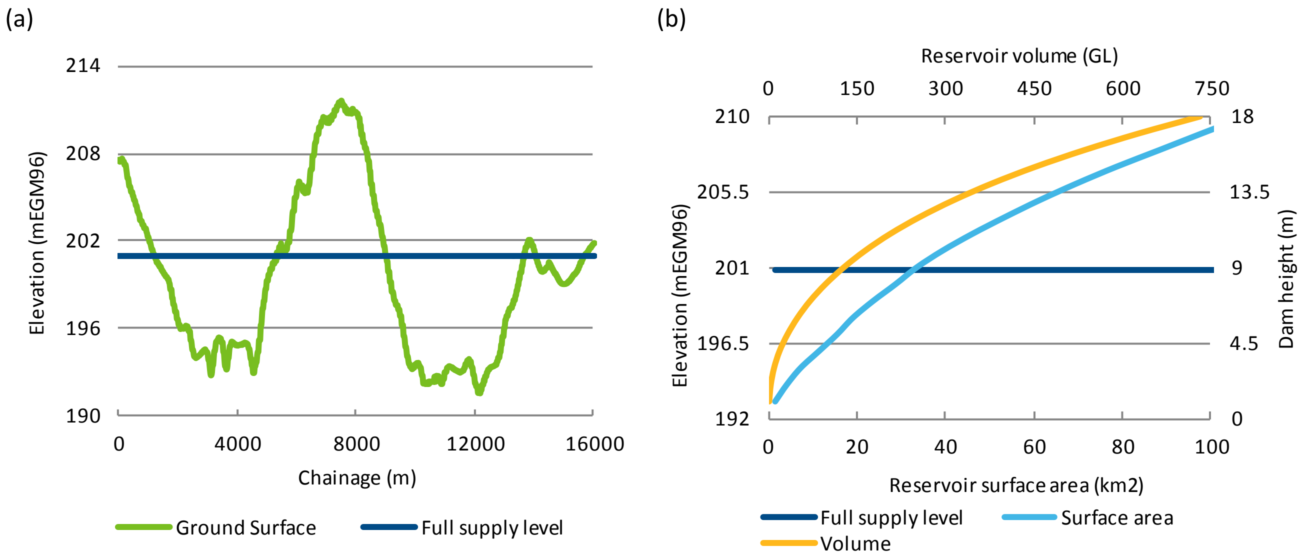


Figure 3.31 Dam cross-section, height, volume and reservoir surface area for O'Connell Creek offstream storage
(a) Cross-section of ground surface along dam axis. (b) Relationship between dam height, reservoir volume and reservoir surface area.

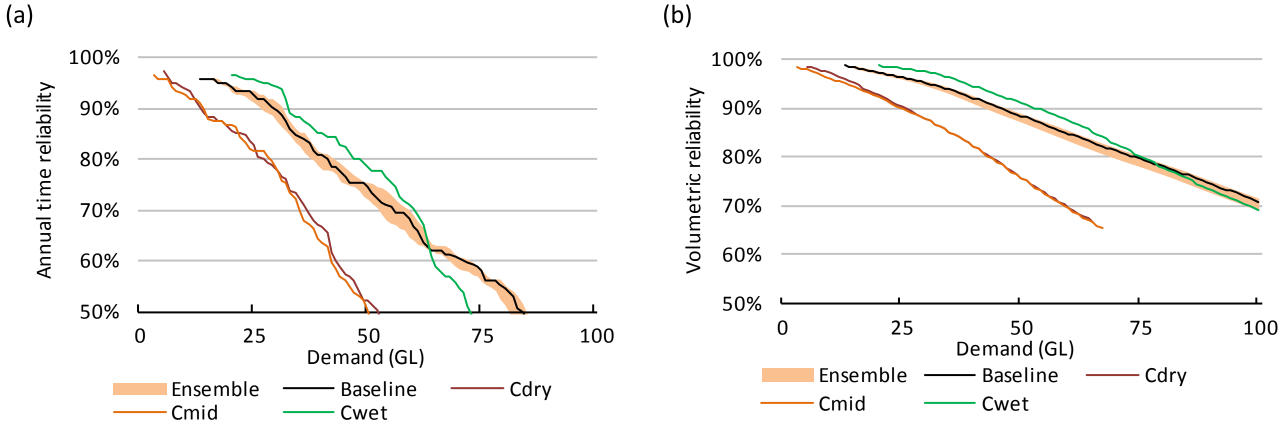


Figure 3.32 Annual time and volumetric reliability for O'Connell Creek offstream storage under scenarios A and C
(a) Annual time reliability. (b) Volumetric reliability. The baseline (i.e. original) model under Scenario A is shown by the black line. The wet future climate (Cwet), mid future climate (Cmid) and dry future climate (Cdry) yield estimates were generated using the baseline model and future climate data. The orange shading indicates the 95% range of the 50 model ensembles under Scenario A. Yields are at the dam wall (i.e. they do not account for distribution losses).

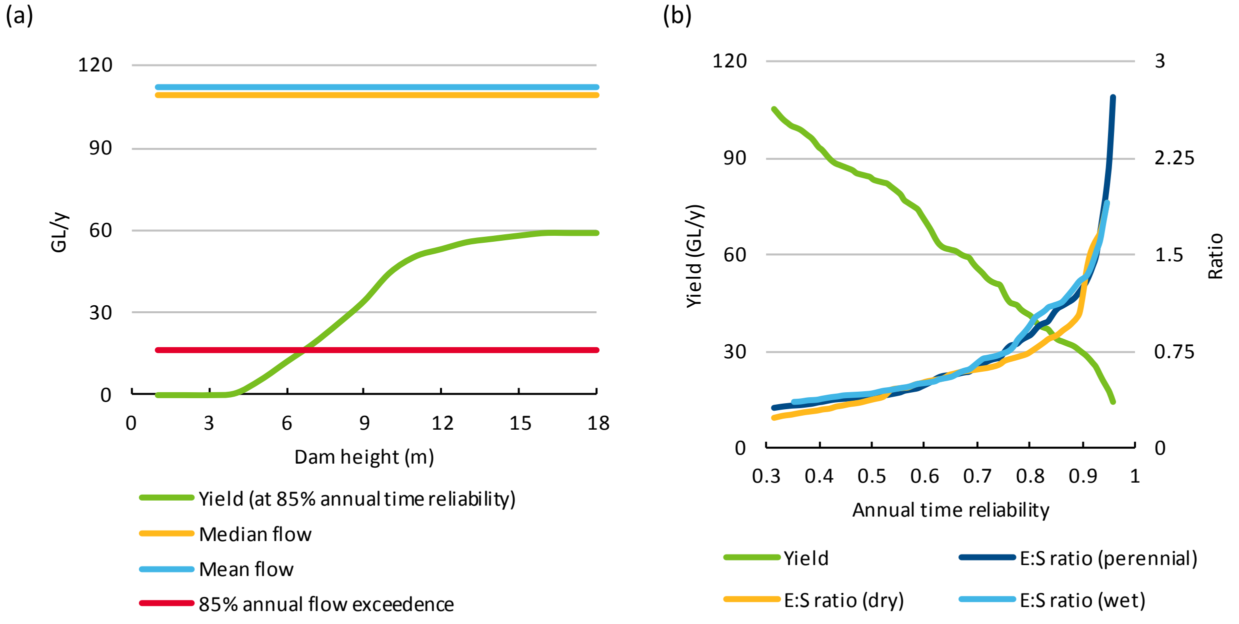


Figure 3.33 (a) Yield at 85% annual time reliability and streamflow at O'Connell Creek offstream storage for different dam heights; (b) Yield and evaporation : water supply ratio at O'Connell Creek offstream storage for different annual time reliability for the selected dam height of 9 m (i.e. FSL 201 m mEGM96)

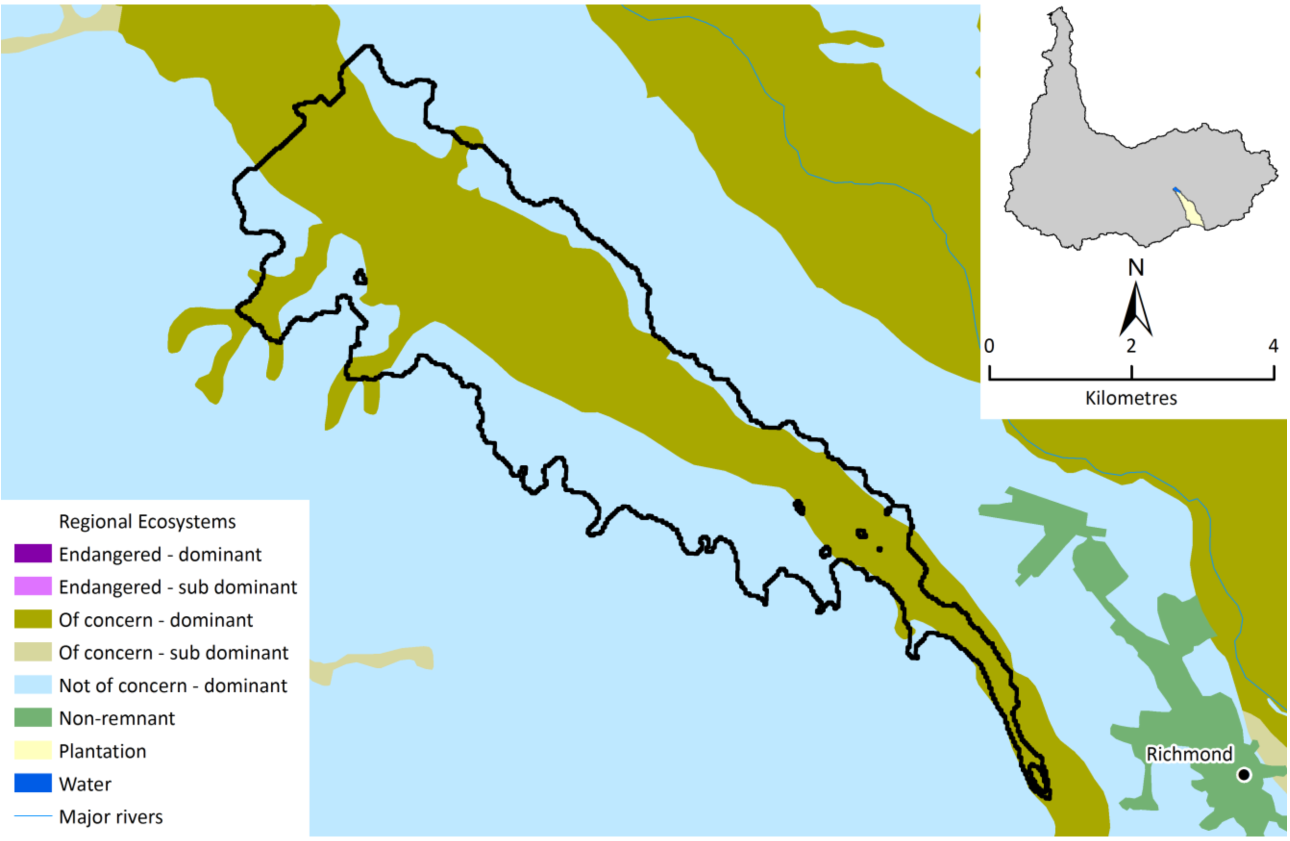


Figure 3.34 Potential O'Connell Creek dam regional ecosystems mapping

3.4.3 PORCUPINE CREEK DAM SITE ON PORCUPINE CREEK; 74.8 KM

PARAMETER	DESCRIPTION
Previous investigations	DPI (1983). Upper Flinders River Irrigation Proposal (soils). QWRC (1990) Appraisal Report on Potential for Irrigated Cotton production – Hughenden Area, Betts Gorge Creek 18.1 km dam site, Flinders River 856 km site, Porcupine Creek 69 km dam site.
Description of proposal	The Porcupine Creek dam site at AMTD 74.8 km (previously 69km) and about 44km north east of Hughenden was one of the three storage proposals in the area investigated by the Queensland Water Resources Commission in the 1980s. For each proposal it was intended to provide supply for irrigated cotton production on lands adjacent to each of the storages. Capacity to irrigate a total area of 10,000 ha was sought to support development of a cotton gin in the area. An area of 2,000 ha on the right bank adjacent to the dam was nominated as the land to be irrigated. Although there was no specific soils assessment of this area, DPI (1990) concluded, based on soils data collected for the Glendower proposal, that the majority of this land may have severe limitations and be unsuitable for irrigation. Water was assumed to be distributed to the irrigation area via a pump station, 6 km long rising main and an open channel distribution system. Based on the soil suitability assessment undertaken by DPI (1990) significant areas of potentially suitable soil were identified some 25km downstream on the left bank between 'Koonkool' and 'Glentor Downs'. A small regulating weir would be needed to minimise transmission losses. Pumping costs to these lands would be substantially less than for the right bank area near the dam site. A photograph of the site is shown in Figure 3.35. A location map and map showing the inundated area at FSL are shown Figure 3.36 and Figure 3.37 respectively.
Regional geology	In this area Porcupine Creek has eroded a gorge through a basalt plateau and into the underlying sedimentary rocks of the Great Artesian Basin. These include the mudstones of the Rolling Downs Group and the sandstones of the Gilbert River Formation and Blantyre Beds. The sandstones of the Blantyre beds are quartzose, porous and permeable. They are important aquifers for groundwater bores to the south of Hughenden. The Gilbert River Formation is composed mostly of clayey quartzose sandstone. The basalt plateau is part of the Sturgeon Basalt Province. The basalt originally flowed down broad shallow valleys. New drainage systems were then established leading to inversion of relief with the former valley filling basalt now occupying areas of higher relief. The contact between the basalt and underlying sedimentary rocks is frequently marked by a layer of gravel deposited in the former stream valleys down which the basalt flowed. Figure 3.38 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	No site investigations have been carried out. Based on a brief site inspection during the Assessment, sandstone of the Gilbert River Formation and Blantyre beds form the cliffs and river bed. The river bed is about 100 m wide and sand covered. The right abutment rises steeply from the river over sandstone outcrop, flattens to a bench then rises steeply again over basalt outcrop. The contact between the basalt and sandstone is marked by a gravel layer at least 1 m thick at a level of about 404 m. The overlying basalt is about 10 m thick. The left abutment is flatter with sandstone outcrop and an intermediate flatter bench.
Reservoir rim stability and leakage potential	The major issue for both stability and reservoir leakage is the unconformity between the Gilbert River Formation and the basalt. As mentioned above, the unconformity is marked by a layer of gravel representing fluvial deposits in an ancient river valley. The unconformity is below the full supply level of the dam so seepage will occur when the dam is full. The nature of the fines in the gravel should be investigated if this proposal is to be considered further to determine whether they are susceptible to piping and hence instability. The Blantyre Sandstone is an important aquifer in the GAB and should also be investigated for seepage losses if this proposal is to be considered further.

PARAMETER	DESCRIPTION
Proposed structural arrangement	A roller compacted concrete (RCC) type dam with a central overflow crest level 35 m (FSL 411) above bed level with RCC abutments extending to the top of the bank was proposed in the earlier investigations. A short earth embankment saddle dam is required on the right bank to contain flood rises in the storage. The dam axis would be aligned as shown in Figure 3.39. The proposed structural arrangement of the potential Porcupine Creek dam is shown in Figure 3.40. A RCC type dam is still considered to be the most suitable dam type for this site. The spillway capacity as assessed by QWRC (1990) was considered adequate for the purposes of the Assessment and therefore the flood inflow hydrology was not reviewed. Outlet works with selective withdrawal provisions would be located on the right bank to enable releases to the stream for extraction in the Koonkool area where a regulating weir would be required to minimise transmission losses. Seepage and uplift pressures would be controlled by a foundation cement grout curtain and by drains in the foundation and dam wall connecting to a gallery. It is proposed that potential seepage and piping through a right bank gravel layer would be controlled by a concrete slab anchored to the abutment extending upstream blanketing the gravel layer or by other suitable treatment. If further investigations were to conclude that clay material in the layer were dispersive, additional treatment such as a downstream filter blanket would be necessary. No provision for fish passage has been made in the proposed arrangement. Access to the site would be via the existing bitumen road from Hughenden which provides access to the Porcupine Gorge National Park area (i.e. the Kennedy Develoment Road), and seen in Figure 3.35.
Availability of construction materials	No investigations for construction materials have been carried out. Aggregate for the proposed RCC dam could be obtained from the basalt cap forming the plateau surface or from the Blantyre Sandstone and Gilbert River Formation. Sand from the riverbed could be used to supplement the basalt aggregate.
Catchment areas	The catchment area at the site is 1051 km^2.
Flow data	Flow data is available from G.S. 915011A – Porcupine Creek at AMTD 122.3 km, catchment area 540 km^2 (approximately 50% of that at the dam site). Flow data is available from September 1971 to date. Maximum recorded annual flow was 137,000 ML Mean annual flow 26,200 ML Median annual flow 16,000 ML Minimum annual flow 164 ML
Storage capacity	31 GL at FSL 411 m (Figure 3.41)
Reservoir yield assessment	11 GL at 85% annual time reliability (Figure 3.43 and Figure 3.42). 10 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 20% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.3
Open water evaporation	Mean annual evaporation is estimated to be 4.9 mm d^{-1} using the bulk aerodynamic formulae. Mean annual evaporation was estimated to be 5.0 mm d^{-1} using Morton's APE.
Impacts of inundation to existing infrastructure	No existing infrastructure has been identified in the inundated area.
Ecological and cultural considerations raised by previous studies	No previous assessments have been identified.

Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)	0.82	6.43	11.62
	100 years (%)	2.73	21.43	38.75

PARAMETER	DESCRIPTION
	Years to infill 3666 467 258
Water quality and stratification considerations	Porcupine Creek reservoir is predicted to be strongly stratified with a single winter deep mixing event each year and a characteristic temperature difference of 7 - 10 °C. The risk of blue-green algal blooms is high with Zsl:Zeu between 1 and 2 from September through April. The very long duration of stratification and weak mixing behaviour suggests this storage is highly susceptible to anoxic conditions and associated water quality issues. Summer inflows may resupplying oxygen near the bottom and may reduce the severity of oxygen depletion and associated metal and nutrient release from the sediments.
Environmental considerations	The storage would extend into the downstream section of the Porcupine Gorge National Park but would not be seen from the park lookout area upstream. Limited specific data on fish were available from this site. The potential dam location is above the distribution of all but a few fish species, all of which breed within freshwater. Hogan and Vallance (2005) surveyed a waterhole in Porcupine Creek on Mt Emu Plains station, upstream of the dam site and found six fish species, all widespread and common species that breed in freshwater. The potential dam has a relatively small catchment area. The values of the aquatic habitat upstream of the proposed dam wall site are not known. If this dam is stocked with recreational fish species such as barramundi, this would greatly extend their distribution within the Flinders catchment. Any unauthorised stockings may also result in those fish species entering downstream reaches of a national park. The site covers regional vegetation communities that are likely to be "Of Concern". This site is also near to the Porcupine Gorge National Park which is listed on the Register of National Estate (Figure 3.44). *Ecosystems Of Concern* Although the area classified 'Of Concern' ecosystem is relatively small, it is likely to include *Fringing woodland* to open-forest of *Eucalyptus camaldulensis*, *E. tereticornis*, *Melaleuca fluviatilis*, *M. leucadendra*, *Casuarina cunninghamiana*, *Corymbia tessellaris*. It is also likely to include a distinct sub-canopy of *Ficus spp*., *Lophostemon spp.* and *Pleiogynium timorense* as well as juvenile canopy species. A shrub layer varies from none to mid-dense *Ficus opposite*, *Melaleuca spp*. and *Acacia crassicarpa*.
Indigenous cultural heritage considerations	The Indigenous Cultural Heritage Body for the area is Yirendali Operations Pty Limited. There are four sites listed in the DATSIMA database: EJ:A16 – Engraving EJ:A17 – Painting EJ:A18 – Engraving EJ:B10 - Engraving No previous archaeological reporting relating specifically to the Porcupine Creek have been located. However, the existence of listed sites indicates that some investigation has been undertaken. Results of investigations in the Flinders catchment more generally indicate that the area is likely to have high archaeological potential. In a site visit the Assessment geologist and water infrastructure planner identified some rock art on the right abutment at the proposed dam site. The investigation of the North Queensland Highlands undertaken by Morwood and others in the 1980s and early 1990s (e.g. Morwood 1990, 1992; Morwood & Godwin 1982) included intensive investigation of the junction of Porcupine and Prairie Creeks, and Prairie Gorge, to the south and east of the Porcupine case study area. The evidence suggested that this area had been occupied from c. 3,400 BP through to the post-contact period. It appears that occupation was focussed on water sources, and that this area was used as a base for the exploitation of the range of environments in the locality. Further investigation, including archaeological survey, would be required to assess the potential Indigenous archaeological impact of works in the area. Any such investigation should be undertaken in consultation with the Indigenous Cultural Heritage Body. Should works proceed in this area, it is recommended that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding

PARAMETER	DESCRIPTION
	contemporary use of water sources in the case study area.
Estimated cost	The capital cost of the dam is estimated to be about $179 million (with a likely range of between $160 m to $230 m). Additional costs would be involved if a downstream regulating weir was required. It should be noted that no provision has been made for a fish transfer facility at the dam because of the high costs involved, the small section of stream impacted upon by the dam and storage and the few fish species, all of which are common and breed in freshwater. Rather, an allowance has been included for other fish management strategies such as trap and transfer operations and for fish habitat improvements in the storage area. Annual operating and maintenance costs for the dam should be relatively low given the type of dam proposed and good access to Hughenden. An allowance of 0.5% of capital cost, that is $900,000 pa, should provide for annual costs as well as intermittent refurbishment and dam safety costs. <u>Previous studies</u> QWRC (1990) estimated the dam and distribution works to cost $44m and $16m respectively. Indexed using CPI to 2012 prices these cost $85m and $31m respectively. Cost escalation in the construction sector, particularly in remote areas is probably significantly higher. A downstream regulating weir, if required, has not been investigated or costed.
Estimated cost / ML of supply	$15,610/ML water supply in 85% of years (does not include transmission/distribution losses or take into account environmental and downstream entitlements).
Potential benefit/cost	The economics of irrigated agriculture development based on this proposal would be highly dependent on high value uses being identified.
Summary comment	The proposed full supply level of the reservoir is above the level of the gravel layer between the sandstone and the basalt. This poses potential leakage and piping problems for the dam and may be a limiting factor on its level of development. Investigations would need to confirm the gravel layers continuity, level and properties. The storage’s impact on the National Park would need to be addressed at an early stage if this proposal was to be further considered. Of the storage options considered in the area upstream of Hughenden, this option appears to offer the better geological conditions. However, the yield is very low and hence the economics of irrigated agriculture development based on this proposal would be highly dependent on high value uses being identified. The SRTM could not adequately resolve the steep cliff lines at the dam site. Nevertheless the volume estimate is expected to be within ±25% for a given FSL.

Figure 3.35 Porcupine Creek dam site looking upstream

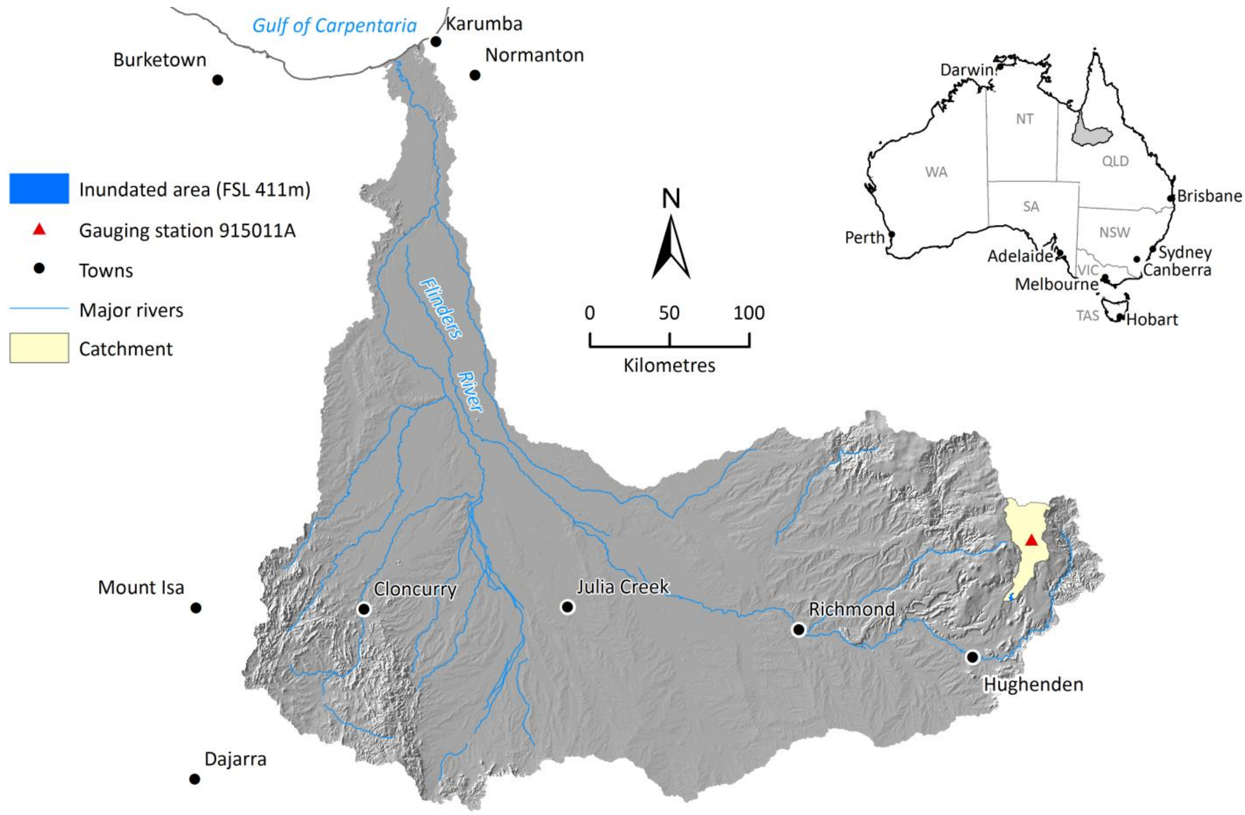


Figure 3.36 Location map of Porcupine Creek potential dam, reservoir and catchment area

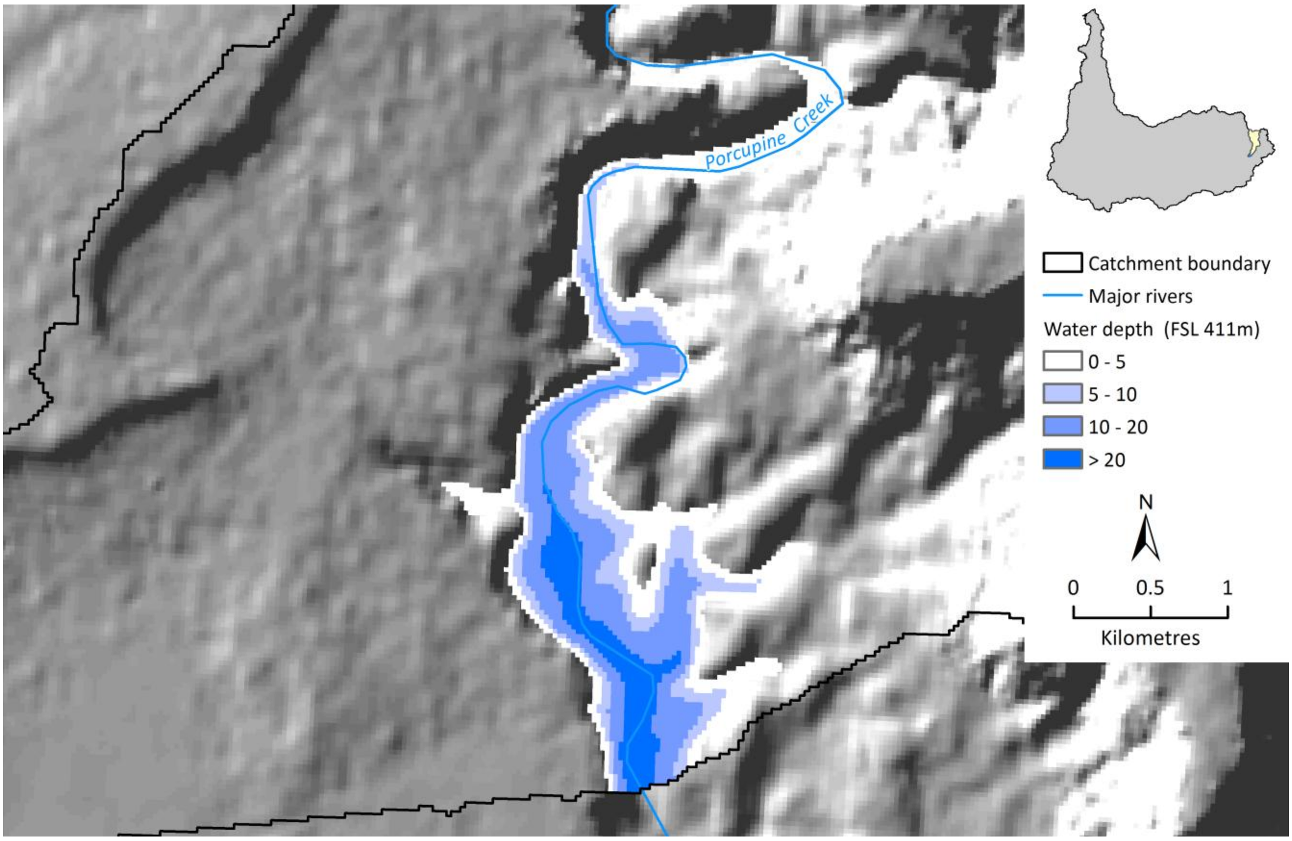


Figure 3.37 Porcupine Creek dam depth of inundation
A short embankment is required on the east bank to contain flood rises at the catchment boundary

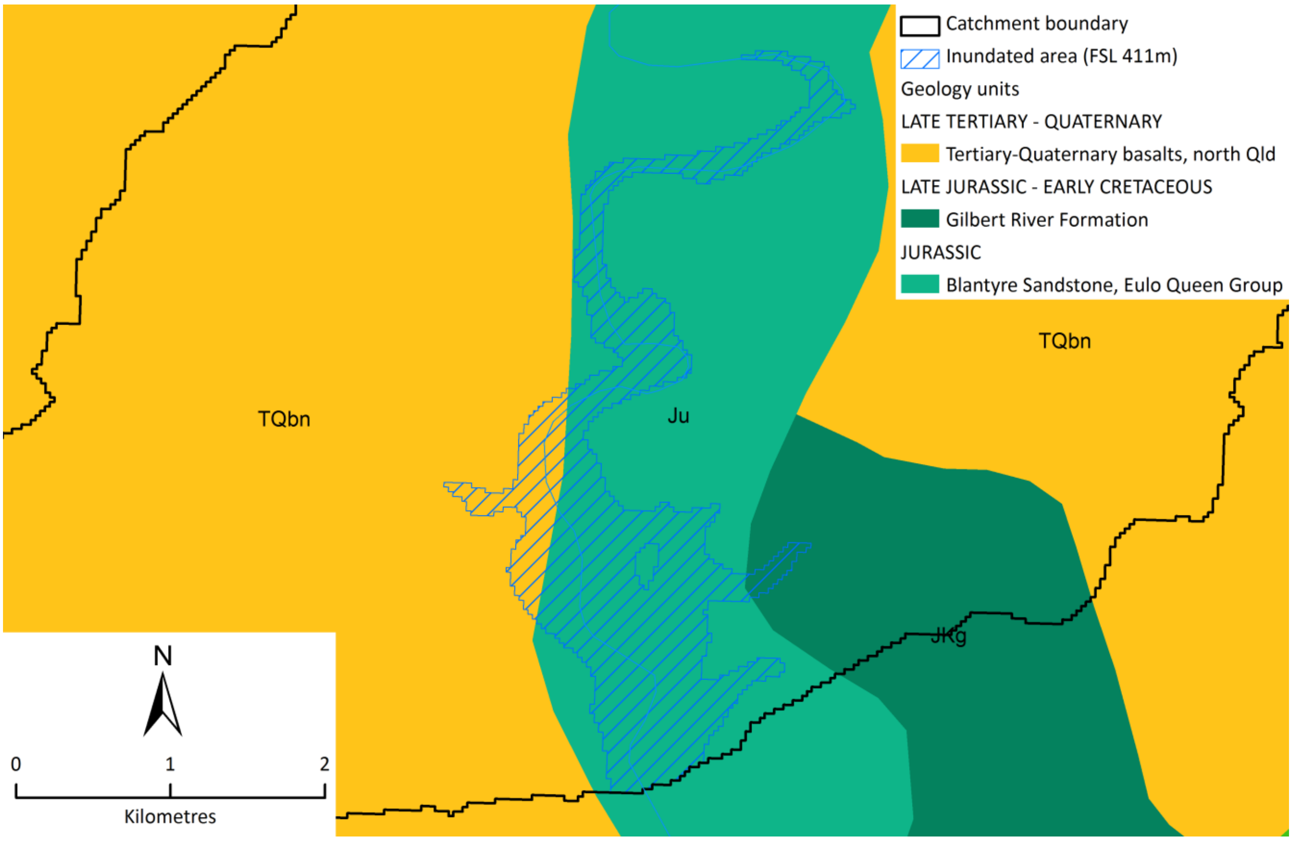


Figure 3.38 Porcupine Creek potential dam underlying geology

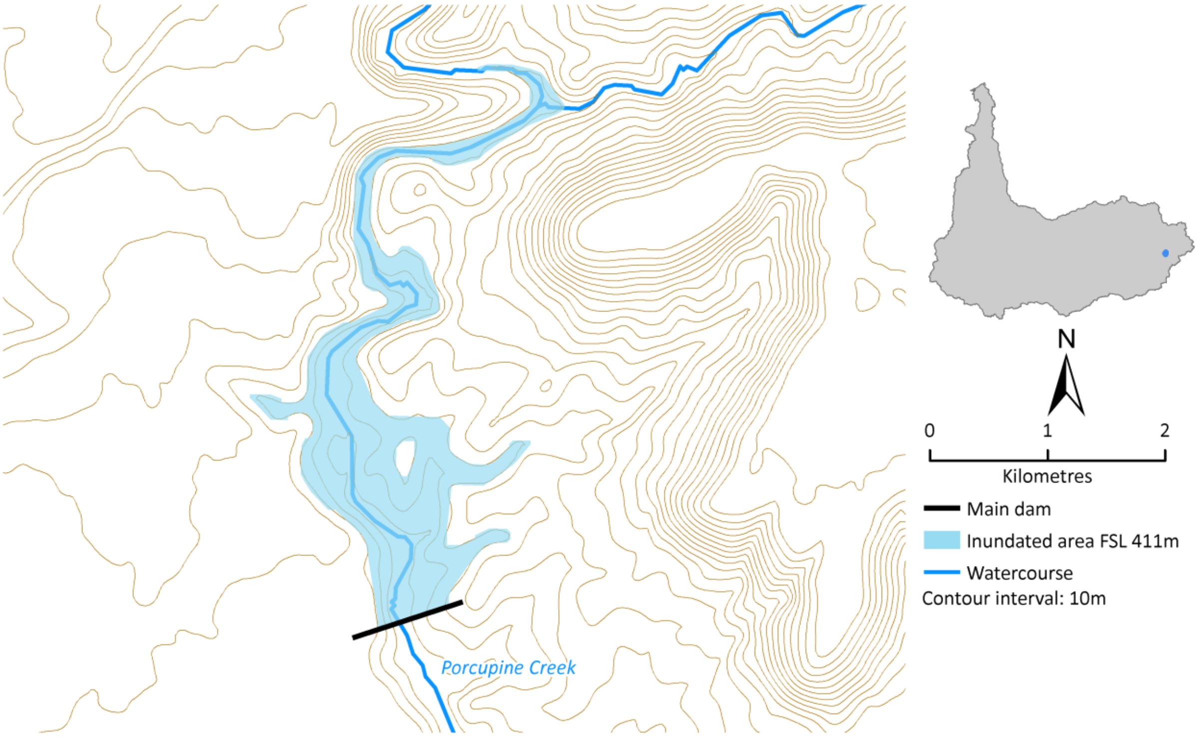


Figure 3.39 Map of conceptual arrangement of dam at Porcupine Creek

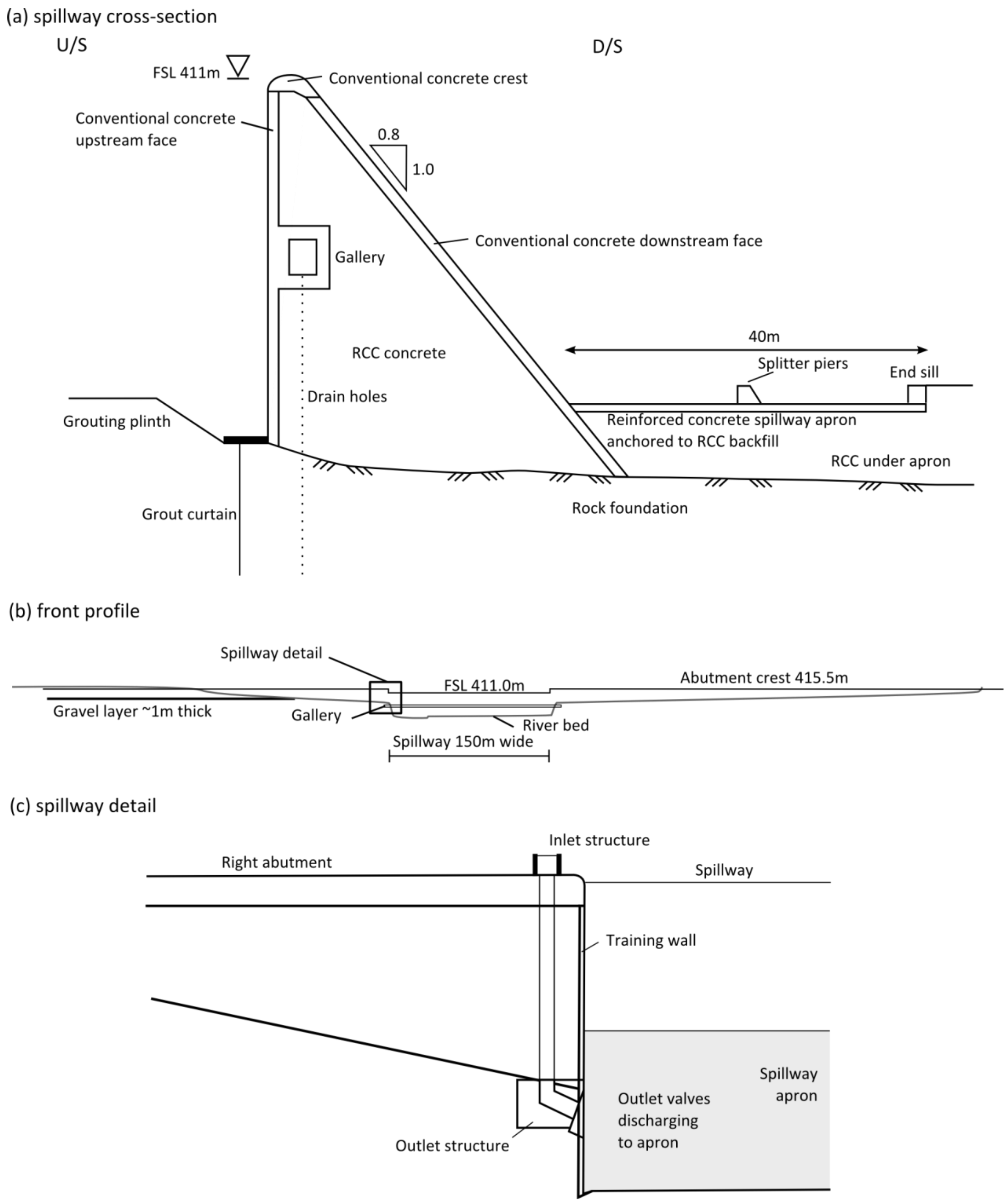


Figure 3.40 Porcupine Creek conceptual arrangement

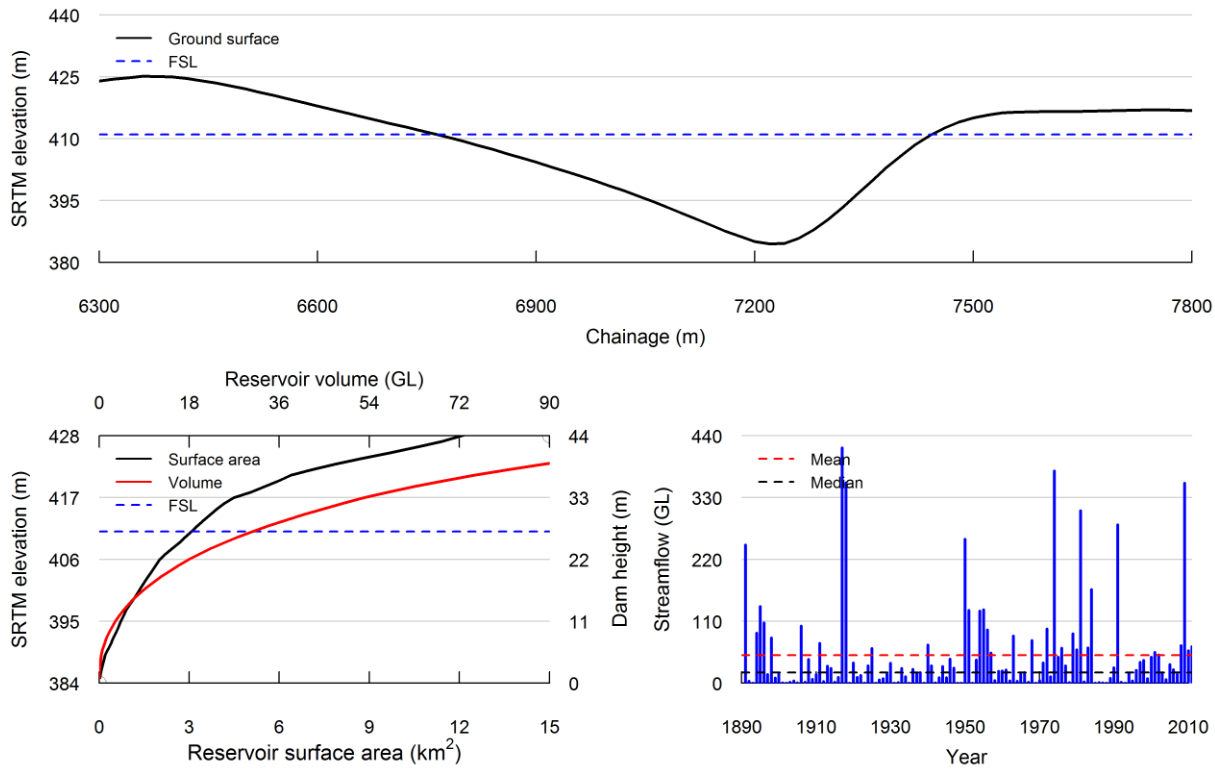


Figure 3.41 Cross section along main dam axis (looking downstream), volume surface area height relationship and annual streamflow at Porcupine Creek potential dam site

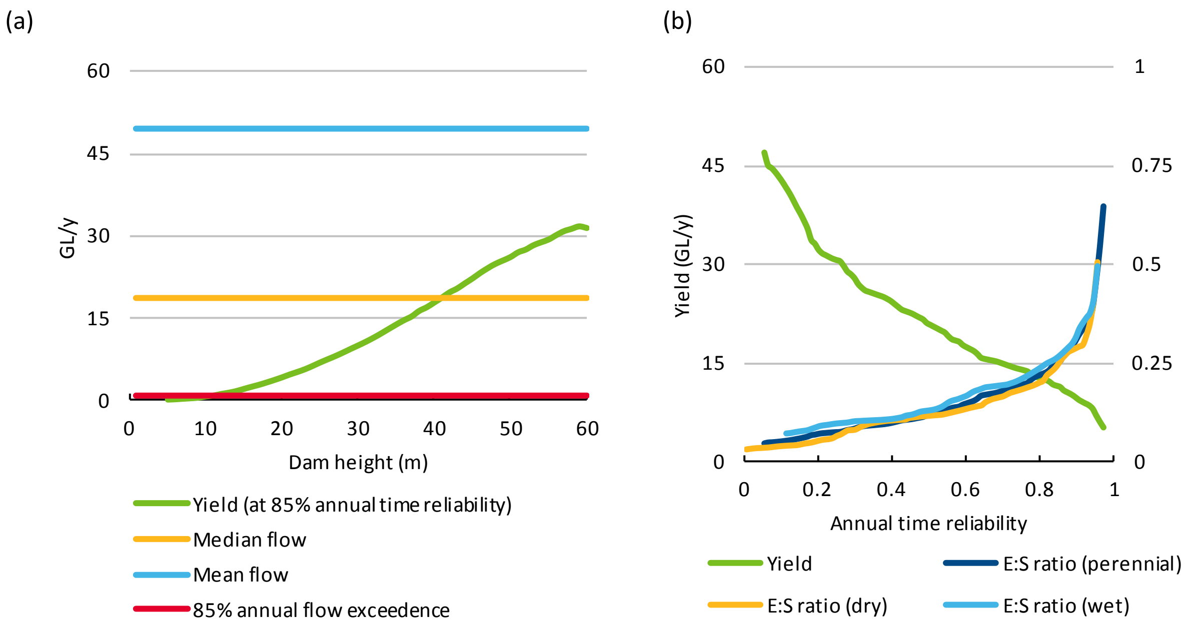


Figure 3.42 (a) Yield at 85% annual time reliability and streamflow at Porcupine Creek dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Porcupine Creek dam site for different annual time reliability for the selected dam height of 35 m

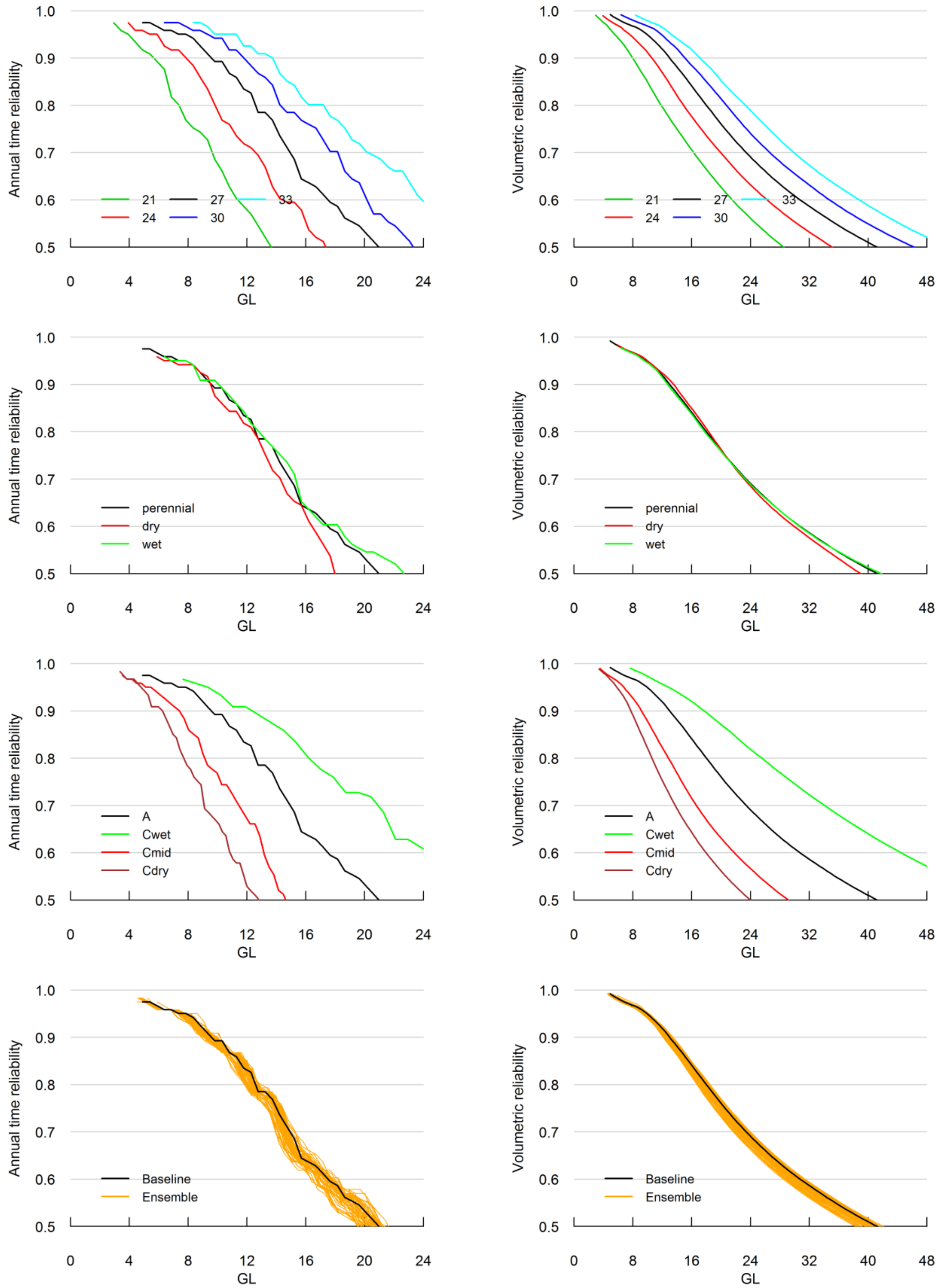


Figure 3.43 Porcupine Creek potential dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 411 m FSL. Third row: YRR under Scenario C for 411 m FSL. Fourth row: YRR for baseline and ensemble model runs for 411 m FSL

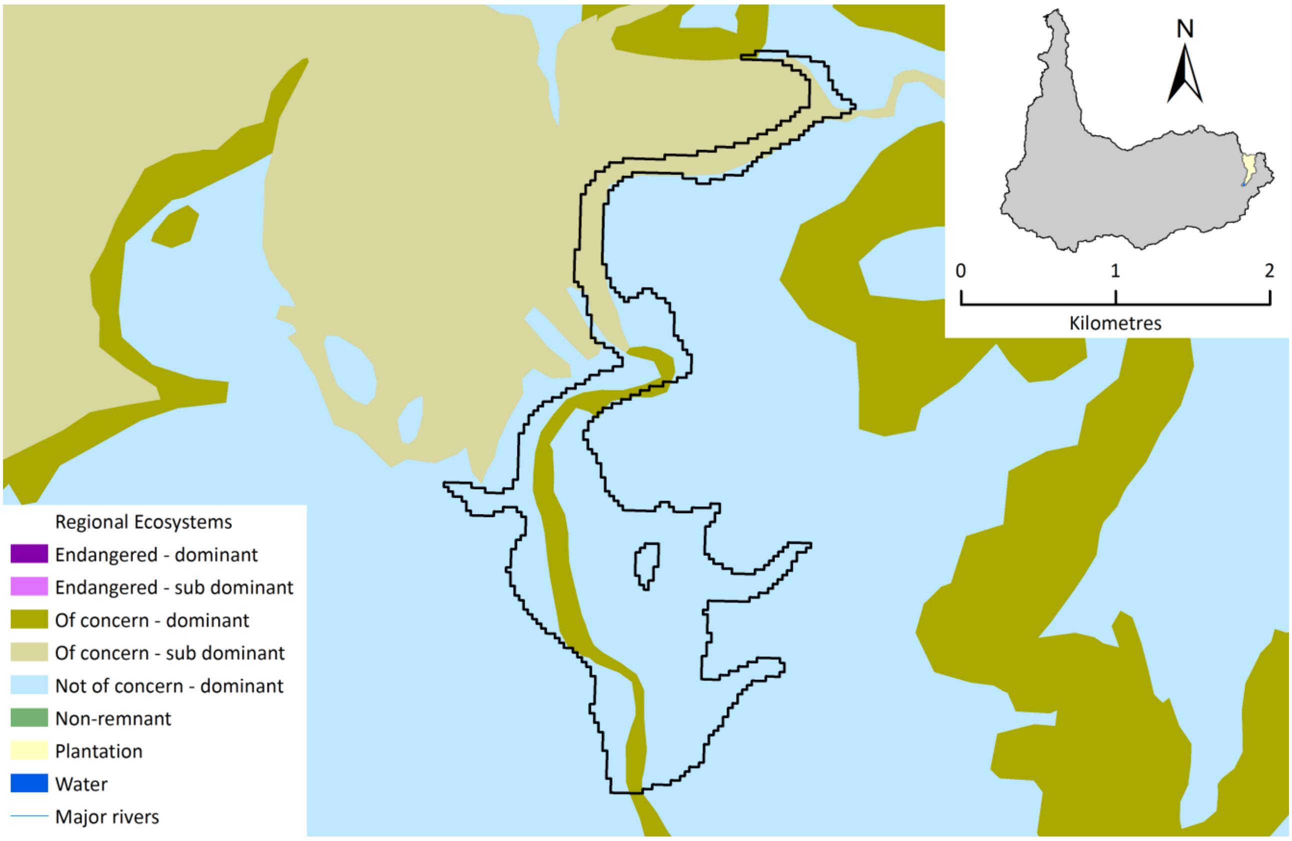


Figure 3.44 Regional ecosystems inundated by the Porcupine Creek dam at full supply level

4 Gilbert catchment

4.1 Study area

4.1.1 OVERVIEW

The Gilbert catchment is located in north-west Queensland and covers an area of 46,354 km^2. It has a population of approximately 1200 with one urban centre, Georgetown (population of 243, Australian Bureau of Statistics, 2011).

4.1.2 GEOLOGY

The geology of the catchment may be divided into three major structural divisions: the Proterozoic age Georgetown Inlier, the overlapping Great Artesian Basin (Mesozoic age) and Karumba Basin (Cenozoic age) sedimentary rocks and Cainozoic age basaltic lava flows. A simplified surface geology map of the Gilbert catchment is shown in Figure 4.1.

Rocks of the Georgetown Inlier have been subdivided into a number of provinces. The significant ones in the catchment area are the Etheridge Province, the Croydon Province, the Pama Province and the Kennedy Province.

Rocks of the Etheridge Province consist of a meta-sedimentary sequence. Major deformational events have metamorphosed these rocks to a variety of grades ranging from low grade greenschist to high grade granulite facies with metamorphic grade increasing from west to east. The deformational events were also accompanied by emplacement of granitic rocks.

The Croydon Province contains rhyolitic to dacitic ignimbrites and related granites and smaller deposits of quartzose sedimentary rocks. The volcanic and granitic rocks are contained within a cauldron subsidence structure.

Rocks of the Pama Igneous consist of Silurian to Devonian granite batholiths. It includes the Puppy Camp Granodiorite north of Einasleigh and the White Springs batholith between the Einasleigh and Etheridge Rivers.

Rocks of the Kennedy Province include both intrusive and extrusive types of Carboniferous to Early Permian age. They occur both as major batholiths and volcanic fields. Extrusive rocks are usually rhyolitic ignimbrites and occur in large cauldron subsidence structures interpreted to have formed as a result of crustal melting in an extensional tectonic environment. Batholiths include the Lochaber Granite near Kidston and the Mount Noble Granite on the Einasleigh River. Extrusive ignimbrites include the Eveleigh Cauldron northwest of Einasleigh, Namarrong Cauldron on the Einasleigh River and Cumberland Cauldron on the Gilbert River.

Sandstones of the Great Artesian Basin (GAB) outcrop in the headwaters of the Gilbert River. These form intake beds for the basin with groundwater flow directed towards the north and northwest. In the lower parts of the catchment the sandstones are overlain by mudstone and siltstone.

Sedimentary rocks of the Karumba Basin overlie the Great Artesian Basin and occur in the north of the catchment area. They consist of a basal quartzose sandstone unit overlain by clayey sands and clay.

Basaltic lava flows have had a significant influence on the riverine geomorphology of the catchment area. Most of the flows are less than 3 Ma with the Undara flow being only 0.2Ma. The current location of the Great Dividing Range and the current drainage system had established before the lava flows took place although further uplift may have accompanied the formation of the lava fields.

The two basaltic provinces affecting the Gilbert catchment are the McBride province centred on Undara Volcano to the east of the Einasleigh River and the Chudleigh province near the headwaters of the Einasleigh, Flinders, Clarke and Basalt rivers.

The Chudleigh province basalt flows have affected the upper reaches of the Copperfield and Einasleigh rivers. Basalt has flowed down the former river valleys and flood plains forming lava fields and in some cases, blocking former river channels. The most northern part of the flow is about 24 km north of Einasleigh. The current river channel now flows to the west of the former river channel in this area.

The Undara flow of the McBride province has affected the middle reaches of the Einasleigh River downstream of its confluence with Junction Creek to its confluence with Parallel Creek – a distance of about 60 km.

Broad scale geological considerations in siting dams in the Gilbert catchment

For the most part the Etheridge province produces topography not favourable for dam construction except where there are resistant units, or where there are resistant granitic intrusions. One such resistant unit is the Dead Horse Metabasalt where the North Head dam site is located. One of the resistant granitic intrusions is the Lochaber Granite where Kidston dam is located.

Sandstone outcrop of the GAB often has favourable topographic expression for dam sites but no suitable sites have been located in this formation within in the Gilbert catchment. There are two main reasons for this. First, the sandstone is often located in the upper reaches of the catchment so that any potential dam sites have catchment areas that are too small. Secondly, at downstream sites, the sandstone often overlies low strength meta-sedimentary rocks of the Etheridge Province forming unstable blocks at the unconformity. Areas of mudstone outcrop have a subdued topography and do not form suitable dam sites.

The best dam sites in the catchment are found where the rivers have eroded through ignimbrites of the Kennedy Province. Ignimbrite from this province is a strong rock formed from the welding and later consolidation of a pyroclastic flow. A pyroclastic flow is a hot mixture of volcanic ash and gas that flows rapidly from a volcano following an eruption. They can form thick deposits covering large areas. These materials are often preserved because of their deposition in subsidence areas (cauldrons). As ignimbrite is resistant to weathering and erosion, river valleys tend to be relatively narrow and the depth of unconsolidated alluvium relatively shallow. Dam sites in the Gilbert catchment within this province include Green Hills and Dagworth.

The basalt flows of the McBride and Chudleigh provinces have adversely affected several sites on the Einasleigh River. At the Mt Alder site downstream of Einasleigh, the river has been diverted from its former course by a basalt flow infilling a valley within the Eveleigh Cauldron. The new course has eroded through a resistant microgranite intrusion to form a site with suitable topography but the course of the river is now considerably steeper than formerly resulting in a relatively small reservoir capacity. At the Mt Noble site a new river course has formed where basalt has infilled the former river valley where it passed through the Mt Noble Granite. These basalt filled former courses now form potential leakage paths around two potential sites.

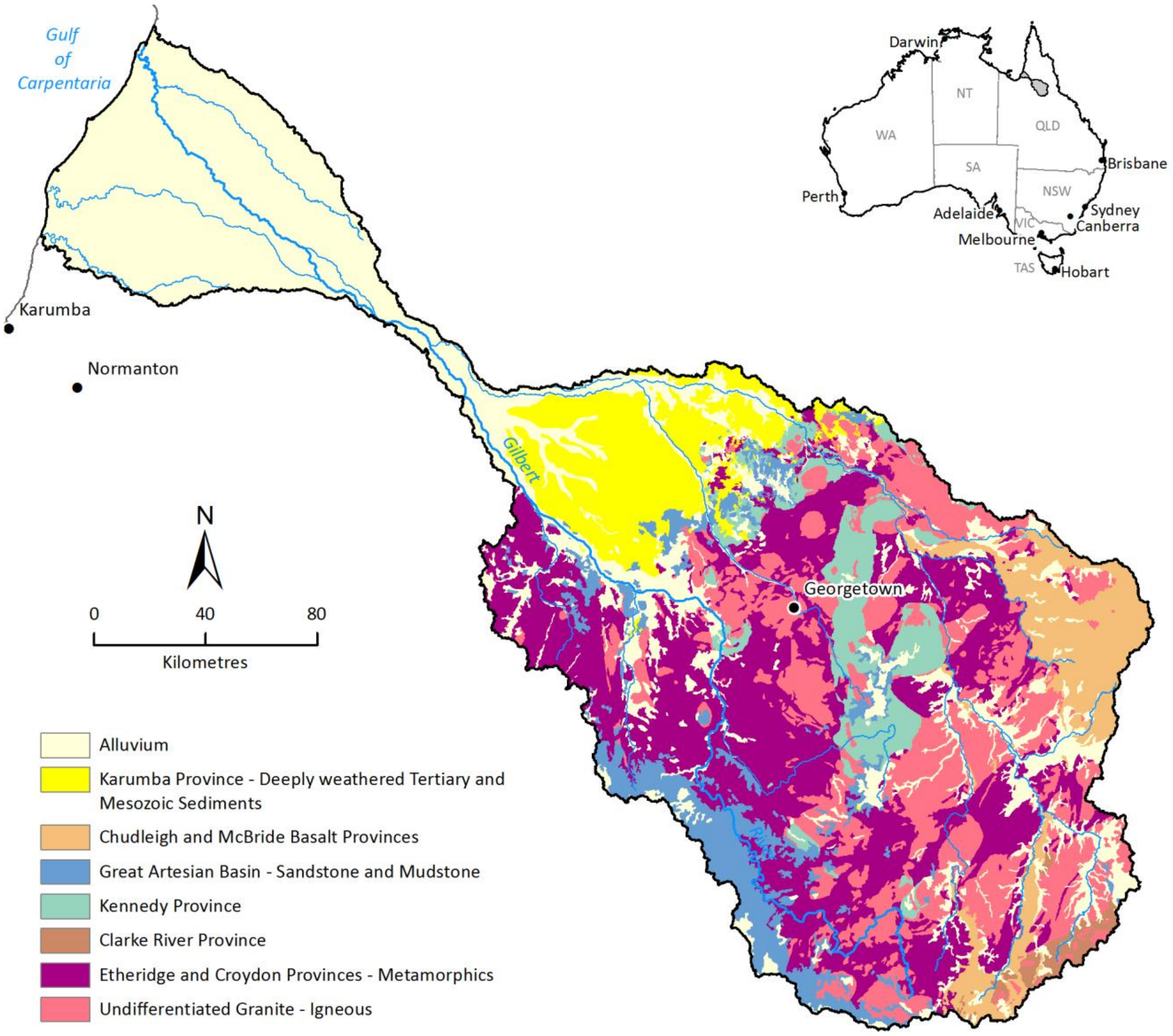


Figure 4.1 Simplified surface geology of the Gilbert catchment

4.1.3 CLIMATE

The Gilbert catchment has a semi-arid tropical climate. The mean and median annual rainfall spatially averaged across the catchment are 775 mm and 739 mm respectively. Spatially, mean annual rainfall varies from about 1050 mm at the coast to about 650 mm in the south-east of the catchment. The historical annual rainfall series shows considerable variation between years. The highest catchment average annual rainfall (2187 mm) occurred in 1974, and was nearly three times the median annual rainfall value (Figure 4.2).

A defining characteristic of the Gilbert's climate is the seasonality of rainfall (Figure 4.3), with 93% of rainfall occurring during the wet season (November to April inclusive). The highest median monthly rainfall in the Gilbert catchment occurs during the months of January and February (~200 mm). The months with the lowest median rainfall are July and August (~ 0.5 mm).

The Gilbert catchment has a mean annual potential evaporation of 1868 mm. Mean wet and dry season potential evaporation is 1067 mm and 815 mm respectively. The majority of the catchment experiences a mean annual rainfall deficit of greater than 600 mm.

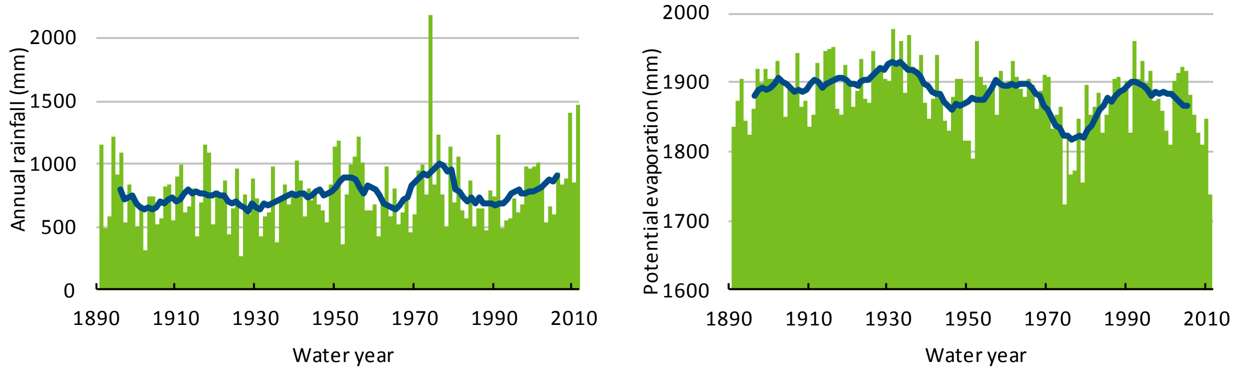


Figure 4.2 Historical annual rainfall and potential evaporation in the Gilbert catchment (Petheram and Yang 2013)

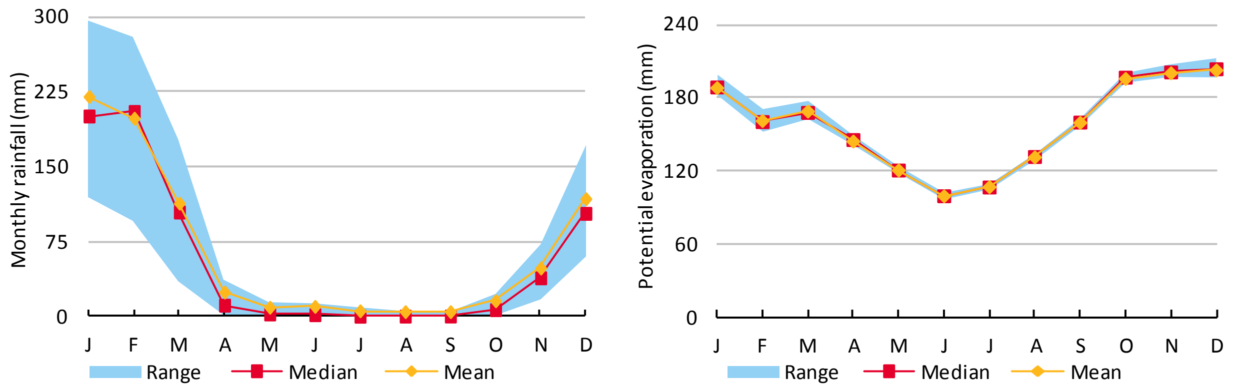


Figure 4.3 Historical monthly rainfall and potential evaporation averaged over the Gilbert catchment (Petheram and Yang 2013)

4.1.4 HYDROLOGY

The Gilbert catchment is comprised of two major rivers, the Gilbert and the Einasleigh (Figure 2.1). Although the catchment shares a name with the Gilbert River (named after the explorer Gilbert), the Einasleigh is the larger of the two rivers. The flow characteristics of the two rivers are quite different, with the Einasleigh and some of its upper tributaries draining the basalt country in the eastern parts of the catchment. This results in extended flows during the dry season in some reaches of the Einasleigh River and its tributaries. In contrast, the Gilbert River and Etheridge River, a major tributary of the Einasleigh, are highly ephemeral and do not flow for more than half the year on average. Downstream of Strathmore station the Gilbert and Einasleigh rivers converge before entering the Gulf of Carpentaria.

Figure 4.4 provides an indication of the quality of the streamflow data in various parts of the Gilbert catchment. Figure 4.5 shows the simulated annual runoff averaged across the catchment between 1890 and 2011 and the monthly runoff averaged across the Gilbert catchment. Figure 4.6 provides an indication of the mean annual flow in different reaches of the Gilbert catchment. It should be noted that the median annual flow in the Gilbert and Einasleigh rivers is considerably less (i.e 30 to 40%) than the mean annual flow (see Lerat et al. 2013).

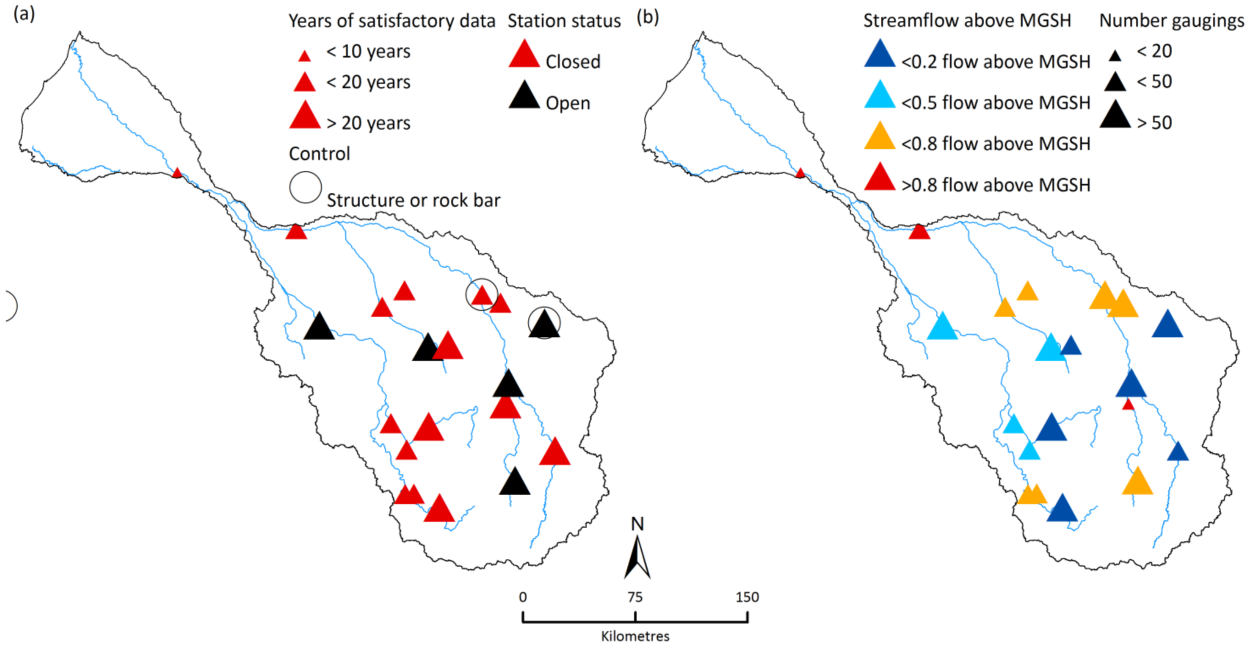


Figure 4.4 Quality of streamflow data in the Gilbert catchment (Lerat et al. 2013) (a) The size of the triangle indicates the number of years of satisfactory data and colour of the triangle indicates the station status; (b) the colour of the triangle indicates the proportion of streamflow above maximum gauged stage height (MGSH) and the size of the triangle indicates the number of stage – discharge gauging

Approximately 97% of runoff occurs during the wet season, with the majority of runoff occurring during the months January to March. Figure 4.5 illustrates the large monthly variability in runoff in the Gilbert catchment.

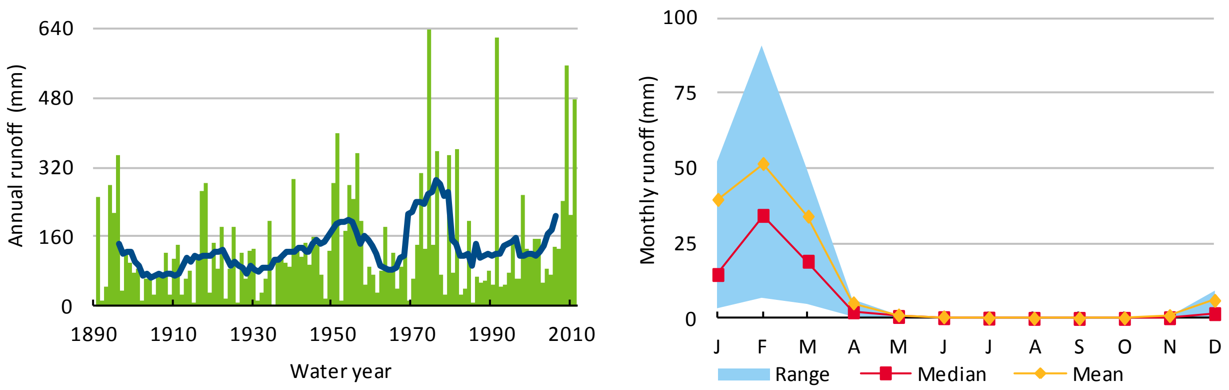


Figure 4.5 Historical annual runoff averaged across the Gilbert catchment (left). Monthly runoff averaged across the Gilbert catchment (right) under Scenario A (Lerat et al. 2013)

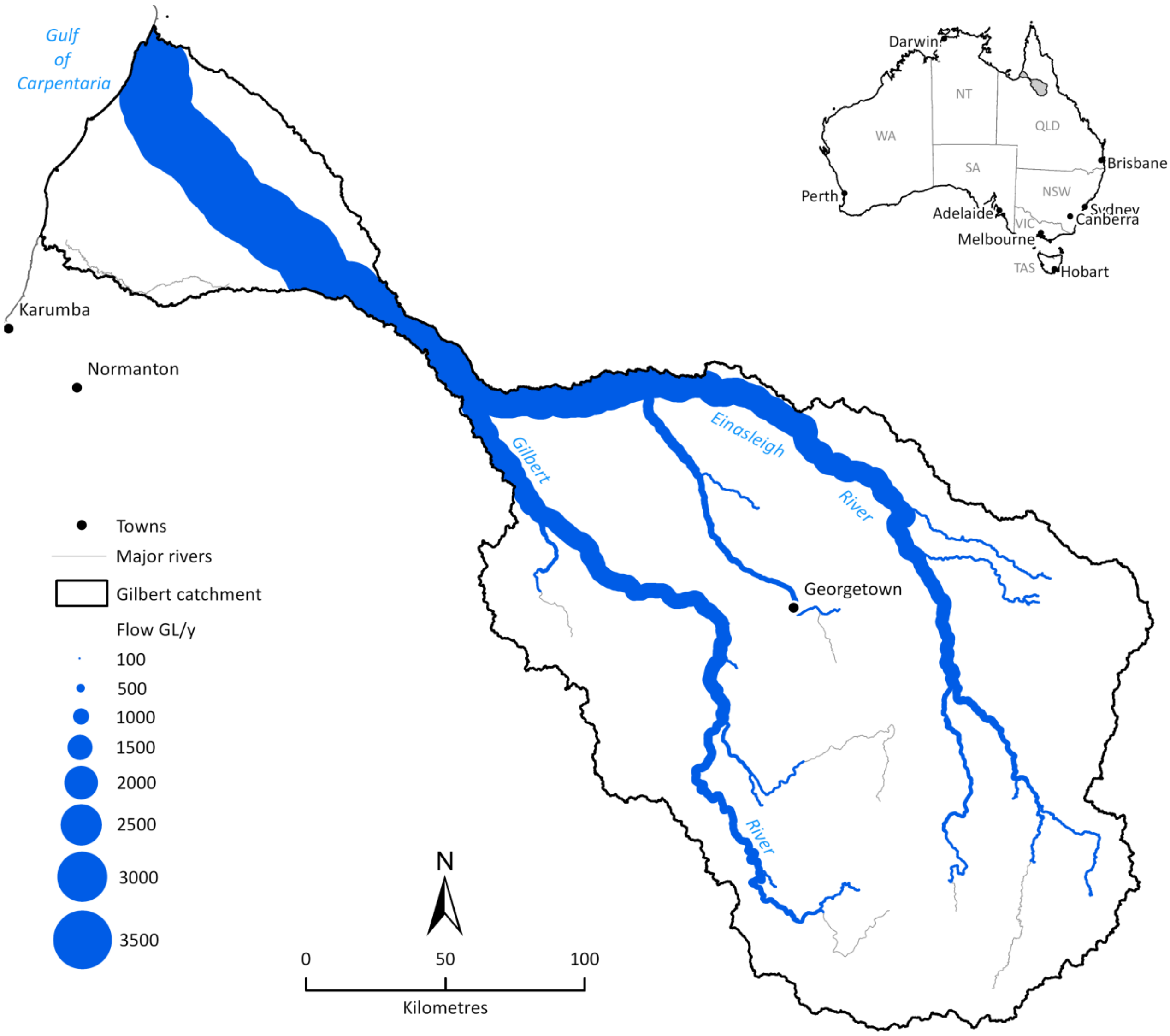


Figure 4.6 Map showing mean annual streamflow in the Gilbert catchments

4.2 Preliminary assessment of potential dam sites in the Gilbert catchment

Six potential locations were identified from published and unpublished literature accessed from the Queensland Government and SunWater archives. The extent of prior investigations ranged from a single reference to potential locations (e.g. Mount Alder and Mount Noble) to moderately detailed hydrological and geotechnical investigations (e.g. Green Hills). These studies were reviewed and all locations were reassessed using a consistent set of methods using updated data where available.

4.2.1 DAMSITE MODEL RESULTS

To ensure that no potential dam options had been overlooked, the DamSite model was used to undertake a preliminary assessment of over 100,000 potential dam sites in the Gilbert catchment. This model is a series of algorithms that automatically locate and assess favourable topographic and hydrological locations in the landscape as sites for intermediate to large water storages (Read et al. 2012). A desktop geological suitability assessment of the results of the DamSite model was undertaken by overlaying the potential dam locations on 1:250,000 geology data. The DamSite model results were then ranked by volume of water supplied per unit cost, and the locations compared to the previously identified potential dam locations and likely arable land. The DamSite model identified numerous locations for siting dams in the Gilbert catchment.

In the first instance it is instructive to examine the best water storage options in terms of reservoir volume at FSL to construction cost i.e. only taking topography into consideration, not hydrology. In Figure 4.7, the dam locations were optimised and then ranked on the basis of storage volume to construction cost, where the construction cost of each dam was based on its dimensions. This figure shows that topographically the parts of the Gilbert catchment most suitable for large dams are on the Einasleigh River at the Mount Noble Range, on Dismal Creek and Little River. However, the optimal potential dams at the Mount Noble Range are between 70 and 90 m high, which is unlikely. Dismal Creek and Little River are small drainage lines and have small streamflow volumes. If water could be economically pumped into the storages in Dismal Creek and Little River from a larger nearby drainage line then these potential dam sites could function as a large offstream storage (provided they were geologically suitable).

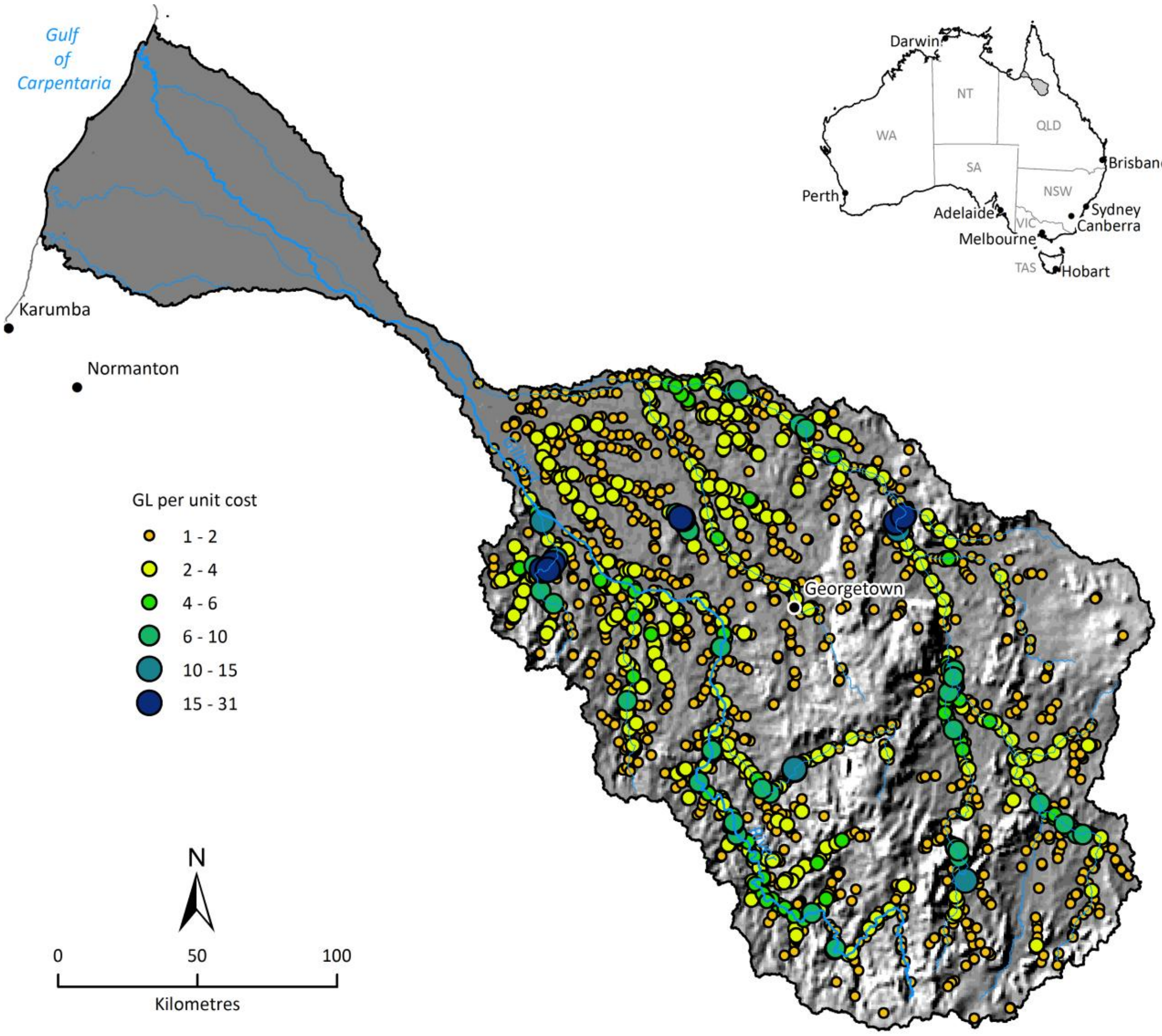


Figure 4.7 Ratio of reservoir volume at FSL to dam cost. Only those dams with a GL per unit cost > 1 are shown

To properly assess the potential of a large instream dam the inflows to the dam need to be considered. This is undertaken in Figure 4.8 where the DamSite model results are ranked by water yield at 85% annual time reliability per unit cost. Taking inflows into consideration the majority of potential dam sites in the Gilbert catchment have a very low yield per unit cost (i.e. less than 2 GL per unit cost).

Because of time and other resourcing constraints, the only new potential dam sites that were investigated further were those identified by the DamSite model that had higher water yields, were situated in geologically favourable formations, and were more favourably located to soil suitable for irrigaiton than known potential dam sites. The most notable of these was Dagworth, a previously undocumented potential site on the lower Einasleigh River situated in extremely high strength dacitic ignimbrite.

The DamSite model identified a second potentially favourable dam site on the lower Einasleigh, approximately 30 km downstream of the Dagworth site. However, based on the regional scale geology mapping this site appears to be located on the Bulimba Formation of Tertiary age (Karumba Basin). The rock types are probably clayey sandstone, conglomerate and sandy claystone of low strength. The rock may be suitable for a dam foundation but finding non-erodible rock in which to locate a spillway would be challenging. The constriction of the river width at this location may make this site suitable for a weir.

The DamSite model identified one site on the Etheridge River with a GL yield per unit cost of greater than 4. Based on regional scale geology mapping this site appears to be located in ignimbrite and andesite of the Kennedy Province (similar to the potential Green Hills dam), so the foundation geology appears to be suitable for a dam and a spillway in the riverbed may be feasible. However, this site is inferior to other sites on the Einasleigh and Gilbert rivers and was not investigated further.

In many cases, the DamSite model confirmed the relative potential of known potential dam locations, such as Green Hills and Mount Noble. In other cases it demonstrated that known dam site locations are topographically and hydrologically inferior to other nearby locations (e.g. North Head). Figure 4.9 to Figure 4.12 provide enlarged views of potential dam sites in key areas of the Gilbert catchment shown in Figure 4.8.

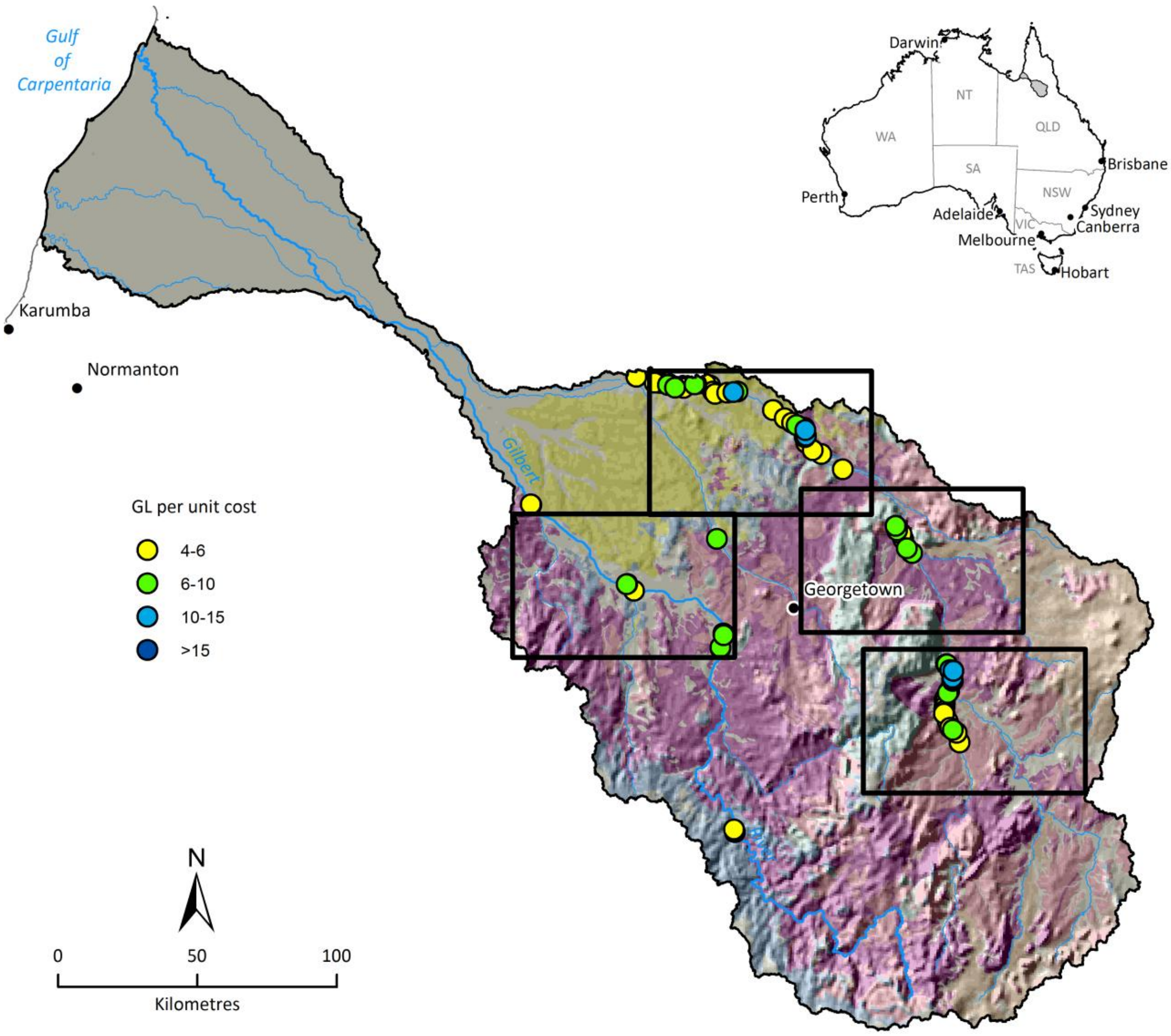


Figure 4.8 Potential dam sites in the Gilbert catchment as identified by the DamSite model. Only those sites > 4 GL per unit cost are shown

Rectangles indicate areas for which enlarge views are provided in Figure 4.9 to Figure 4.12.

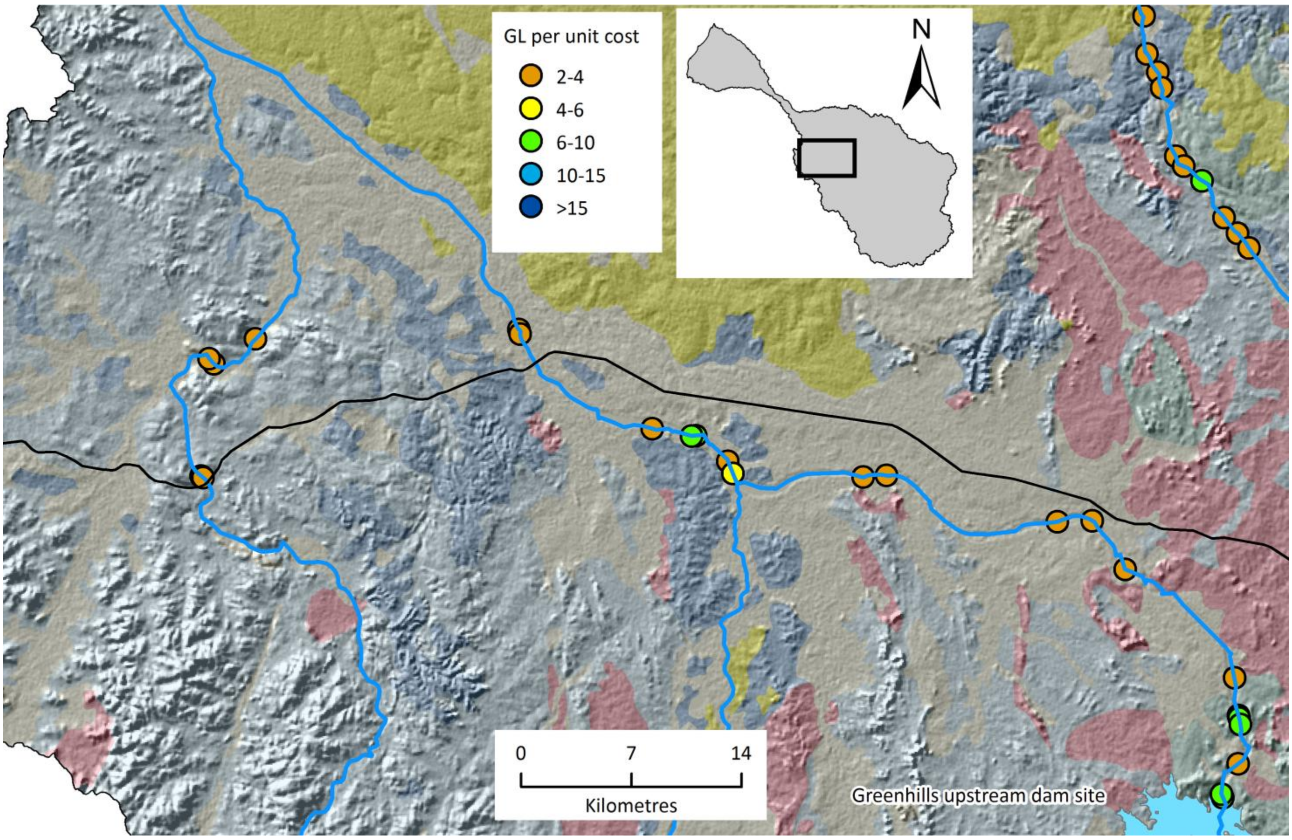


Figure 4.9 DamSite model results for the Gilbert River downstream of the Green Hills dam site. Only those potential dam sites > 2 GL per unit cost are shown. The light blue polygon indicates the potential reservoir of Green Hills upstream dam site

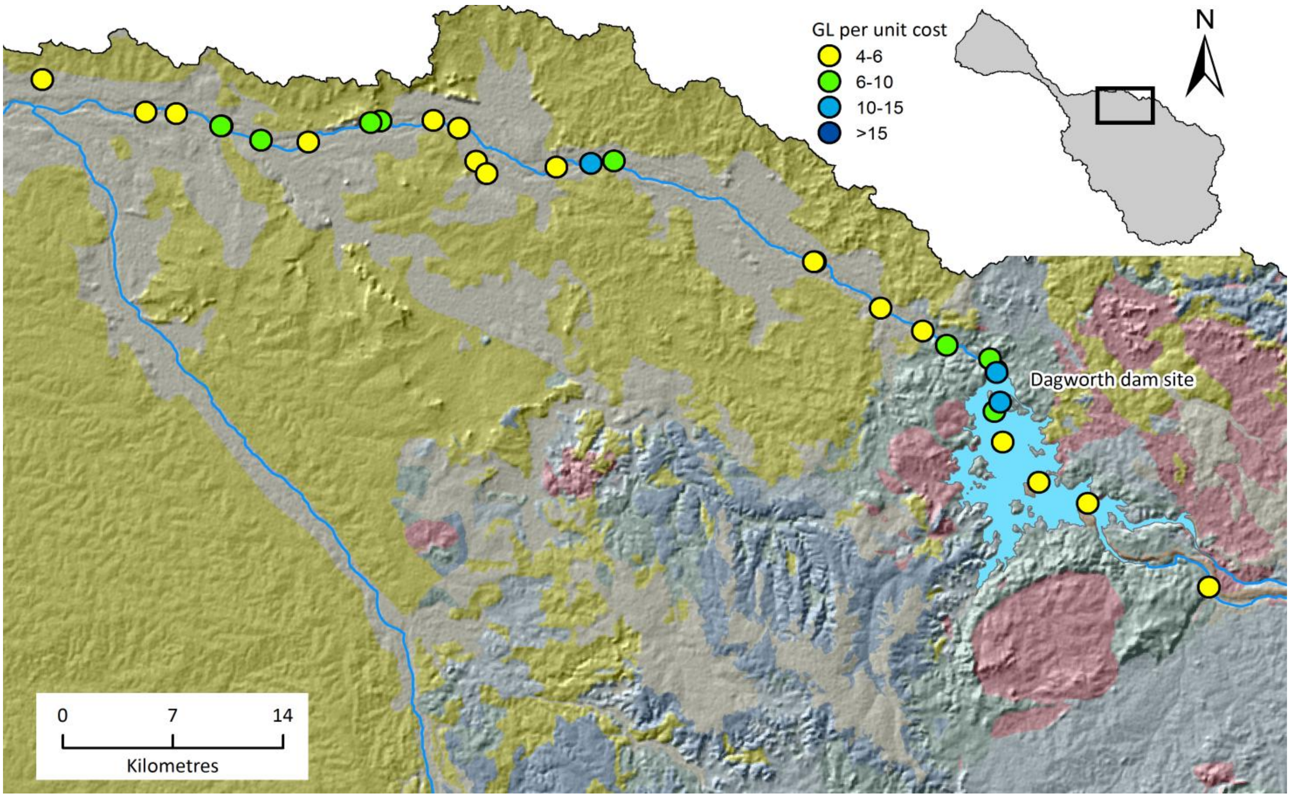


Figure 4.10 DamSite model results for the mid-reaches of the Einasleigh River. Only those potential dam sites > 4 GL per unit cost are shown. The light blue polygon indicates the potential reservoir of Dagworth upstream dam site

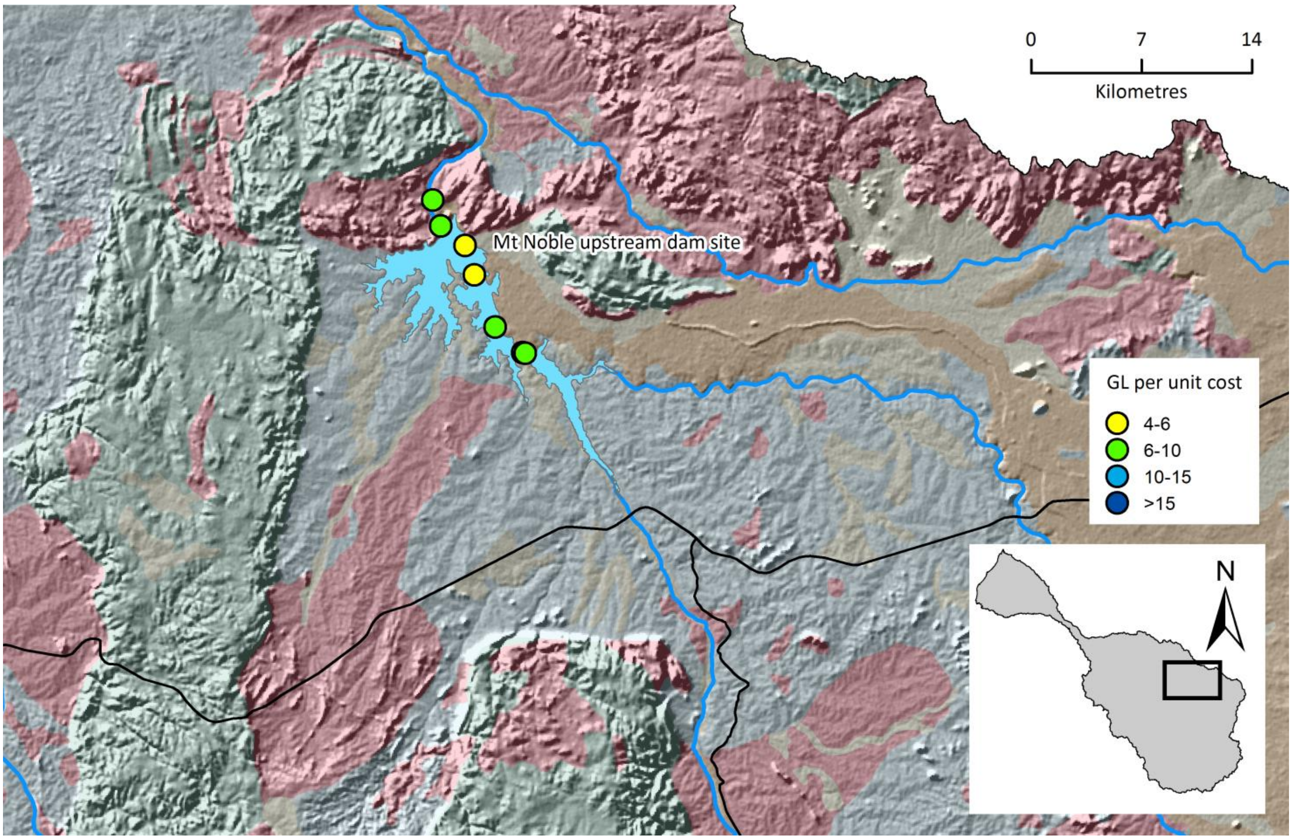


Figure 4.11 DamSite model results for the Einasleigh River. Only those potential dam sites > 4 GL per unit cost are shown. The light blue polygon indicates the potential reservoir of Mount Noble upstream dam site

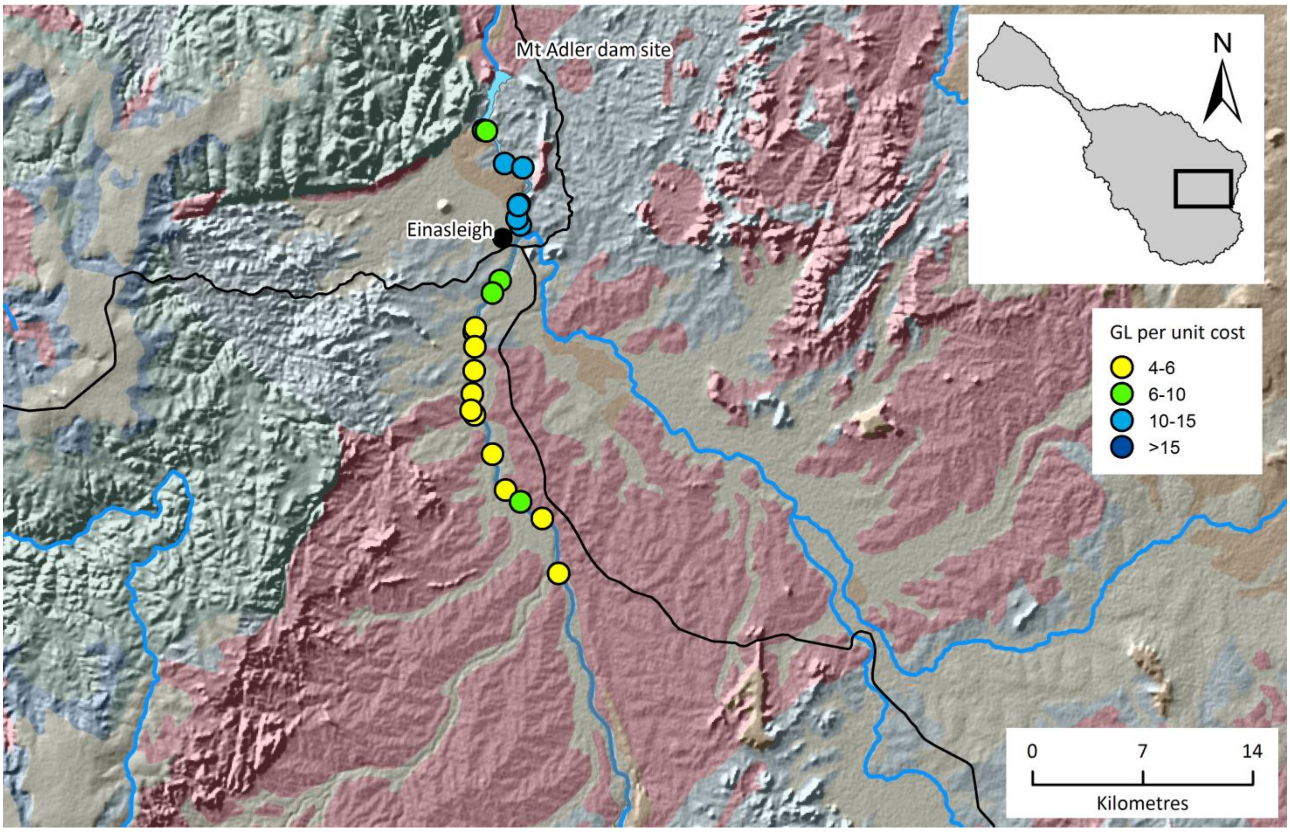


Figure 4.12 DamSite model results for the Einasleigh River near Einasleigh. Only those potential dam sites > 4 GL per unit cost are shown. The light blue polygon indicates potential reservoir of Mount Alder dam site

4.2.2 SUMMARY OF POTENTIAL DAMS ASSESSED IN THE GILBERT CATCHMENT

The most favourable sites at seven potential dam locations in the Gilbert catchment are summarised in Table 4.1 and a short comment provided in Table 4.2. In presenting this information it should be noted, however, the geological structure at a particular dam site can be very complex, is always unique and requires thorough investigation because of the high financial risks involved. The investigation of a potential dam site generally involves an iterative process of increasingly detailed studies over a period of years, occasionally as few as two or three years but often over ten or more years. For any of the options listed in this report to advance to construction, far more comprehensive studies would be needed than were possible in this regional scale assessment.

An important consideration in assessing a dam for use for irrigation is its proximity to suitable soils. As part of the Assessment 76 crop and irrigation type combinations were assessed, see Bartley et al. (2013) for a full description of the land suitability methods and all land suitability maps. Across the Gilbert catchment there is about 2 million ha of land that is classed as moderately suitable under a range of crop and irrigation methods (Bartley et al. 2013). Figure 4.13 maps the existing and potential dam sites assessed in the Gilbert catchment together with the land suitability map for wet season sorghum (grain) under spray irrigation. This figure indicates that the potential dams closest to large contiguous areas of land moderately suitable for irrigation are Green Hills on the Gilbert River and Dagworth on the Einasleigh River.

Three potential dam sites in the Gilbert catchment were selected for further analysis because each was deemed to be most likely site to proceed in three distinct geographical areas. The assessment of the three most promising sites was based on expert knowledge and primarily took into consideration topography of the dam axis, geological conditions, proximity to soils suitable for irrigation and water yield. The short-listed sites entailed raising the existing Kidston Dam, and potential dams at Dagworth and Green Hills. The Dagworth site had not been previously identified. As part of the Assessment, the majority of sites were visited by an experienced infrastructure planner and engineering geologist (Table 2.2).

Table 4.1 Potential dams assessed in the Gilbert catchment

At some locations, up to three alternative sites were assessed. For these locations, the most suitable alternative site is reported.

DAM ID	DAM NAME	DAM TYPE*	CATCHMENT AREA (km^2)	SPILLWAY HEIGHT** (m)	FULL SUPPLY LEVEL (mEGM96)	CAPACITY (GL)	ANNUAL WATER YIELD*** (GL)	CAPITAL COST# ($ million)	UNIT COST## ($/ML)	EQUIVALENT ANNUAL UNIT COST### ($ per year per ML)
1	Bundock Creek	EB/ RCC	205	14	659	30	8.8	$225☐	$25,590	$ 1794
2	Dagworth	RCC	15,351	30	227	498	326	$474 ◘	$1450	$102
3	Green Hills	RCC	8,310	20	253	227	172	$335 ◘	$1950	$137
4	Raising Kidston Dam	CC	1,244	40	588	25^	17^	$34 ■	$1990	$139
5	Mount Alder	RCC	8,641	20	425	31	37	$275 ☐	$7510	$526
6	Mount Noble	RCC	12,383	20	337	103	113	$375 ☐	$3322	$233
7	North Head	EB/ RCC	4,680	30	344	136	108	$325 ☐	$3013	$211

* Conventional concrete (CC), embankment dam (EB), roller compacted concrete dam (RCC). The existing Kidston Dam is a RCC dam but it would be raised using CC.
** The height of the dam abutments 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.

■ cost estimate based on schedule of quantities estimated by McIntyre and Associates (1998). This includes raising of the dam and diversion infrastructure. ◘ indicates preliminary cost estimate is likely to be –10% to +30%. ☐ indicates preliminary cost estimate is likely to be –10% to +50%. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher. Operation and maintenance costs are typically about 0.4% of the capital cost.
This is the unit cost of annual water supply and is calculated as the capital cost divided by the water yield at 85% annual time reliability.
Assuming a 7% real discount rate and a dam life of 100 years. Capital cost only. Does not include operation and maintenance costs.
^ Existing Kidston Dam capacity is 20 GL and the annual water yield at 85% time reliability is 15 GL.

Table 4.2 Summary comments for potential dams in the Gilbert catchment

DAM NAME	COMMENTS
Bundock Creek	Very remote and low water yield. To increase the water yield water could be diverted from the upper Einasleigh River. This would be a very expensive option.
Dagworth	Large catchment and highest water yield of potential dam sites assessed in Gilbert catchment. Saddle dam embankments designed for 1-in-10,000-year flood event, rather than probable maximum flood. Best potential dam site on Einasleigh River, but is still a moderate distance upstream of suitable soils.
Green Hills	Large catchment and highest water yield of potential dam site on Gilbert River. Saddle dam embankments designed for 1:10,000 year flood event, rather than probable maximum flood. Close to suitable soils.
Raising Kidston Dam	Raising existing dam by 2 m. One of the more potentially viable options in the Gilbert catchment. Small water yield and moderate distance upstream of suitable land.
Mt Alder	Low storage capacity. Relatively high risk of sediment infill. Long distance upstream of suitable land.

DAM NAME	COMMENTS
Mt Noble	Effected by basalt flows which limits dam height and may act as leakage path under the dam. Long distance upstream of suitable soils.
North Head	Remote. Long distance upstream of large areas of suitable soils.

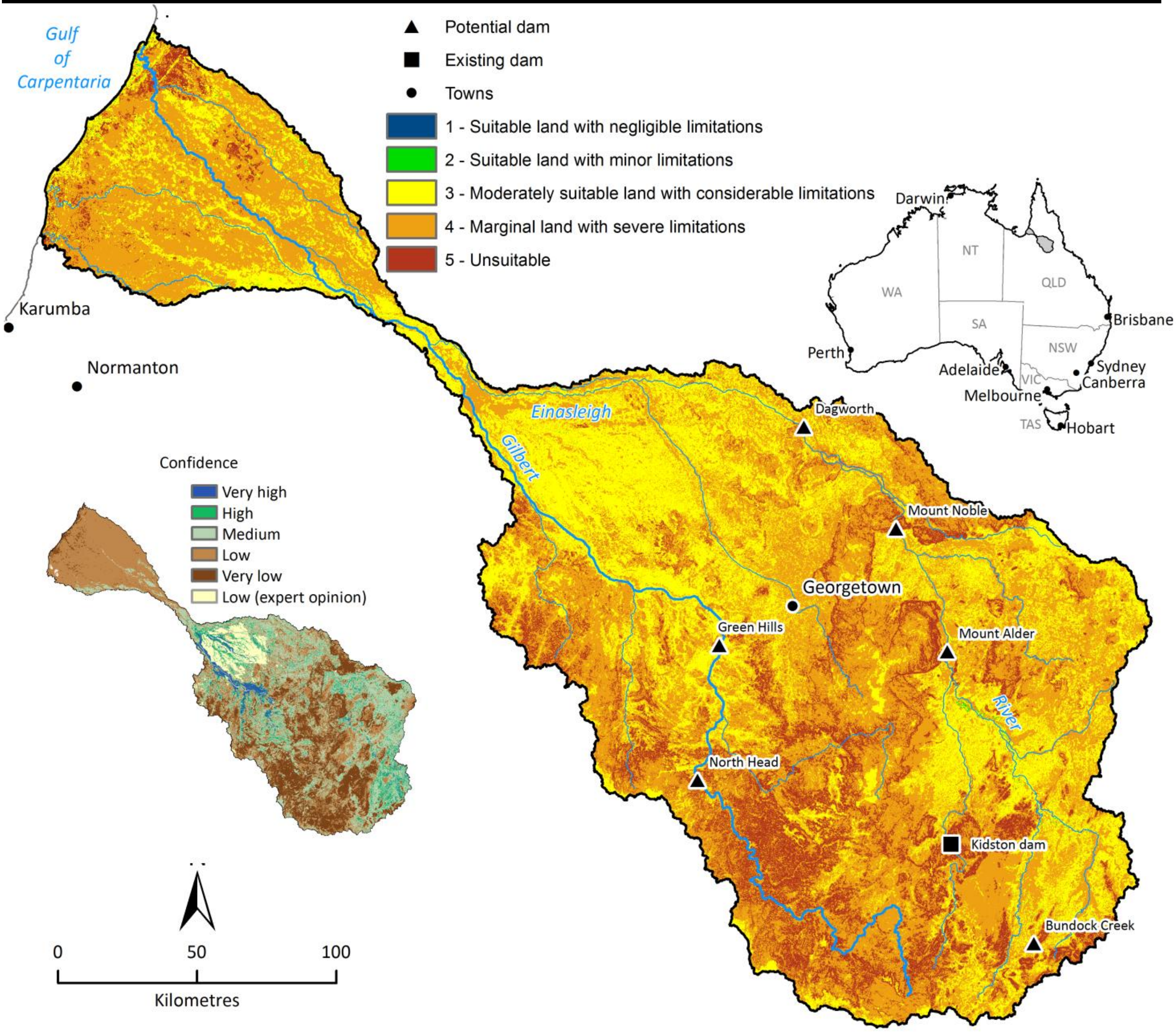


Figure 4.13 Existing and potential dam locations in the Gilbert catchment and modelled land suitability for wet season sorghum (grain) under spray irrigation. Confidence map insert is associated with land suitability mapping. Note that this land suitability map does not take into consideration flooding, risk of secondary salinisation or availability of water.

Land suitability data were sourced from the companion technical report on land suitability, Bartley et al. (2013). See Bartley et al. (2013) for a full description of the methods and explanation of the confidence map.

4.3 Broad scale environmental and cultural heritage considerations

4.3.1 INSTREAM CONSIDERATIONS

There are fewer data available on fish distribution for the Gilbert catchment compared to the Flinders catchment. A total of 42 fish species are known to occur in the Gilbert catchment (Waltham et al., 2013). The gradient of declining numbers of fish species with increasing distance from the ocean, so widely recognised in other catchments, is not clear here (Figure 4.14) due to a lack of survey data availability in the lower reaches, where the greatest diversity is to be expected. In contrast to the Flinders catchment, several of the potential dam sites in the Gilbert catchment are located in the middle reaches rather than just the upper reaches, and thus intersect with the distribution of a greater number of fish species. Available records for barramundi, freshwater sawfish and the freshwater whipray are scant (Figure 4.14), although both barramundi and sawfish are likely to occur further upstream than the currently available records suggest. Consequently it is thought likely that their distribution may intersect with some potential dam sites. In the Gilbert catchment freshwater sawfish are likely to be able to penetrate upstream of the Green Hills dam site on the Gilbert River and possibly as far as the Mt. Noble site on the Einasleigh River. The frequency of their occurrence in these upstream reaches would be less than the downstream reaches. The freshwater whipray may not reach far enough upstream to intersect with any dams. Sawfish and whiprays are typically not readily detected in standard fisheries surveys and need to be specifically targeted in surveys in order to gain a better understanding of their actual distribution. Additionally, because of their size and very distinctive saw-like rostrum, sawfish are readily identified and memorable, so interviews with local people should help better elucidate their known range. The Einasleigh River would provide a greater abundance of more suitable habitat for freshwater sawfish than the drier and more ephemeral Gilbert River.

Although fish stocking may have occurred in private dams in the Gilbert catchment, there has been no official stocking of barramundi, or any other fish into the rivers or Kidston Dam. This is relatively rare in Queensland, where fish stocking is a widespread practice (Holloway and Hamlyn 2001, Moore 2007). Vallance et al., (2000) undertook an initial appraisal of fisheries aspects associated with several dam proposals in the Gilbert catchment. However, no site-specific fish data were included in that report. A catchment-wide survey of fish was undertaken by Ecowise (2007) but the sites surveyed and fish species found at each site was not presented in that report and could not be obtained from its custodians. The Queensland Department of Primary Industries and Fisheries undertook brief surveys at numerous sites in the middle to upper reaches of the Einasleigh catchment from 2006 to 2009 as part of a surveillance program looking for pest fish (of which none were found in the Gilbert catchment). Raw data were obtained from that study.

Large, major permanent waterholes have been mapped as part of the Assessment, but only within the selected reaches as shown in Figure 4.15. Permanent waterholes are more common in the Gilbert catchment compared to the Flinders catchment. In general most of the permanent waterholes are downstream of the potential dam sites, however, in the Einasleigh catchment many permanent waterholes are located upstream of potential dam sites at Mt. Alder and Mt. Noble (Figure 4.15). The waterholes downstream of dams may be affected by alterations to flow regimes from water resource developments, but not by inundation from a dam. The method used to maps pools is not able to detect smaller pools that may be locally important as refuges, so more detail would need to be obtained on these habitats potential dam sites were to be investigated further.

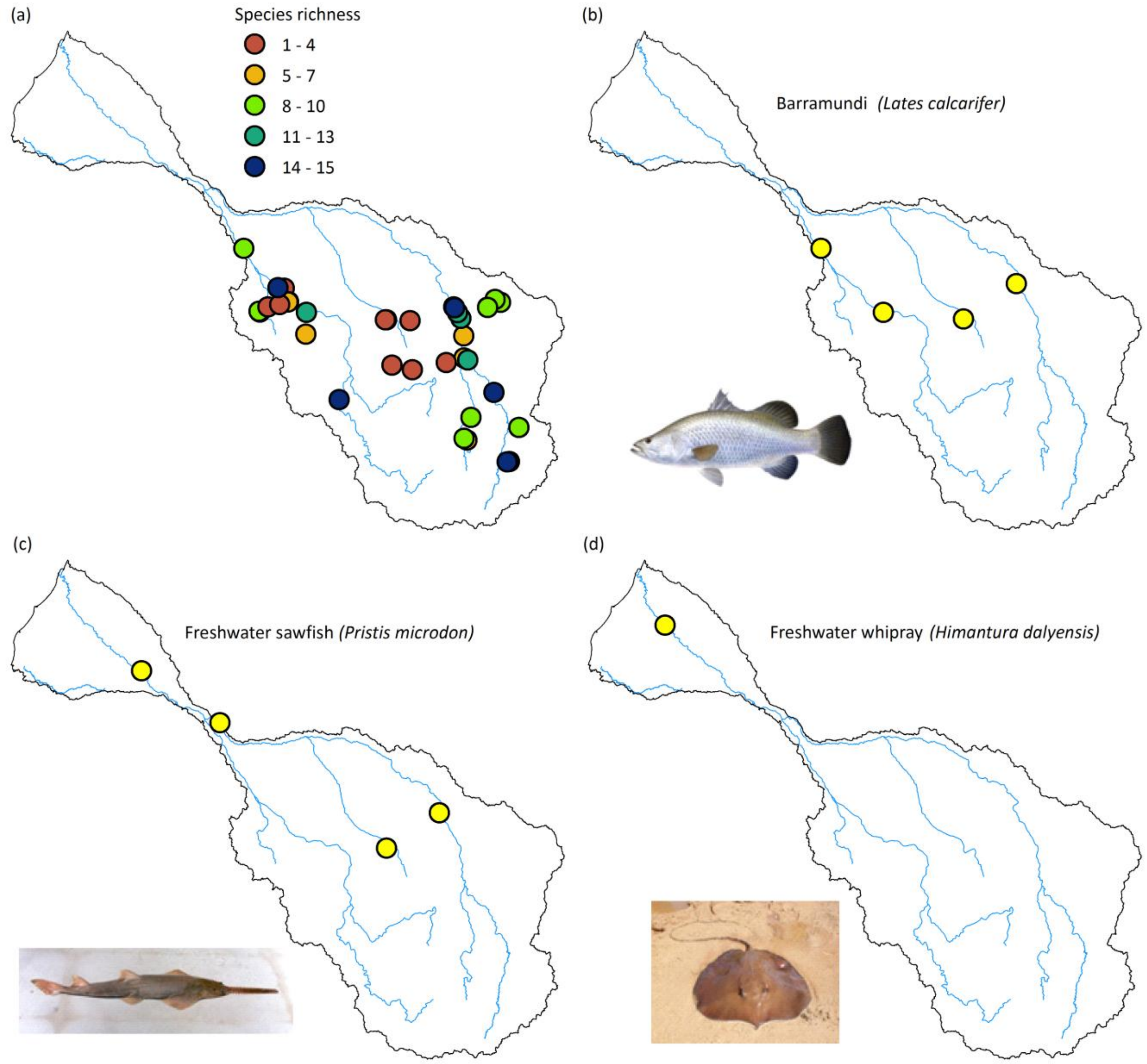


Figure 4.14 Fish distribution in the Gilbert catchment

(a) Number of species found in fish surveys. (b) Known extent of barramundi (*Lates calcarifer*); photo: <www.anima.net.au>, used with permission. (c) Reliable captures or sightings of freshwater sawfish (*Pristis microdon*); photo: S. Peverell, used with permission. (d) Reliable captures or sightings of freshwater whipray (*Himantura dalyensis*). Photo: B. Pusey, used with permission. (Figure sourced from companion technical report on aquatic ecology, Waltham et al., 2013).

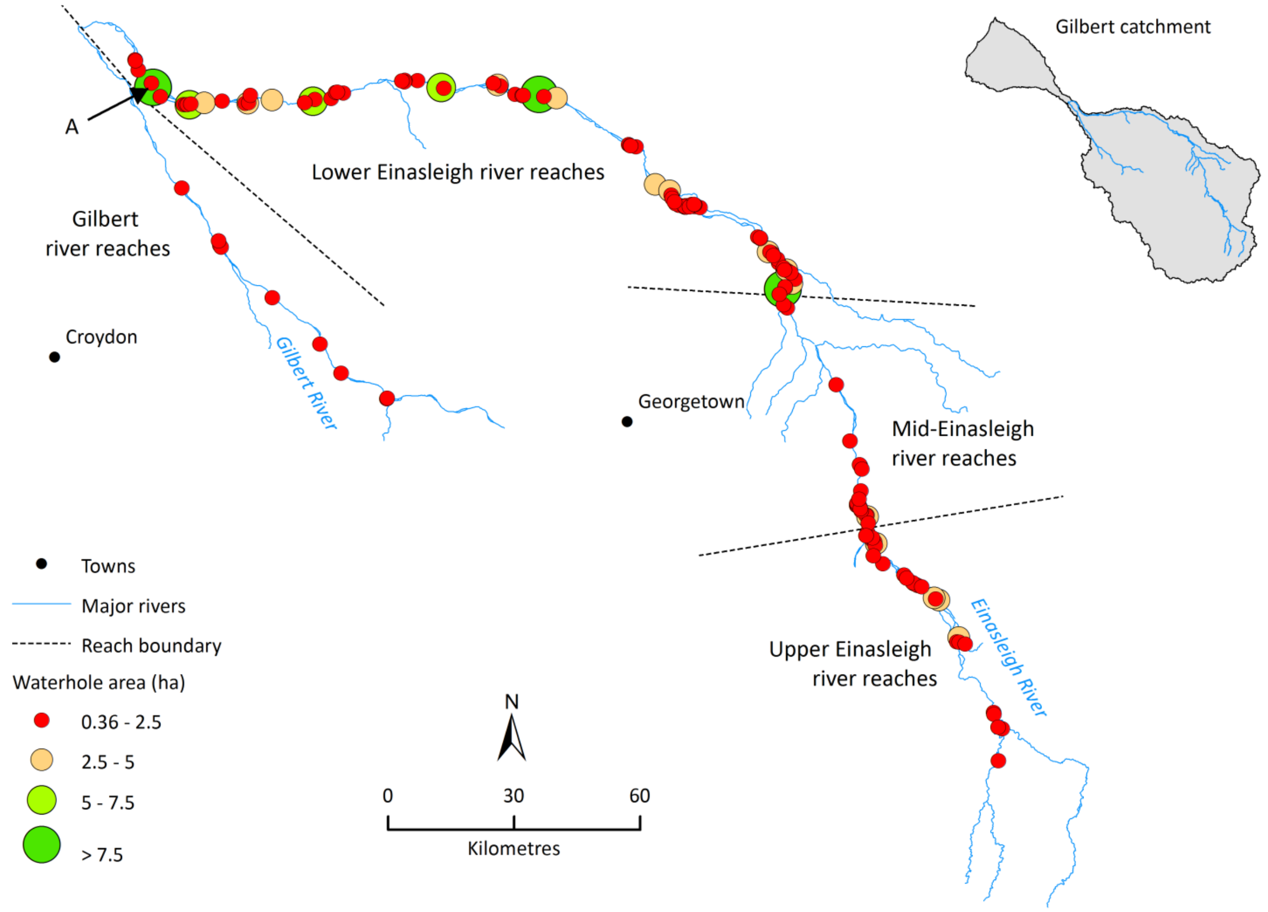


Figure 4.15 Location of key aquatic refugia identified in the Gilbert catchment

Key aquatic refugia are defined as those waterholes which are present for more than 90% of the time. Inset shows the river reaches that were examined (persistent pool data sourced from McJannet et al., 2013)

4.3.2 REGIONAL ECOSYSTEMS

Regional ecosystem (vegetation) communities that were present at each potential water storage site within the catchment were examined using the Queensland Herbarium's *Regional Ecosystem Description Database* (Queensland Herbarium, 2013) and were categorised as per Table 4.3. In general, most of the Gilbert catchment, within the Assessment area, includes 'not of concern' vegetation communities, which means that the area of remnant vegetation extends more than 30% of the pre-clearing extent across the catchment. However, the Assessment undertook a desktop assessment of vegetation communities located within the potential water storage sites, and many would inundate areas of 'of concern' vegetation because they contain riparian vegetation. Local vegetation surveys would be necessary to provide greater resolution of likely losses of vegetation communities as a result of inundation by a potential reservoir.

A more detail examination of this mapping is shown for each potential dam site, where the proposed inundation area has been superimposed over the regional ecosystem mapping. If any potential dam site is considered for further investigation, the vegetation and fauna communities present would need to be investigated much more thoroughly.

Table 4.3 Categories of regional ecosystem (vegetation) communities
These biodiversity codes come from the *Vegetation Management Act 1999.*

CATEGORY	DEFINITION	SUBCLASS*	AREA (ha)	PERCENTAGE OF CATCHMENT
Endangered	Remnant vegetation is less than 10% of its pre-clearing extent across the bioregion; or 10 to 30% of its pre-clearing extent remains and the remnant vegetation is less than 10,000 ha.	Dominant	1,354	0.0%
		Sub dominant	2,208	0.0%
Of concern	Remnant vegetation is 10 to 30% of its pre-clearing extent across the bioregion; or more than 30% of its pre-clearing extent remains and the remnant extent is less than 10,000 ha.	Dominant	847,050	18%
		Sub dominant	303,920	7%
No concern at present, least concern	Remnant vegetation is over 30% of its pre-clearing extent across the bioregion, and the remnant area is greater than 10,000 ha.	Dominant	3,442,160	74%
Non-remnant	Native vegetation		20,565	0.5%
Plantation	Plantation		98	0.0%
Water	Water		4,850	0.1%

* 'Dominant' subclass means greater than 50% of polygon contains the regional ecosystem mapping. 'Sub dominant' subclass means that less than 50% of the polygon contains the regional ecosystem mapping.

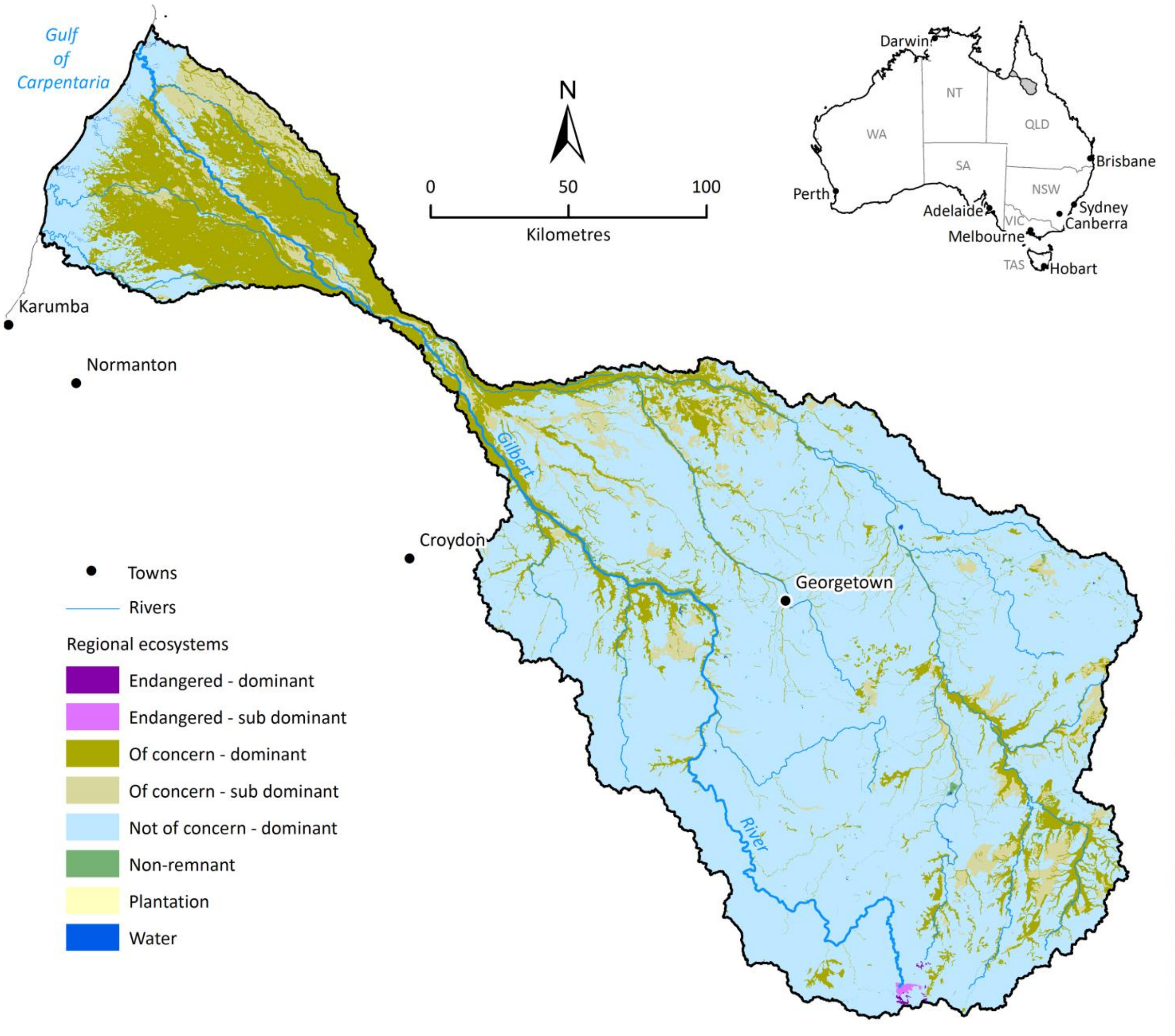


Figure 4.16 Status of regional ecosystem biodiversity for the Gilbert catchment
Definitions and data sourced from Queensland's *Regional Ecosystem Description Database* (Queensland Herbarium, 2013).

4.3.3 INDIGENOUS CULTURAL HERITAGE CONSIDERATIONS

In comparison to the Flinders catchment, the Gilbert catchment appears to have been subject to less archaeological investigation. Much of the work has been in the context of consulting projects, undertaken with relatively limited geographic scope related to proposed developments such as quarries, or linear projects such as transmission lines and road developments. However, several relevant detailed academic research projects have been undertaken in the general area, which assist in providing a framework through which to view the results of the consulting projects. The information available indicates that the area has a rich assemblage of archaeological sites. Sites tend to be found most frequently in the vicinity of permanent or semi-permanent water, and/or on or adjacent to prominent natural features.

Intensive investigations have been undertaken at Esmerelda Station, within the Norman River catchment to the south of Croydon (AHR June 2003; Grant 1992; Salmon 1992). Almost 400 archaeological sites were recorded here, the most common type being artefact scatters and rock shelters with art. Other site types recorded include axe-grinding grooves and food grinding patches (Gorecki *et al.* 1994). The latter site types are concentrated on sandstone outcrops along seasonal watercourses. Gorecki and Grant developed a model for pre-contact Indigenous settlement pattern for the region based largely on the seasonal availability of water and food resources (Gorecki & Grant 1994 cited in NAC 1999:9)

Hatte (1989) notes that throughout the Etheridge Shire archaeological sites are frequently located where semi-permanent and reliable sources of fresh water are found (e.g. large waterholes, gorges, natural springs and native wells). This is consistent with research in the wider Georgetown area (Lovell 1994 and 1995).

Based on the sites registered with DATSIMA, quarry sites appear to be more common, or at least more commonly recorded in the Gilbert catchment than in the Flinders catchment. The stone would have been used locally, but it is also thought that stone axes were traded with other groups in the Gulf region and to the west. Other site types in the region include bora grounds, and burials are known to be present outside Georgetown (NAC June 2003).

There are anecdotal accounts of Indigenous massacres and frontier killings in the area and further historical investigation and Indigenous community consultation is required to verify these and identify whether specific locations are known. In past cultural heritage assessments Ewamian people have reported that the forcible removal of people from their traditional homelands continued until as recently as the 1930’s (Ron Richards pers. Comm. cited in NAC 2003:17) and this would also suggest that there will be significant contact and post-contact sites in this region dating to the period from initial European settlement until well into the twentieth century. Historical accounts from the region also confirm the Indigenous focus on the resources of rivers and lagoons. Several explorers reported on the economic richness of local rivers and lagoons, the large numbers of Indigenous people inhabiting them and the specialised material culture such as finely made nets, fishing spears and fish traps (e.g. Jardine cited in Byerley 1867; Leichhardt 1847). This reliance on riverine resources was also reflected in the Indigenous foods that explorers noted such as mussels, crocodiles, fish, water birds and aquatic plants (Wegner 1990).

The evidence available emphasises the importance of conducting detailed studies of heritage sites and values of local people in the area of any water storage proposals, well before decisions and construction are made.

4.4 Three short-listed potential dam sites

The three short-listed sites are described in alphabetical order.

4.4.1 DAGWORTH DAM SITE ON THE EINASLEIGH RIVER; 166.9 KM

PARAMETER	DESCRIPTION
Previous investigations	No record of any investigation of this site has been located. Two sites within close proximity were identified with the use of the DamSite model as part of the Assessment. The sites were inspected by Assessment team members on 14 December 2012. The upstream site was selected for further investigation and unless stated otherwise all data presented in this table are for the upstream site.
Description of proposal	The Dagworth (upstream) damsite at about AMTD 150 km on the Einasleigh River and about 60 km due north of Georgetown, has not previously been investigated by a Queensland state agency. The proposal is for an on river storage to supply water to land considered to be moderately suitable for irrigation on and downstream of the Abingdon property (downstream of Dagworth). The height of the dam spillway was selected to be 30 m above bed level (FSL 227 m) based on topography and computed flood storage rises (see companion technical report on flood storage design ; Lee et al., 2013). A photograph of the site is shown in Figure 4.17. A location map and map showing the inundated area at FSL are shown in Figure 4.18 and Figure 4.19 respectively.
Regional geology	The site is located where the Einasleigh River departs from its usual north-westerly course to a northerly course as it passes through the Galloway Volcanic Group (Carboniferous). The river direction appears to be influenced by joint orientations in the Galloway Volcanics that are predominantly NNE and NW. Downstream and north of the site, the Galloway Volcanics are

PARAMETER	DESCRIPTION
	overlain by the Bulimba Formation (Cainozoic). The Galloway Volcanics are composed of high strength, rhyolitic to dacitic ignimbrite. The Bulimba Formation is within the Karumba Basin. It is composed of clayey quartzose sandstone and sandy claystone. Figure 4.20 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	No site investigations have been carried out at the AMTD 150 km site. The following comments are based on a brief site inspection by Assessment team members in December 2012. At the site the right abutment commences with a cliff face, about 15 m high above the riverbed. Rock outcrop is dark grey, extremely high strength dacitic ignimbrite. Beyond the cliff face the terrain is undulating and rises gradually. The left abutment rises gradually from the riverbed and is also undulating. The riverbed is covered with coarse sand and the low flow channel is on the left side. (An alternative downstream site at AMTD 148 km would involve a main dam cross river section and a right bank saddle dam about 3 km long. The main dam has similar geological conditions to the upstream site. The left abutment of the saddle dam is within the Galloway Volcanics but the right abutment would be within the Bulimba Formation.) Based on the site inspection, it has been assumed that 12 m of sand material will need to be excavated from the river bed to reach a sound foundation and that 2 m of excavation will be required on each abutment.
Reservoir rim stability and leakage potential	The materials on the reservoir rim are composed of ignimbrite, granite and metamorphic rocks of the Einasleigh Metamorphics together with sandstone and claystone of the Bulimba Formation. Except for terrain adjoining the main dam at the upstream site, slopes are gentle and unlikely to become unstable on filling of the reservoir. The steep slopes adjoining the upstream dam site are in massive ignimbrite and are unlikely to become unstable on filling of the reservoir. The potential for leakage from the upstream site is low. The reservoir rim on the right bank does overlap the Bulimba Formation, which is known to contain groundwater aquifers. However, this part of the Bulimba Formation is an outlier and leakage paths are likely to be restricted. At the downstream site, a significant length of the reservoir rim overlaps terrain underlain by the Bulimba Formation. If the downstream site were to be considered further, leakage potential should be investigated.
Proposed structural arrangement	A concrete gravity dam with central overflow spillway 30 m above river bed level is proposed with the main dam wall RCC construction. Conventional concrete would be placed on the upstream face of the spillway and abutment sections and on the downstream face of the spillway section forming a smooth profile. Twin large diameter conduits would be located at the toe of the left abutment to provide for diversion during construction and for installation of permanent river outlets. An intake tower anchored to upstream face of the dam would provide for selective withdrawal from the storage and for maintenance of the outlets. A bi-directional fish lift type transfer facility similar to that recently installed at Wyaralong Dam would also be located on the left abutment. An earth and rock fill embankment saddle dam approximately 650 m long and 22 m maximum height would be required on the right bank side. The crest level of the saddle dam embankment would be set to contain the 1 in 1000 year AEP flood and in the event of more extreme flood events, to erode away to form an auxiliary spillway. A concrete gravity spillway section with crest level at EL 227 m in the upstream section of the embankment is intended to retain the dam’s storage capacity. The impact of erosion of the large volume of fill from the saddle dam in the event of floods of this magnitude would need to be assessed in greater detail if this proposal is to be considered further as would the potential impact of the increase in flood discharge from the dam in such an event. A concrete retaining wall would be required between the saddle dam and the RCC section at the top of the right bank. Seepage and uplift pressures in the main dam foundation area would be controlled by a cement grout curtain and by drains in the foundation and in the dam wall connecting to a

<table>
<tr><th>PARAMETER</th><th>DESCRIPTION</th></tr>
<tr><td></td><td>gallery. Seepage in the saddle dam foundation area would also be controlled by a conventional grout curtain.
The dam axis and embankment section would be aligned as shown in Figure 4.21. The proposed structural arrangement is shown in Figure 4.22.
Permanent operations and visitor recreation facilities for the dam would be located on the left bank side. A permanent low level culvert river crossing would be provided on the downstream side of the dam to provide access to the right bank area when stream flow conditions permit.
Access to the dam from Georgetown would largely follow the existing property access road branching from the Gulf Development Road on the eastern bank of the Etheridge River. This road would be upgraded to a two lane gravel all weather standard.
Supply would be released to the river for diversion to the irrigation areas. A regulating weir may be required to minimise transmission losses. Detailed consideration of the distribution arrangements in the irrigation areas has not been possible within the scope of this study.</td></tr>
<tr><td>Availability of construction materials</td><td>No investigations have been carried out. Potential quarry sites within ignimbrite and suitable for the production of RCC aggregate are expected to be available within 2 km of the dam site.
Quartz sandstone that may also be suitable for RCC aggregate is located about 4.5 km north of the site. Large quantities of coarse sand are available from the riverbed immediately downstream of the site.</td></tr>
<tr><td>Catchment area</td><td>15,351 km^2</td></tr>
<tr><td>Flow data</td><td>Flow data is available from GS 917109 Einasleigh River at Lake Cawana AMTD 206 km for the period 1968-1988. Over the period,
Maximum recorded annual flow was 8,411,000 ML
Mean annual flow 1,415,000 ML
Median annual flow 500,000 ML
Minimum annual flow 54,000 ML
Flows at the Dagworth dam site would be significantly higher given the larger catchment area at the site.</td></tr>
<tr><td>Storage capacity</td><td>498 GL at FSL 227 m (Figure 4.23).</td></tr>
<tr><td>Reservoir yield assessment</td><td>326 GL at 85% annual time reliability (Figure 4.24 and Figure 4.25)
342 GL at 95% monthly time reliability
Evaporation as percentage of regulated flow (at 85% annual time reliability): 13%
Ratio of evaporation to water supplied (at 85% annual time reliability): 0.15
No assessment of water yield has previously been made at this site.</td></tr>
<tr><td>Open water evaporation</td><td>Mean annual evaporation is estimated to be 4.8 mm d^{-1} using bulk aerodynamic formulae. Mean annual evaporation was estimated to be 5.3 mm d^{-1} using Morton’s APE.</td></tr>
<tr><td>Impacts of inundation to existing infrastructure</td><td>The storage area appears to be predominately grazing country.</td></tr>
<tr><td>Ecological and cultural considerations raised by previous studies</td><td>No previous studies.</td></tr>
<tr><td>Estimated rates of reservoir sedimentation</td><td><table>
<tr><th></th><th>Best case</th><th>Expected</th><th>Worst case</th></tr>
<tr><td>30 years (%)</td><td>0.68</td><td>5.33</td><td>9.63</td></tr>
<tr><td>100 years (%)</td><td>2.26</td><td>17.76</td><td>32.11</td></tr>
<tr><td>Years to infill</td><td>4424</td><td>563</td><td>311</td></tr>
</table></td></tr>
<tr><td>Water quality and stratification considerations</td><td>Dagworth upstream reservoir is predicted to experience persistent thermal stratification with a top-to-bottom temperature change of 6-10 °C during most of the simulation. The risk of blue-green algal blooms is very high with $Z_{sl}:Z_{eu} \leq 3$ at virtually all times and approximately 1 throughout spring and summer.</td></tr>
</table>

PARAMETER	DESCRIPTION
	The water column is predicted to mix on only a few occasions during the simulation. The very long duration of stratification and weak mixing behaviour suggests this storage is susceptible to experiencing profound anoxic conditions and associated water quality issues.
Environmental considerations	This potential dam site has a large catchment area and the Einasleigh River up and downstream of the site has numerous large permanent waterholes (Figure 4.15). Anecdotal evidence also suggests this location is within the distribution of barramundi and freshwater sawfish. A dam in this location would provide a barrier to the upstream and downstream migration of numerous fish species and would therefore require a fish transfer facility. The potential dam would inundate a mixture of dominant "Of Concern", "Not of Concern" and "Non-remnant" regional ecosystem. Figure 4.26 shows that about one quarter of the surface is likely to cover regional ecosystems 'Of Concern'. *Ecosystems Of Concern* The site covers mixed woodland to open-woodland dominated by *Eucalyptus leptophleba* but also combinations of the species *E. platyphylla*, *Corymbia clarksoniana*, *E. crebra*, *C. tessellaris*, *Erythrophleum chlorostachys*, *C. grandifolia* and *C. polycarpa*. An open sub-canopy dominated by canopy species often occurs. A mid-dense shrub layer of *Melaleuca spp*., *Planchonia careya*, *Carissa lanceolata* and juveniles of canopy species occur. The mid-dense to dense ground layer is dominated by *Heteropogon spp*., *Themeda triandra* and *Sarga plumosum*. There are also riverine wetland or fringing riverine wetland. Sandy river beds sometimes with patches of ephemeral grassland, herbland or sedgeland, which can include *Heteropogon contortus*, *Bothriochloa spp*., and *Ammannia multiflora*. There can be clumps of shrubs (or isolated emergents), which can include *Lophostemon grandiflorus*, *Melaleuca spp*., *Eucalyptus camaldulensis* and *Casuarina cunninghamiana*.
Indigenous cultural heritage considerations	At present there is no Indigenous Cultural Heritage body for the area. There are two Indigenous Parties: • Ewamian People #2 (QC99/13 - QUD6009/99), • Ewamian People #3 (QC01/16 - QUD6018/01). There are no sites listed in the DATSIMA database. No previous archaeological reporting relating specifically to the Dagworth area has been located. However, results of investigations in the catchment more generally indicate that the area is likely to have high archaeological potential. Further investigation, including archaeological survey, would be required to assess the potential Indigenous archaeological impact of works in the area. Any such investigation should be undertaken in consultation with the Indigenous Parties. Should works proceed in this area, it is recommended that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding contemporary use of water sources in the area.
Estimated cost	The capital cost of the dam is estimated to be $474 million not including the cost of any downstream distribution works (likely cost range is $430 m to $620 m). Annual operating and maintenance costs are likely to be relatively low for the type of dam proposed although the site is remote from service centres. An annual allowance of 0.4% of capital cost, that is some $1.9 million is likely to be necessary to cover normal costs. In the event of an extreme event (greater than 1:1000 AEP) causing erosion of the right bank saddle dam, major costs would be involved in reconstructing the saddle dam and in managing any scour damage.
Estimated cost / ML of supply	$1450/ML water supply at the dam wall in 85% of years (does not include transmission/distribution losses or take into account environmental and downstream entitlements).
Summary comment	Although the site is remote from transport and other infrastructure and is located about 50 km upstream of likely areas of irrigation, it offers less complex geological conditions, better storage characteristics, higher yield potential and is closer to areas of land considered to be potentially suitable for irrigation compared to alternative sites on the Einasleigh River.

Figure 4.17 Dagworth upstream dam site looking upstream
Photo: CSIRO

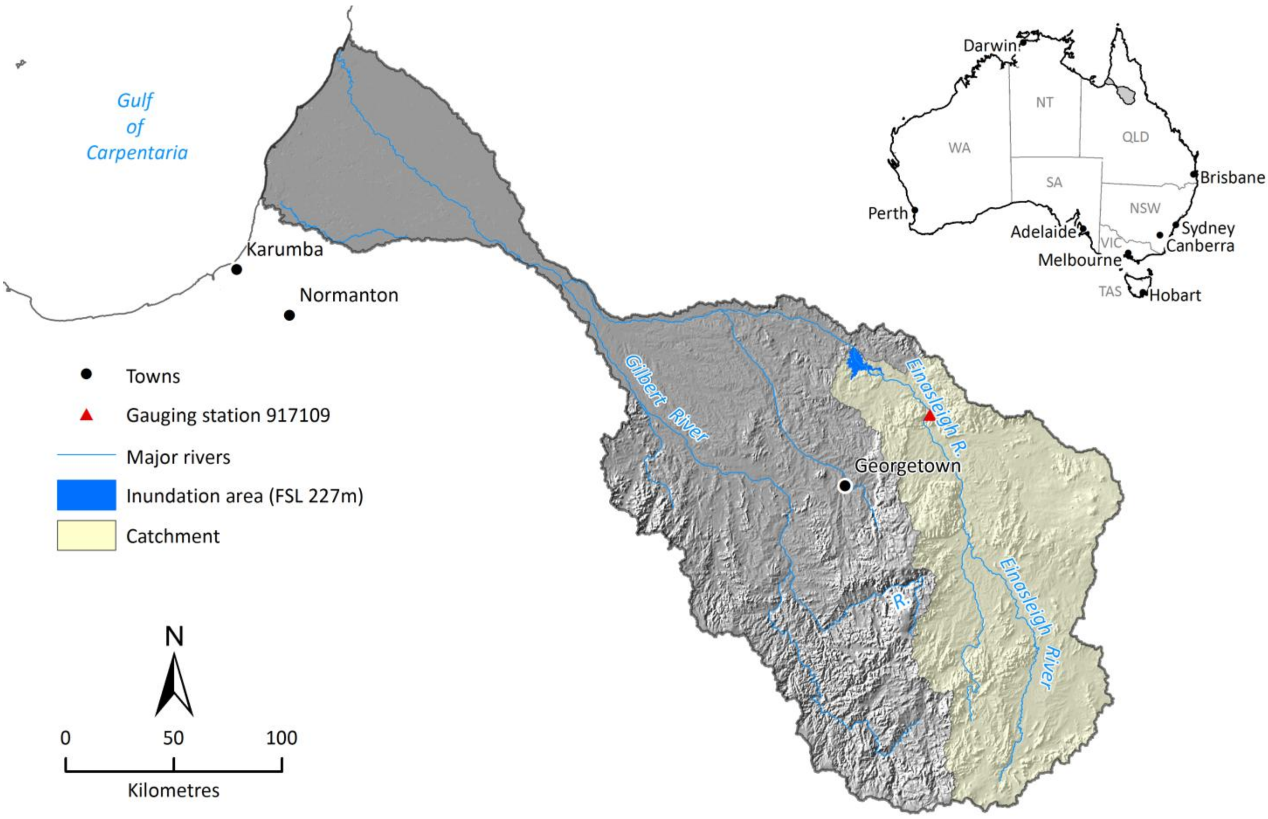


Figure 4.18 Location map of Dagworth upstream dam, reservoir and catchment area

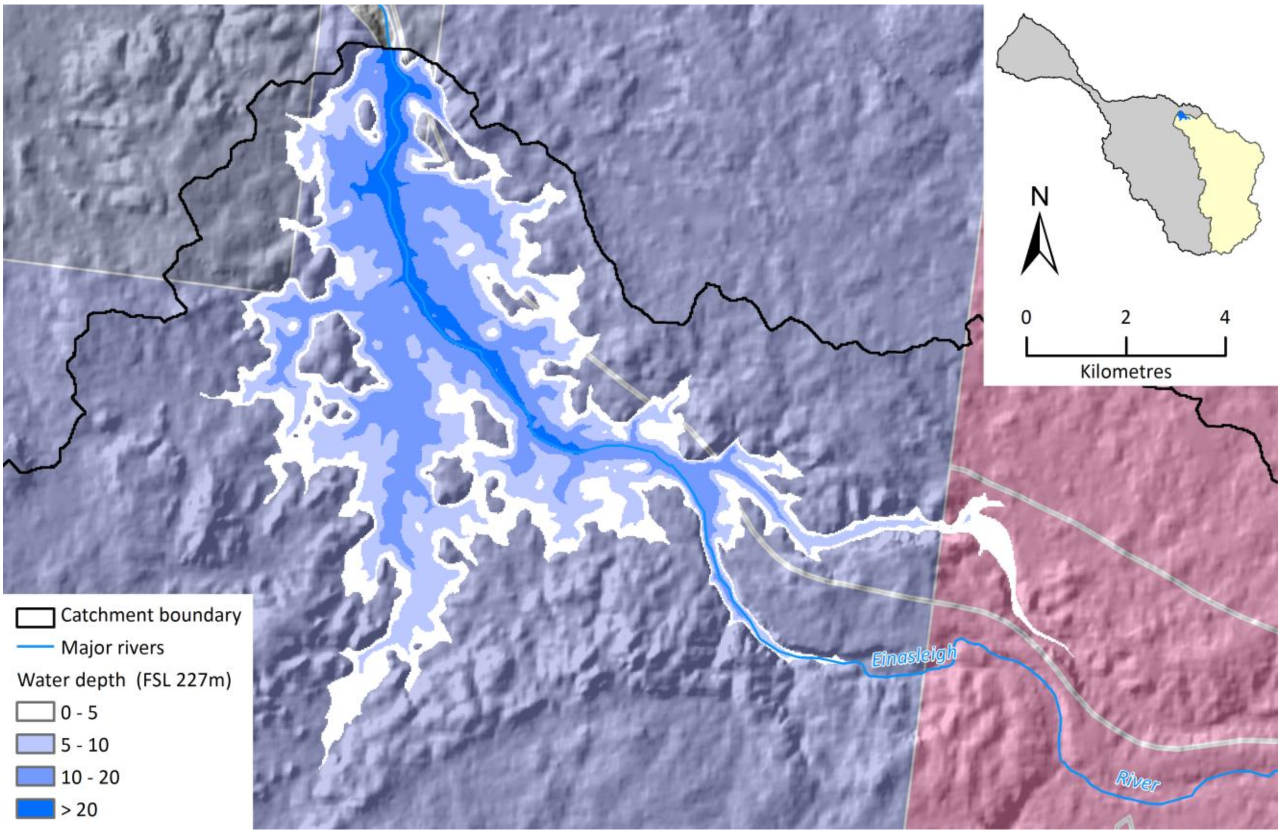


Figure 4.19 Dagworth upstream dam depth of inundation and property boundaries (indicated by coloured shading)

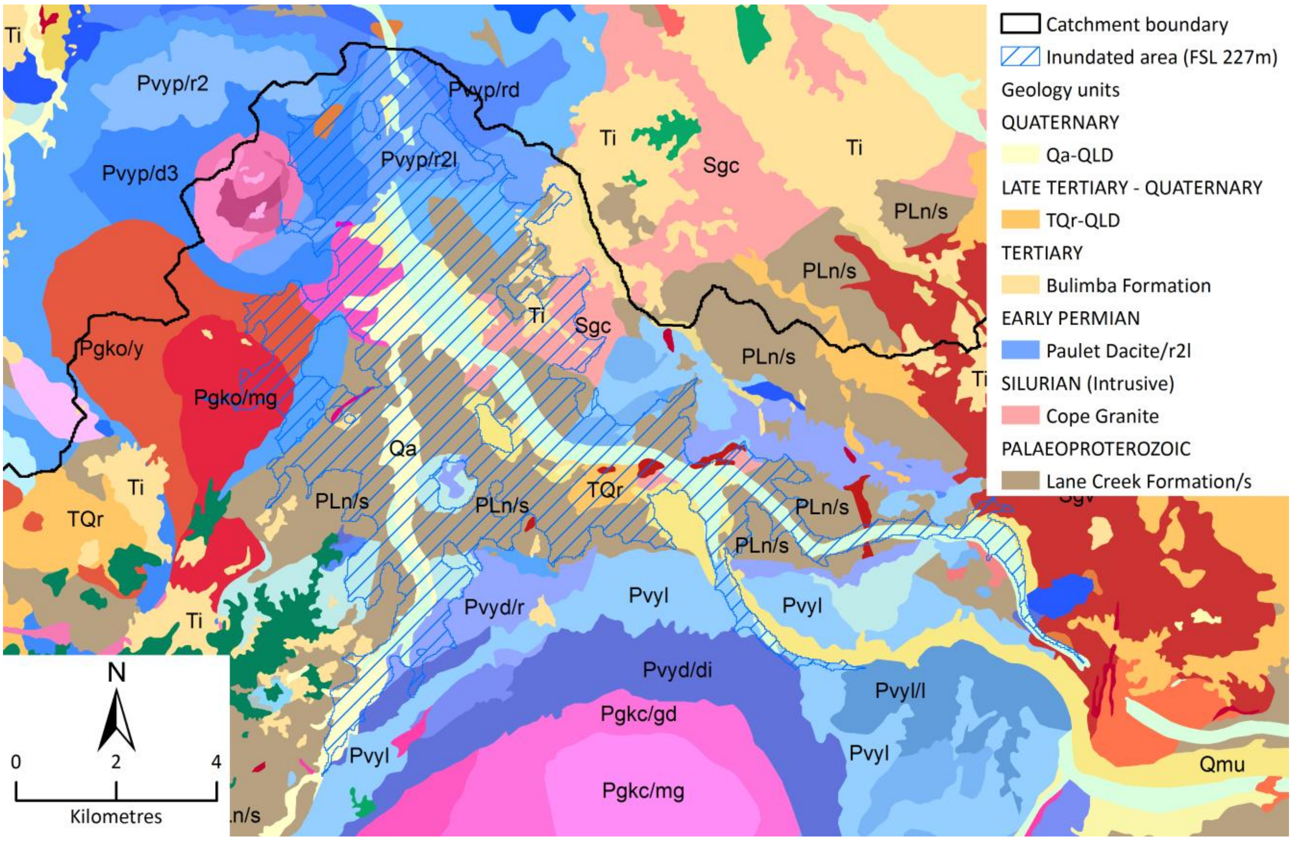


Figure 4.20 Dagworth upstream dam underlying geology

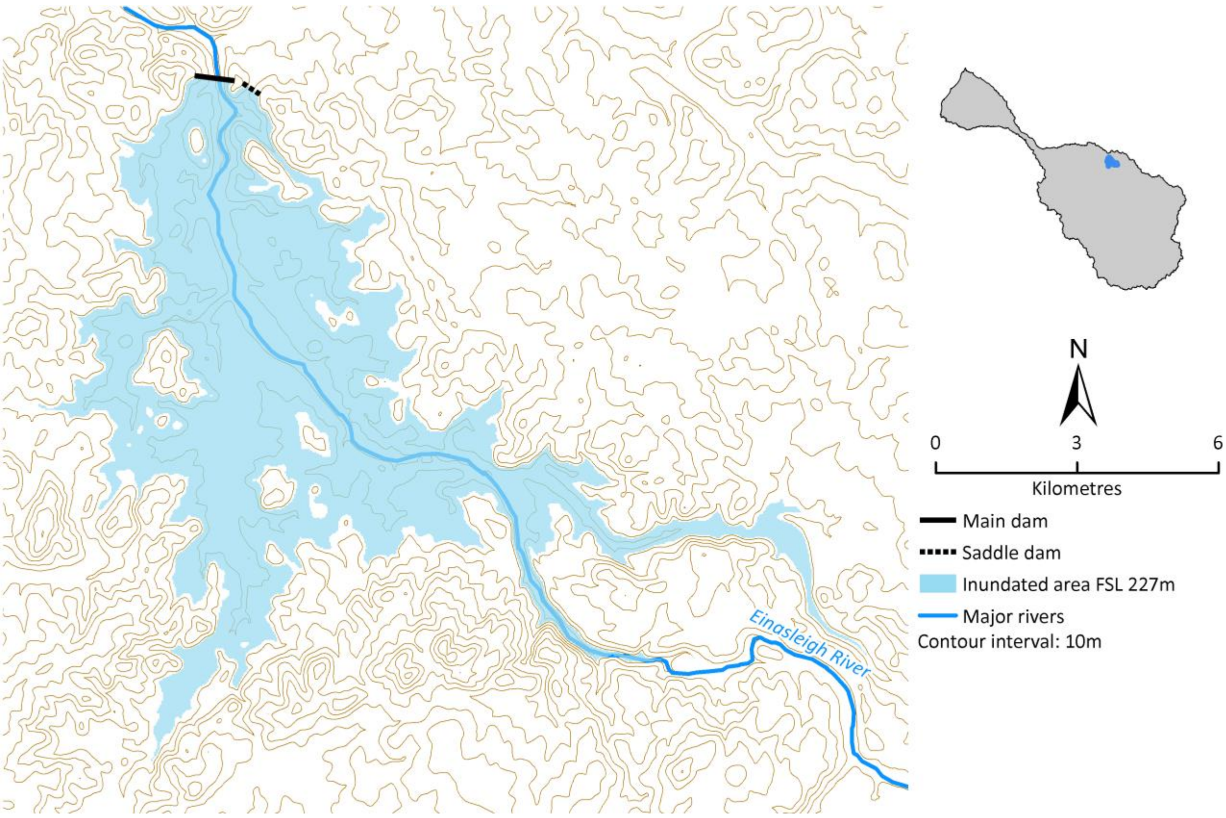


Figure 4.21 Location map for the Dagworth storage

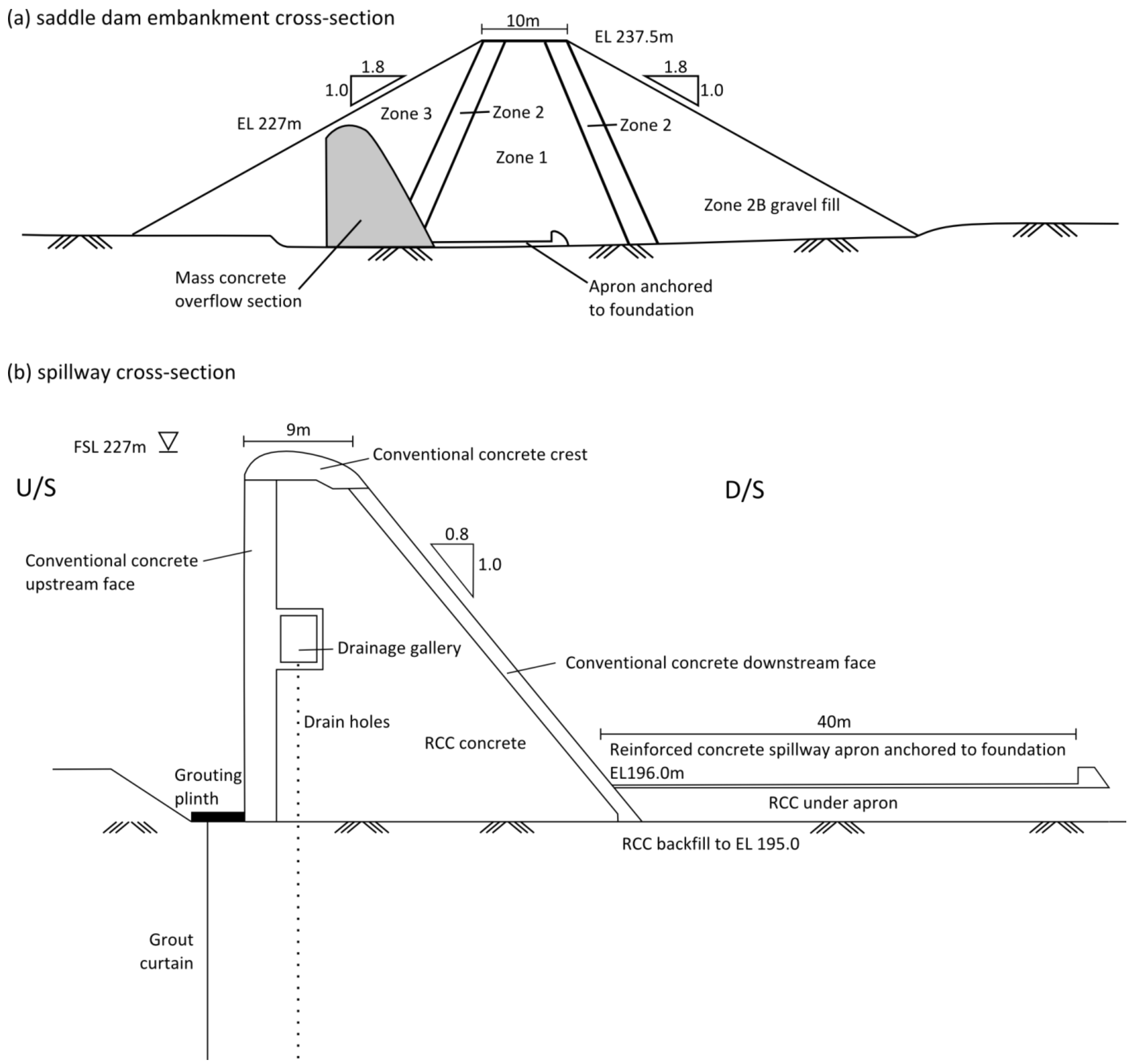


Figure 4.22 Embankment and spillway cross-sections for Dagworth dam

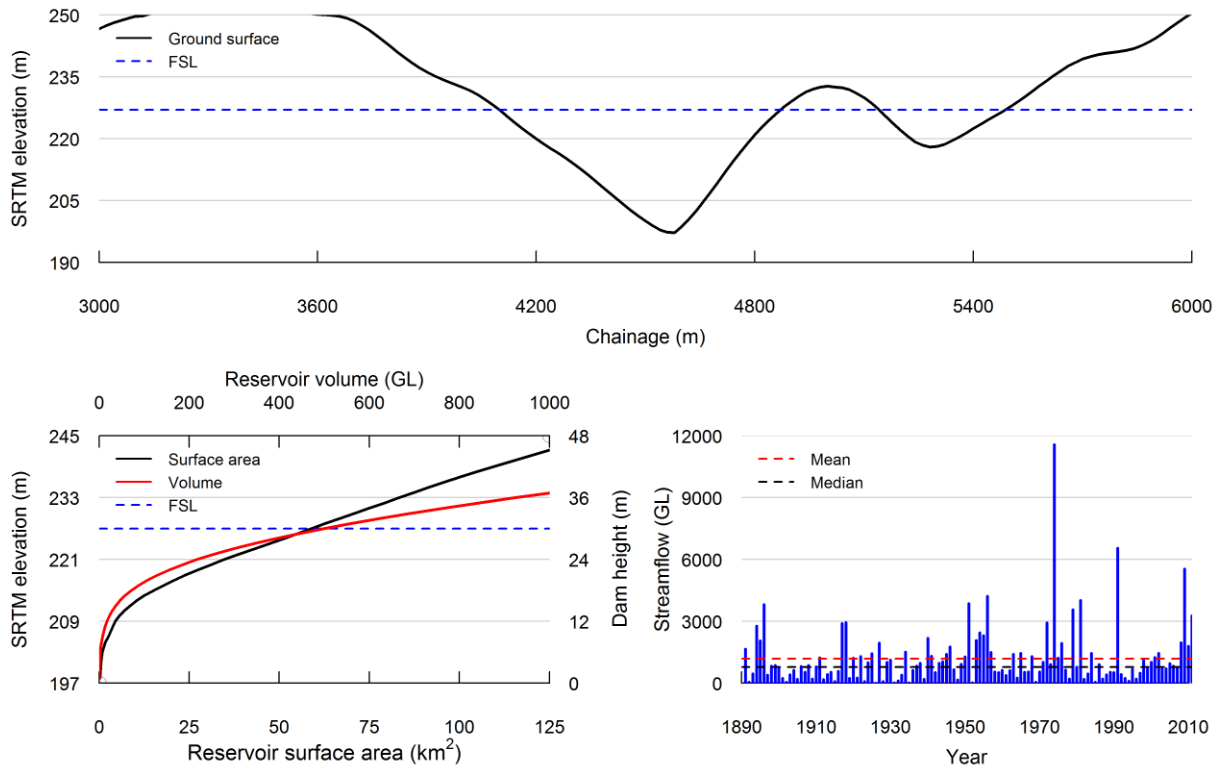


Figure 4.23 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Dagworth upstream dam site

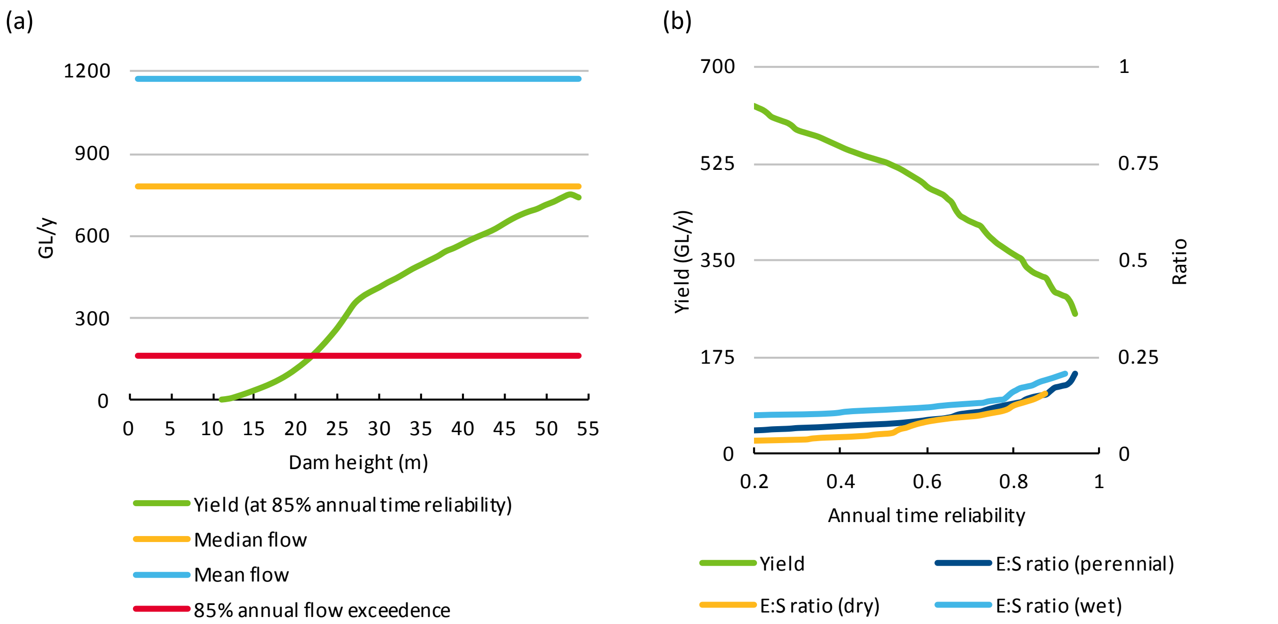


Figure 4.24 (a) Yield at 85% annual time reliability and streamflow at Dagworth dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Dagworth dam site for different annual time reliability for the selected dam height of 30 m

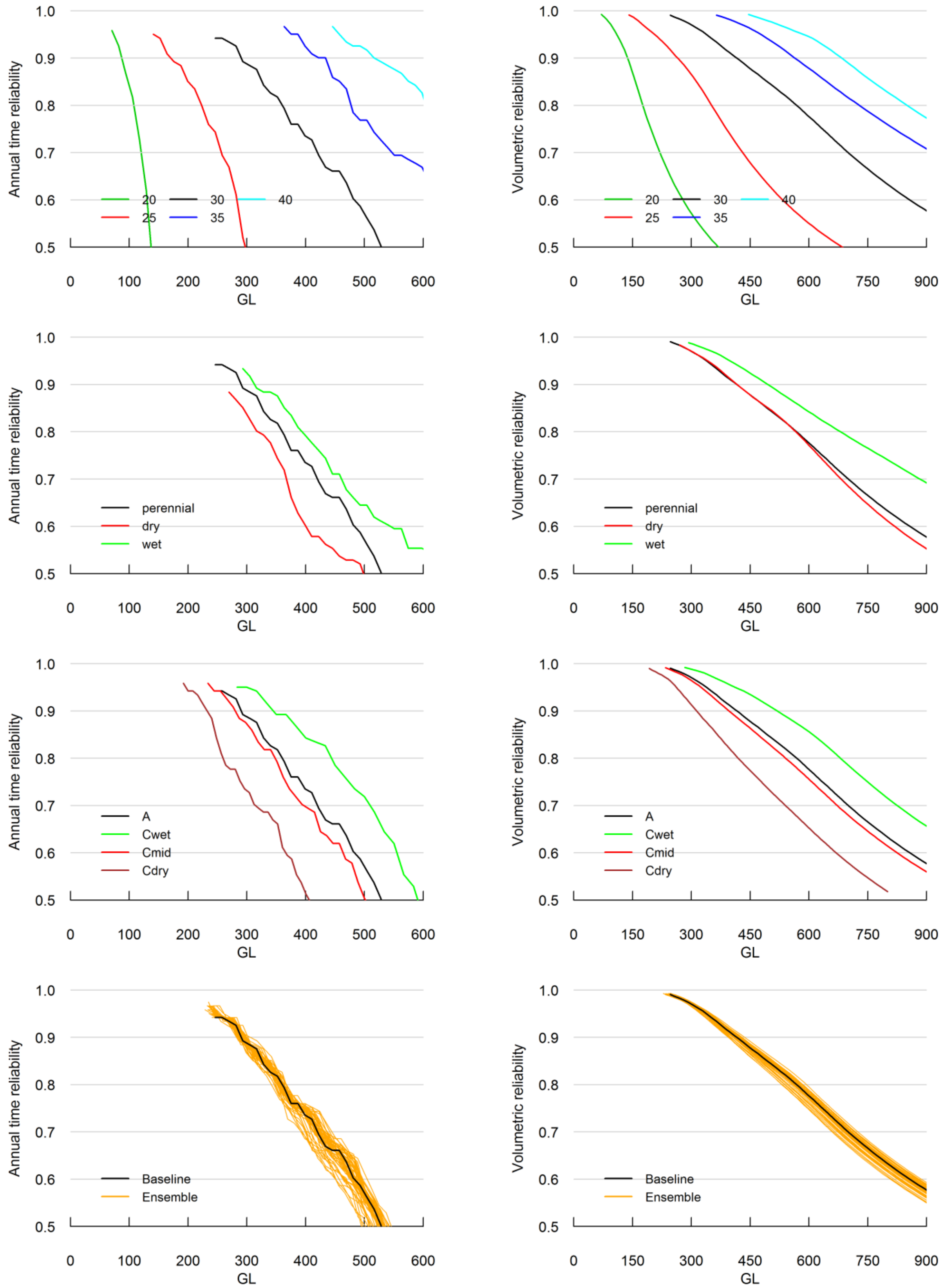


Figure 4.25 Dagworth upstream dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: SYR for different FSL. Second row: YRR for different demand patterns for 227 m FSL. Third row: YRR under Scenario C for 227 m FSL. Fourth row: YRR for baseline and ensemble model runs for 227 m FSL

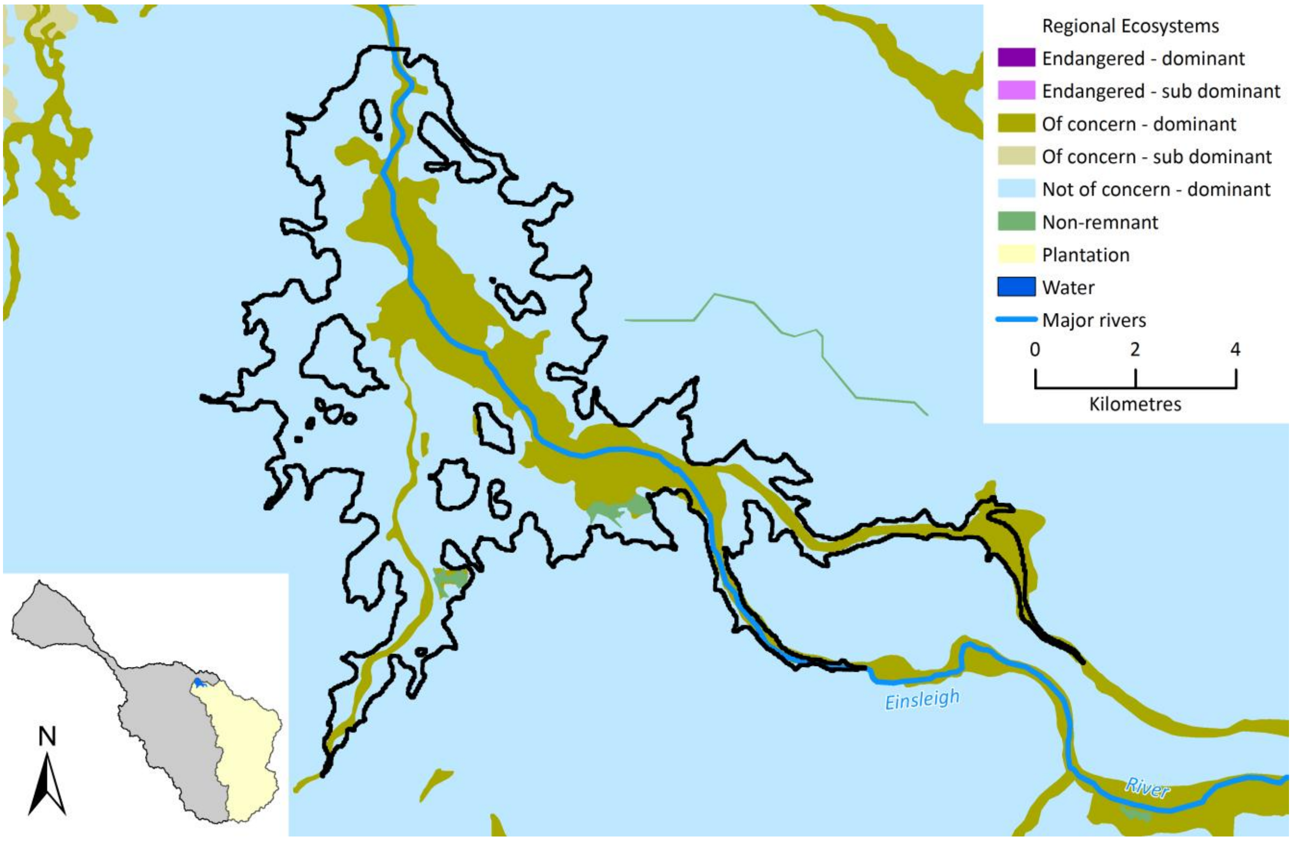


Figure 4.26 Regional ecosystems inundated by the potential Dagworth dam reservoir at full supply level

4.4.2 GREEN HILLS DAM SITE ON GILBERT RIVER; 371.6 KM

PARAMETER	DESCRIPTION
Previous investigations	DNR (1998a) Engineering Assessment of Storage Options. Feasibility Studies for Dams and Weirs on Bundock Creek and Gilbert River. DNR (1998b) Exploratory Drilling Program – Gilbert River Bed Sand Investigation. DNR (1999). Preliminary Geotechnical Assessment of Dams & Weir Sites on Bundock Creek & Gilbert River. DNRM (2001). Natural Resource Assessment and Water Infrastructure Planning Study, Gulf Region. DNRW (2004). Agricultural Land and Water Resource Assessment Report Gulf and Mitchell Water Resource Planning. DNRW (2006a). Economic and Social Assessment Report, Gulf Water Resource Planning. DNRW (2006b). Ecological and Geomorphological Assessment Report, Gulf Water Resource Planning.
Description of proposal	The preferred Green Hills damsite is at AMTD 371.6 km (previously 338.6 km) on the Gilbert River and is about 30km south west of Georgetown. The site and storage area were surveyed by aerial photography in 1999 as was an alternative site at previous AMTD 333.6 km. The proposal is for an on river storage to supply water for an irrigation development on land upstream and downstream of the Gulf Development Road bridge, where a number of landholders have in recent years developed irrigation enterprises based on extracting water from the river bed sands. A regulating weir was proposed at Rockfields. The height of the dam spillway was selected to be 20 m above bed level (FSL 253 m) as this was deemed to be the optimal dam height without excessively large saddle dam requirements, and accounting for flood storage rise (which was not assessed in previous studies). A photograph of the site is shown in Figure 4.27. A location map and map showing the inundated area at FSL are shown in Figure 4.28 and Figure 4.29 respectively.
Regional geology	Rock at the dam site belongs to the Namul Dacite, part of the Cumberland Range Volcanic Group. This is one of a number of major volcanic fields extending from Mornington Island to Townsville in North Queensland. They are dominated by thick piles of dacitic to rhyolitic ignimbrites and some lavas. The rocks are of Carboniferous to Permian age and are little disturbed by deformation. The outcrop area of the volcanic field is elliptical in shape and probably indicates a caldera related origin. Figure 4.30 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	The dam site has been investigated by limited surface mapping and seismic traverses. Slightly weathered high strength ignimbrite belonging to the Namul Dacite outcrops on both abutments at the dam site. The river bed is about 200 m wide and composed of sand and gravel. Investigations reported by DNR (1998b, 1999) above suggest that the depth of loose sand at the site might be about 2 m overlying some 10 m of intermediate velocity material, possibly saturated gravelly alluvium. Below this level seismic velocity is high indicating slightly weathered to fresh rock. At the downstream weir site, low to medium strength sandstone is reported to outcrop on the right abutment whereas the river bed and left abutment comprise alluvial materials. Based on the available information, it is expected that some 12 m of sand and gravel will need to be excavated across the river bed to reach a rock foundation and that a nominal 1.5 m of excavation will be required on the abutments.
Reservoir rim stability and leakage potential	Materials on the reservoir rim range from high strength ignimbrite to sandstone, mudstone and siltstone of the Etheridge Group of Proterozoic age. Although the ignimbrite forms steep slopes, its strength and structure is such that these slopes are stable. Slopes in the sandstones and mudstones are relatively gentle and are unlikely to become unstable on filling of the reservoir. There is potential for leakage from an area of Tertiary and Quaternary outwash fan deposits

PARAMETER	DESCRIPTION
	on the right bank in the vicinity of Western Creek about 5 km from the main dam. This area should be investigated should this proposal be considered further.
Proposed structural arrangement	A concrete gravity dam of RCC construction with central overflow spillway 20 m above river bed level is proposed for the dam wall. Conventional concrete would be placed on the upstream face of the spillway and abutment sections and on the downstream face of the spillway section forming a smooth profile. Twin large diameter conduits would be located at the toe of the right abutment to provide for diversion during construction and for installation of permanent river outlets. An intake tower anchored to upstream face of the dam would provide for selective withdrawal from the storage and for maintenance of the outlets. A bi-directional fish lift type transfer facility similar to that recently installed at Wyaralong Dam would also be located on the right abutment. The dam axis and embankment sections would be aligned as shown in Figure 4.31. The proposed structural arrangement of the potential Green Hills dam is shown in Figure 4.32. Seepage and uplift pressures in the main dam foundation area would be controlled by a foundation cement grout curtain and by drains in the foundation and dam wall connecting to a gallery. Four saddle dams will be required to contain the storage during flood events. Three of the saddle dams will be on the left bank side and the other on the right bank side. The three larger saddle dams are proposed to be of earth and rockfill type construction, the largest being 2400 m long with a maximum height of some 10 m. Foundation cement grouting is proposed to control seepage under the higher sections of the three larger saddle dams. Crest level of saddle dam Number 2 would be set at a level (EL 264.5 m) to contain the critical duration 1 in 1000 year AEP peak flood level and would be expected to fail in the event of more extreme floods to create an auxiliary spillway. Crest level of saddle dam Number 3 would be 0.5 m higher and would also be expected to fail in the event of a more extreme flood event again to increase the auxiliary spillway discharge capacity. Crest level of saddle dams Number 1 and 4 and of the main dam embankments would be at EL 265.5m and expected to contain the PMF peak flood level. The viability of this arrangement will need to be confirmed by further analyses should this proposal be advanced further. Any impact of the discharges through saddle dams Number 2 and 3 would also need to be assessed. Permanent operations and visitor recreation facilities for the dam would be located on the right bank side. A permanent low level culvert river crossing would be provided on the downstream side of the dam to provide access to the left bank area when stream flow conditions permit. Access to the dam from Georgetown would largely follow the existing property access road branching from the Gulf Development Road on the eastern bank of the Gilbert River. This road would be upgraded to a 2 lane gravel all weather standard. The dam site is probably suitable for an EB or a RCC dam. Given spillway and energy dissipation requirements, an RCC dam is likely to be preferred. DNR (1998a) describes the Rockfields weir site as having up to 32 m of sands and gravel in the river bed overlying silty clays with some sandstone outcrop on the right bank. Although there have been no surveys of the potential storage area, it has been assumed that a weir 5-10 m high would store some 5,000 to 10,000 ML of waer. A site inspection of the area in November 2012 suggests that weir development would be limited to 5m or less in height. A stepped steel sheet piling weir appears to be the most suitable type. DNR (1998a) describes an alternative weir site 4 km upstream of the Prestwood homestead. This site is only 17 km downstream of the Green Hills dam site and at the upstream limit of the potentially irrigable land and therefore not as well located as a regulating weir further downstream. However, DNR (1998) assumes that a reinforced concrete weir could be constructed on rock at this site to a crest level 8m above bed level. Again, there has been no survey at this site.
Availability of construction materials	No site investigations have been carried out. Quarry sites suitable for the production of RCC aggregate and rockfill material for the saddle

<table>
<thead>
<tr><th>PARAMETER</th><th>DESCRIPTION</th></tr>
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<tbody>
<tr><td></td><td>dams should be available within 2 km of the dam site. Sand from the riverbed and adjacent river terraces would be available for augmenting the crushed rock product to produce a suitable mix.</td></tr>
<tr><td>Catchment area</td><td>The catchment area is 8310 km^2.

The catchment area at the Rockfields potential weir site is approximately 10,900 km^2.</td></tr>
<tr><td>Flow data</td><td>The nearest gauging station is at Rockfields AMTD 276 km, (some 63 km downstream of the dam site) record from January 1967 to current;

Mean annual flow at the Rockfields GS, catchment area 10,900 km ^{2}, over the period of record is 1,106,000 ML

Median annual flow at the G.S. is 582,800 ML. Minimum annual flow recorded over the period was 175,000 ML.</td></tr>
<tr><td>Storage capacity</td><td>227 GL at FSL 253 m (Figure 4.33).

A storage capacity curve for the weir site has not been developed.</td></tr>
<tr><td>Reservoir yield assessment</td><td>172 GL at 85% annual time reliability (Figure 4.34 and Figure 4.35).
189 GL at 95% monthly time reliability

Evaporation as percentage of regulated flow (at 85% annual time reliability): 18%
Ratio of evaporation to water supplied (at 85% annual time reliability): 0.2

<u>Previous studies</u>

Analyses by DERM (2001) using the WRP IQQM hydrologic model indicate that the dam/weir system could supply water at the weir as follows (assuming 20% transmission losses between the dam and the weir storage):

• Dam capacity 300,000 ML – 100,000 ML/a supply at 90% annual reliability.
• Dam capacity 260,000 ML – 100,000 ML/a supply at 85% annual reliability.
• Dam capacity 60,000 ML - 20,000 ML/a supply at 85% reliability.</td></tr>
<tr><td>Open water evaporation</td><td>Mean annual evaporation is estimated to be 4.9 mm d^{-1} using the bulk aerodynamic formulae.
Mean annual evaporation was estimated to be 5.3 mm d^{-1} using Morton’s APE.</td></tr>
<tr><td>Impacts of inundation to existing property and infrastructure</td><td>An area of approximately 5100 ha of mostly grazing land would need to be acquired for the dam storage area.</td></tr>
<tr><td>Ecological and cultural considerations raised by previous studies</td><td>Regional ecosystems on the right bank of the Gilbert downstream of Prestwood station are described in section 6.3 of Ref. 6 above.</td></tr>
<tr><td>Estimated rates of reservoir sedimentation</td><td><table>
<tr><td></td><td>Best case</td><td>Expected</td><td>Worst case</td></tr>
<tr><td>30 years (%)</td><td>0.63</td><td>4.48</td><td>8.91</td></tr>
<tr><td>100 years (%)</td><td>2.09</td><td>14.94</td><td>29.71</td></tr>
<tr><td>Years to infill</td><td>4781</td><td>669</td><td>337</td></tr>
</table></td></tr>
<tr><td>Water quality and stratification considerations</td><td>The Green Hills upstream reservoir is predicted to experience persistent thermal stratification with a top-to-bottom temperature difference of about 5 °C during most of the year from mid-September to mid-May. However, summer inflow events in February and May appear to cause short-term deep mixing of the water column. The risk of blue-green algal blooms is moderate to high with Zsl:Zeu approximately 1 during summer and from 2 to 3 during spring.

The water column is predicted to be poorly mixed during periods of stratification each year when dissolved oxygen concentrations fall. Inflow-induced deep mixing during summer inflows is expected to resupply oxygen to the deeper waters and low dissolved oxygen with associated nutrient and metal releases from the sediments is less likely to be experienced in most years in the Green Hills reservoir than in reservoirs not experiencing summer mixing events.</td></tr>
</tbody>
</table>

PARAMETER	DESCRIPTION
Environmental considerations	This potential dam site captures a large catchment area and a large inundation area. This site on the Gilbert River hosts much less instream habitat than similarly-located dam options on the Einasleigh River (Figure 4.15). Anecdotal evidence also suggests this location is within the distribution of barramundi and possibly freshwater sawfish. A dam in this location may thus therefore require a fish transfer facility. Figure 4.36 indicates that about half of the area inundated by the potential Green Hills reservoir is likely to comprise “Of Concern” regional ecosystems. *Ecosystems Of Concern* Both the upstream and downstream dam sites are likely to inundate mixed woodland to open-woodland dominated by *Eucalyptus leptophleba* but also including combinations of the species *E. platyphylla*, *Corymbia clarksoniana*, *E. crebra*, *C. tessellaris*, *Erythrophleum chlorostachys*, *C. grandifolia* and *C. polycarpa*. An open sub-canopy dominated by canopy species often occurs. An absent to a mid-dense shrub layer of *Melaleuca spp*., *Planchonia careya*, and *Carissa lanceolata*. The mid-dense to dense ground layer is dominated by *Heteropogon spp*., *Themeda triandra* and *Sarga plumosum*. The sandy river bed channels include patches of ephemeral grassland, herbland or sedgeland, which can include *Heteropogon contortus*, *Bothriochloa spp*., and *Ammannia multiflora*. There can be clumps of shrubs (or isolated emergents), which can include *Lophostemon grandiflorus*, *Melaleuca spp*., *Eucalyptus camaldulensis* and *Casuarina cunninghamiana*.
Indigenous cultural heritage considerations	At the time of writing there is no Indigenous Cultural Heritage body for the Green Hills area. There are three Indigenous Parties: • Ewamian People #2 (QC99/13 - QUD6009/99), • Ewamian People #3 (QC01/16 - QUD6018/01), • Tagalaka People #2 (QC01/22 DET - QUD6020/01). Part of the area has no Indigenous Party at present. There are no sites listed in the DATSIMA database. No previous archaeological reporting relating specifically to the area has been located. However, results of investigations in the catchment more generally indicate that the area is likely to have high archaeological potential. Further investigation, including archaeological survey, would be required to assess the potential Indigenous archaeological impact of works in this area. Any such investigation should be undertaken in consultation with the indigenous Parties and other relevant Indigenous stakeholders. Should works proceed in this area, it is recommended that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding contemporary use of water sources in the area.
Estimated cost	The capital cost of the dam is estimated to be $335 million not including the cost of any downstream distribution works (the likely cost range $300 m to $435 m). Annual operating and maintenance costs are likely to be relatively low for the type of dam proposed although the site is remote from major service centres. An annual allowance of 0.4% of capital cost, that is some $1.34 million is likely to cover normal costs. In the event of an extreme event (greater than 1:1000 AEP) causing erosion of the left bank saddle dams, major costs would be involved in reconstructing the saddle dams and in managing any scour damage.
Estimated cost / ML of supply	$1950/ML water supply at the dam wall in 85% of years (does not include transmission/distribution losses or take into account environmental and downstream entitlements).
Summary comment	Subject to determining that an adequate foundation is available across the river bed, dam construction at the Green Hills site appears to be technically feasible with sound foundations being available on both abutments.

Figure 4.27 Green Hills upstream dam site looking upstream

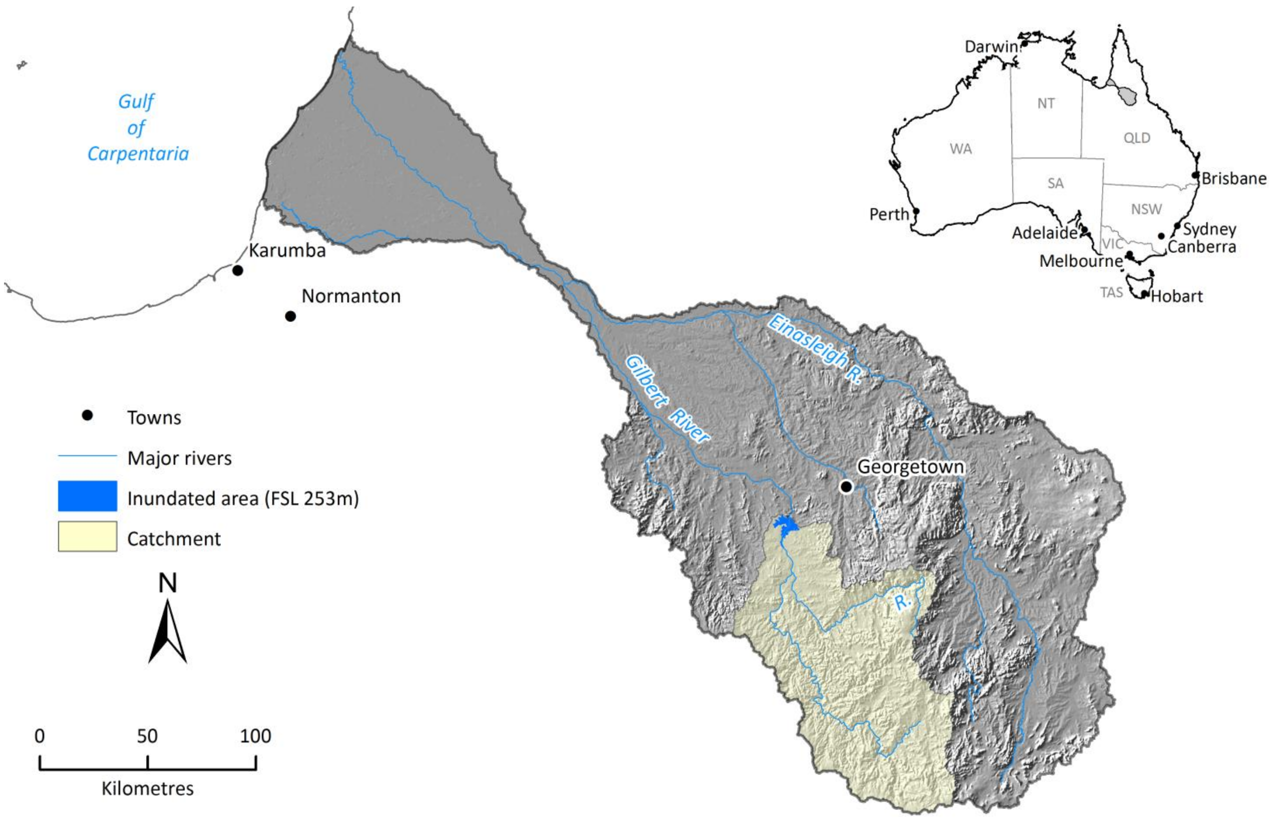

Figure 4.28 Location map of Green Hills upstream dam, reservoir and catchment area

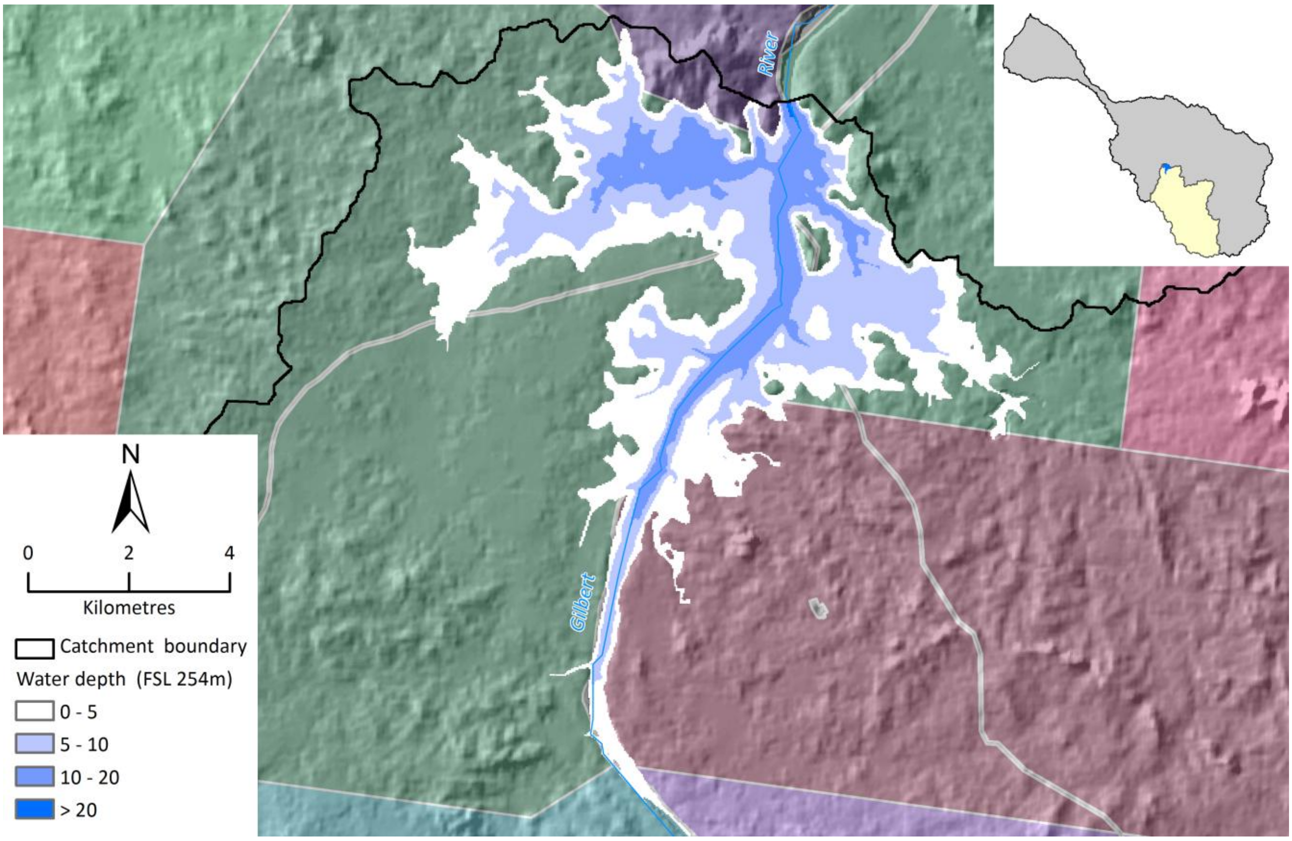

Figure 4.29 Green Hills upstream dam depth of inundation and property boundaries (indicated by coloured shading)

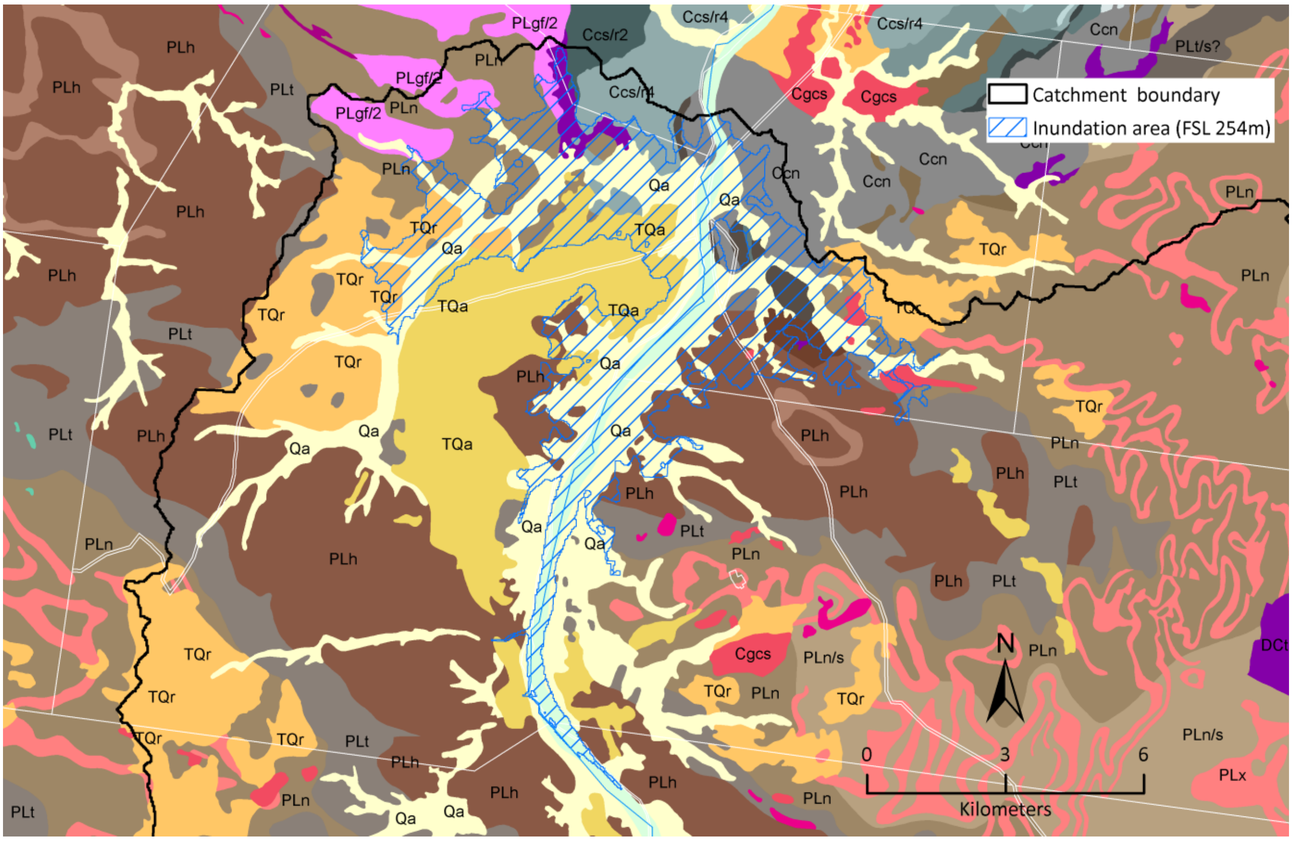

Figure 4.30 Green Hills upstream dam underlying geology

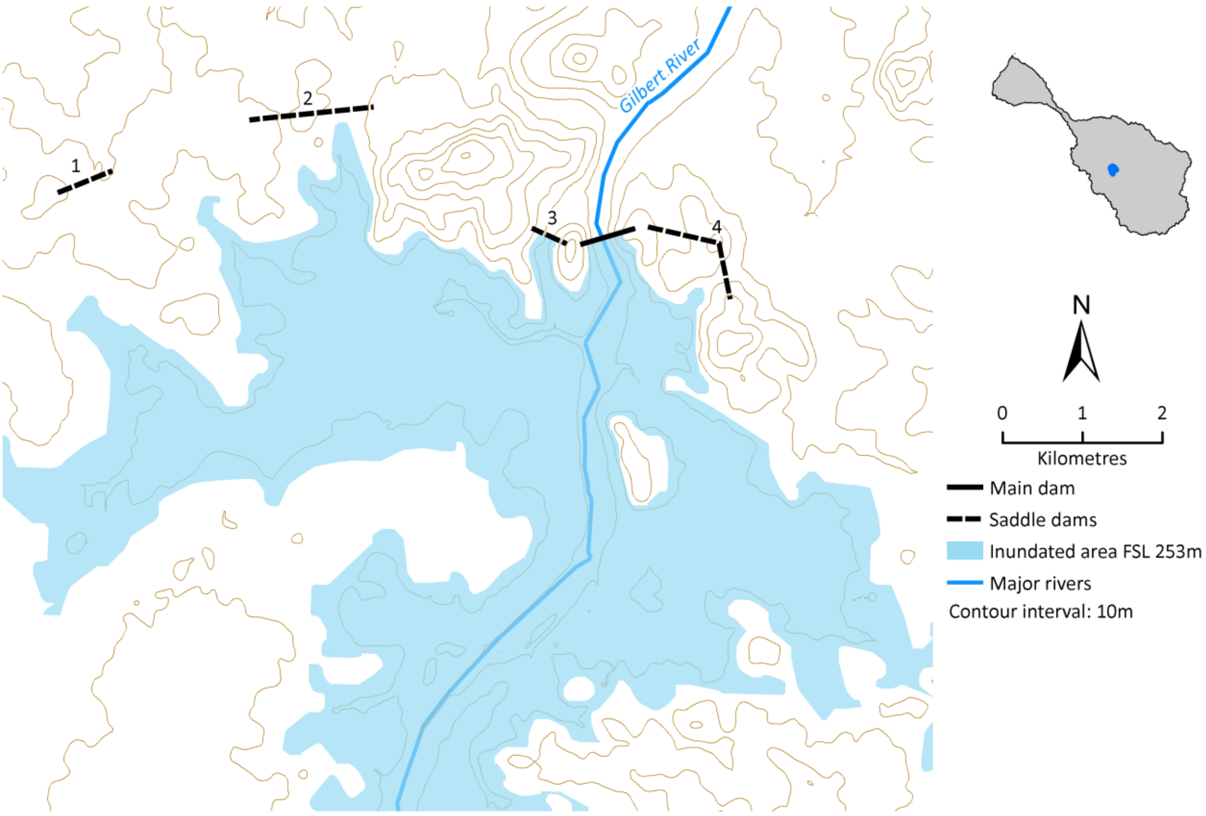

Figure 4.31 Location map of the Green Hills upstream dam site

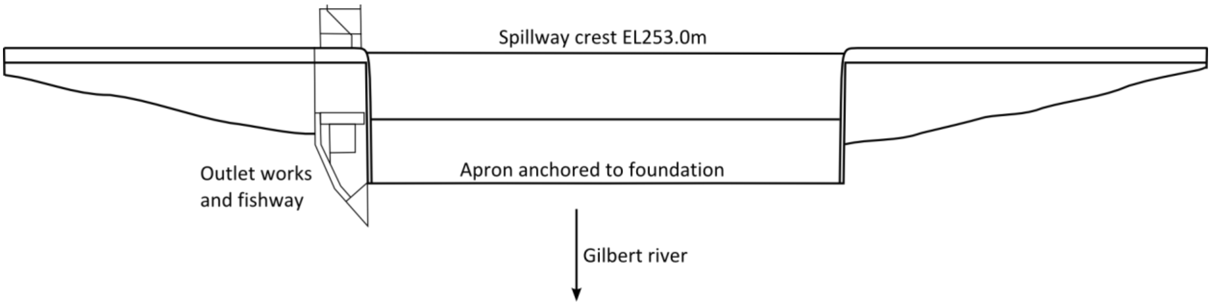

Figure 4.32 Plan of the Green Hills upstream dam site

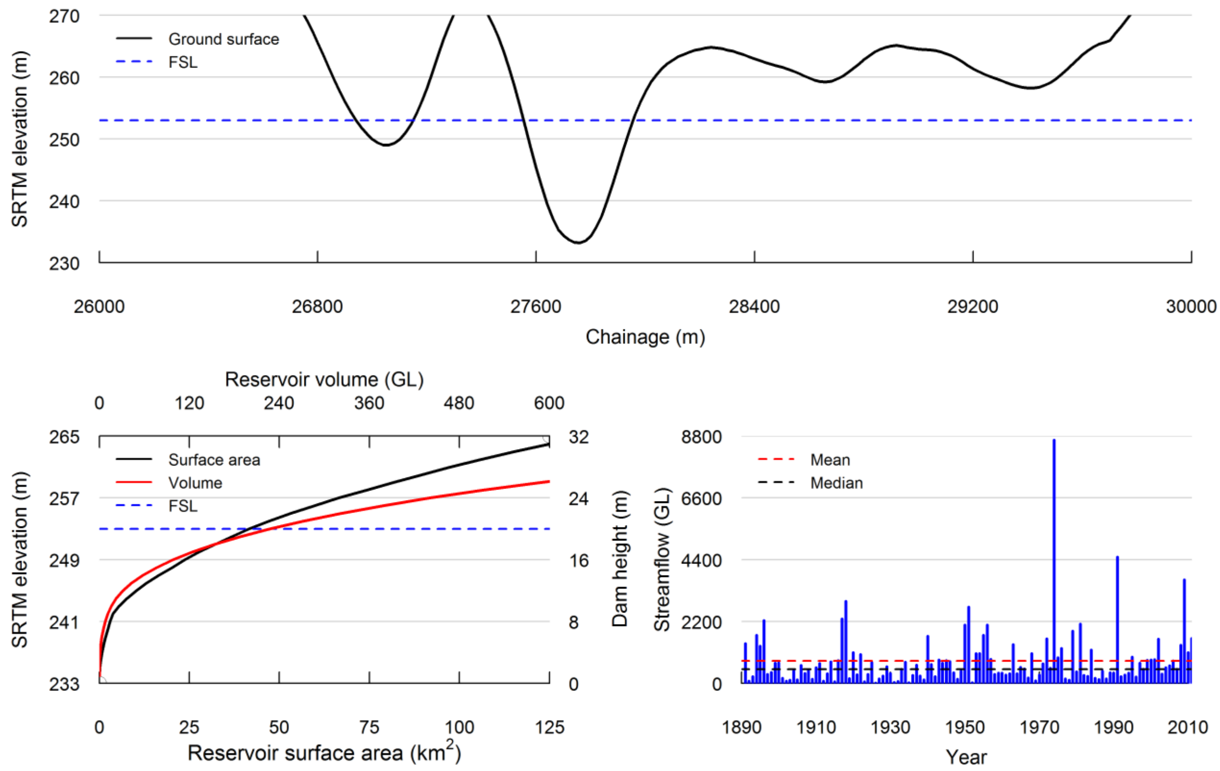

Figure 4.33 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Green Hills upstream dam site

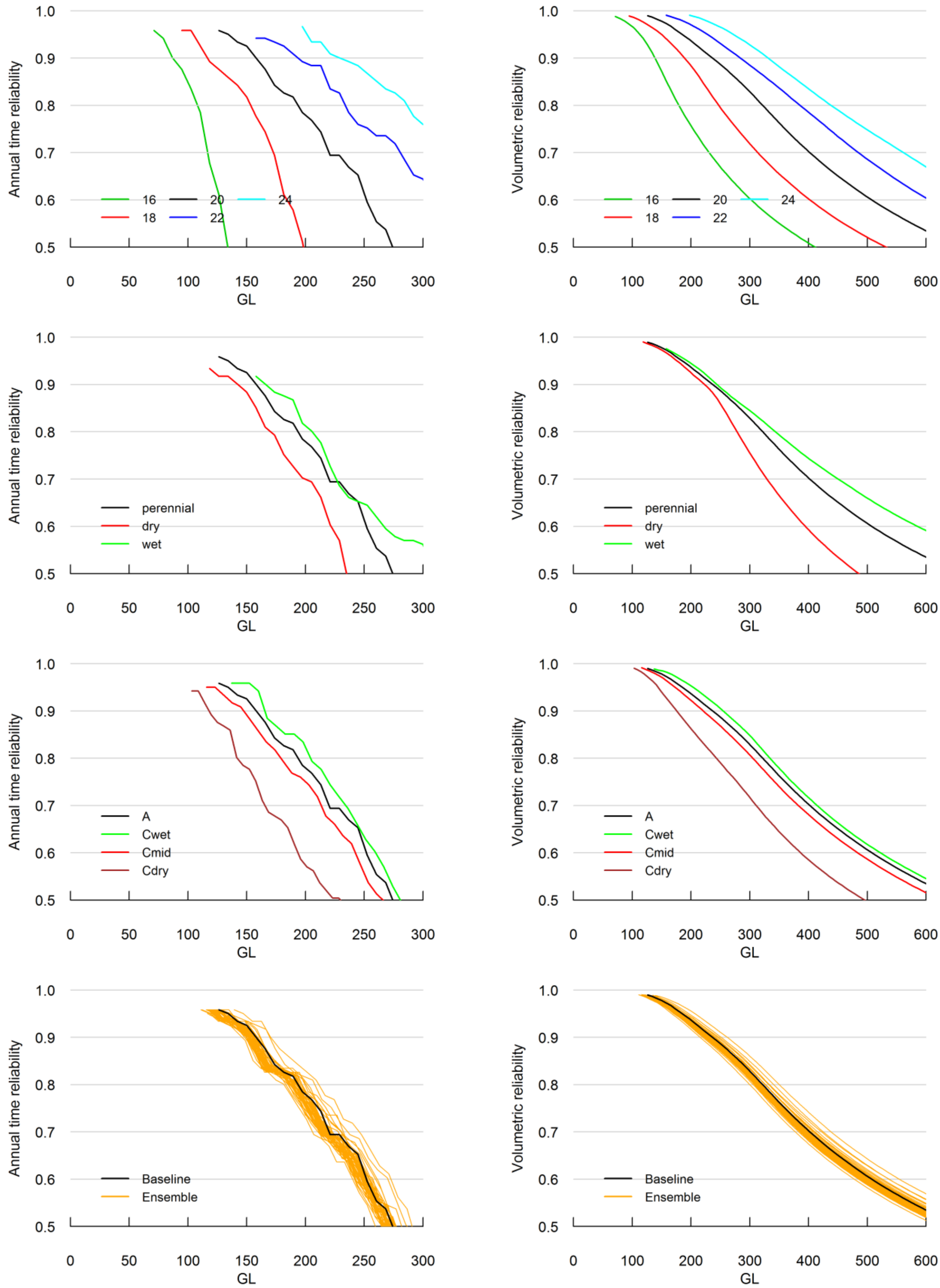

Figure 4.34 Green Hills upstream dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 253 m FSL. Third row: YRR under Scenario C for 253 m FSL. Fourth row: YRR for baseline and ensemble model runs for 253 m FSL

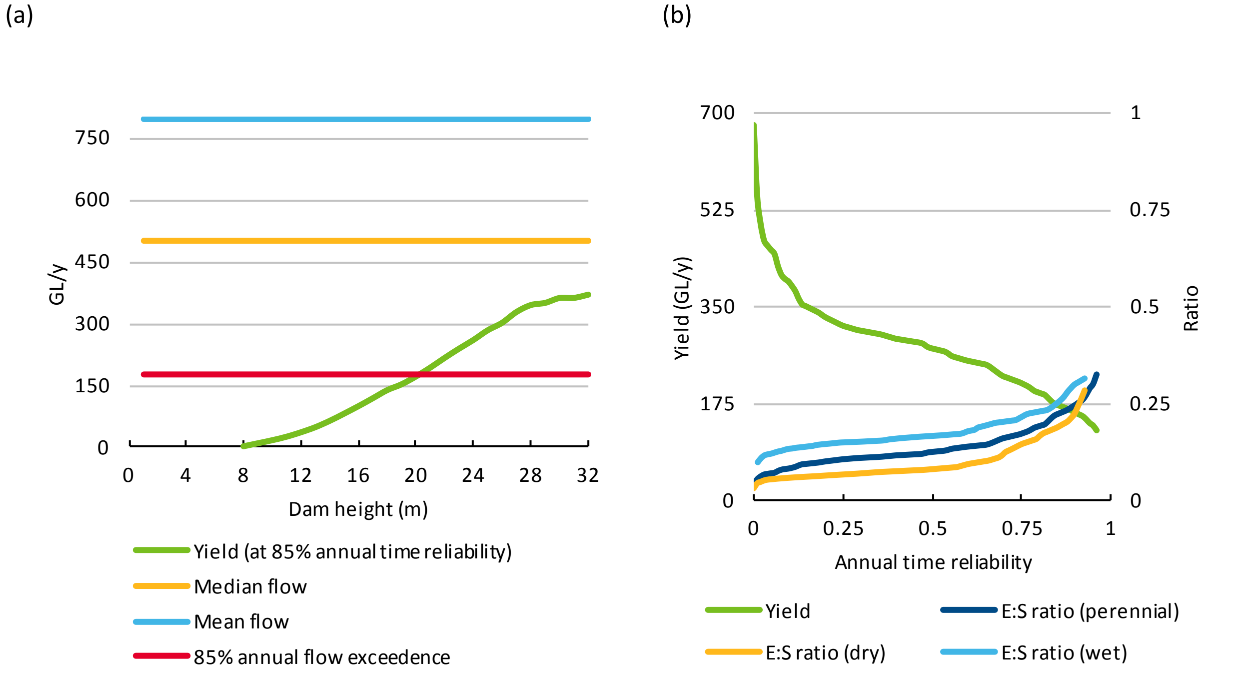

Figure 4.35 (a) Yield and at 85% annual time reliability and streamflow at Green Hills dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Green Hills dam site for different annual time reliability for the selected dam height of 20 m

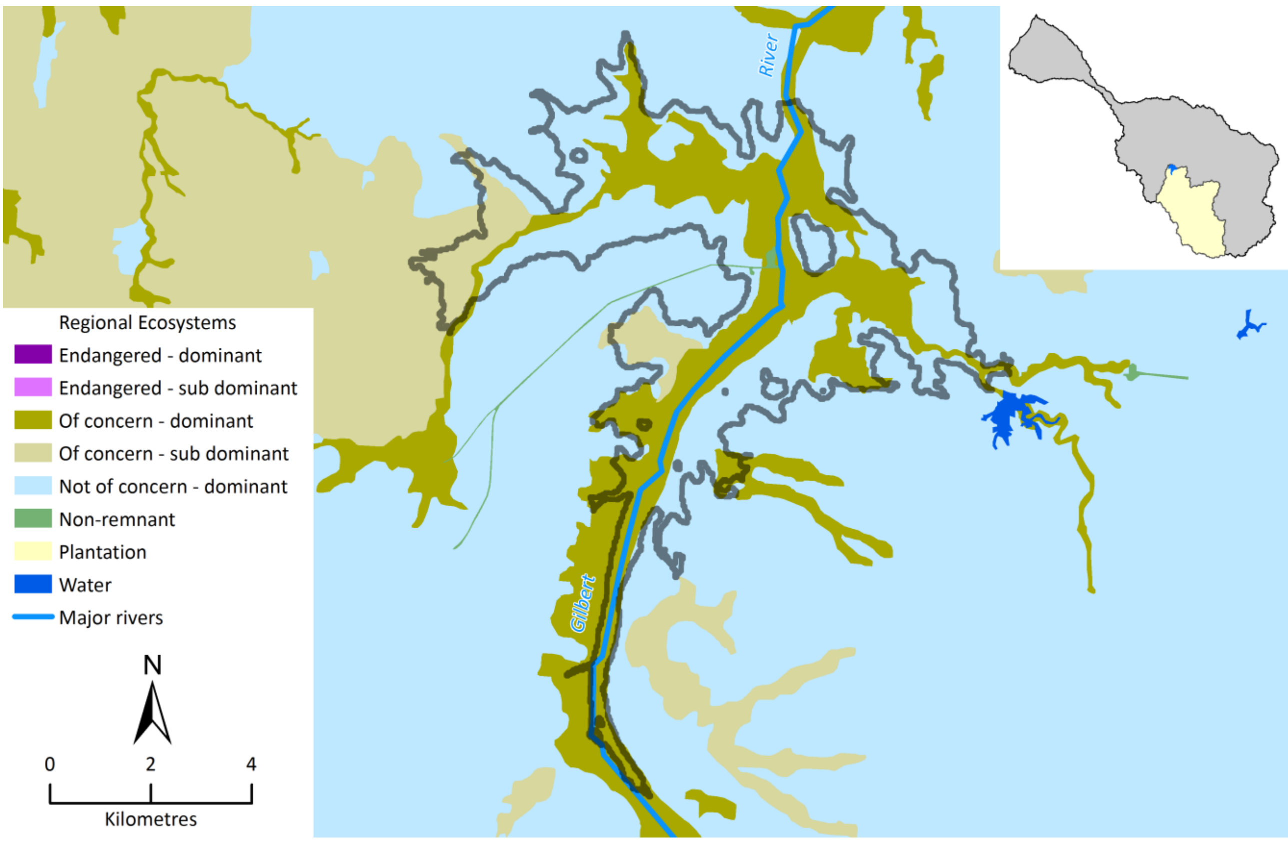

Figure 4.36 Green Hills upstream dam site regional ecosystems mapping

4.4.3 KIDSTON DAM ON THE COPPERFIELD RIVER; 87.2 KM

PARAMETER	DESCRIPTION
Previous investigations	DEWS (2013) A comprehensive list of references relevant to the dam. McIntyre & Associates (1998) Etheridge Shire Council, Water Resources Development of the Einasleigh Area, Pre-Feasibility Study. PPK Environment and Infrastructure (1999). Assessment of Potential Irrigation Hazards; Einasleigh Common and Gilbert River Areas, North Queensland. Enderlin, N. (2000). Soils of the Einasleigh Town Common Area, North Queensland. SKM (2000). Kidston/Einasleigh Copperfield River Project. SunWater (2005) Dam Safety Review Report.
Description of proposal	The existing Kidston Dam (officially known as Copperfield River Gorge Dam) was constructed in 1984 to provide a water supply to the Kidston Gold Mine. Under the terms of the lease of land covering the dam and storage area, the lease to the company ended when mining activity ceased in 2005. The dam is now owned by the state of Queensland and is managed by the Department of Energy and Water Supply (DEWS). Since the closure of the mine, the only use of the dam has been to provide via the original mine water supply pipeline, stock and domestic water supply to a number of properties downstream of the dam and to a number of houses in the Kidston township and a small outback resort In 1998, consultants engaged by the Etheridge Shire Council examined a proposal to raise the dam to provide a water supply to irrigate land in the Einasleigh Common area some 70 km downstream of the dam. The proposal involved a 2 m raising of the dam full supply level to increase the available supply, with water to be released downstream as required to small downstream weirs from which water would be diverted to irrigation areas on each bank of the Copperfield River. This proposal was not advanced further at the time primarily because the consultants concluded that the soils in the proposed irrigation areas were not suitable for irrigated production without severe limitations. A photograph of the site is shown in Figure 4.37. A location map and map showing the inundated area at FSL are shown in Figure 4.38 and Figure 4.39 respectively.
Regional geology	The dam and reservoir area lie within the Lochaber Granite. The rock is a fine to medium grained biotite granite of Carboniferous age. The reservoir area is in hilly terrain with interlocking ridges and valleys. The river course follows the dominant northwest and northeast trending joint pattern. Upstream of the reservoir area the river flows through a relatively flat basaltic plain. The dam site was chosen where granite outcrops over most of the stream channel. Downstream of the dam the river channel is sand filled and confined by steep banks. Figure 4.40 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams
Site geology	The site was extensively investigated between October 1980 and December 1983 by geological mapping, seismic refraction survey, trenching and borehole drilling including water pressure testing. The dam foundation is characterised by ‘corestone’ weathering typical of granite. This is where weathering proceeds inwards from orthogonal joints leaving a rounded corestone surrounded by extremely weathered rock. In most places stripping of 2 m was required to expose slightly weathered to fresh rock of high to extremely high strength (50-200 MPa). At the base of the right abutment, deeper stripping was required where the remnant of a basalt flow had preserved a deep layer of weathered rock. Two major sheared zones trending 45° to the dam axis cross it on the right bank. These have a steep dip and vary between 5 and 10 m in thickness with a persistence of more than 50 m. There was little or no evidence of sub-horizontal defects in the foundation. Weathered seams left in the foundation were locally removed and backfilled by dental concrete. Curtain grouting along the dam axis appears to have been successful in providing a low permeability foundation. In addition to the central overflow spillway there is a fuse plug spillway located adjacent to the right bank. The fuse plug is an earth and rockfill embankment that is designed to erode to

PARAMETER	DESCRIPTION
	a pre-determined sill level for large flood events. In the central part of the embankment the foundation is moderately weathered granite. The abutments are in better quality rock. The reservoir rim has slopes approaching 35°. The presence of large boulders in the riverbed indicates that small slips have occurred in the past but the reservoir area contour plan does not suggest there are any large deep-seated landslides in the reservoir area.
Reservoir rim stability and leakage potential	The reservoir rim has slopes approaching 35° in granite. The presence of large boulders in the riverbed indicates that small slips have occurred in the past but the reservoir area contour plan does not suggest there are any large deep-seated landslides in the reservoir area. It is unlikely that any slips that may occur in future will have an adverse effect on the dam because of the elongated nature of the reservoir area. The potential for reservoir leakage is low.
Proposed structural arrangement	The existing dam is a RCC structure 40 m in height above lowest foundation level with a 100 m wide central overflow spillway, crest level EL 586 m, with a roller bucket energy dissipater. A 13 m high fuse plug embankment secondary spillway, (crest EL 593.5m) is set to discharge to an unlined gully through the right abutment when head water level reaches 0.5 m of the dam abutments. The dam has a river outlet with a 600mm diameter fixed cone regulating valve and has two 500 mm diameter outlet conduits one of which serviced the mine water supply pipeline. It is important to note that the existing dam was designed to be constructed to a very tight time frame and to provide a water supply to a mine whose operational life was expected to be only 15 to 20 years. The dam type adopted by the original designers was a concrete gravity structure with the concrete being a lean mix material placed in continuous horizontal layers, this being the first large dam of this type (now referred to as Roller Compacted Concrete (RCC)) constructed in Australia. Given the short mine life, the original designer adopted a low cost approach where possible so that for some items, such as the dam outlet works, the provisions made were not of the standard normally adopted for a long life asset. The intake provisions for the outlet works on the upstream face of the dam for example, cannot be readily be maintained or upgraded so that serviceability issues are likely to impact upon the dam’s performance from time to time. It should also be noted that the existing dam has no fish passage provision having been constructed prior to the enactment of state legislation requiring approval if it is proposed that fish passage not be provided at a new or raised waterway barrier. Importantly however, SunWater (2005) concluded that the dam foundations and the main dam wall are of an adequate standard to ensure the dam’s stability over the long term and are suitable to support a raising of the dam by 2m as proposed. <u>The proposed raising</u> The most appropriate form of raising is considered to be by placing conventional mass concrete on the downstream face of the dam to raise the spillway crest by 2m and the abutment sections by a similar amount as shown on Figure 4.41. The new concrete would be anchored to the old concrete and drainage would be provided at the interface to ensure that full reservoir head does not build up against the new concrete. The dam axis would be aligned as shown in Figure 4.42. Similarly the fuse plug embankment would be raised as shown by excavating the downstream section of the embankment to expose the Zone 1 material to enable the Zones 1 and 2A to be raised. In addition to the major works, a number of deficiencies in the existing works would need to be addressed. These include an upgrading of the existing access track to the dam including reconstruction of the culvert crossing of Christmas Creek and action to address the loss of fines from the concrete layers at the upstream face of both abutments. To deliver water to the proposed irrigation areas, it was proposed by the McIntyre and Associates (1998) that releases would be made through the existing river outlet as follows; • To a small steel sheet piling weir (Narrawa Weir) from which supply would be diverted to serve lands on the southern side of the river, and • To a small concrete weir on a rock bar near the township (Einasleigh Weir) from

PARAMETER	DESCRIPTION
	which supply would be diverted to serve lands on the northern side of the river. As part of this investigation, consideration was given to also diverting 'run of river' flows from the Einasleigh River to serve the south bank lands to reduce the periods during which releases would need to be made from the dam. This approach potentially provides a considerable increase in the available supply from the system but would require a small additional weir on the Einasleigh River to provide a pumping pool and a third pumping facility. This proposal has an additional potential benefit in that transmission losses from the dam to the Einasleigh area over the some 70 km of river section are likely to be significant. McIntyre and Associates (1998) assumed that bed losses would be 15% of the released flow. Comment from DEWS staff is that operational experience suggests that the bed losses are much higher than 15% although, with the regulating weirs in place, more effective release strategies could be employed than are currently used. There has been no site investigation of any of the proposed regulating weirs or pumping facilities so that the costs estimates for them summarised below should be regarded as indicative only and subject to further investigation. The cost estimates of the weirs in particular seem low.
Availability of construction materials	An instream gravel deposit located downstream of the dam was used as a source of RCC aggregate for the existing dam but was exhausted before completion of the dam. The shortfall was made up from a hard rock deposit located midway between Christmas Creek and the dam. Material was ripped, crushed and screened to produce a product with a maximum size of 60 mm. This deposit will have to be assessed to determine whether sufficient resources remain for a 2 m raising of the dam.
Catchment area	The catchment area is 1243 km^2
Flow data	Stream flows have been recorded at GS 917115A on the Copperfield River at Spanner Waterhole AMTD 80km, which is about 10 km upstream of the dam wall. Annual flows recorded at the gauge from 1983 to date are as follows; Maximum annual flow - 836,000 ML Mean annual flow - 163,000 ML Median annual flow - 75,000 ML Minimum annual flow - 7,000 ML
Storage capacity	27 GL Estimate based on storage – height – surface area relationship provided by McIntyre & Associates (1998) (Figure 4.43). Storage capacity of the existing dam is 20,600 ML at dam full supply level. (ANCOLD Register of Large Dams). A 2 m increase in FSL would increase capacity by some 5,500 ML.
Reservoir yield assessment	17 GL at 85% annual time reliability (Figure 4.44) 18 GL at 95% monthly time reliability Existing dam has a yield of 15 GL at 85% annual time reliability. Evaporation as percentage of regulated flow (at 85% annual time reliability): 11% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.1 <u>Previous studies</u> A supply of 4,650 M/a (reliability not stated) can be provided from the existing *20GL dam. Yield estimates by McIntyre and Associates (1998) indicate that a yield of 4,650 ML/a would have a high reliability, close to 100% and that yield at 80% reliability would be approximately 15,300 ML/a. If supply was released down river, transmission losses would significantly reduce the available supply depending on the distance to the extraction point. SKM (2000) assumed that losses to the Einasleigh area would be 15% – actual losses are likely to be significantly higher without at least one regulating weir.
Open water evaporation	Mean annual evaporation is estimated to be 4.4 mm d^{-1} using bulk aerodynamic formulae. Mean annual evaporation was estimated to be 4.9 mm d^{-1} using Morton's APE.

<table>
<tr><th>PARAMETER</th><th>DESCRIPTION</th></tr>
<tr><td>Potential use of supply</td><td>Land adjacent to the township of Einasleigh some 70 km downstream of the dam was initially proposed as a potential area for irrigation production based on supply from the dam.

However, a land suitability assessment of some 6060ha by Enderlin (2000) identified that approximately 50% of the area as incapable of agricultural production due to extensive gully erosion, rock outcrops and step hilly land.

Of the balance, the majority was assessed as poorly drained with increasing sodic content with depth with only 960 ha assessed as having moderate to well drained non-saline soils.

Rising groundwater levels were identified as a major risk if the area were irrigated.

Apart from some 200 ha of land on either side of the river for a distance of about 50 km upstream of Einasleigh, no other areas of suitable land were identified.</td></tr>
<tr><td>Impacts of inundation to existing infrastructure</td><td>Existing reservoir, hence impacts would be minimal.</td></tr>
<tr><td>Ecological and cultural considerations raised by previous studies</td><td>No specific assessment were identified.</td></tr>
<tr><td>Estimated rates of reservoir sedimentation</td><td><table>
<tr><th></th><th>Best case</th><th>Expected</th><th>Worst case</th></tr>
<tr><td>30 years (%)</td><td>1.13</td><td>6.07</td><td>16.10</td></tr>
<tr><td>100 years (%)</td><td>3.78</td><td>20.23</td><td>53.65</td></tr>
<tr><td>Years to infill</td><td>2648</td><td>494</td><td>186</td></tr>
</table></td></tr>
<tr><td>Water quality and stratification considerations</td><td>The existing dam has provision for making releases to the river from selected levels within the reservoir with an inclined pipe stack mounted on the upstream face of the dam. The pipe stack is equipped with 5 gate valves at 3m vertical intervals.

For the 2 m raising, it has been assumed that the pipe stack would be extended and a further gate valve installed.

It should be noted, however, that the valves and pipe work can only be accessed for maintenance when the storage is drawn down to low levels so that operational difficulties are likely to arise from time to time.

To develop a selective withdrawal system with serviceability standards consistent with a long life asset would involve significant costs and could only be established when the storage was near empty.

The Kidston reservoir is predicted to experience persistent thermal stratification with a top-to-bottom temperature change of 8-10 °C during most of the simulation. The risk of blue-green algal blooms is very high with Zsl:Zeu ≤ 3 from September through May and approximately 1 throughout most of spring and summer.

The water column is predicted to mix annually during winter. The very long duration of stratification and weak mixing behaviour suggests this storage is highly susceptible to anoxic conditions and associated water quality issues. However, summer inflows may resupply some oxygen to deeper waters and reduce some symptoms of low dissolved oxygen.</td></tr>
<tr><td>Environmental considerations</td><td>A 2m raising of the existing dam would result in a 25% increase in storage volume and a 17% increase in inundated area.

A fish survey of this dam by the Queensland Department of Primary Industries in 1987, found 7 fish species (Barlow 1987), though several more are likely to be present. This dam was also surveyed by Vallance et al. (2000) but the fish species found were not specified. Tait (1998b) assessed this site, discussing a number of issues associated with further development. This included the identification of a number of vine-thickets in the proposed inundation area, which may be too small to appear on the existing vegetation mapping.

A raising of the dam would trigger the need to assess the requirement for a fish transfer facility.

Increasing the area of inundation of this impoundment is not likely to flood any regional ecosystems of concern (Figure 4.45).</td></tr>
<tr><td>Indigenous cultural heritage considerations</td><td>At the time of writing there is no Indigenous Cultural Heritage Body for the Kidston area. There are two Indigenous Parties:</td></tr>
</table>

PARAMETER	DESCRIPTION
	• Ewamian People #2 (QC99/13 - QUD6009/99), • Ewamian People #3 (QC01/16 - QUD6018/01). There are no sites listed in the DATSIMA database. Construction and use of the Kidston Dam is likely to have resulted in the destruction of Indigenous archaeological sites within the footprint. However, it is considered that archaeological potential exists within the Kidston area outside the reservoir. A desktop assessment of the area was undertaken by Northern Archaeology Consultancies in May 1998 (NAC 1998). The study found that the most common recorded site type in the locality are artefact scatters, and that stone arrangements, quarries, axe-grinding grooves, scarred trees and rock shelters with art are also present. Sites are frequently located in proximity to water and/or prominent natural features. The assessment concluded that the case study area has high archaeological potential and is likely to contain a range of sites. The region is known to have a large number of sites, and the available information indicates that major watercourses, such as the Einasleigh and Copperfield rivers, were a focus of occupation. Further investigation, including archaeological survey, would be required to assess the potential Indigenous archaeological impact of works in the area. Any such investigation should be undertaken in consultation with the Indigenous Parties. Should works proceed in this area, it is recommended that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding contemporary use of water sources in the area.
Estimated cost	Capital and annual operating costs have been estimated in 2013 $'s for the dam raising and distribution works. Costs for the dam are based on a schedule of quantities for the major items based on those derived by the McIntyre and Associates (1998) and on unit rates derived from recent similar construction projects. As above, estimated costs for the downstream regulating weirs and pump stations should be regarded as indicative only and other than indexing the costs to 2012 using the CPI, the cost of the regulating weirs and pump stations were not reassessed as part of the Assessment. There has been no investigation of a suitable weir site for an Einasleigh River weir, pump station and pipeline. Estimated costs have been assumed to be similar to those for the Copperfield River weir and pump station. The estimated capital cost for a 2m raising of dam full supply level, Narrawa Weir supply system to southern irrigation area, Einasleigh Weir supply system to northern irrigation area and a diversion from Einasleigh River to southern irrigation area in 2013 $'s is $34 million (and is likely to be between $29m and $40m). No allowance has been made in the dam estimate for the cost for a fish transfer facility on the basis that the existing barrier has been in place for nearly 30 years so that there has been no movement of native fish from downstream to the storage area over that time. If a fish transfer facility were to be required, the capital cost would increase by $5m or more. Nor has any estimate been made for the cost of distributing supplies within the nominated irrigation areas. Annual operating and maintenance costs for the dam should be relatively low given the type of dam raising proposed. Annual costs for the downstream distribution works are likely to be relatively higher. An allowance of 1.00% of capital cost, that is some $340,000 is expected to provide for annual costs (not including pumping costs at the downstream weirs) An estimate of cost for a 2m raising of the dam and irrigation infrastructure was prepared by McIntyre & Associates (Ref 2.) as follows. Dam raising $12.1m Water delivery system $ 3.4 m Irrigation system $ 7.0 m Total capital cost $22.5 m CPI adjustment to 2012 prices indicates a capital cost of $32.5m at 2012 prices although construction costs are likely to have risen at a higher rate than CPI, particularly in remote

PARAMETER	DESCRIPTION
	areas. No provision in this estimate was made for a fish transfer facility which, if required, would add a further $1-2 miliion to the cost of the proposal.
Estimated cost / ML of supply	$1990/ML water supply at the dam wall in 85% of years (does not include transmission/distribution losses or take into account environmental and downstream entitlements).
Potential cost/benefit	SKM (2000) reported that the estimated net present value of irrigation development as proposed would be small compared with the risks involved and recommended *“that development of broad scale irrigation in the Einasleigh Common does not occur.”* Highly managed irrigation practises may however be sustainable.
Summary comment	SKM (2000) noted that alternative uses of the supply including tourism development, aquaculture, irrigated pasture, stock and domestic supply, mining supply and research opportunities may warrant consideration. If use of the existing or a raised dam were to be considered further as a supply for irrigated production in the Einasleigh Common area, water use would need to be highly managed for irrigated production to be sustainable.

Figure 4.37 Downstream face of Kidston Dam on Copperfield River, Gilbert Catchment

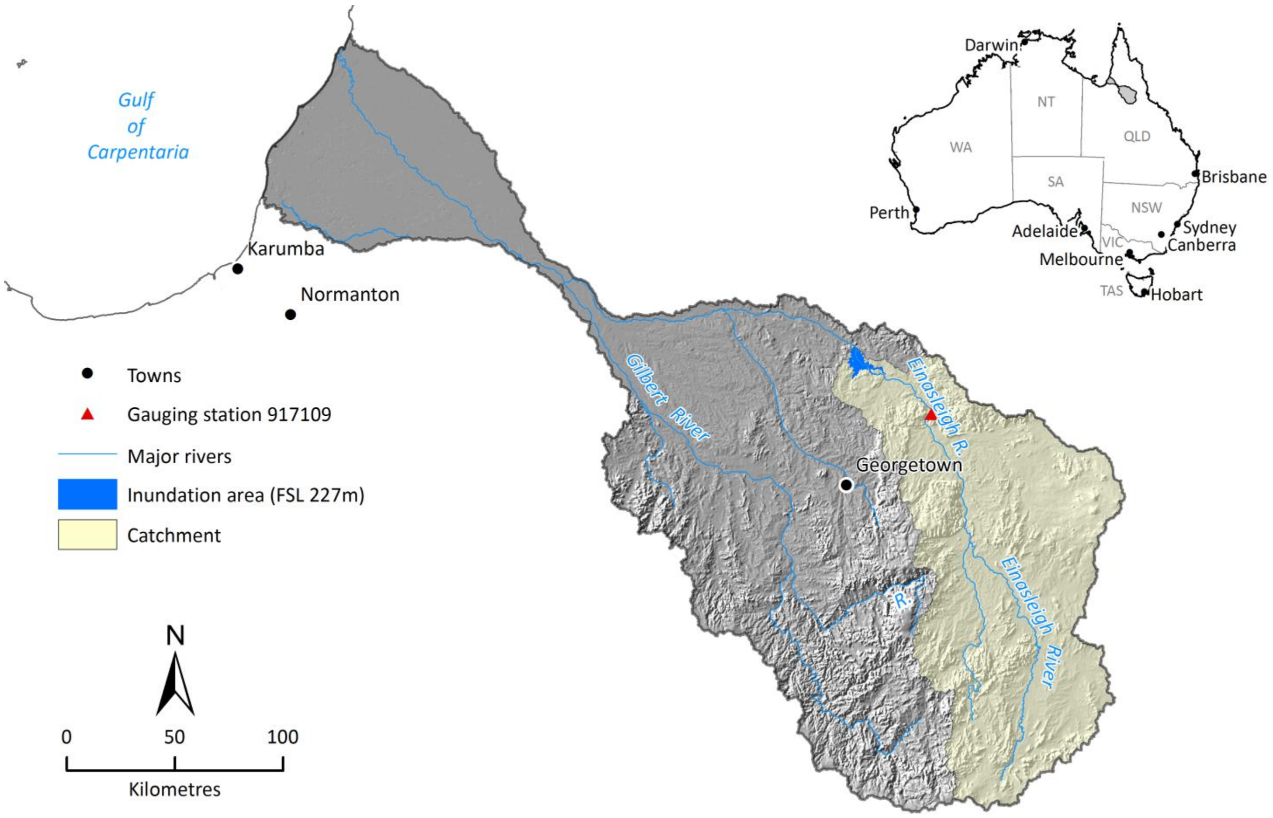

Figure 4.38 Location map of Kidston Dam, reservoir and catchment area

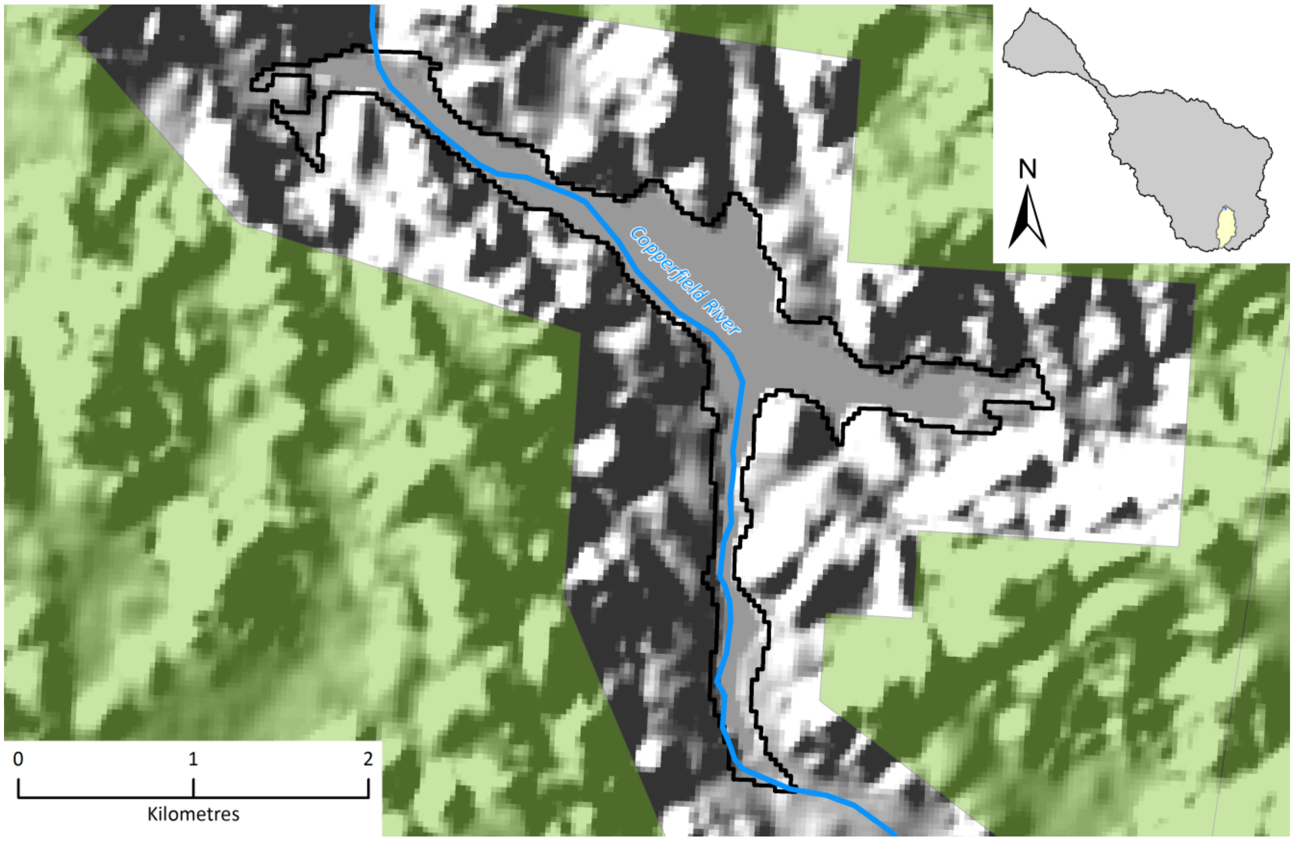

Figure 4.39 Raised Kidston Dam extent of inundation and property boundaries (indicated by coloured shading)

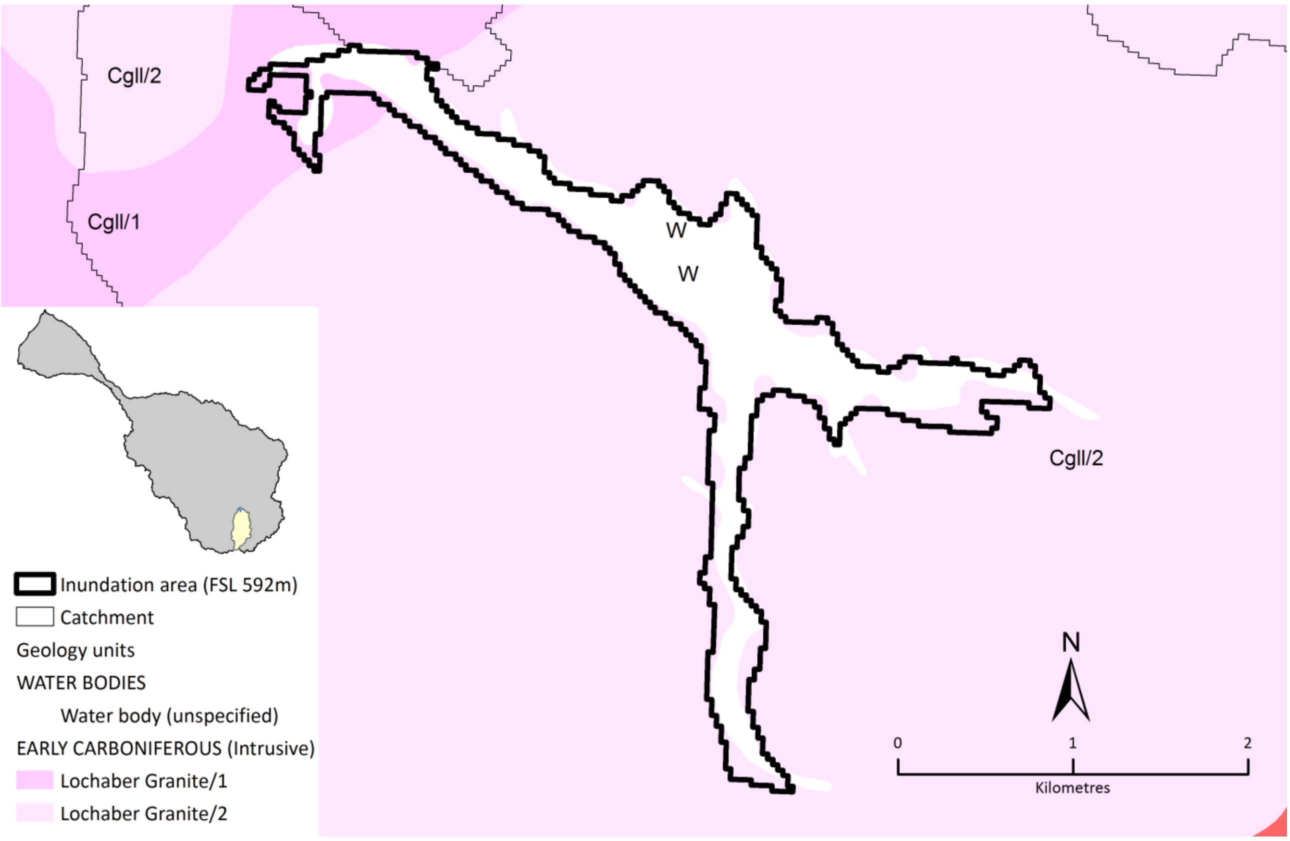

Figure 4.40 Kidston Dam underlying geology

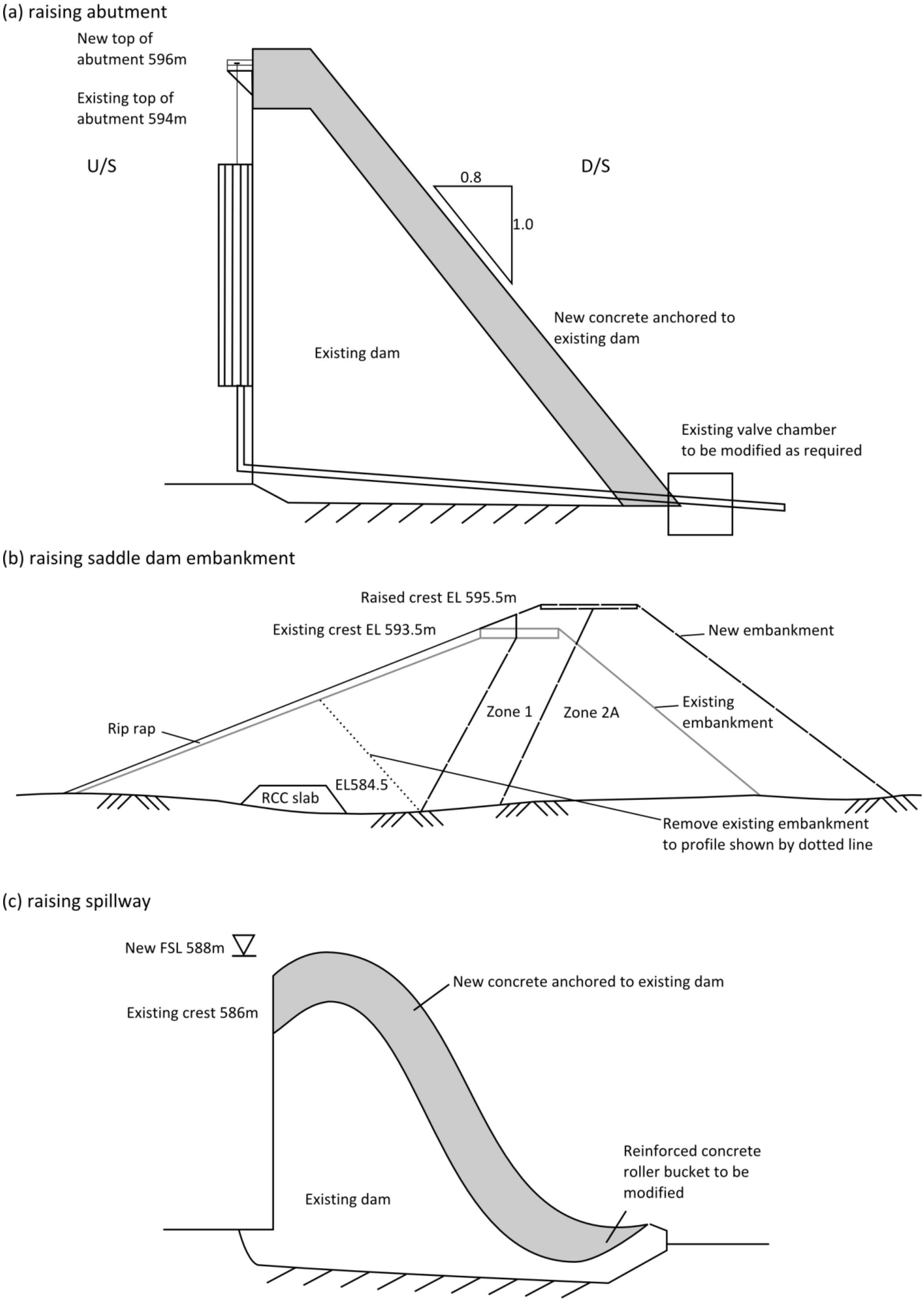

Figure 4.41 Raising abutment, saddle dam embankment and spillway for the Kidston Dam

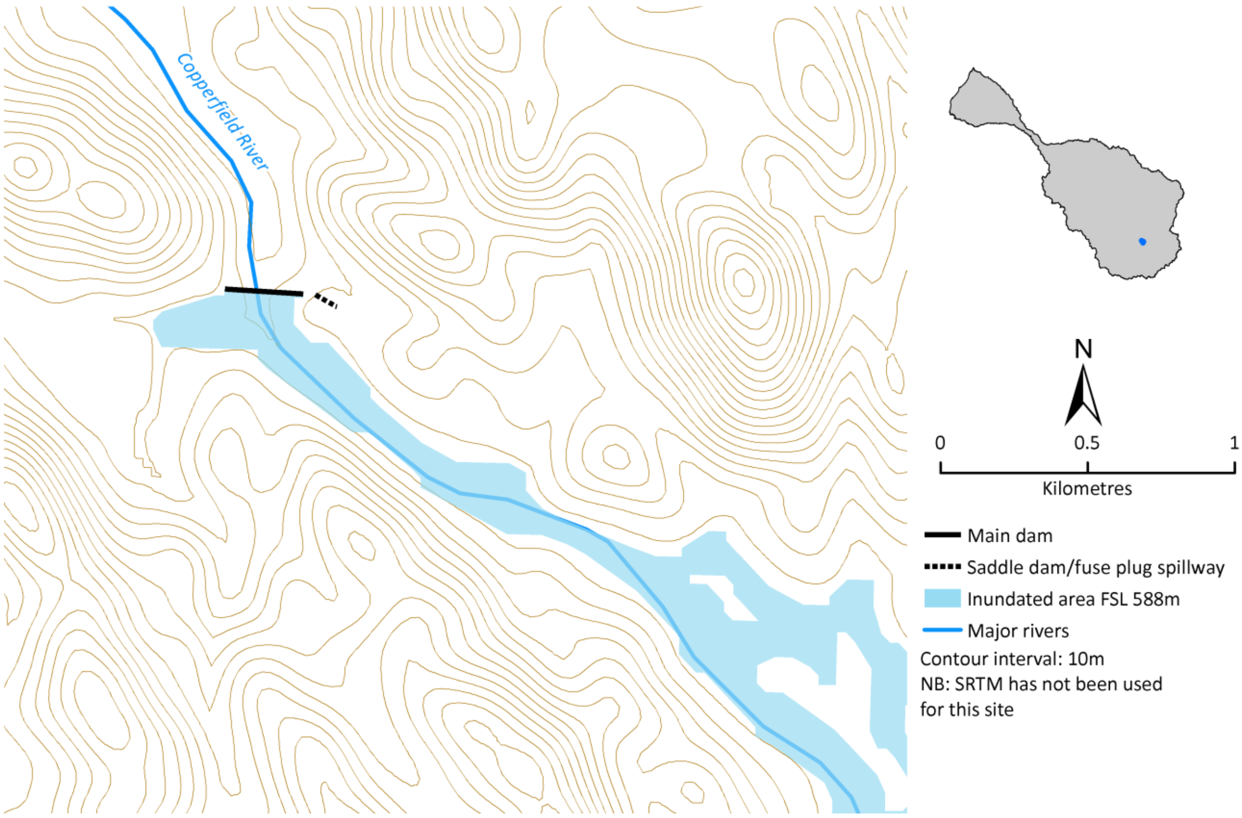

Figure 4.42 Orientation of Kidston Dam axis and saddle dam

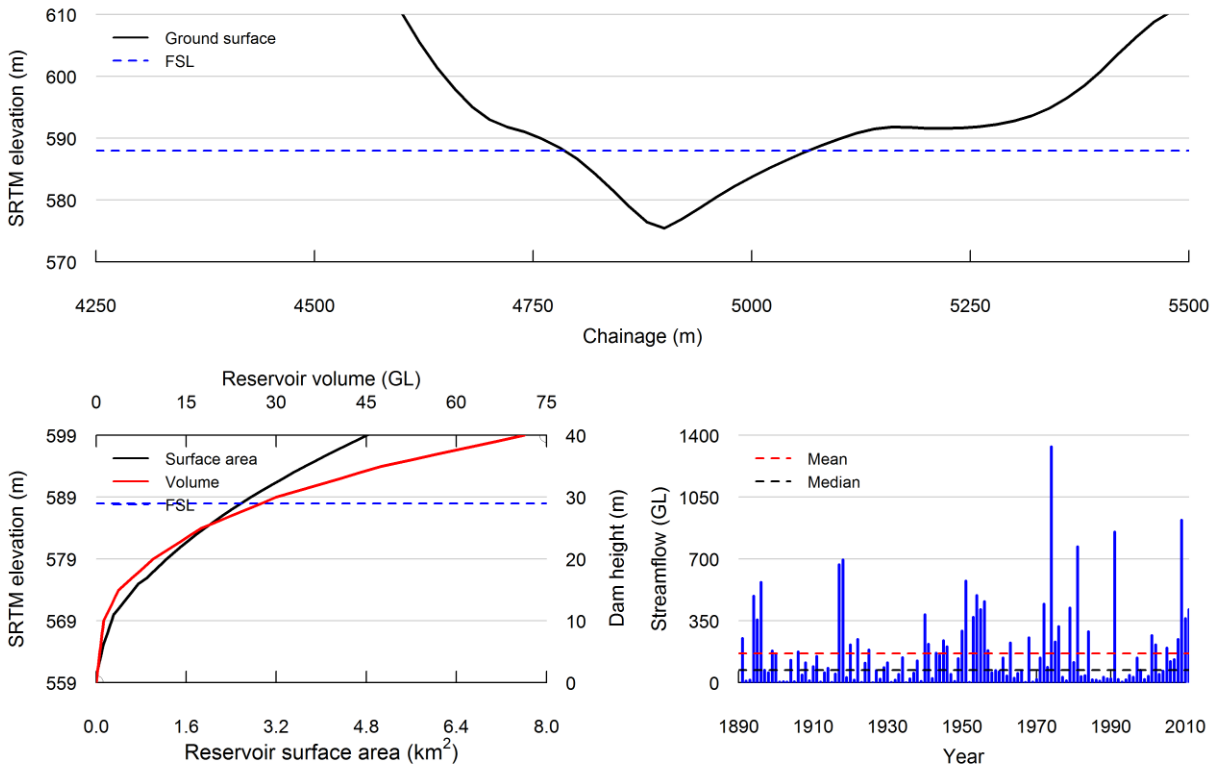

Figure 4.43 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Kidston Dam

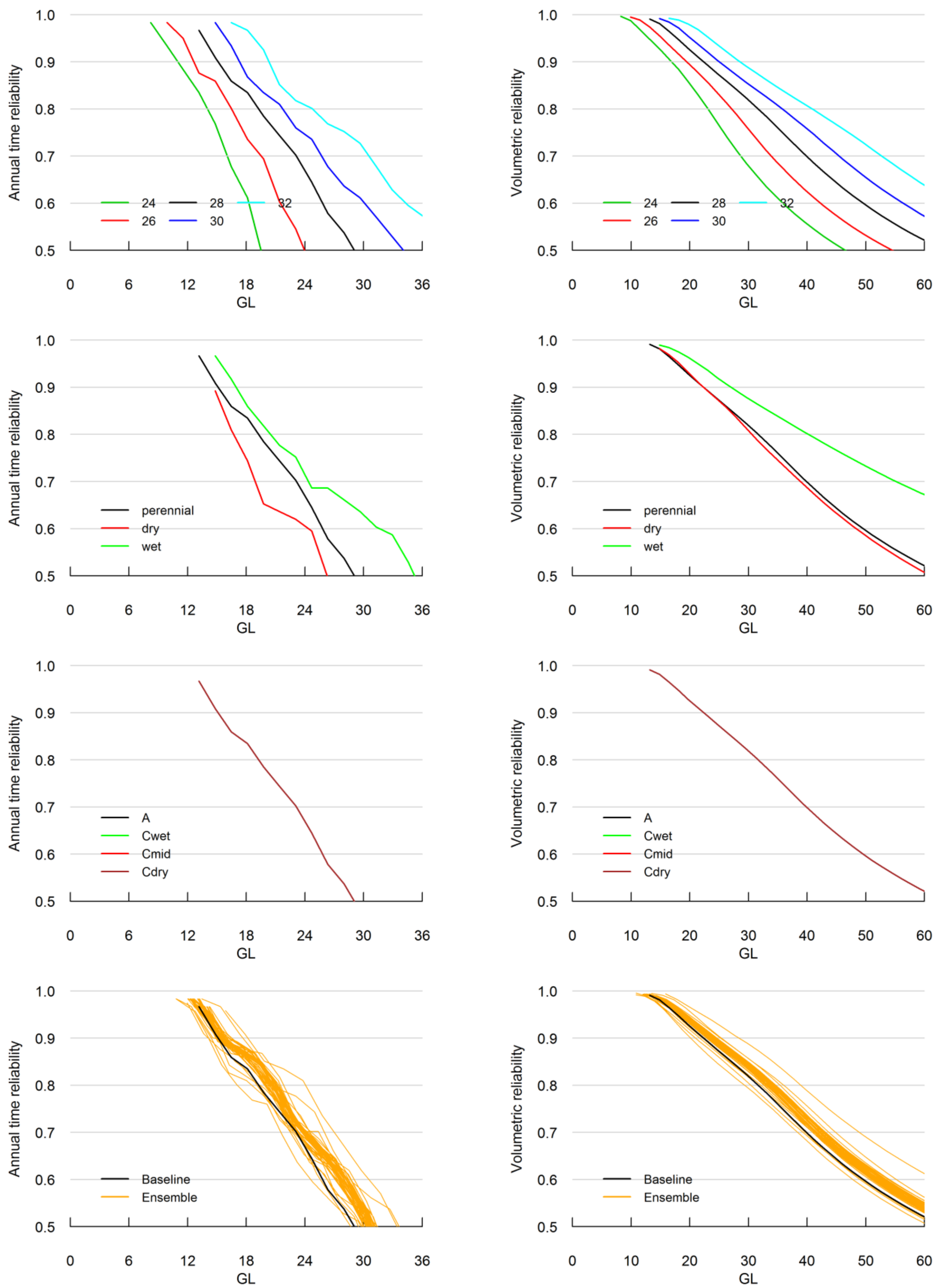

Figure 4.44 Kidston Dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: Yield-reliability relationship (YRR) for different FSL. Second row: YRR for different demand patterns for 588 m FSL. Third row: YRR under Scenario C for 588 m FSL. Fourth row: YRR for baseline and ensemble model runs for 588 m FSL

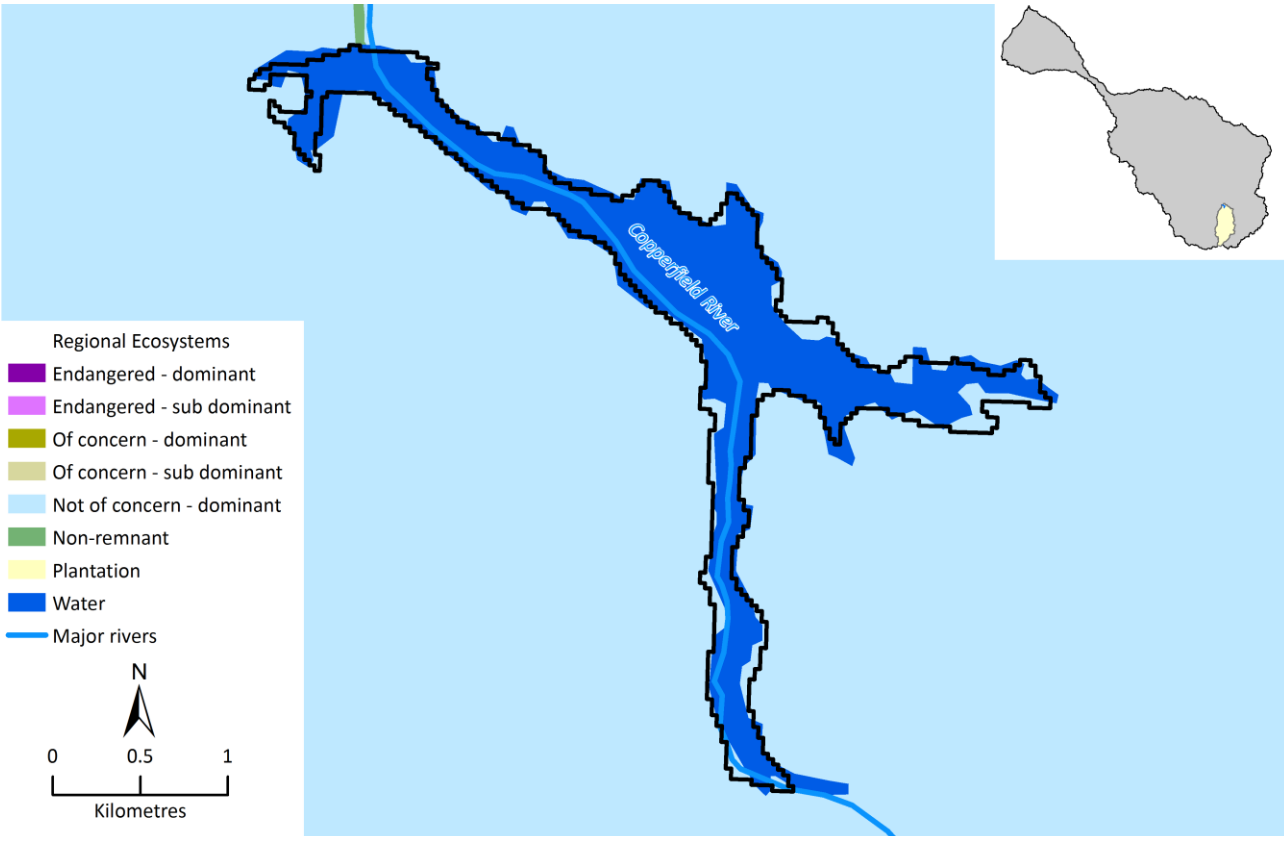

Figure 4.45 Kidston regional ecosystems mapping

Part 3 Offstream storages and regulating structures

5 Farm scale offstream water storage structures

The primary aim of this section is to provide a broad-scale assessment of the suitability of farm scale offstream water storage locations in the Flinders and Gilbert catchments. However, in assessing region-scale economics of water harvesting schemes, local variations in scale and site-specific nuances can present challenges. These can result in considerably different construction and ongoing operational costs from one site to the next (e.g. length of supply channel, amount of diesel required for pumping, removal of sediment deposited in diversion channels, replacement of worn and damaged equipment). Hence, operationally, each site would require its own specifically tailored engineering design. Besides, most producers will have observed the way in which water moves across their land and will have given considerable thought to their most suitable water harvesting configurations. Hence, this report does not attempt to produce engineering water harvesting infrastructure designs for individual producers.

Nor does this report seek to provide instruction on the design and construction of offstream water storages. Numerous other texts and on-line tools already provide detailed information on nearly all facets of offstream water storage. For instructional information the reader is directed in the first instance to Lewis (2002) and IAA (2007).

This section is structured as follows. Section 5.1 assesses the suitability of the Flinders and Gilbert catchments for siting offstream storages in terms of suitable soil and topography. Section 5.2 examines aspects of their operation. Section 5.2.1 reports generic costs of construction and operation of offstream storages. Section 5.2.2 provides a review of an existing study on a large offstream storage in the Flinders catchments. A brief overview of cultural heritage considerations of offstream storages is then provided in provided in Section 5.2.3.

5.1 Suitability assessment of offstream storages in the Flinders and Gilbert catchments

This section provides a broad scale assessment of the suitability of offstream water storages in the Flinders and Gilbert catchments.

This section presents the results of a desktop land suitability assessment for farm scale offstream storages. The assessment is based on the available soils data in the top 1.5 m (see companion technical report on land suitability; Bartley et al. 2013) of the soil profile. Because of a lack of data on soils below a depth of 1.5 m this land suitability assessment does not consider the suitability of subsurface material below this depth. Furthermore the siting of farm scale offstream storages requires considerations at a scale far finer than is possible to assess in a regional scale scoping study. Hence these results are indicative of where suitable locations are likely to occur and should not be used as the sole basis for siting individual farm storages. The investigation and design of an offstream storage should be undertaken following a site investigation by a suitability qualified professional.

Method

Four variables were considered in assessing the suitability of offstream storages in the Flinders and Gilbert catchments. These were soil depth, soil permeability, slope and geology. The suitability of land for offstream storages was ranked using a 1 to 4 ranking as described in Table 5.1.

The suitability of land for offstream storage maps were generated by overlaying raster maps of the suitability of individual parameters listed in Table 5.1. The overall suitability value took the value of the least suitable parameter.

Table 5.1 Suitability of individual soil and geological parameters for siting an offstream storage

SUITABILITY RANKING	SUITABILITY DESCRIPTION	SOIL DEPTH	SOIL PERMEABILITY[1]	SLOPE %	UNDERLYING GEOLOGY
1	Likely to be suitable	> 1.5 m	Permeability class 1	0-5	NA
2	Possibly suitable	1 to 1.5 m	Permeability class 2	5-10	Rolling Downs Group
3	Unlikely to be suitable	0.5 to 1 m	Permeability class 3	10-15	Limestone, basalt
4	Not suitable	0 to 0.5 m	Permeability class 4	> 15	NA

[1] Description of permeability classes found in McDonald et al. 1990.

It should also be noted that this assessment does not take into account other factors important in siting farm scale water storages, such as flooding or economics in terms of the maximum distance a ring tank or turkey's nest can be located from suitable drainage lines. Flooding was not included in this assessment due to the unavailability of a reliable flood map over the entire Assessment area (see companion technical report on flood mapping and modelling; Dutta et al. 2013).

Results

Figure 5.1 indicates the suitability of the top 1.5 m of the land surface for offstream storages. Major drainage lines are provided for spatial context.

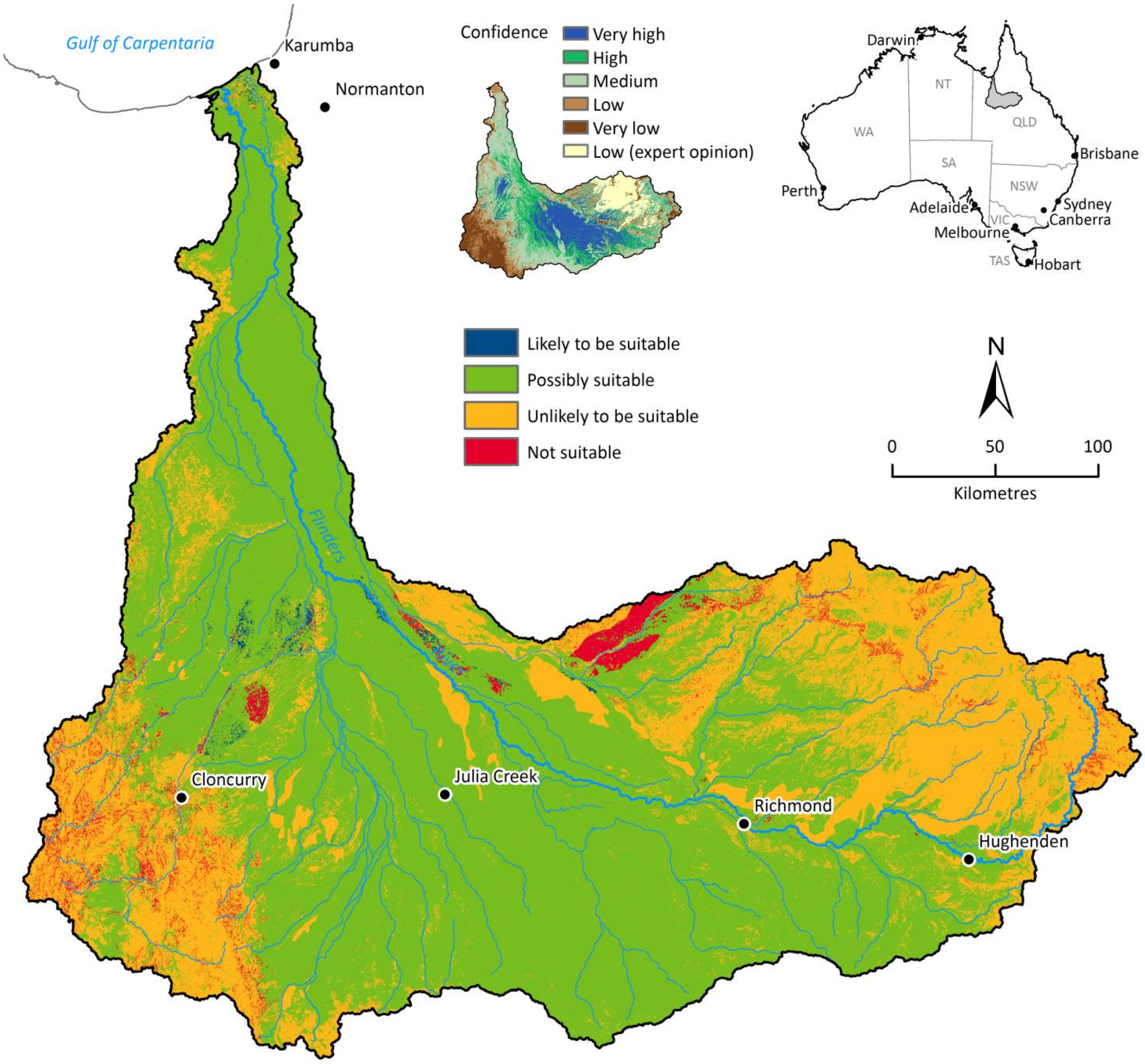

Figure 5.1 The suitability of offstream water storage in the Flinders catchment.
Soil and subsurface data were only available to a depth of 1.5 m. This figure does not take into consideration flood risk or the availability of water.

Figure 5.2 suggests that the majority of the Gilbert catchment is not well suited for the construction of offstream storages, except in the lower reaches.

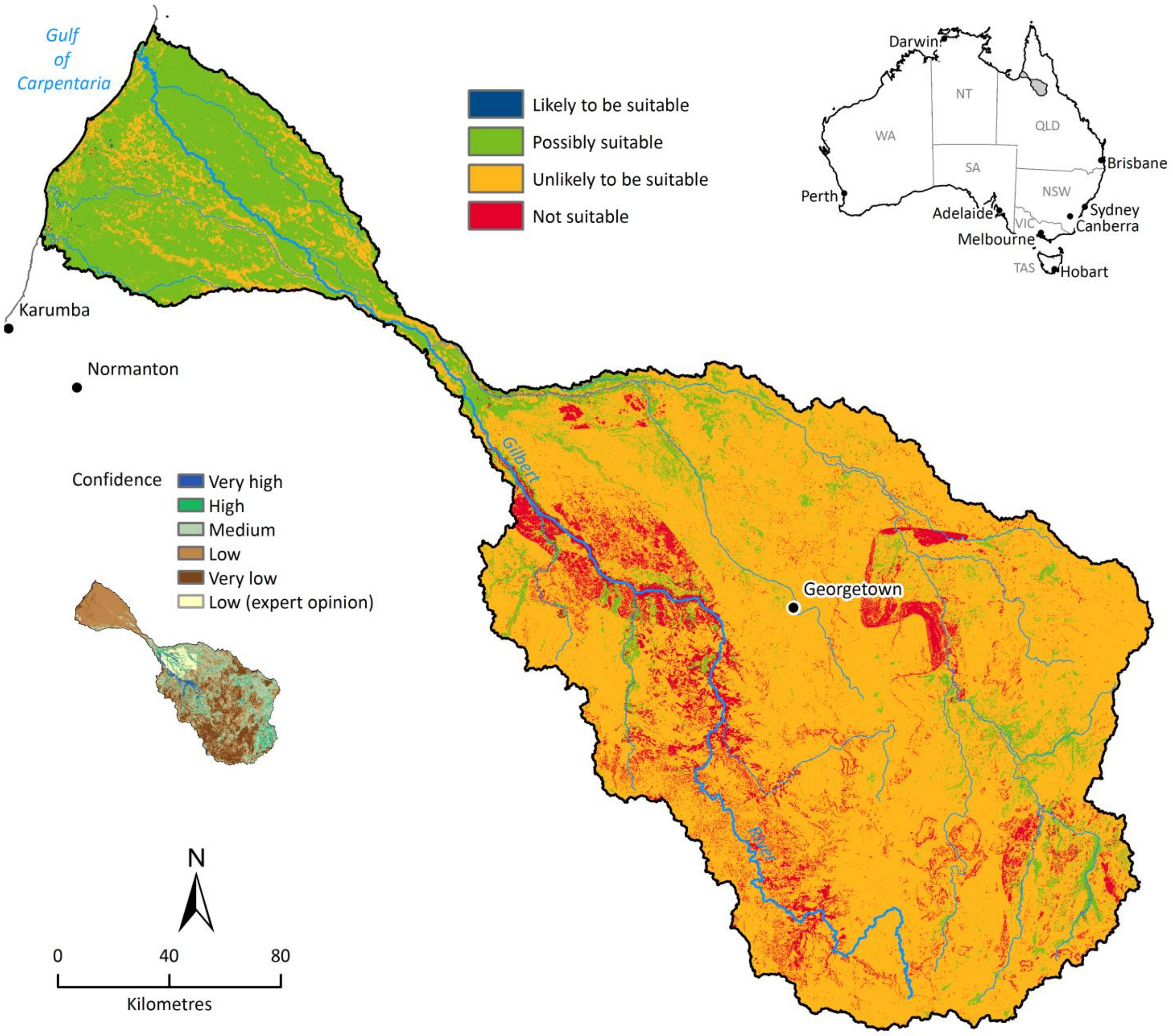

Figure 5.2 The suitability of offstream water storage in the Gilbert catchment
Soil and subsurface data were only available to a depth of 1.5 m. This figure does not take into consideration flood risk or the availability of water.

5.2 The cost of offstream storage construction, operation and maintenance

This section provides a generic analysis of the cost of a small offstream storage (i.e. 1000 ML) in the Flinders and Gilbert catchments for the purpose of illustrating the cost of storing water for different periods of time. This is then followed by a detailed costing of a large offstream storage (i.e. 8000 ML).

5.2.1 GENERIC COST ANALYSIS FOR A SMALL OFFSTREAM STORAGE

The cost of an offstream storage scheme needs to include the cost of the water storage, pumping infrastructure, supply channels, levee banks and the operation and maintenance of the structures. For a given storage capacity the construction costs (and opportunity cost of land used in the construction) vary considerably, depending on the way the storage is built. For example circular storages have a better storage volume to cost ratio than rectangular or square storages. It is also considerably more expensive to double the height of an embankment wall than double its length. Further offstream storages will be sited at different distances from a river, which will necessitate different supply channel costs. In this analysis only the cost of the offstream storage and the pumping infrastructure are considered.

In the Flinders and Gilbert catchments most of the streamflow has occurred by the end of February. Assuming the storage is full at this time, one strategy is to sow suitable crops during the late wet season (i.e. March) to minimise evaporative and seepage losses and enable crops to utilise existing soil water. Hence the configurations provided in Table 5.2 and Table 5.3 refer to a crop planted in March. Sorghum planted for hay is an example of a crop grown for about four months, sorghum planted for grazing an example of a crop grown for about six months and Rhodes Grass an example of a perennial crop.

However, the longer water is stored the more water is lost through evaporation and seepage. Mean daily evaporation losses from open water in the Assessment area has been modelled to be between 4.5 and 6 mm. Figure 3.3b and Figure 4.3b show the monthly pattern of potential evaporation in the Flinders and Gilbert catchments respectively. When computing evaporative losses from a water storage it is important to compute net evaporation (i.e. evaporation minus rainfall) rather than just evaporation. Strategies to minimise evaporation include liquid and solid barriers, but these are typically expensive per unit of reservoir/inundated area (e.g. $10/m^2 to $26/m^2). A reservoir constructed on suitable soils will have seepage losses equal to or less than 1 to 2 mm/day and losses will be greater than 5 mm/day if sited on less suitable (i.e. permeable) soils (IAA, 2007).

The effect of evaporation and seepage loss on offstream storages is explored in Table 5.2 and Table 5.3 for the Flinders (using Richmond climate) and Gilbert (using Georgetown climate) catchments respectively. This is done through the use of the terms effective volume and effective cost. Effective volume refers to the actual volume of water that could be used for consumptive purposes after losses due to evaporation and seepage. For example if water is stored for 12 months in the Flinders catchment and there is only 1 mm/day seepage loss, nearly half the stored volume would be lost to evaporation and seepage (Table 5.2). Effective cost is the cost of the storage divided by the effective volume.

Data in Table 5.2 and Table 5.3 are based on $4/m^3 of earthworks. Recent estimates of cost of earthworks from companies in the Flinders catchment ranged from $3 to $5/m^3 (B Cornfoot and W Lillyman, 2013, pers. comm.) depending on the site. Ring tank construction costs in the Flinders were also reported at $4/m^3 by Mason and Larard (2011).

Table 5.2 Construction costs for a 1000-ML storage based on $4/m^3 of earthworks near Richmond (Flinders catchment)

Assumes a 4:1 storage to excavation ratio. Effective volume refers to the actual volume of water that could be used for consumptive purposes as a result of losses due to evaporation and seepage. Does not include cost of supply channels, levees or pumping infrastructure.

BANK HEIGHT (m)	AREA (ha)	CON-STRUCTION COST ($)	COST ($/ML)	SEEPAGE LOSS (mm/day)	EFFECTIVE VOLUME (ML)	EFFECTIVE COST ($/ML)	EFFECTIVE VOLUME (ML)	EFFECTIVE COST ($/ML)	EFFECTIVE VOLUME (ML)	EFFECTIVE COST ($/ML)
					4 months (March to June)		6 months (March to August)		12 months	
5	25	$1,000,000	$1000	1	855	$1170	785	$1273	528	$1894
5	25	$1,000,000	$1000	2	824	$1213	739	$1352	437	$2290
5	25	$1,000,000	$1000	5	732	$1365	601	$1663	163	$6135

Table 5.3 Construction costs for a 1000-ML storage based on $4/m³ of earthworks near Georgetown (Gilbert catchment)

Assumes a 4:1 storage to excavation ratio. Effective volume refers to the actual volume of water that could be used for consumptive purposes as a result of losses due to evaporation and seepage. Does not include cost of supply channels, levees or pumping infrastructure.

BANK HEIGHT (m)	AREA (ha)	CON-STRUCTION COST ($)	COST ($/ML)	SEEPAGE LOSS (mm/day)	EFFECTIVE VOLUME (ML)	EFFECTIVE COST ($/ML)	EFFECTIVE VOLUME (ML)	EFFECTIVE COST ($/ML)	EFFECTIVE VOLUME (ML)	EFFECTIVE COST ($/ML)
					4 months (March to June)		6 months (March to August)		12 months	
5	25	$1,000,000	$1000	1	866	$1155	791	$1264	607	$1648
5	25	$1,000,000	$1000	2	836	$1197	745	$1342	516	$1940
5	25	$1,000,000	$1000	5	744	$1344	607	$1647	242	$4136

Ignoring the cost of supply channels and levee banks, which will vary from one station to the next, the cost of an offstream storage should also include the cost and operation of pumping infrastructure.

The analysis summarised in Table 5.4 makes the following assumptions:

- Pumping infrastructure costs $850/ML per day and to fill the storage in most years the pumps have to extract the required water in only five days (see Holz et al. 2013).
- The cost of pumping is $16/ML (or $11/ML after a full rebate of $0.38/l) (assumes about a 10 m head is required). See Brenan McKellar et al. 2013.
- The water storage has a life span of 40 years and operation and maintenance costs are 1% of the capital costs.
- The pumping infrastructure has a life span of 15 years and an operation and maintenance cost of 2% of capital costs.
- A discount rate of 7%.

Table 5.4 Annualised cost of the construction and operation of a 1000-ML ring tank and 200 ML/day pumping infrastructure assuming a discount rate of 7%

ITEM	COST ($)	LIFESPAN (y)	EQUIVALENT ANNUAL COST ($)	OPERATION AND MAINTENANCE COST ($/y)
Offstream storage (ring tank)	$1,000,000	40	$75,000	$10,000
Pumping infrastructure	$170,000	15	$18,650	$3400
Pumping cost (diesel)	NA	NA	NA	$16,000

The total equivalent annual costs for the construction and operation of a 1000-ML ring tank and 200 ML/day pumping infrastructure is $123,000/year or $123 per year per ML of stored water. In Table 5.5 and Table 5.6 the equivalent annual unit cost of the water yield from the offstream storage takes into consideration evaporation and seepage loss from the storage, which increase with the length of the crop growing season (i.e. time required to store water). In this table results are presented for the equivalent annual cost of water yield from an offstream storage for different seepage rates and lengths of time for storing water.

Table 5.5 Equivalent annual cost per ML for storages with different seepage rates near Richmond (Flinders catchment)

BANK HEIGHT (m)	AREA (ha)	EQUIVALENT ANNUAL COST ($)	SEEPAGE LOSS (mm/day)	EFFECTIVE VOLUME (ML)	EQUIVALENT ANNUAL UNIT COST ($ per year per ML)	EFFECTIVE VOLUME (ML)	EQUIVALENT ANNUAL UNIT COST ($ per year per ML)	EFFECTIVE VOLUME (ML)	EQUIVALENT ANNUAL UNIT COST ($ per year per ML)
				4 months (March to June)		6 months (March to August)		12 months	
5	25	$123,000	1	855	$144	785	$157	528	$233
5	25	$123,000	2	824	$149	739	$166	437	$281
5	25	$123,000	5	732	$168	601	$205	163	$755

Table 5.6 Equivalent annual cost per ML for storages with different seepage rates near Georgetown (Gilbert catchment)

BANK HEIGHT (m)	AREA (ha)	EQUIVALENT ANNUAL COST ($)	SEEPAGE LOSS (mm/day)	EFFECTIVE VOLUME (ML)	EQUIVALENT ANNUAL UNIT COST ($ per year per ML)	EFFECTIVE VOLUME (ML)	EQUIVALENT ANNUAL UNIT COST ($ per year per ML)	EFFECTIVE VOLUME (ML)	EQUIVALENT ANNUAL UNIT COST ($ per year per ML)
				4 months (March to June)		6 months (March to August)		12 months	
5	25	$123,000	1	866	$142	791	$155	607	$203
5	25	$123,000	2	836	$147	745	$165	516	$238
5	25	$123,000	5	744	$165	607	$203	242	$508

5.2.2 REVIEW OF LARGE WATER HARVESTING INVESTIGATION NEAR RICHMOND

SunWater (2009) reported on a preliminary study of water harvesting options in the Richmond area of the Flinders catchment, which was intended to provide a basis for a comparison of the costs in developing on farm irrigation enterprises with the O'Connell Creek offstream storage proposal.

The key assumptions made were that:

- The required capacity of each offstream storage was 8,000 ML.
- Diversion capacity was 5 cu m/s assuming about 20 days pumping opportunity per annum.
- A total of 10 to 12 storages would be developed in a "mosaic" style of development rather than the 'irrigation area' type of development proposed for the O'Connell Creek development.

Details of the SunWater (2009) offstream water storage

The study assumed details of the storage facility was as follows:

- Square storage formed by an embankment, maximum height 8 m.
- Embankment batters 1 in 2.5.
- Embankment crest width 4 m.
- Freeboard at FSL 0.5 m.
- Stripping depth 0.5 m.
- Floor of storage fully clay lined.
- Internal batters rock protected against erosion.

An additional 15% cut was allowed to cover placement and compaction.

The study made the following assumptions of the diversion works:

- by 1 cu m/s capacity diesel powered "China" mixed flow type pumps mounted on a concrete slab on ground adjacent to the storage,
- Inlet channel from the river to the pump station site 5,000 m long, bed width 6.0m, water depth 1.8m, bed slope 1:15,000,
- Maximum pump lift including pipe losses 15 m.

The length of diversion channel was taken as that required to locate the storage out of the major flood lines and closer to the area of irrigation development.

Comments on the SunWater (2009) offstream water storage

It could reasonably be assumed that storage sites will be available in the Flinders catchment where the surface soils are relatively impermeable and clay lining of the floor will not be required.

Few private offstream storages use rock protection on internal batters. Most landholders have equipment on site and repair batter slopes as needed, preferring intermittent annual costs rather than high up front costs.

An inlet channel 5 km long appears to be longer than would be necessary at the more suitable possible storage sites along the Flinders River – Tritton's Silver Hills storage is, for example, less than 1 km from the river main channel.

Revised estimate of capital construction costs

The quantities for the works as estimated by SunWater (2009) have been modified in light of the above comments:

- Floor lining has been removed.
- Rock protection of the upstream batters has been removed.
- The diversion channel has been reduced to 2 km length.

A revised estimate of construction cost of $16.5 million is provided as detailed in Table 5.7.

Table 5.7 Estimate of construction costs for hypothetical offstream storage near Richmond (Flinders catchment)

ITEM	UNIT	QUANTITY	RATE	TOTAL
Diversion embankment	Lump sum			100,000
Clear and grub for channel	ha	3.2	1,500	4,800
Excavation for channel	cu m	49,000	7.5	367,500
Storage				
Clear and grub embankment area	ha	21	1,500	31,500
Excavation for embankment	cu m	98,700	6.5	642,000
Place embankment fill	cu m	901,400	7.5	6,760,000
Outlet pipe work and control gate	lump sum			100,000
Pump station				

ITEM	UNIT	QUANTITY	RATE	TOTAL
Supply pump and engine sets	no	5	100,000	500,000
Concrete to floor slab	cu m	25	1,000	25,000
Suction lines	no	5	10,000	50,000
Check valves	no	5	12,000	60,000
Discharge pipe work	lump sum			25,000
Roof	lump sum			25,000
Outlet structure	lump sum			10,000
Total direct costs				**8600000**
Contractor overheads				
Mobilisation/demobilisation	5%			430000
Obligations and set out	5%			430000
Site risks	10%			860000
Site overheads (accommodation etc)	10%			860000
Corporate and profit	8%			688000
Contingencies	10%			860000
Total construction cost				**12730000**
Design costs and approvals	10%			1273000
Other project risks	20%			2546000
TOTAL COST			**$**	**16,549,000**
				$16.5 m

Annual costs associated with water pumping operation and maintenance

Because the offstream storages are likely to be remote from the electricity distribution grid, it is assumed that the pump stations would be powered by diesel engines.

Each pump will require an engine set with approximately 150 kw power rating, assuming a total pumping head of some 12 m. Engines of this rating typically have a fuel consumption of 40 l/hr or 960 l/day so that over a 20 day pumping period, the 5 sets would consume some 96,000 l of fuel at a cost of approximately $150,000 (not taking into account any fuel tax credits or subsidies).

Other operation and maintenance costs associated with the pumping facility are likely to be in the order or $50,000 pa.

Assuming that 20 day pumping opportunities arise in 4.5 years of every 5 years, the mean annual pumping costs would be about $180,000 pa.

If the off stream storages were conveniently located near the power grid, annual pumping costs would be significantly lower than that above.

Annual costs associated with water storage facility maintenance

Maintenance costs associated with the storage facility are likely to primarily arise from scour damage to earthworks batters along the diversion channel and in storage itself due to wave action. Scour damage is also likely at the diversion bank location. Maintenance requirements are likely to vary significantly from year to year but to average at approximately $ 120,000 pa (1% of total construction cost).

Summary comments

The above estimates are intended to be consistent with the costs likely to be incurred if the works were undertaken by a regionally based contractor, with investigation and design being undertaken by an engineering consultant.

It is recognised however, that many facilities of this type across the state have been constructed using landholder owned plant and that if the facility is not a referable dam under the Water Act, then the requirement for involvement of a registered professional engineer under the Act does not apply. Under these circumstances, contractor and other project overheads could be substantially less than those indicated in Table 5.7.

Additionally, opportunities may exist to acquire used pumping machinery if suitable equipment is available.

Further, topographic conditions may exist in the Richmond area, which are more favourable for siting offstream water storage facilities than those assumed.

In some circumstances therefore, it could be expected that storage facilities of the capacity assumed above could be constructed and operated for significantly lower costs than those indicated.

5.2.3 CULTURAL HERITAGE CONSIDERATIONS OF OFFSTREAM WATER STORAGES

All options for the construction of offstream water storages incorporate earthworks and inundation of the storage area, along with works to transfer water to the storage. Construction and use of offstream water storage therefore has the potential to have major impacts to Indigenous archaeological sites, the Indigenous cultural landscape and an array of tangible and intangible cultural sites and values. However, if the offstream storage options offer some flexibility in terms of location, it may be possible to minimise this impact through the variation of size and location of water storage areas to avoid identified cultural heritage places. If adequate archaeological surveys and consultation occurs prior to determining the fixed locations of access roads, storage areas and pipelines, the potential for impact on significant places may be reduced or avoided. This may be more difficult to achieve in large storage areas located on the rivers/streams themselves, especially, as noted previously, because Indigenous archaeological sites are likely to be clustered along the margins of water courses.

6 Regulating structures

Given that there has been no specific investigation of possible regulating weir sites, the objective of this chapter is to develop a range of preliminary cost estimates for possible regulating weirs based on river sections varying in width between 100 and 200 metres. Table 6.1 provides estimates of construction costs for a sheet piling weir of different weir crest length. The assumptions and qualifications associated with these cost estimates are provided below.

For each cost estimate the following assumptions were made.

- Access to weir site 2 km from existing roads.
- Weir height bed level to crest - 3 m.
- Overflow sections a nominal 100, 150 and 200 m wide,
- River section – bed flat from bank to bank, banks rising at least 6 m above bed level at a slope of 1:3.
- River bed – sand; banks – alluvial materials with no rock.
- Type of weir – steel sheet piling – 3 rows forming 2 steps each 1.75m high (allowing for 0.5 m of excavation).
- Piling lengths as follows; Row 1 - length 12 m, Row 2 – length 8 m, Row 3 – length 6 m.
- Sheet piling assumed to be U section 600 mm effective width 72 kg/m section.
- Compacted clay material placed upstream of Row 1 and compacted sand material between Rows 1 and 2.
- Scour protection by reinforced concrete aprons between each row of piling with rockfilled mattresses downstream of the aprons.
- Single outlet pile with one regulating valve.
- Vertical slot type fish ladder.
- No storage impacts.

For each of the cost estimates the cost of the weir would be sensitive to a number of factors, including:

- Site location – for more remote sites, access costs will be higher and freight and travelling times will also impact on costs.
- Piling costs – the largest single cost item is the cost of steel sheet piling delivered to site. Piling of the type required is imported into Australia and costs are therefore subject to currency exchange rates. Freight rates to site (e.g. from Townsville), will be subject to site location. On the other hand, the pile lengths assumed above are generous and subject to detailed design, somewhat shorter lengths may be feasible particularly at sites with flatter bed slopes and lower flow velocities.
- There has been no geotechnical investigation at any site. The presence of rock for example at a shallow depth would require different weir arrangements to be used and possibly result in higher costs.

Table 6.1 Estimated construction cost of 3m high sheet piling weir

WEIR CREST LENGTH (m)	ESTIMATED CAPITAL COST ($ million)
100	24
150	31
200	37

Annual operating costs are likely to be low, but varying with location.

However, depending on the frequency and magnitude of flood events, significant costs could be involved from time to time in the repair of scour damage, e.g. replacement of mattresses. Annual operating costs could average between 1 and 2% of the capital cost.

Part 4 Summary comments

7 Discussion

7.1 Comparison of yields for dams in the Flinders and Gilbert catchment

The assessment of 22 dams in the Flinders and Gilbert catchments presents a unique opportunity to examine and compare yield derived from various models. Table 7.1 provides a comparison of yield for all 22 existing and potential dams in the Flinders and Gilbert catchments. The table enables a comparison between the baseline and the 50 ensemble river models, scenario A and C and the use of perennial, dry and wet season demand patterns.

Table 7.1 Comparison of estimates of annual yield for existing and potential dams in the Flinders and Gilbert catchments

In the table heading 'baseline' refers to the baseline river system model. Ensemble 10% and 90% refers to the 10% and 90% exceedance values respectively from the 50 river system model ensembles (Lerat et al. 2013). Scenario A, Cwet, Cmid and Cdry are the historical climate (i.e. 1890 to 2011), wet, mid and dry future climate respectively (see Petheram and Yang 2013). The river models were run under these scenarios to generate the streamflow data for use in the behaviour analysis model. Perennial, dry and wet pattern refer to the monthly pattern of water demand (see Section 2.3.2). All yield estimates are for an 85% annual time reliability.

Dam name	Baseline Scenario A Perennial demand pattern (GL)	Baseline Scenario A Dry demand pattern (GL)	Baseline Scenario A Wet demand pattern (GL)	Ensemble 10% Scenario A Perennial demand pattern (GL)	Ensemble 90% Scenario A Perennial demand pattern (GL)	Baseline Scenario Cwet Perennial demand pattern (GL)	Baseline Scenario Cmid Perennial demand pattern (GL)	Baseline Scenario C dry Perennial demand pattern (GL)
Bundock	9	9	9	10	8	10	8	5
Dagworth	326	294	329	335	320	395	313	247
Green Hills	172	158	178	173	161	187	162	137
Kidston existing	15	14	16	19	18	16	14	11
Kidston raised	17	16	17	19	18	19	16	13
Mt Alder	37	33	36	40	36	40	36	33
Mt Noble	113	101	115	118	107	130	110	95
North Head	108	93	117	108	103	113	103	86
Alston Vale	12	12	12	13	11	21	4	3
Black Fort	20	18	19	19	18	24	21	14
Cameron Ck	8	8	8	8	7	12	9	2
Cave Hill	40	36	41	40	36	61	44	21
Corella Dam	4	4	4	4	4	5	4	2

Dam name	Baseline Scenario A Perennial demand pattern (GL)	Baseline Scenario A Dry demand pattern (GL)	Baseline Scenario A Wet demand pattern (GL)	Ensemble 10% Scenario A Perennial demand pattern (GL)	Ensemble 90% Scenario A Perennial demand pattern (GL)	Baseline Scenario Cwet Perennial demand pattern (GL)	Baseline Scenario Cmid Perennial demand pattern (GL)	Baseline Scenario C dry Perennial demand pattern (GL)
Corella River	9	8	9	10	9	12	10	5
Glendower	57	59	58	57	57	84	38	35
Flinders 856 km *	39	38	38	39	39	49	28	27
Mt Beckford	45	48	45	46	43	59	21	19
Mt Oxley *	22	21	21	22	22	29	16	15
O’Connell Ck	34	38	34	35	33	40	22	22
Porcupine Ck	11	11	12	12	11	15	8	7
Richmond dam	30	33	32	33	28	52	14	10
White Mountains *	34	33	33	34	34	47	23	21

*There were no streamflow ensembles generated for these sites. See Lerat et al. 2013.

The results in Table 7.1 are summarised in Table 7.2,which presents ranges in yield values between i) the 10% and 90% exceedance of the 50 ensemble river models, ii) the maximum range between the three constant monthly demand patterns; and iii) the range in values under scenario Cwet and Cdry. These data enable exploration of the range in yield estimates as a result of different demand patterns, uncertainty in streamflow data and uncertainty in future climates. The results are presented graphically in Figure 7.1 and Figure 7.2. Dams with the largest yields showed the largest range in yield estimate (Figure 7.1). When the range in yields is normalised by the yield for the baseline model under Scenario A for a perennial demand pattern, potential dams in the Flinders catchment have a larger range in yield under scenarios Cwet and Cdry than dams in the Gilbert catchment. This is likely to be because the yield from dams in the Flinders catchment is more constrained by dam inflows than dams in the Gilbert catchment.

Figure 7.1 and Figure 7.2 show that the range in yield values is largest as a result in uncertainty in future climate data and that the range in yield values is similar as a result of different demand patterns and uncertainty in streamflow data. It should be noted, however, that 60% of the 15 GCM-ES (Global Climate Models empirically scaled, see Petheram and Yang 2012) examined as part of the Assessment indicated that there is unlikely to be a large change in rainfall under a climate that is 2° C warmer. So while the range in the 10^{th} and 90^{th} GCM-ES results are large, most GCM-ES indicate there will not be a major change in future rainfall in northern Australia and hence yield. However, these results do illustrate there is considerable uncertainty in yield predictions under a future climate.

Table 7.2 The range in estimates of 22 water yield for existing and potential dams in the Flinders and Gilbert catchments under different demand patterns, uncertainty in streamflow and uncertainty in future climate
All yield estimates are at 85% annual time reliability.

Dam name	Baseline model under Scenario A and perennial demand pattern (GL)	Maximum range of demand patterns (GL)	Range of 10% and 90% exceedance ensemble model results (GL)	Range between scenarios Cwet and Cmid (GL)
Bundock	8.8	0.3	2.3	5.2
Dagworth	325.9	35.3	15.2	148.4
Green Hills	171.9	20.1	11.8	50.6
Kidston existing	15.1	2.7	1.7	4.9
Kidston raised	17.1	1.4	1.7	5.9
Mt Adler	36.6	4.0	3.9	7.1
Mt Noble	112.9	14.0	11.2	34.9
North Head	107.9	24.0	5.0	27.3
Alston Vale	11.7	0.5	2.1	18.2
Black Fort	20.2	2.4	1.8	9.5
Cameron Ck	7.7	0.1	1.0	9.5
Cave Hill	40.4	5.5	4.0	39.7
Corella Dam	3.7	0.4	0.5	2.6
Corella River	9.1	0.6	1.0	7.7
Glendower	30.2	3.2	4.2	41.9
Flinders 856 km*	38.7	0.7	0.0	22.0
Mt Beckford	45.0	3.4	2.9	40.2
Mt Oxley*	21.9	0.9	0.0	14.3
O'Connell Ck	33.9	4.0	2.5	18.1
Porcupine Ck	11.5	0.8	0.9	7.8
Richmond dam	57.0	1.5	0.0	49.3
White Mountains*	33.5	0.3	0.0	25.7

*There were no streamflow ensembles generated for these sites. See Lerat et al. 2013.

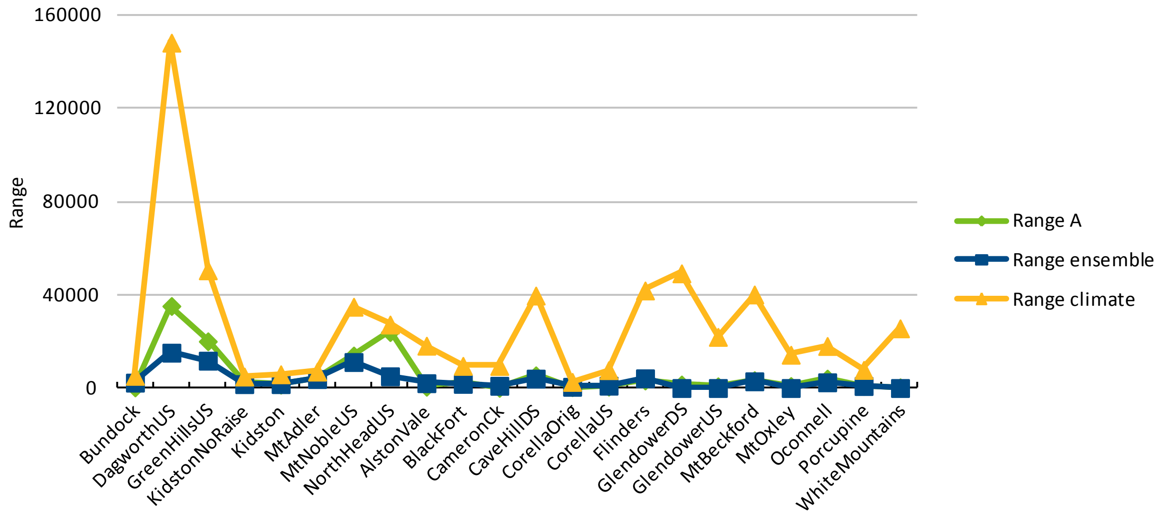

Figure 7.1 The range in estimates of water yield for existing and potential dams in the Flinders and Gilbert catchments a result of different demand patterns, streamflow uncertainty and uncertainty in future climate
All yield estimates are for an 85% annual time reliability.

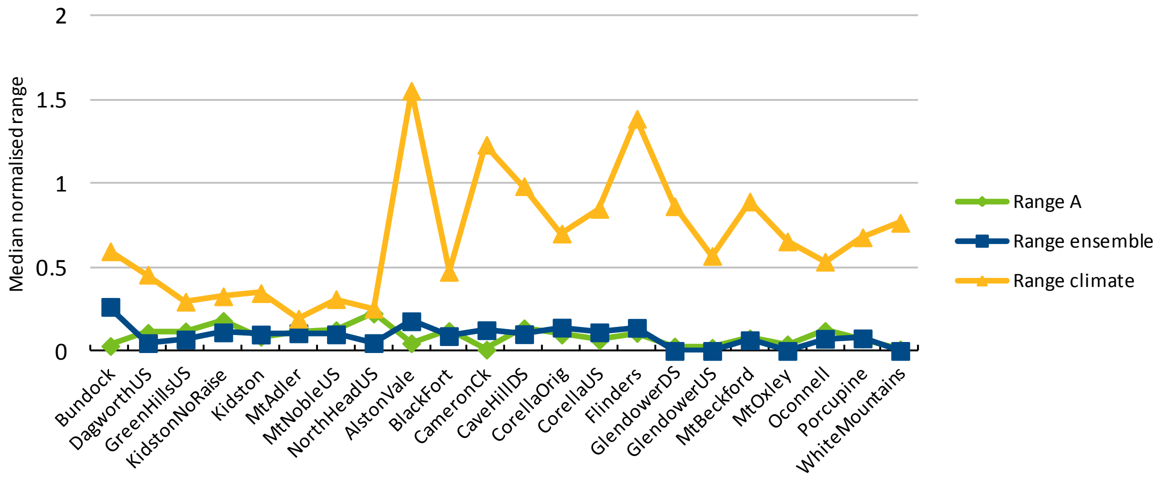

Figure 7.2 The normalised range in estimates of water yield for existing and potential dams in the Flinders and Gilbert catchments as a result of different demand patterns, streamflow uncertainty and uncertainty in future climate
The range values have been normalised by the median water yield for the baseline model under Scenario A using a perennial demand pattern. All yield estimates are for an 85% annual time reliability.

Figure 7.3 illustrates the range in the uncertainty in streamflow and dam yield as a result of uncertainty in the streamflow gauging station rating table, plotted on a log scale. For all dams examined the range in uncertainty in streamflow is considerably larger than the range in uncertainty in yield. Generally the uncertainty (i.e. range) in yield from the 50 model ensembles increases with uncertainty (i.e range) in streamflow data. However, for potential dams with small storage volumes (e.g. Mt Alder, Kidston, Bundock) the uncertainty in yield is smaller than dams with larger storage volumes and comparable streamflow uncertainty because the dams with small storage volumes spill most years regardless of whether the 10th or 90th percent exceedance streamflow was used for the analysis. Hence dams with a large streamflow to storage volume ratio have low uncertainty in their yield estimates.

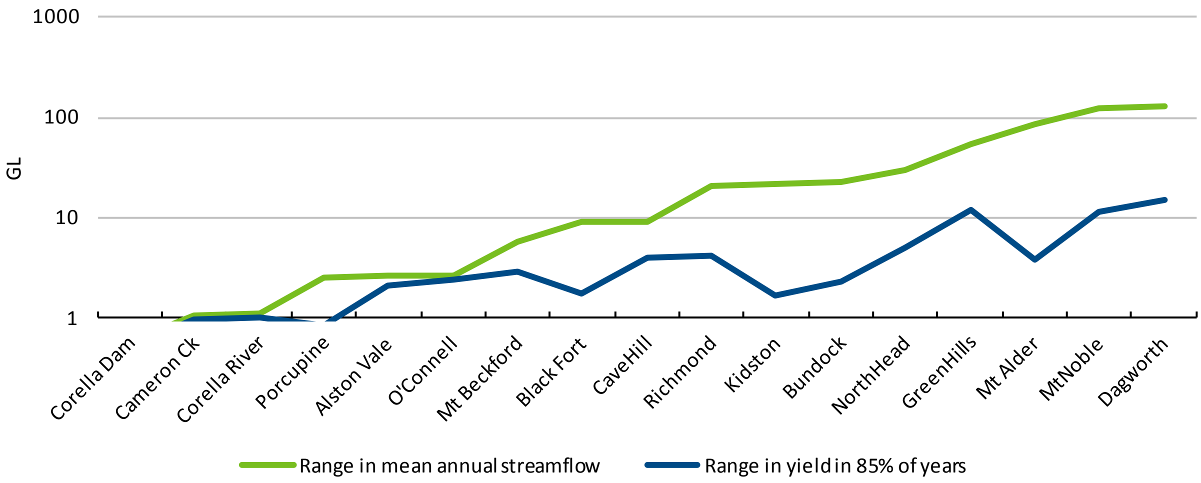

Figure 7.3 Comparison of uncertainty in mean annual streamflow and yield at 85% annual time reliability as a result of uncertainty in the streamflow gauging station rating table
The range in mean annual streamflow is the difference between the 10th and 90th percentile mean streamflow generated by the 50 river model ensemble. The range in yield is the difference between the 10th and 90th percentile yield using the 50 streamflow replicates generated by the 50 river model ensembles.

7.2 Appropriateness of using Morton's areal wet potential evaporation for computing evaporation from an open water body

A comparison of Morton's APE and evaporation computed using the stability corrected bulk aerodynamic formulae (see Section 2.3.4) for 20 actual and potential dam sites across the Assessment area are shown in Figure 7.4. Based on the data shown in Figure 7.4, Morton's APE estimates of open water evaporation at 70% of the dam sites are within ±10% of the evaporation estimates using the bulk aerodynamic formulae, and the evaporation estimates using Morton's APE at all sites are within ±20%. Given the other uncertainties in streamflow and other data, the results of this comparison suggest that Morton's APE is appropriate for use in this regional scale scoping study. It should be noted, however, that there is little relationship between the two datasets, in part because of local site characteristics, particularly wind, which is accounted for in the bulk aerodynamic formulae but not Morton's APPE calculation.

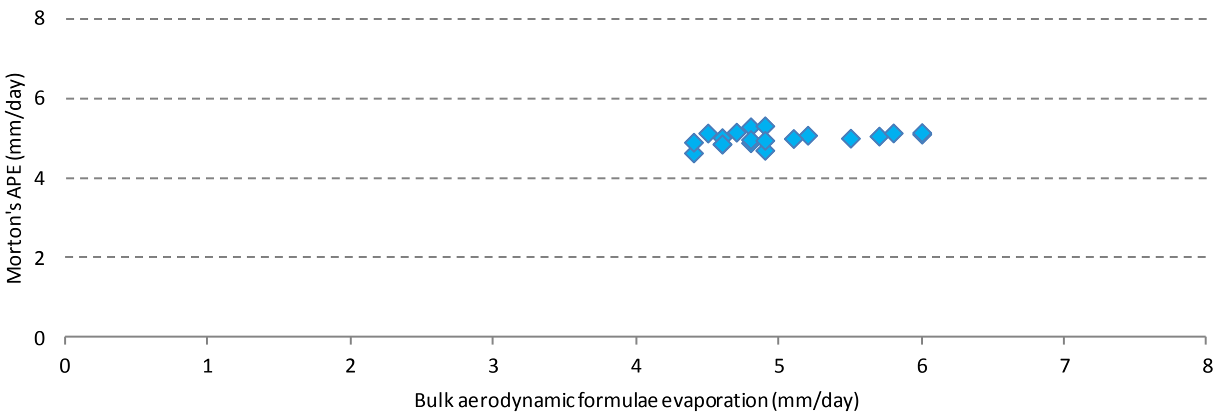

Figure 7.4 Comparison between Morton's APE and evaporation computed using bulk aerodynamic formulae

In a companion technical report on climate in the Assessment area (Petheram and Yang 2013) it was shown that using the Morton's APE formulation, APE under Scenario C increased by between 3 to 9% compared to under Scenario A. This change was predominantly driven by the increase in air temperature, which affects Morton's wet area potential both directly via its influence on surface temperature and indirectly via its effect on vapour pressure and on long-wave radiation. However, as previously discussed, Morton's formulation of APE does not incorporate the effects of wind speed, even though wind speed is a key variable in the aerodynamic component of evaporation. Recently (McVicar et al., 2008) showed that all of northern Australia has experienced declines in wind speed of approximately 0.01 m/second/year over the last 30 years, and this has been shown to be the primary factor driving the observed decreases of pan evaporation across much of Australia, including northern Australia, over the same time period (Roderick et al., 2007). The effect of decreasing wind speed is to moderate the effect rising temperatures will have on potential evaporation rates. If decreasing wind speeds were to hold into the future, the projections of APE used in the Scenario C reservoir yield assessments (i.e. using Morton's wet area potential formulation) will be higher than they would be if a fully physical potential formation were to be used (that is, one that incorporates net radiation, humidity, wind speed and temperature).

7.3 Comparison of estimated capital costs with past studies

Cost estimates derived by many past studies and adjusted for inflation using the CPI are considerably lower than those estimates reported by the Assessment (Figure 7.5). This is likely to be in part because i) construction costs, particularly in remote areas, have almost certainly escalated at a higher rate than the CPI, particularly during the recent boom period of mining activity; ii) the costs estimated by many past studies almost certainly did not reflect the uncertainty in these projects; iii) PMF estimates have steadily increased over the last 40 years with larger spillway and higher embankment requirements to contain the flood rises; and iv) stricter environmental provisions such as fish passage facilities and variable outlet towers and more rigorous and expensive environmental approval and community consultation processes.

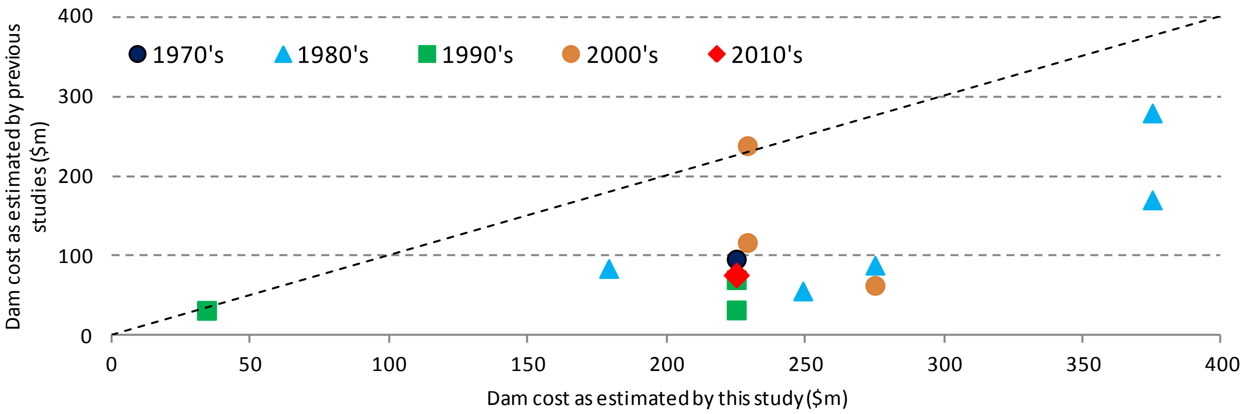

Figure 7.5 Comparison of dam cost estimated in this report to previous studies for 13 potential sites. All costs indexed to 2012. Dashed line indicates 1:1 line

In the Flinders and Gilbert catchments, the two largest existing dams, Corella Dam and Kidston Dam (see Section 1.5), were both constructed by private (mining) companies to supply water to nearby mine operations. These dams were designed to be constructed to a very tight time frame and to provide water to mines with an expected operational life of only 15 to 20 years. With the closure of the mines, these dams are now owned by the state of Queensland (managed by the Department of Energy and Water Supply) who are now responsible for their upkeep and maintenance.

At Corella Dam, embankment settlement has led to numerous areas of cracking of the face slab which has worsened as the slab reinforcing mesh corroded. Seepage through the face as measured through a V- notch weir at the downstream toe has been as high as 300 l/s (26 ML/day). Repairs to the upstream face undertaken when the storage level has been low have reduced leakage but new areas of cracking progressively appear. Repairing the existing dam is likely to be as expensive as constructing a new dam at the same site.

In the case of Kidston Dam the dam foundations and the main dam wall are reported to be of adequate standard to ensure the dam's stability over the long term. However, the low cost approach adopted by the previous owners meant that for some items, such as the dam outlet works, the provisions made were not of the standard normally adopted for a long life asset. The intake provisions for the outlet works on the upstream face of the dam for example, cannot be readily be maintained or upgraded, so serviceability issues are likely to impact upon the dam's performance from time to time.

These examples highlight some of the challenges posed by private construction and (long-term) ownership of large dams.

7.4 Indigenous heritage cultural considerations

Archaeologists often use 'predictive models' to make statements about the expected nature and distribution of cultural heritage sites and places across the landscape. Paton (1997:3.1.1) notes that predictive modelling is a very useful tool for development projects, "where one of the prime goals is to assign degrees of archaeological sensitivity to various land units, which in turn can be used to assess the nature of a particular development's impact on cultural resources". The shortfall of predictive modeling is that it is difficult to predict the likely occurrence and distribution of some sites or areas that show no archaeological evidence but that are nevertheless very significant to Indigenous people. Paton suggests that the strength of the predictive model "lies primarily in its ability to predict the occurrence of the most typical site types" (Paton 1997:3.1.1).

The assessment (and predictive statements) are made here primarily on the basis of the results of the literature reviews and heritage searches outlined in this report (see AHMS 2013 for a more detailed discussion of the literature). No detailed consultation has been undertaken with the Traditional Owners about the specific sites mentioned here. Some general predictive statements and a preliminary assessment of indigenous cultural heritage potential are provided for the short-listed potential dam sties. These are that:

- The short-listed potential dam sites will potentially impact on large tracts of country. This type of development can be assessed as a high impact development, potentially resulting in major transformation of the existing landscape. The size and scale of some of the potential dams mean that they have the potential to impact upon cultural heritage sites and values.
- The cultural heritage potential will vary according to the various landforms and environmental zones, and to the degree of previous disturbance. Some areas (such as elevated river banks and rocky outcrops and escarpments) can be expected to have a moderate to high level of cultural heritage potential, while other areas may have lower levels of cultural heritage potential (e.g.: low-lying, flood prone areas and heavily disturbed areas where there has been extensive surface and subsurface ground disturbance due to farming, land clearing).
- Previous archaeological investigations in the broader study area have consistently confirmed that major watercourses and their tributaries tend to be highly sensitive environments from a cultural heritage point-of-view.
- Previous studies show clearly that Indigenous people have always located their campsites and subsistence activities along major watercourses and drainage lines. The cultural heritage potential of these landforms and their immediate surrounds is therefore assessed as moderate to high.
- Sizeable watercourses, especially those with semi-permanent water, have been found to contain archaeological evidence for ephemeral 'dinnertime camps', and also more complex Indigenous base camps. Low-density stone artefact scatters, isolated artefacts and hearths, appear to be relatively common on the elevated banks and terraces of watercourses throughout the general area. Overall, the potential for watercourses to retain intact archaeological sites and evidence may depend upon the degree of previous disturbance and degradation along elevated banks and terraces.
- At this stage it is difficult to assess the potential for intact subsurface cultural sites and/or deposits to exist. The potential for subsurface remains can be better assessed at a later time, following comprehensive surface archaeological surveys, consultation with the Traditional Owners, detailed field observations of local microenvironments, and the extent to which some of these environments might be conducive to the long-term preservation of archaeological sites and remains.

- Given the geology of the short-listed potential dam sites, it is possible that rock shelters or overhangs containing Indigenous cultural sites such as rock art and cultural deposits mayexist . Systematic cultural survey may locate highly significant cultural sites and values, which might be best managed by avoidance.
- It is predicted that the most common Indigenous cultural heritage sites or finds will be low-density stone artefact scatters and isolated artefact finds. A range of artefact types might occur (e.g. grindstones, hammer-stones, anvils, blades, stone axes). However, the most common stone artefacts are very likely to include primary and secondary waste flakes, cores and core fragments and debitage.
- Scarred trees may exist if there is remnant or old growth native vegetation in the case study areas. Previous research indicates that scarred trees are often located on large, mature trees in the vicinity of major watercourses.
- The areas surrounding the short-listed dam sites may contain (non-tangible) cultural sites of significance to the Indigenous Traditional Owners. These sites include story places, ceremonial places, burial places, dreaming tracts, myth cycles, etc. In most cases, these types of cultural sites leave no physical trace in the archaeological record and can only be identified by knowledgeable Elders or senior Traditional Owners/custodians.
- There is potential for early European settlement and historical sites and features across, such as old roads, stock routes, coach stops, hotels, bottle dumps, telegraph lines, homesteads, historical graves and World War 2 sites. Many of these may also be of significance to Indigenous people because of their historical involvement in these places.
- There is potential for places of contemporary value to Indigenous communities to occur, such as resource (or wild food) collection places zones, swimming holes, and places of continuing cultural or spiritual practice. To date there has been little research in the area relating to the contemporary Indigenous values of rivers and water sources (see Jackson et al 2013).

Any detailed assessment of the impact of the proposed water storage options will require consultation with Indigenous people and will require both systematic field survey to identify Indigenous cultural heritage protected under Queensland legislation and comprehensive consultation with Indigenous people about the archaeological sites and to identify places of contemporary significance. The consideration of wild resource use values for Indigenous people should be included in such studies.. Ideally these would be completed across the better potential dam sites so that the selection of viable options can include criteria relating to avoiding cultural heritage impact. These baseline studies involve:

- A regional thematic history at least at catchment level that identifies relevant historical themes and targets references to contact and post places in the individual storage areas;
- A comprehensive survey of each storage area in partnership with the relevant Indigenous community and/or Indigenous Cultural Heritage Body that identifies sites and/or potential archaeological deposits (PADs) and other places/ landscapes of cultural heritage significance and value. The survey would fully address the proponents' statutory obligations under the Indigenous Cultural Heritage Act 2003;
- Some archaeological testing of sites or PADs may be necessary to determine the scientific significance of cultural heritage sites.

Any future studies should provide cultural heritage management strategies and options for identified cultural sites and values, formulated in conjunction with the Indigenous Parties and consistent with the provisions of the *Aboriginal Cultural Heritage Act, Qld 2003*.

7.5 Total divertible yield

This section examines the divertible yield in the Flinders and Gilbert catchments as a result of incremental increases in dams, where divertible yield is the amount of water than can be released annually from one or more storages in a controlled manner.

To undertake this analysis the number of dams simulated in the Flinders and Gilbert river models (Lerat et al. 2013) were incrementally increased, starting with the most viable dam and finishing with the worst combination of the seven and six most promising dams respectively. In both catchments the Scenario B0 river model was used (see Holz et al. 2013 for model description) to undertake this analysis.

7.5.1 THE TOTAL DIVERTIBLE YIELD IN THE FLINDERS CATCHMENT

The total divertible yield, before losses, from six of the most promising dam sites in the Flinders catchment is about 140 GL in 85% of years. Cost estimates were obtained from Table 3.1 and do not include the cost of irrigation distribution infrastructure.

In Figure 7.6a the water yield from each dam was calculated at 85% annual time reliability at the dam wall. In Figure 7.6b the water yield from each dam was calculated at 85% annual time reliability and a 30% loss was applied to the water yield to approximate the loss of water that occurs during conveyance between the dam wall and the farm gate (see Holz et al. 2013). Given the distance between many of the dams in the Flinders catchment and suitable soil, 30% is likely to be an underestimate. It is important to note that these estimates of divertible yield take into consideration evaporation losses, and seasonality and inter-annual variability in streamflow. They do not, however, take into account environmental, social, cultural or economic factors or downstream entitlement holders.

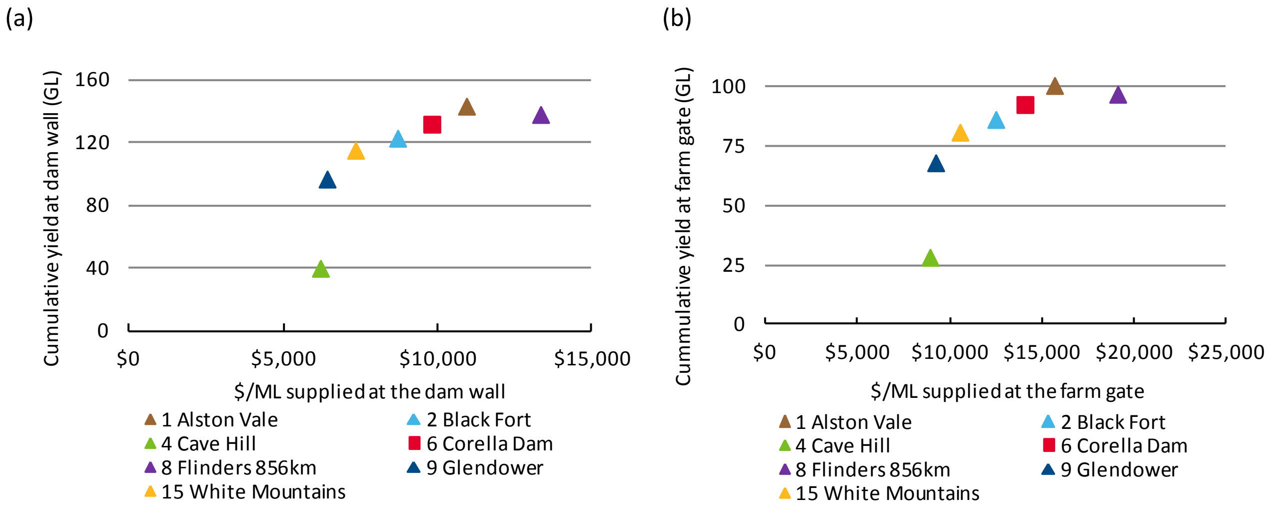

Figure 7.6 Cost of water in $/ML versus cumulative divertible yield at 85% annual time reliability
(a) At dam wall and (b) at farm gate. A 30% loss between dam wall and farm gate is assumed. Dots indicate combined water yield at 85% annual time reliability of one or more dams, with the colour of the dot indicating the most recently included dam in the cumulative yield calculation. For example, Cave Hill has a yield at the dam wall of 40 GL; Cave Hill and Glendower have a cumulative yield of 97 GL; Cave Hill, Glendower and White Mountains have a cumulative yield of 115 GL. See Figure 3.8 for dam locations. Squares indicate existing dams, triangles indicate proposed dams.

Figure 7.6 illustrates that with the addition of more dam sites, the construction cost per ML of yield increases considerably with the third and subsequent dams. This is in part because i) each subsequent potential dam site is less favourable than its predecessor; and ii) in those instances where a dam is constructed upstream of an existing dam, their combined yield is less than the sum of their individual yields because the upstream dam reduces inflows to the downstream dam. An extreme example of this is provided with the addition of the 7th dam (i.e. for a combined cost of $13,360/ML). This dam (Flinders 456) and the dam upstream (White Mountains) reduced the inflows to Glendower dam to the extent that the storage volume of Glendower dam rarely exceeded the dead storage volume (i.e. the volume below which there can be no outflow).

It should be noted that the purpose of this analysis is to broadly illustrate the viability of incrementally constructing additional dams in the Flinders catchment. In an operational environment (e.g. the day to day supply of water to a large city or series of irrigation districts) numerous dams in parallel and in series would be operated in combination, to achieve an optimum yield across the entire system. Consequently the yield of the system (i.e. the combined yield from multiple dams) would be slightly higher than the yield values presented here. For the purposes of the Assessment this level of detail of analysis was not warranted.

7.5.2 THE TOTAL DIVERTIBLE YIELD IN THE GILBERT CATCHMENT

The total divertible yield, before losses, from six of the most promising dam sites in the Gilbert catchment is about 630 GL in 85% of years.Cost estimates were obtained from Table 4.1 and do not include the cost of irrigation water distribution infrastructure.

In Figure 7.7a the water yield from each dam was calculated at 85% annual time reliability at the dam wall. In Figure 7.7b the water yield from each dam was calculated at 85% annual time reliability and a 30% loss was applied to the water yield to approximate the loss of water that occurs during conveyance between the dam wall and the farm gate (Section 5.3). Given the distance between many of the dams in the Gilbert catchment and suitable soil, a 30% loss is likely to be conservative. It is important to note that these estimates of divertible yield take into consideration evaporation losses, and seasonality and inter-annual variability in streamflow. They do not, however, take into account environmental, social, cultural or economic factors or downstream entitlement holders.

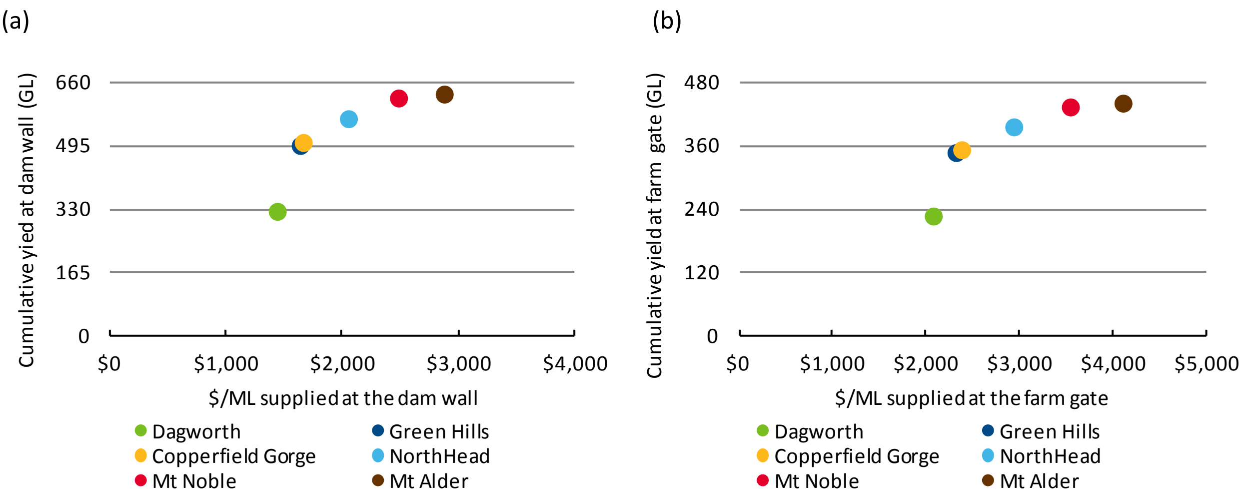

Figure 7.7 Cost of water in $/ML versus cumulative divertible yield at 85% annual time reliability
(a) At dam wall. (b) At farm gate. A 30% loss between dam wall and farm gate is assumed. Dots indicate combined water yield at 85% annual time reliability of one or more dams, with the colour of the dot indicating the most recently included dam in the cumulative yield calculation. For example, Dagworth has a yield at the dam wall of 326 GL; Dagworth and Green Hills have a cumulative yield of 498 GL. Dam locations are shown in Figure 4.8. Squares indicate existing dams, triangles indicate proposed dams.

Figure 7.7 illustrates that with the addition of more dam sites, the construction cost per ML of yield increases considerably with the third and subsequent dams. This is in part because i) each subsequent potential dam site is less favourable than its predecessor; and ii) in those instances where a dam is constructed upstream of an existing dam, their combined yield is less than the sum of their individual yields because the upstream dam reduces inflows to the downstream dam. An example of this is provided with the addition of Mount Alder on the Einasleigh River in addition to dams at Kidston, Mount Noble and Dagworth. The effect of adding a dam at Mount Alder reduces the inflows to Mt Noble and Dagworth dams downstream such that their combined yield (at 85% reliability) is reduced by 25 GL, yet the Mount Alder dam only contributes an additional yield of 35 GL to the system.

It should be noted that the purpose of this analysis is to broadly illustrate the viability of incrementally constructing additional dams in the Gilbert catchment. In an operational environment (e.g. the day to day supply of water to a large city or series of irrigation districts) numerous dams in parallel and in series would be operated in combination, to achieve an optimum yield across the entire system. Consequently the yield of the system (i.e. the combined yield from multiple dams) would be slightly higher than the yield values presented here. For the purposes of the Assessment this level of detail of analysis was not warranted.

8 Conclusions

The relatively undeveloped nature of the water resources across northern Australia represents a globally unique opportunity to take a long term view to water resource development and strategically investigate different potential development options. This report documents the results of a catchment scale scoping study of potential dam sites in the Flinders and Gilbert catchments. Large instream dams and offstream storages were examined, though the major focus was on the large instream dams as the design and construction of small offstream storages is highly site specific.

The Flinders catchment does not have any favourable locations for siting large instream dams. Areas with suitable topography are limited to the headwater catchments where reservoir yields are low or the geology for dam construction is unfavourable. Siting dams on the flat to mid reaches of the Flinders River, where yields are higher, would require excessively long embankments to provide adequate storage capacity, and the construction and operation of a spillway to cope with the large flood events would entail significant costs and risk. Nevertheless 15 potential dam locations and up to three sites at each location were assessed in the Flinders catchment using a consistent set of methods. The best of these locations were O'Connell Creek offstream storage near Richmond and the Cave Hill dam site upstream of Cloncurry. Nevertheless, either location would cost in excess of $6000/ML at 85% annual time reliability just for the construction of the dam. Both locations have major uncertainties, O'Connell Creek has considerable uncertainty associated with its potential yield and Cave Hill has considerable geological uncertainty. Hence for any of these options to advance to construction, far more comprehensive studies would be needed.

The soils of the Flinders catchment appear to be generally suitable for siting farm scale offstream storages. However, very little information was available below 1.5 m depth. In many parts of the Flinders catchment no local runoff is generated in at least 50% of years, making gully or hillside dams unreliable in these areas. Ring tanks or turkey nest storages along major drainage lines (e.g. Flinders River) would appear to be the most likely water storage option in the Flinders catchment, however no assessment of the reliability of filling these ring tanks or on the quantity of ring tanks possible in the Flinders catchment is provided here. This assessment was undertaken in the companion technical report on River modelling simulation (i.e. Holz et al. 2013).

The Gilbert catchment has a number of suitable locations for siting large instream dams. This is because the catchment is topographically favourable, has relatively high runoff and in places the rivers have eroded through high strength ignimbrites, which is geologically favourable for siting large instream dams. Six potential locations and one existing dam were reviewed in the Gilbert catchment. Five of the potential locations had been previously listed, though reports could only be found for three. The sixth potential location was a previously unidentified location (with two possible sites) on the Einasleigh River at Dagworth. The Dagworth upstream site is the best dam site on the Einasleigh River in terms of its yield, geology and proximity to the better soils in the Gilbert catchment. The best dam site on the Gilbert River is the Green Hills upstream site, which although smaller than the Dagworth site, is situated closer to soils suitable for irrigated agriculture. The construction of costs of dams at either of these sites were estimated at less than $2000/ML at 85% annual time reliability, not including distribution costs.

The mid reaches of the Gilbert River and Einasleigh River adjacent to the potential irrigation area are about 400 m and 1000 m wide respectively. Hence sheet piling regulating weirs downstream of the potential dam sites would be very expensive and impractical. Futhermore, unlike the lower Burdekin River, the banks along both the Einasleigh and Gilbert rivers are relatively low (i.e. <6 m), which limits the height of regulating structures. One option could be to use sand dams as regulating structures, similar to those used in the lower Burdekin, but this would probably incur high losses and would require annual rebuilding.

The sandy texture of the soils adjacent to the potential irrigation area along the Gilbert River and to a lesser extent the Einasleigh River, would also limit the scale of water harvesting into offstream storages.

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Appendix A Non short-listed potential dams in the Flinders Catchment

Alston Vale dam site on Betts Gorge Creek; 20.3 km

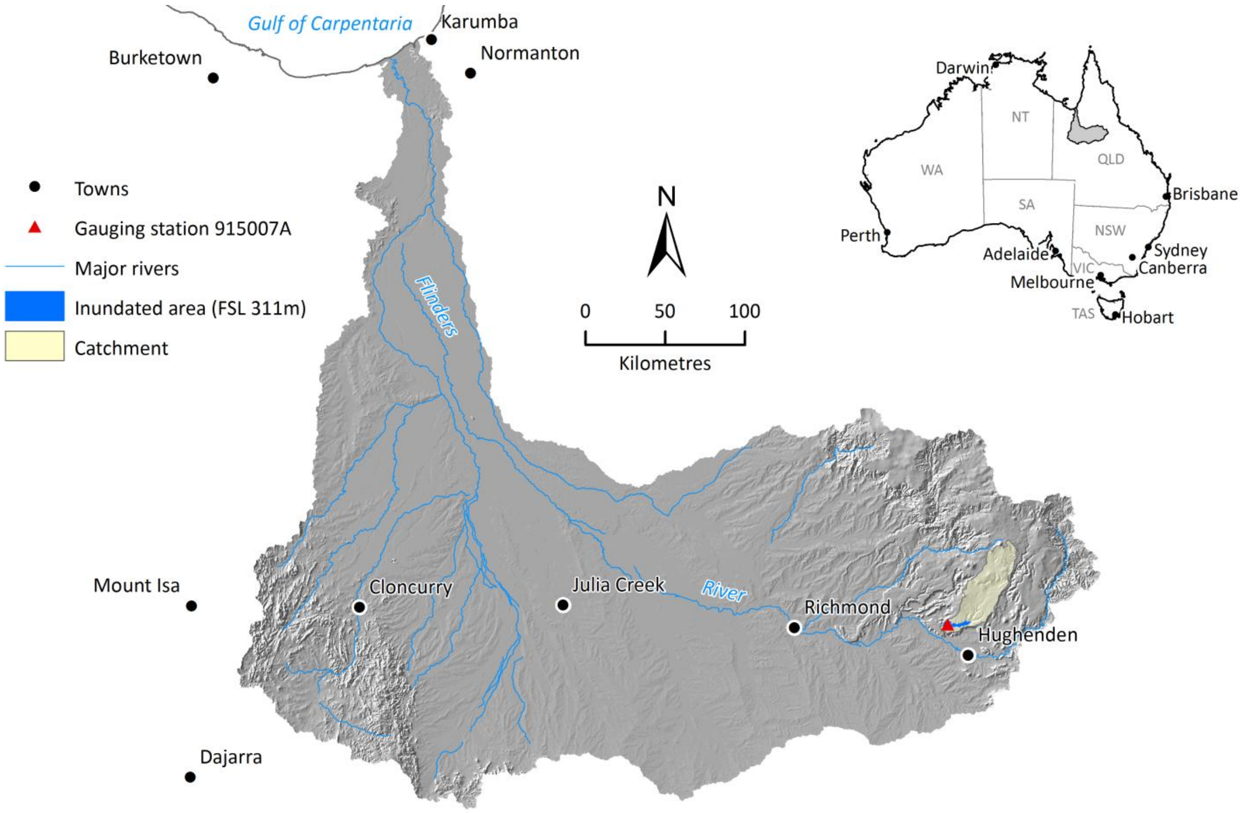
PARAMETER	DESCRIPTION
Previous investigations	QWRC (1990). Appraisal Report on Potential for Irrigated Cotton Production – Hughenden Area. Turner and Hughes (1983) Upper Flinders River irrigation Proposal. Hughes. GHD (2000). Potential Irrigation Scheme at Hughenden – Preliminary Investigation. DNR (2001). Natural Resource Assessment and Water Supply Appraisal Study – Gulf Region. SMEC (2003). Irrigation Project – Alston Vale. Flinders Shire Council.
Description of proposal	SMEC (2003) reported two proposals as follows. 1. A 22 m high dam to FSL 302 m or a 30 m high dam to FSL 310 m on Betts Gorge Creek at the 18.1 km site providing supply to an irrigation area in the Soda Valley area 2. A dam as above supplemented by diversion of high flows from Porcupine Creek via a canal and tunnel through 'the wall' of Betts Gorge. For both options, delivery canals 35 km in length to the irrigation area were assumed.
Regional geology and topography	Betts Gorge Creek has incised a gorge into a basaltic plateau at the site (Apx Figure A.1). The basalt flows forming the upper surface of the plateau are less than 30 m thick. The underlying rocks are mostly mudstones belonging to the Wallumbilla Formation – part of the Rolling Downs Group of Early Cretaceous age. They are much less resistant to erosion than the basalt, and Betts Gorge Creek has eroded a gorge more than 50 m deep upstream of the dam site. The upper slopes of the gorge are steep and covered with colluvium where the mudstones adjoin the basalt. Landslides are a common feature on these slopes. A location map and map showing the inundated area at FSL are shown in Apx Figure A.2 and Apx Figure A.3 respectively.
Site geology	No investigations have been carried out at the site. Basement rock consists of mudstone belonging to the Doncaster Member of the Wallumbilla Formation. The creek and floodplain are about 200 m wide. The creek channel is about 50 m wide and contains coarse sand and fine gravel. The slopes of the gorge are blanketed with colluvium derived from erosion of the basalt cap. The slopes consist of high plasticity brown clays covered by scattered basalt boulders. The left abutment rises at a moderate angle (13˚) from the floodplain and contains at least two flatter terrace areas. The right abutment is similar. The presence of terraces indicates potentially unstable slopes. (At the Glendower site on the Flinders River in similar terrain and of similar geology, landslides 20 m deep have occurred on one of the abutments.) Both abutments at this site may be similarly affected. Apx Figure A.4 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Reservoir rim stability and leakage potential	The reservoir will overlie thin deposits of alluvium and colluvium sitting on top of weathered mudstone belonging to the Doncaster Member. As mentioned previously, the dam abutments are potentially unstable. Similarly, there may be locations on the reservoir rim that are also unstable because of pre-existing, dormant landslides. If these are reactivated by higher groundwater levels resulting from the reservoir, they could affect the dam and its intake or outlet works. There may also be partial blocking of the reservoir. Feasibility investigations will be required to investigate these possibilities. Provided that the full supply level is below the level of the basalt/mudstone unconformity, the

<table>
<tr><th>PARAMETER</th><th>DESCRIPTION</th></tr>
<tr><td></td><td>potential for reservoir leakage is low.</td></tr>
<tr><td>Proposed structural arrangement</td><td>SMEC (2003) assumed the following structure types;
Dam – Roller compacted concrete (RCC) with central spillway section founded on mudstone.
Diversion weir – Concrete sill and piers with radial gates, overhead roadway and sheet pile cut off.
Diversion tunnel – Concrete lined in mudstone.
Canals – Excavated into natural soil and mudstone with high density polyethylene (HDPE) liner.</td></tr>
<tr><td>Availability of construction materials</td><td>No assessment of construction materials has been carried out. For the proposed RCC dam, basalt from the plateau cap may be suitable for aggregate. There appears to be small deposits of sand in the creek channel that could be used to supplement the basalt aggregate although these may be too small to economically extract.</td></tr>
<tr><td>Catchment areas</td><td>Catchment area at the dam site is 1132 km^2.</td></tr>
<tr><td>Flow data</td><td>Data were collected at streamflow gauging station 915007A Betts Gorge Creek at Alston Vale from 1969 to 1988. Over that period:
Maximum annual flow 221,170 ML
Mean annual flow 46,520 ML
Median Annual flow 21,450 ML</td></tr>
<tr><td>Storage capacities</td><td>240 GL (FSL 311) (Apx Figure A.5)</td></tr>
<tr><td>Reservoir yield assessment</td><td>12 GL at 85% annual time reliability (Apx Figure A.6)
10 GL at 95% monthly time reliability
Evaporation as percentage of regulated flow (at 85% annual time reliability): 60%
Ratio of evaporation to water supplied (at 85% annual time reliability): 1.5
<u>Previous studies</u>
SMEC (2003) reported that Option 1 would supply an irrigable area of 4,800 ha (at 4 ml/ha – industrial hemp) in Soda Valley and that Option 2 would supply an area of 9,200 ha including land along Canterbury Creek.
No details were provided in SMCEC (2003) as to how these estimates were developed or whether any allowance was made for distribution losses. No indication was given as to the reliability of supply.</td></tr>
<tr><td>Open water evaporation</td><td>Mean annual evaporation is estimated to be 5.2 mm d^{-1} using a bulk aerodynamic approach.
Mean annual evaporation was estimated to be 5.1 mm d^{-1} using Morton’s APE.</td></tr>
<tr><td>Impacts of inundation to existing infrastructure</td><td>Dirt access road along Betts Gorge.</td></tr>
<tr><td>Ecological and cultural considerations raised by previous studies</td><td>Not specifically assessed.
SMEC reported that the proposed storage site and associated infrastructure areas are in existing grazing areas “which are largely disturbed” generally being grassland with scattered eucalyptus tree vegetation.</td></tr>
<tr><td>Estimated rates of reservoir sedimentation</td><td><table>
<tr><th></th><th>Best case</th><th>Expected</th><th>Worst case</th></tr>
<tr><td>1 year (%)</td><td>0.004</td><td>0.033</td><td>0.053</td></tr>
<tr><td>10 years (%)</td><td>0.037</td><td>0.334</td><td>0.531</td></tr>
<tr><td>30 years (%)</td><td>0.11</td><td>1.00</td><td>1.59</td></tr>
<tr><td>100 years (%)</td><td>0.37</td><td>3.34</td><td>5.31</td></tr>
</table></td></tr>
</table>

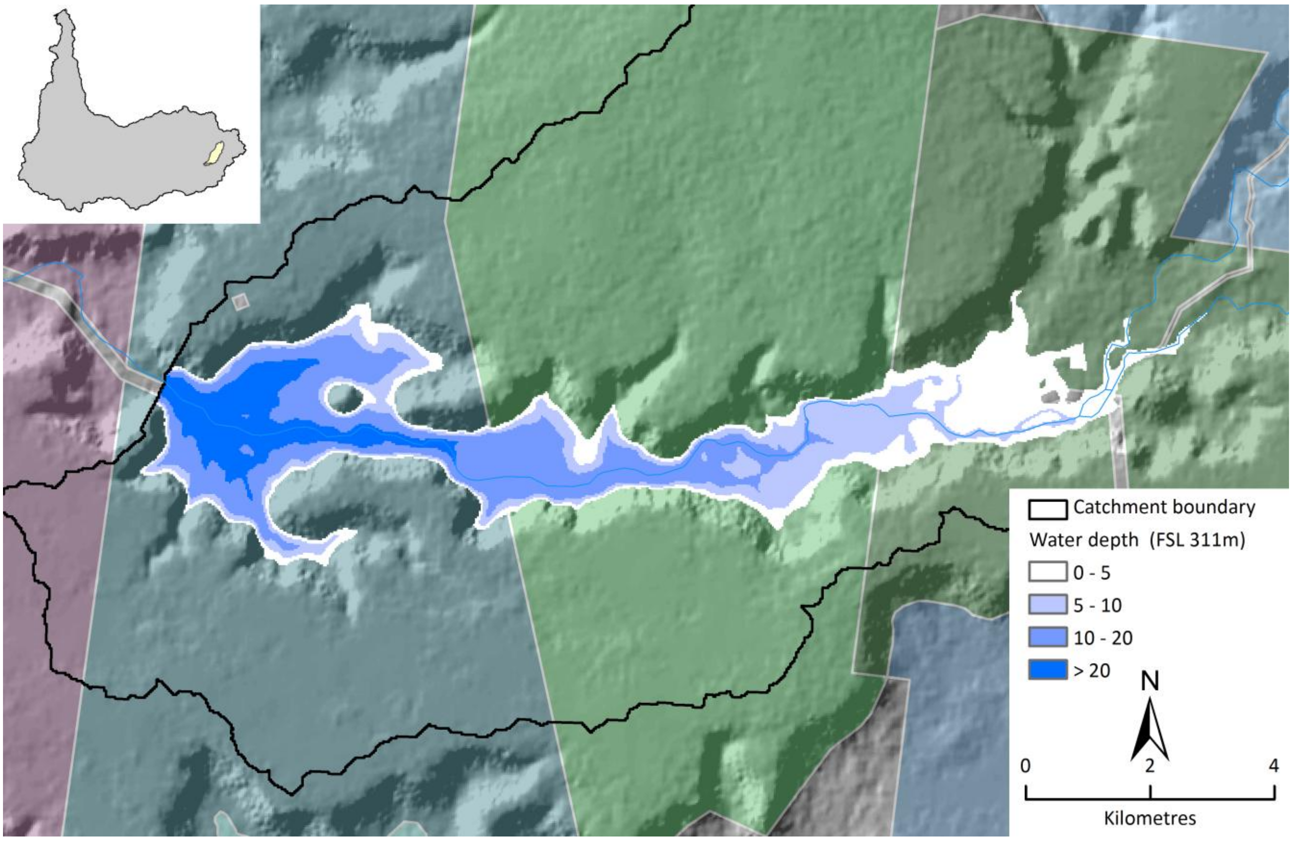
PARAMETER	DESCRIPTION
	1000 years (%) 3.7 33.4 53.1
	Years to fill 26764 2998 1884
Water quality and stratification considerations	Alston Vale reservoir is predicted to experience moderate seasonal stratification with a top-to-bottom temperature change of 5-9 °C during most years. The risk of blue-green algal blooms is high during summer when the estimated surface layer depth to euphotic depth ratio is consistently between 2 and 3 from January to March. During drier years the reservoir is likely to be persistently stratified from mid-August to mid-May and may experience low dissolved oxygen concentrations for extended periods. Low dissolved oxygen reduces available habitat for fish and other organisms as well as potentially causing elevated release of nutrients, Fe, and Mn from the sediments.
Environmental considerations	<u>*Fish*</u> Specific data on fish species were not available from this site. Less than 10 species are likely to be present in Betts Creek and barramundi, freshwater sawfish and freshwater whipray are unlikely to occur there. The dam captures a relatively small catchment area so impacts on fish passage should be minimal. The values of the aquatic habitat upstream of the proposed dam wall are not known. The inundated area covers a mixture of dominant “Endangered” and “Of Concern” ecosystems. Apx Figure A.7 shows the relative area in each category. <u>*Endangered ecosystems*</u> This site supports an endangered regional ecosystem with *Lysiphyllum carronii* as a very sparse canopy. *Eremophila mitchellii* present or dominating the very sparse tall shrub to low tree layer. *Enneapogon spp*. sometimes dominates the very sparse ground layer. <u>*Ecosystems Of Concern*</u> The site covers mixed woodland to open-woodland often dominated by *Eucalyptus leptophleba* but including combinations of the species *E. platyphylla*, *Corymbia clarksoniana*, *E. crebra*, *C. tessellaris*, and *Erythrophleum chlorostachys*, *C. grandifolia* and *C. polycarpa*. An open sub-canopy dominated by canopy species often occurs. An absent to a mid-dense shrub layer of *Melaleuca spp*., *Planchonia careya*, *Carissa lanceolata* and juveniles of canopy species can occur. The mid-dense to dense ground layer is dominated by *Heteropogon spp*., *Themeda triandra* and *Sarga plumosum*. In addition, a dam at the site would inundate a mixed woodland ‘Of Concern’, with combinations of *Eucalyptus crebra*, *E. platyphylla* and *E. tereticornis*, *E. camaldulensis*, *C. clarksoniana*. A sub canopy dominated by canopy species often occurs. The shrub-layer varies from none to scattered juvenile canopy species and *Carissa lanceolata* and *Capparis lasiantha*. The ground layer is dense grassy and is dominated by *Heteropogon* contortus.
Estimated cost	$250 m to $410m (dam cost only) <u>Previous studies</u> SMEC (2003) provided summary cost estimates as follows. (no cost breakdownsof quantities were supplied) Option 1. FSL 302 m $41.4 million FSL 310 m $63.8 million Option 2. FSL 302 m $107.0 million FSL 310 m $129.5 million The above estimated cost for the FSL 302m option was lower than an estimate of cost prepared by the Water Resources Commission in 1990. No explanation for this difference was given by the consultants. NB: Assuming these estimates were prepared in June 2002 prices, significant price escalation would apply to June 2012 prices.

PARAMETER	DESCRIPTION
	The CPI variation over this period suggests a 32% escalation over this period. Cost escalation in the construction sector particularly n remote areas is probably significantly higher.
Estimated cost / ML of supply	$23,510/ML (at 85% annual time reliability) <u>Previous studies</u> At June 2002 prices, the cost of supply based on the 115,000 ML capacity dam was as follows; Option 1 $2,156 /ML Option 2 $2,908 /ML Again, significant differences in the estimates of cost have not been explained and cost escalation since 1990 would result in much higher costs of supply.
Potential benefit/cost	<u>Previous studies</u> SMEC (2003) undertook a financial analysis which examined discounted cost and revenues for Options 1 and 2 based on the FSL 302m dam over a 35 year period. For a discount rate of 6%, Net Present Values were negative for both Options 1 and 2. For higher discount rates, Net present values were more strongly negative. No analysis was reported of the economics of hemp production or of other irrigated crops.
Summary comment	The geological concerns and very high capital cost make this proposal unattractive. SMEC (2003) concluded: • The proposed tunnel through 'The Wall' of Betts Gorge or the alternative open cut excavation for the canal is feasible but the cost is very high due to the weak mudstone and basalt capping on the Wall." • These two findings essentially eliminate the Alston Vale dam proposal from further consideration on the basis of engineering practicality and cost."

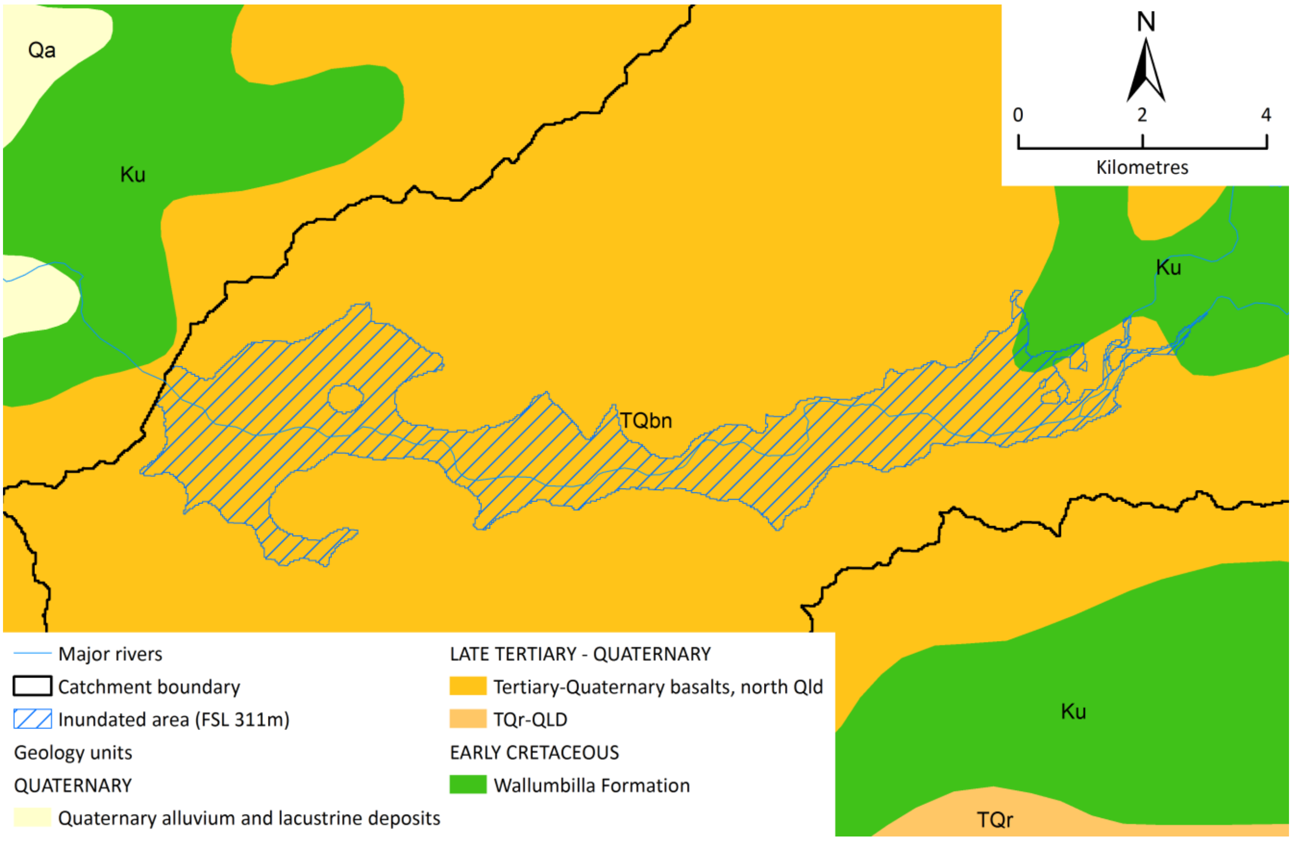
Apx Figure A.1 Alston Vale dam site looking downstream



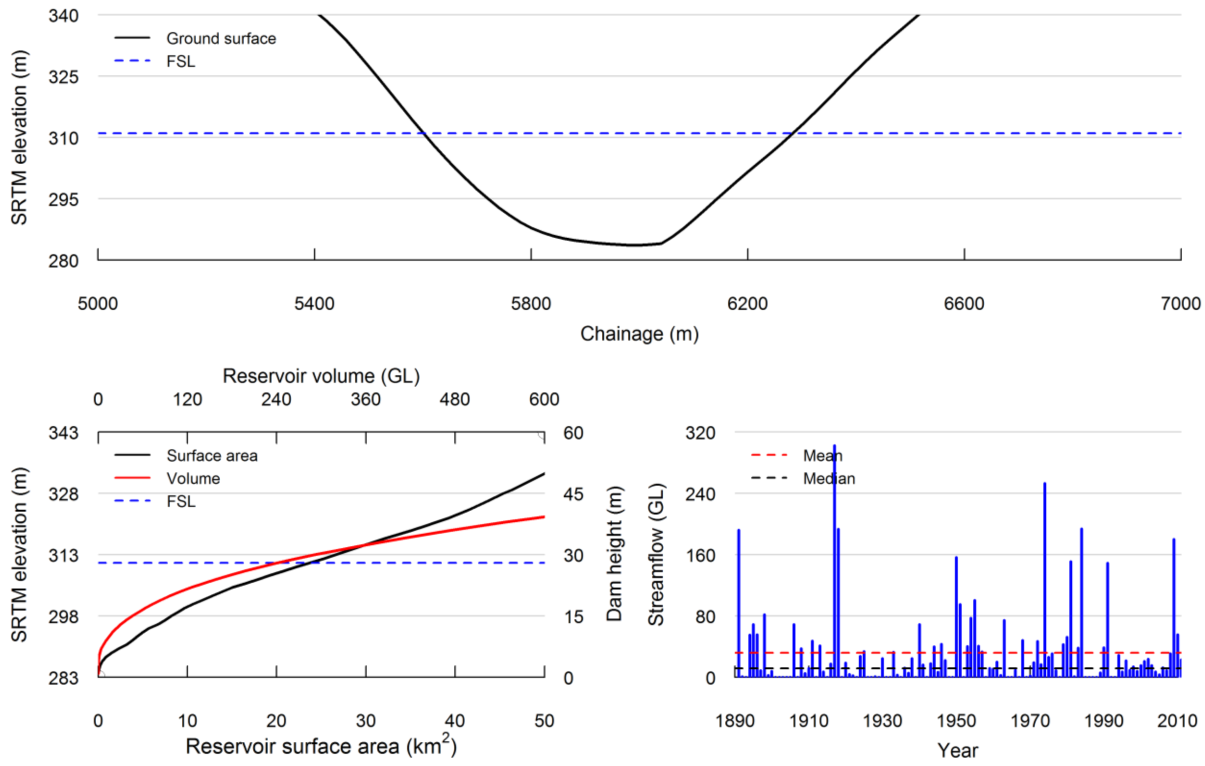
Apx Figure A.2 Location map of Alston Vale dam, reservoir and catchment area



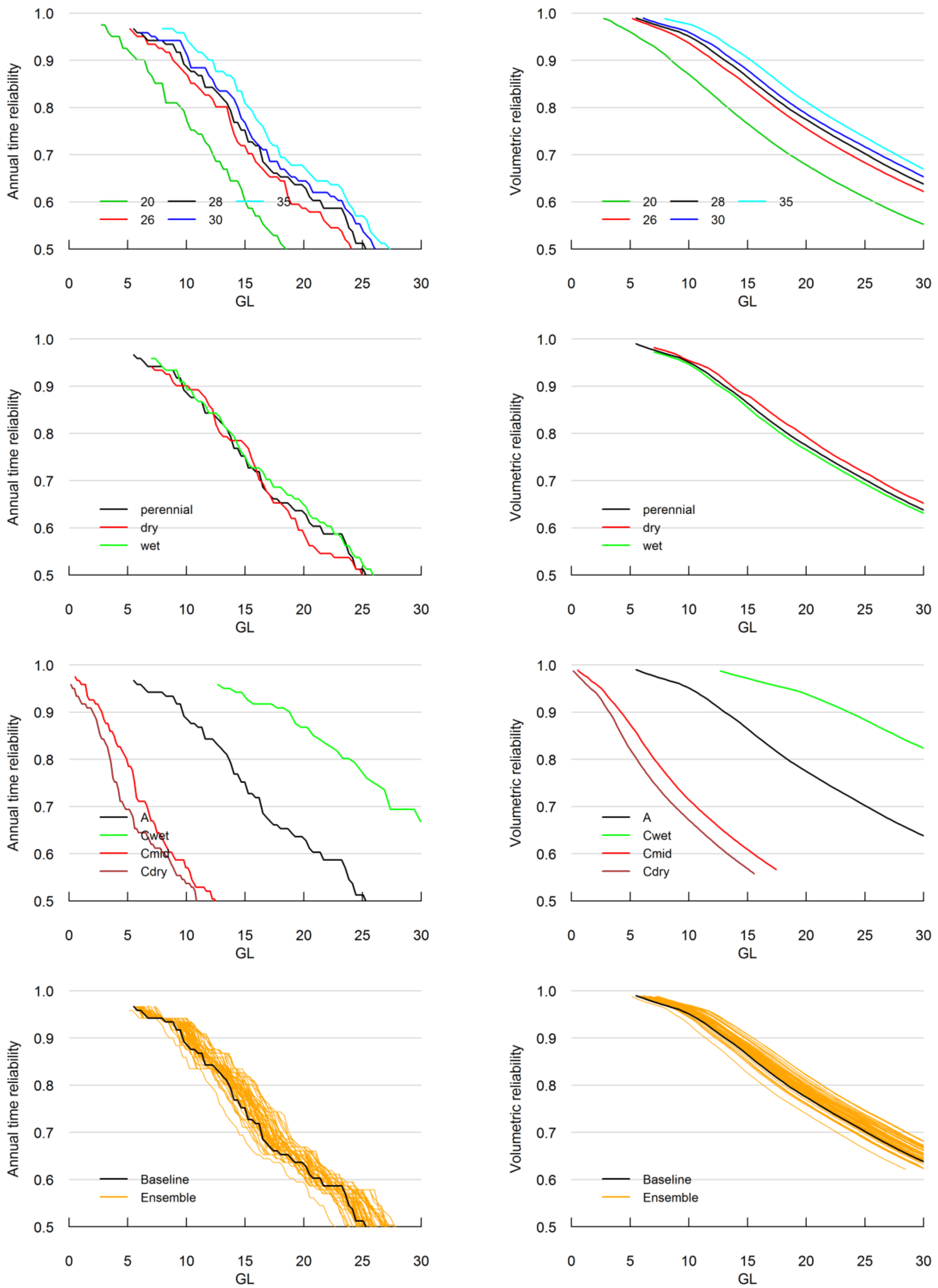
Apx Figure A.3 Alston vale dam proposed inundated area



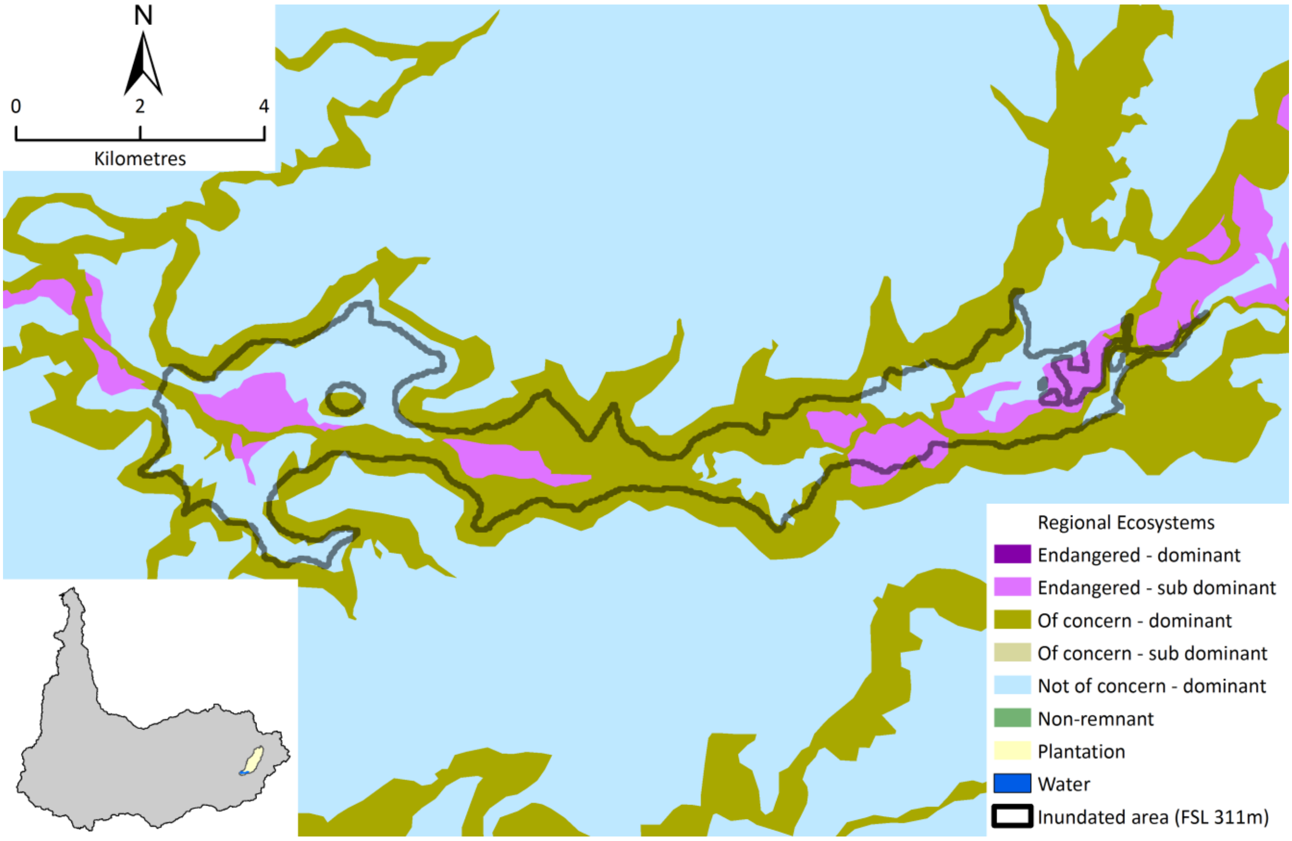
Apx Figure A.4 Alston Vale dam underlying geology



Apx Figure A.5 Cross section along main dam axis, volume surface area height relationship and annual streamflow Alston Vale dam site



Apx Figure A.6 Alston Vale dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: Yield-reliability relationship (YRR) for different FSL. Second row: YRR for different demand patterns for 311 m FSL. Third row: YRR under Scenario C for 311 m FSL. Fourth row: YRR for baseline and ensemble model runs for 311 m FSL



Apx Figure A.7 Alston Vale dam regional ecosystem mapping

Black Fort dam site on Cloncurry River; 415.8 km

PARAMETER	DESCRIPTION
Previous investigations	The Black Fort site and the nearby Painted Rock dam site at AMTD 377.1km were investigated in 1967 and again in 1974 as potential sources of water supply for mining ventures including a proposed phosphate deposit south of Duchess. Possible supply to shale oil developments in the Julia Creek area is reported in QWRC (1980). <u>References</u> Geological Survey of Queensland, Record (1971) Cloncurry River Damsites, Preliminary Geological Report –. McIntyre & Associates (No date) Duchess phosphates – water supply, Preliminary report on water supply from surface storages,. QWRC (1980). Cloncurry River Basin 915 AMTD 346.8km, 371.1km Flood Hydrology. Queensland Water Resources Commission, July 1980. Bartlett N (1980) Basin 915 Report on Yield Studies for the Cloncurry River; at Black Fort damsite; and (ii) at Cave Hill damsite AMTD 346.8 km. Queensland Water Resources Commission,. QDPI (1987) Cloncurry River Irrigation and Water Supply Project – Department of Primary Industries.
Description of proposal	On river storage dam. A pipeline would be required to allow supply to be pumped from the dam storage southwards to the Duchess area. A photograph of the site is shown in Apx Figure A.8. A location map and map showing the inundated area at FSL are shown in Apx Figure A.9 and Apx Figure A.10 respectively.
Regional geology	The basement rocks are of Palaeoproterozoic age intruded by granite. The rock in the reservoir area is part of the Mitakoodi Block and consists of highly deformed sandstone, slate, quartzite, limestone and jaspilite of the Mitakoodi Quartzite, Overhang Jaspilite and Marimo Slate. Rock underlying the Cloncurry River upstream of its confluence with the Malbon River consists of limestone, dolomite, sandstone and shale that are part of the Georgina Basin of Cambrian age.
Site geology	The right abutment is a north-northeast trending ridge of slate and quartzite topped by iron-manganese cemented chert. The chert is cavernous and may have formed by silicification of limestone. The left abutment consists of a highly deformed complex of silicified slate, sandy limestone, breccia and chert. These rocks have been intruded by granodiorite upstream of the axis. The riverbed area contains up to 15 m of alluvium overlying siltstone and quartzite. High water losses occurred in boreholes on the left abutment where voids up to 370 mm were penetrated. Apx Figure A.11 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Reservoir rim stability and leakage potential	The rock in the reservoir rim is mostly high strength and highly deformed. It is unlikely to become unstable when the reservoir is filled. There are potential leakage issues associated with the limestone and dolomite underlying the Cloncurry River in the upper reaches of the reservoir. These rocks are dense and strong but may contain solution cavities that give rise to high permeability. The cavities are sometimes overlain by residual or transported soils that conceal potential sinkholes. Elsewhere sinkholes may be visible at the ground surface. Feasibility should include an investigation of this area.
Proposed structural arrangement	No details of a structural proposal have been located.
Availability of construction materials	Potential earth fill materials would be available from terrace alluvium and fine slopewash adjacent to the Cloncurry River and its tributaries. Concrete aggregate and filter materials are available from channel alluvium in the river. This consists of well to poorly graded sand-gravel mixtures. Potential quarry sites in chert, sandstone and quartzite are available within 2 km of the dam site.

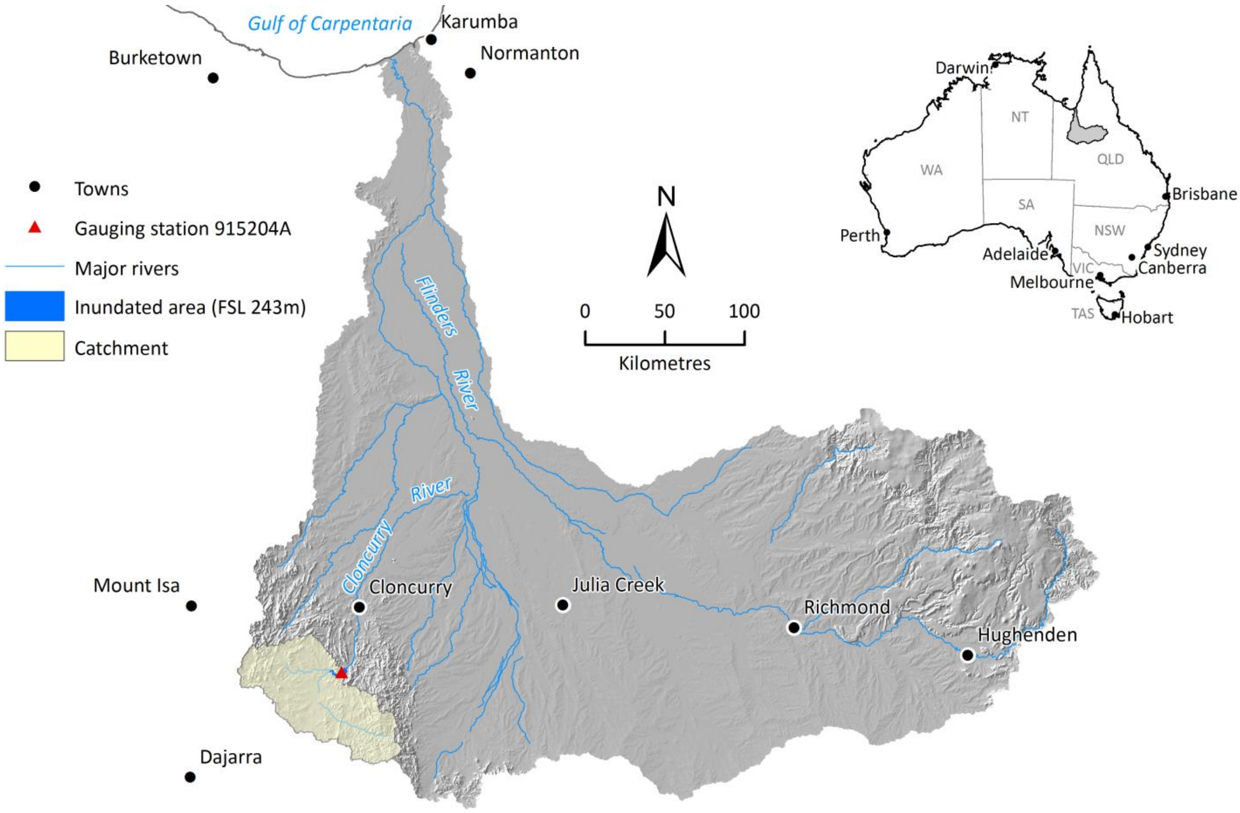
PARAMETER	DESCRIPTION
Catchment area	4249 km^2.
Flow data	Flow data were collected from gauging station 915204A from 1968 until 1994. Over this period recorded flows were as follows; Maximum recorded annual flow 1,018,000ML Mean annual flow 209,000 ML Median annual flow 101,000 ML Minimum annual flow 13,000 ML
Capacity	43 GL at FSL 243 (Apx Figure A.12).
Reservoir yield assessment	20 GL at 85% annual time reliability (Apx Figure A.13 and Apx Figure A.14). 21 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 35% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.5 <u>Previous studies</u> Geological Survey of Queensland (1971) indicates that 'safe' yield of these sites at their full development would be about 10,000 ML/a.
Open water evaporation	Mean annual evaporation is estimated to be 6.0 mm d^{-1} using a bulk aerodynamic approach. Mean annual evaporation was estimated to be 5.1 mm d^{-1} using Morton's APE.
Impacts of inundation to existing infrastructure	None
Ecological and cultural considerations raised by previous studies	No specific assessment has been located. Indigenous paintings have been recorded at the Painted Rock site.
Estimated rates of reservoir sedimentation	(see table below)
Water quality and stratification considerations	Black Fort Dam is predicted to experience very limited stratification with a top-to-bottom temperature change of 5-6 °C during summer in less than 1/3 of the simulated years. The risk of blue-green algal blooms is low with a typical Zsl:Zeu > 3. The water column is predicted to be frequently mixed and dissolved oxygen drawdown is unlikely to be a problem.
Environmental considerations	Specific data on fish are not available from this site. However, given its location not far upstream from Chinaman Creek Dam, fish species are likely to be the same. The dam captures a relatively small catchment area. With the exception of Chinaman Creek Dam, the values of the aquatic habitat upstream of the proposed dam wall site are not known. The inundated area covers a mix of "Endangered" and 'Of Concern' regional ecosystems. Apx Figure A.15 shows the relative areas in each category. *<u>Endangered ecosystems</u>* This site includes endangered vegetation ecosystems that follow the main river channel and the smaller tributaries. These communities are not specifically listed in the Queensland Herbarium mapping database of regional ecosystems. *<u>Ecosystems of Of Concern</u>* The site covers woodland and low woodlands of *Corymbia aparrerinja* and *C. terminalis*. *Acacia cambagei* with a sparse ground layer of tussock grasses with *Triodia longiceps* in some places.

Estimated rates of reservoir sedimentation:

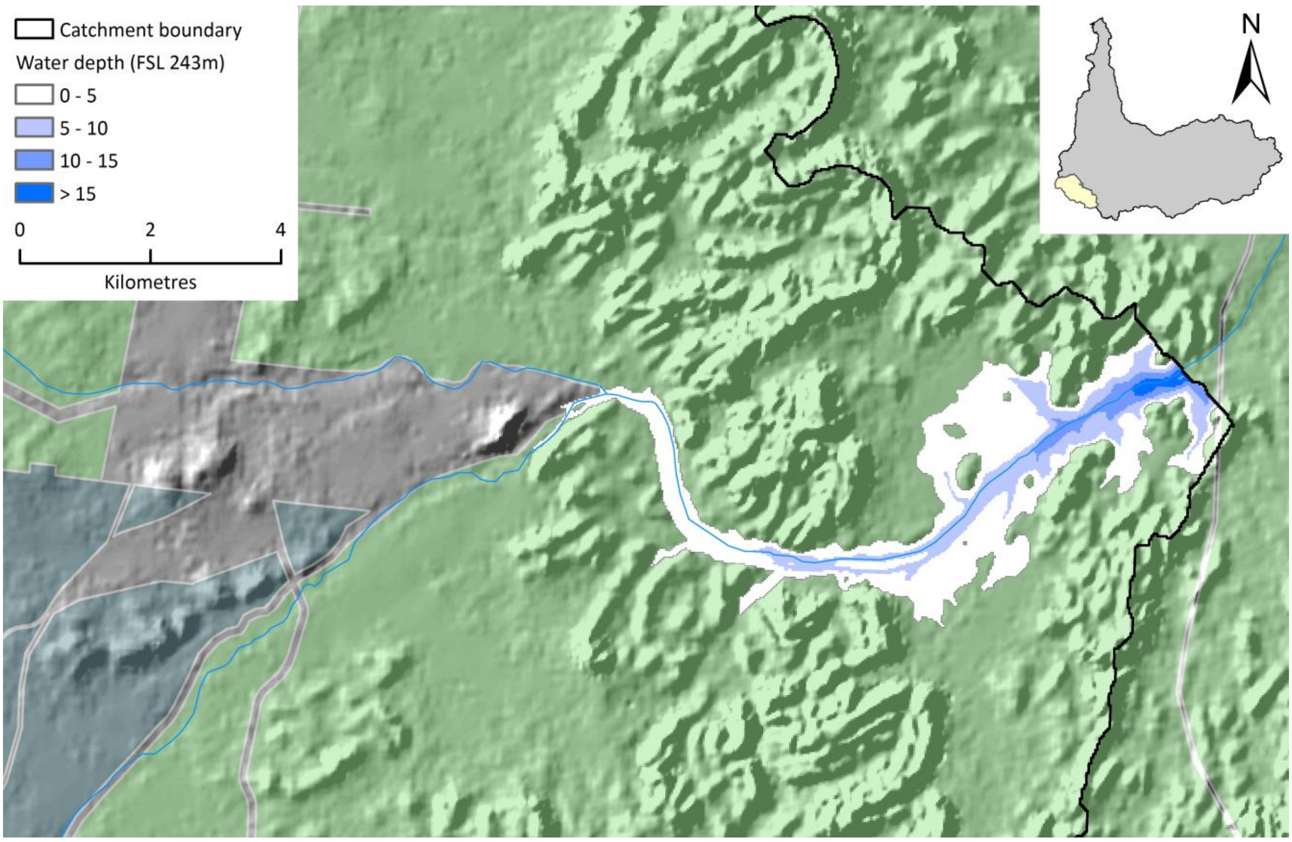
	Best case	Expected	Worst case
30 years (%)	0.26	1.89	3.75
100 years (%)	0.88	6.28	12.50
Years to infill	11368	1592	800

PARAMETER	DESCRIPTION
	The area also supports *Eucalyptus leucophylla*, *E. pruinosa* open-woodland, *Corymbia terminalis*, *Acacia cambagei*, *Atalaya hemiglauca*, *Grevillea striata* and *C. aparrerinja*, with a scattered shrub layer and mid-dense ground layer of tussock grasses and *Triodia spp*.
Estimated cost	$200 m to $340 m. Previous studies Cost of the dam in 1974 $'s was estimated to be $13 m. CPI escalation to 2012 prices suggests a dam cost of $96.7 m. Construction costs, particularly in remote areas have almost certainly increased at a higher rate than CPI over this period.
Estimated cost / ML of supply	$11,170/ML (at 85% annual time reliability)
Summary comments	Reasonable distance upstream of moderately suitable land. As a result the small water yield at the dam wall would be further reduced by river conveyance losses.

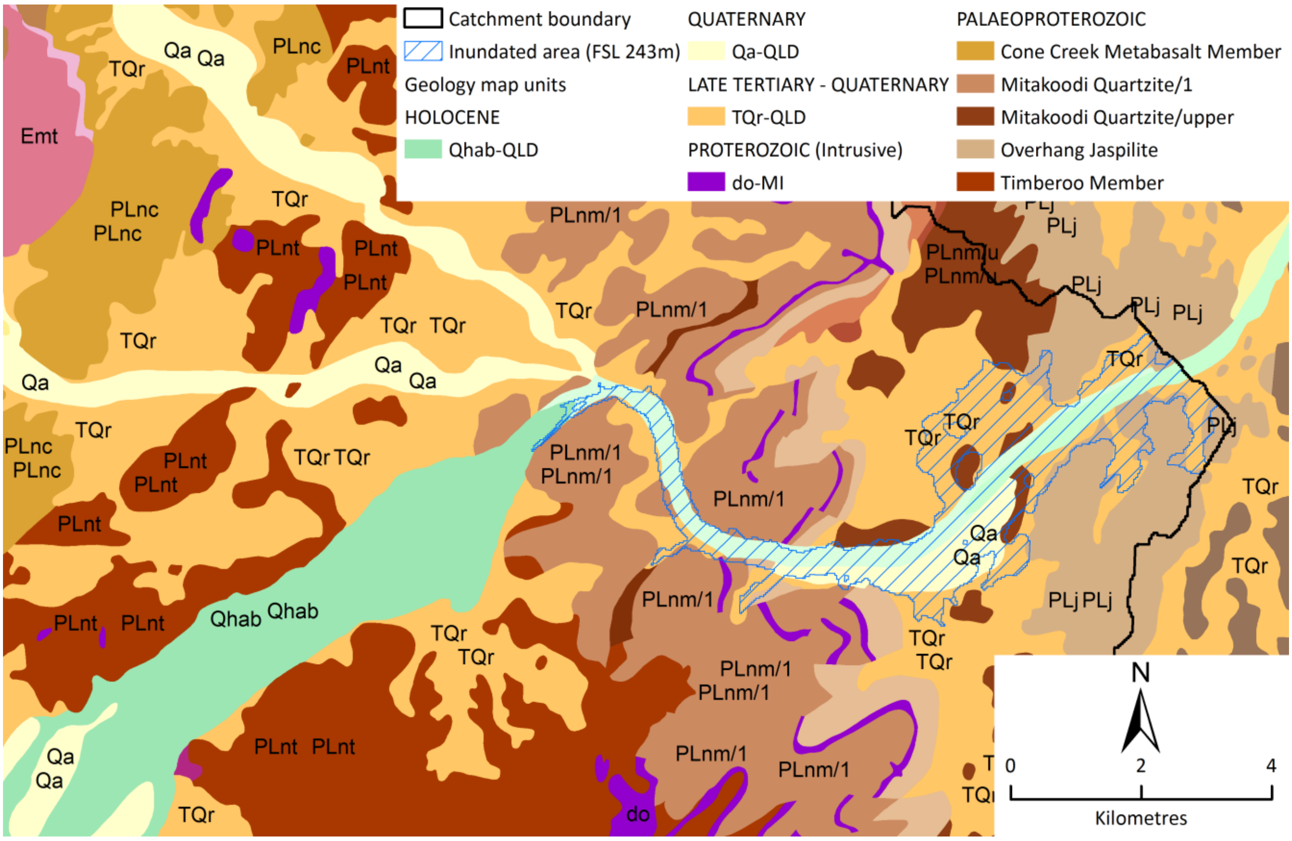
Apx Figure A.8 Black Fort dam site looking upstream



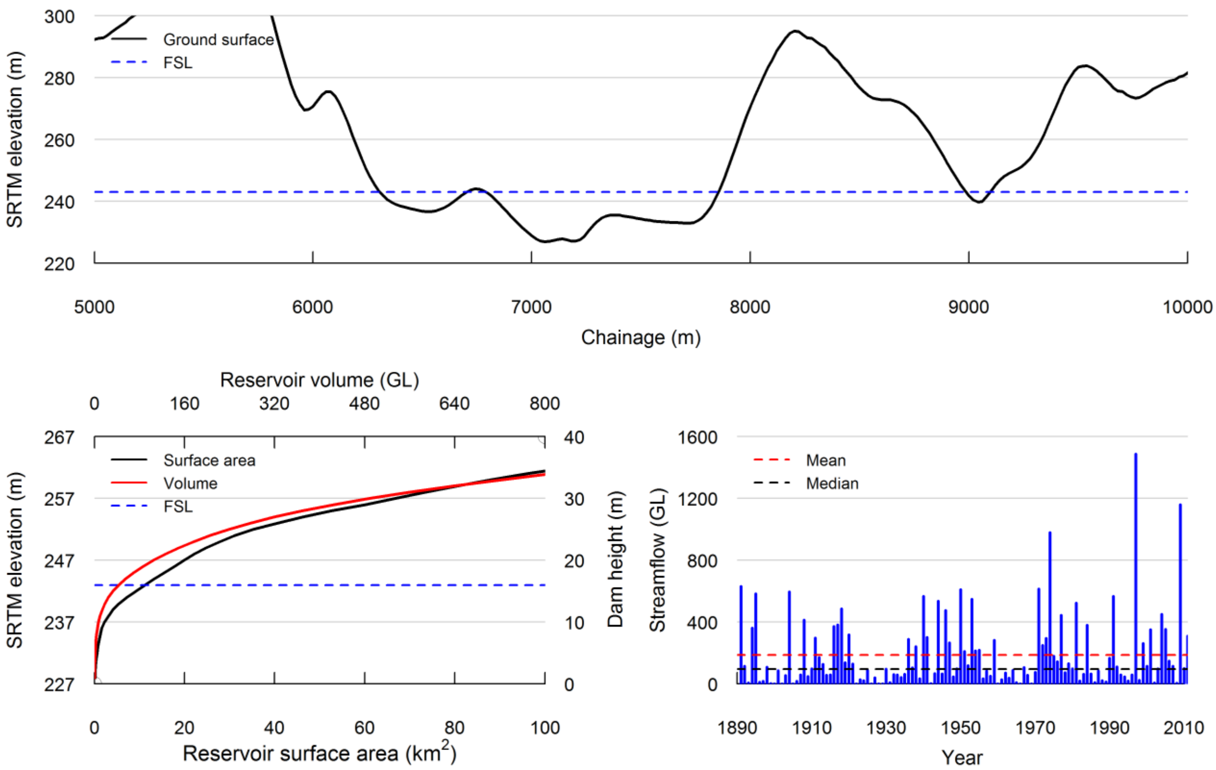
Apx Figure A.9 Location map of Alston Vale dam site, reservoir and catchment area



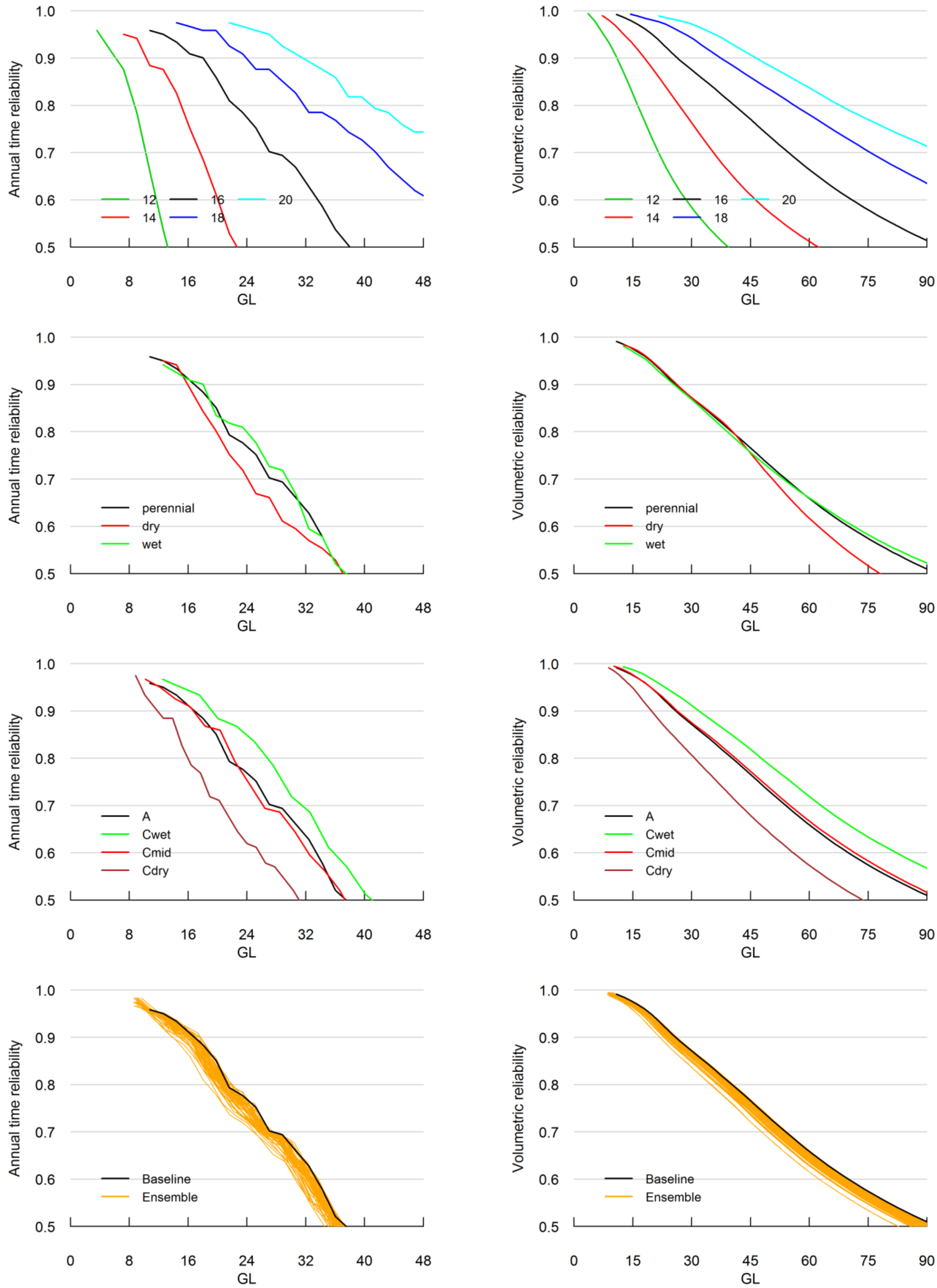
Apx Figure A.10 Black Fort dam site inundated area and property boundaries (indicated by coloured shading)



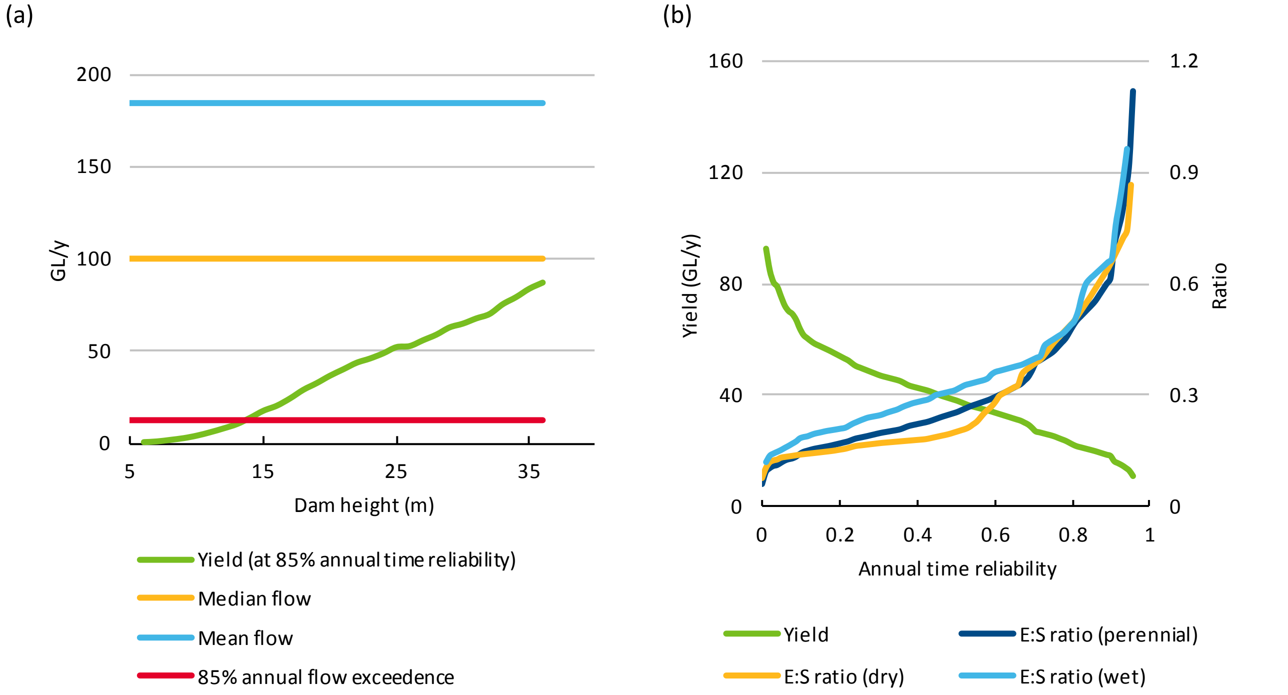
Apx Figure A.11 Black Fort dam site underlying geology



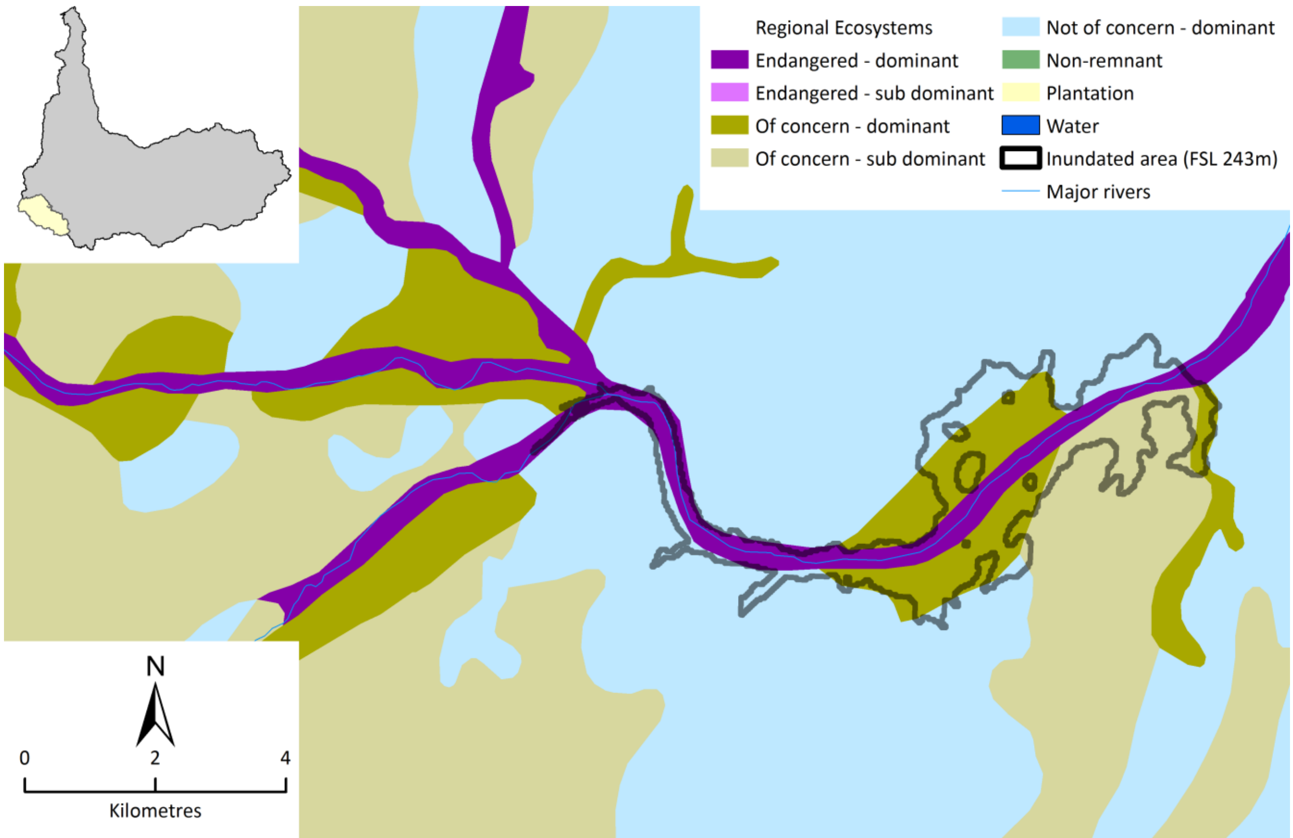
Apx Figure A.12 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Alston Vale dam site



Apx Figure A.13 Black Fort dam site performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 243 m FSL. Third row: YRR under Scenario C for 243 m FSL. Fourth row: YRR for baseline and ensemble model runs for 243 m FSL



Apx Figure A.14 a) Yield at 85% annual time reliability and streamflow at Black Fort dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Black Fort dam site for different annual time reliability for the selected dam height of 16 m



Apx Figure A.15 Black fort dam regional ecosystems mapping

Cameron River dam site on the Cameron River; 6.7 km

PARAMETER	DESCRIPTION
Previous investigations	An unpublished desktop study of this site was undertaken by the Queensland Department of Energy and Water Supply (DEWS) in 2012 as part of the North West Queensland Regional Water Supply Strategy development with the objective of increasing the availability of water supplies to meet urban and mining demands in the NW minerals province area.
Description of proposal	For mining, delivery of supply by pipeline. For irrigation, on stream dam releasing to stream for downstream extraction. A photograph of the site is shown in Apx Figure A.16. A location map and map showing the inundated area at FSL are shown in Apx Figure A.17 and Apx Figure A.18 respectively.
Regional geology	The site is located where the Cameron River cuts through a north-northeast trending range formed from the Quamby Conglomerate of Proterozoic age. The reservoir area is an alluvial floodplain overlying deformed and metamorphosed calcareous sandstone and limestone of the Corella Formation.
Site geology	Based on a brief site inspection in January 2013 and SRTM data, the riverbed and floodplain alluvium is about 250 m wide with a deeply incised flow channel at the toe of the left abutment. The abutments are composed of sandstone and conglomerate. The rock has been haematised and silicified and is very high strength. The strata have been folded to form a syncline structure. The syncline axis has been offset where the river cuts through the range indicating a west trending fault.
Reservoir rim stability and leakage potential	The rock on the reservoir rim is high strength and moderately to highly deformed. It is unlikely to become unstable when the reservoir is filled. The potential for leakage from the reservoir is low (Apx Figure A.19).
Proposed structural arrangement	A roller compacted concrete (RCC) dam was proposed by Department of Energy and Water Supply (DEWS).
Availability of construction materials	No investigations have been carried out. The sandstone and conglomerate near the site would be suitable for crushed aggregate for a RCC structure or for rockfill. Silty sand possibly suitable for augmenting a RCC mix is available on the floodplain adjoining the stream channel. Materials suitable for impermeable earthfill may be available upstream of the site. Sand is present in the stream bed.
Catchment area	Catchment area at the site is estimated to be 494 km^2.
Flow data	No flow data has been collected in the Cameron River catchment. However, runoff characteristics could be expected to be similar to those of the Corella River catchment.
Storage capacity	25 GL at a FSL 225 (Apx Figure A.29).
Reservoir yield assessment	7.7 GL at 85% annual time reliability (Apx Figure A.30 and Apx Figure A.31). 6.0 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 67% Ratio of evaporation to water supplied (at 85% annual time reliability): 2.1 <u>Previous studies</u> Initial estimates by Queensland Hydrology indicated yields as follows; Historic No Failure Yield - 300 Ml/a At 95% annual reliability - 1,900 ML/a. A critical period of 1919 to 1935 limits the available yield, probably even for much larger storages.

<table>
<tr><th>PARAMETER</th><th colspan="4">DESCRIPTION</th></tr>
<tr><td></td><td colspan="4">Yields at lower reliabilities, for example at 85%, are likely to be substantially higher.</td></tr>
<tr><td>Open water evaporation</td><td colspan="4"></td></tr>
<tr><td>Impacts of inundation on existing infrastructure</td><td colspan="4">An area of approximately XX ha of mostly grazing land would need to be acquired for the dam storage area.</td></tr>
<tr><td>Ecological and cultural considerations raised by previous studies</td><td colspan="4">No previous studies undertaken</td></tr>
<tr><td rowspan="4">Estimated rates of reservoir sedimentation</td><td></td><td>Best case</td><td>Expected</td><td>Worst case</td></tr>
<tr><td>30 years (%)</td><td>0.06</td><td>0.27</td><td>0.9</td></tr>
<tr><td>100 years (%)</td><td>0.21</td><td>0.91</td><td>3.00</td></tr>
<tr><td>Years to fill</td><td>47284</td><td>11033</td><td>3328</td></tr>
<tr><td>Environmental considerations</td><td colspan="4">Specific data on fish species are not available from this site. The values of the aquatic habitat upstream of the proposed dam wall site are not known. However, the dam location is high upstream on a tributary stream and only captures a relatively small catchment area so impacts upon fish passage should be minimal.

The site covers a mixture of dominant “Endangered” and “Of Concern” ecosystems. Apx Figure A.32 show relative areas in each category.

Endangered ecosystems

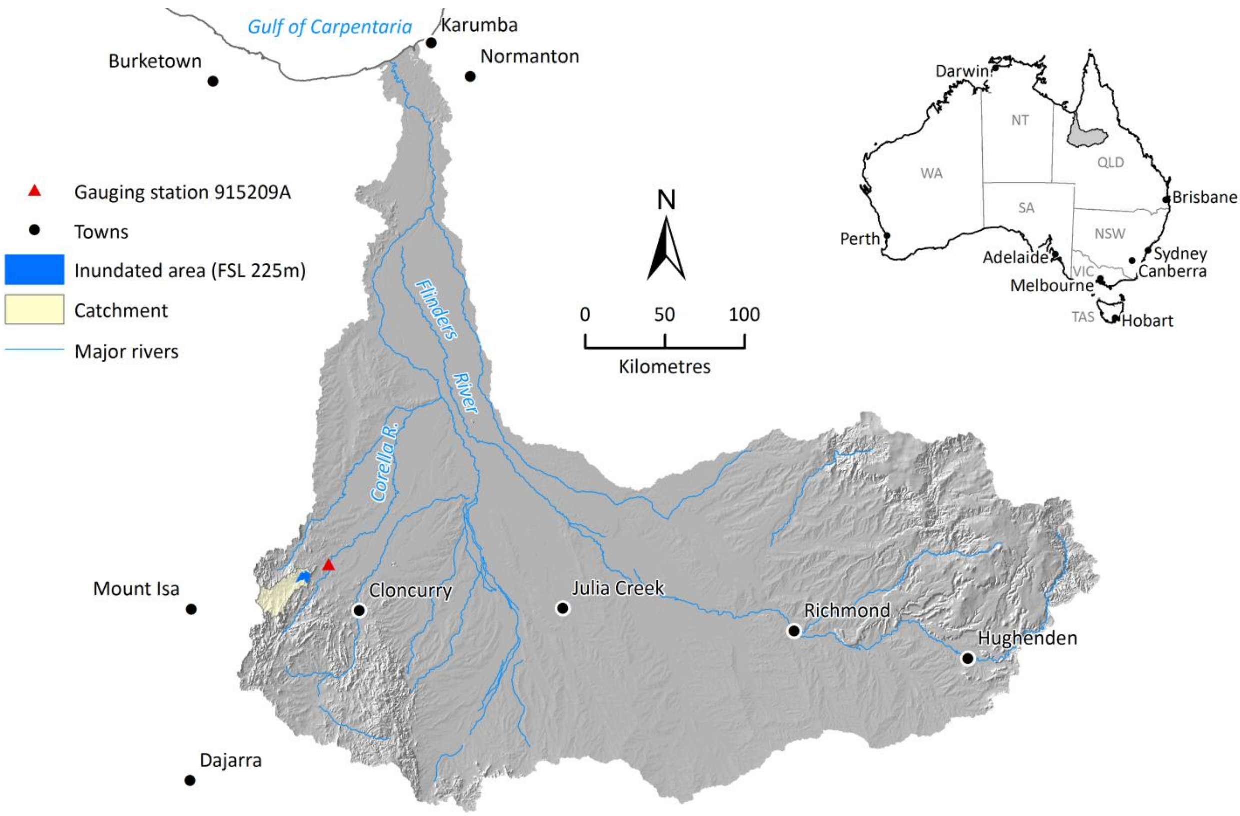
Fringing woodland of Eucalyptus camaldulensis, with Melaleuca bracteata on levees of smaller channels and M. argentea on those of larger ones. Lophostemon grandiflorus usually present, occasional Terminalia aridicola. Eucalyptus microtheca or E. leucophylla on finer textured soils. Melaleuca leucadendra may dominate creek lines where water is available for extended periods each year.

Ecosystems Of Concern

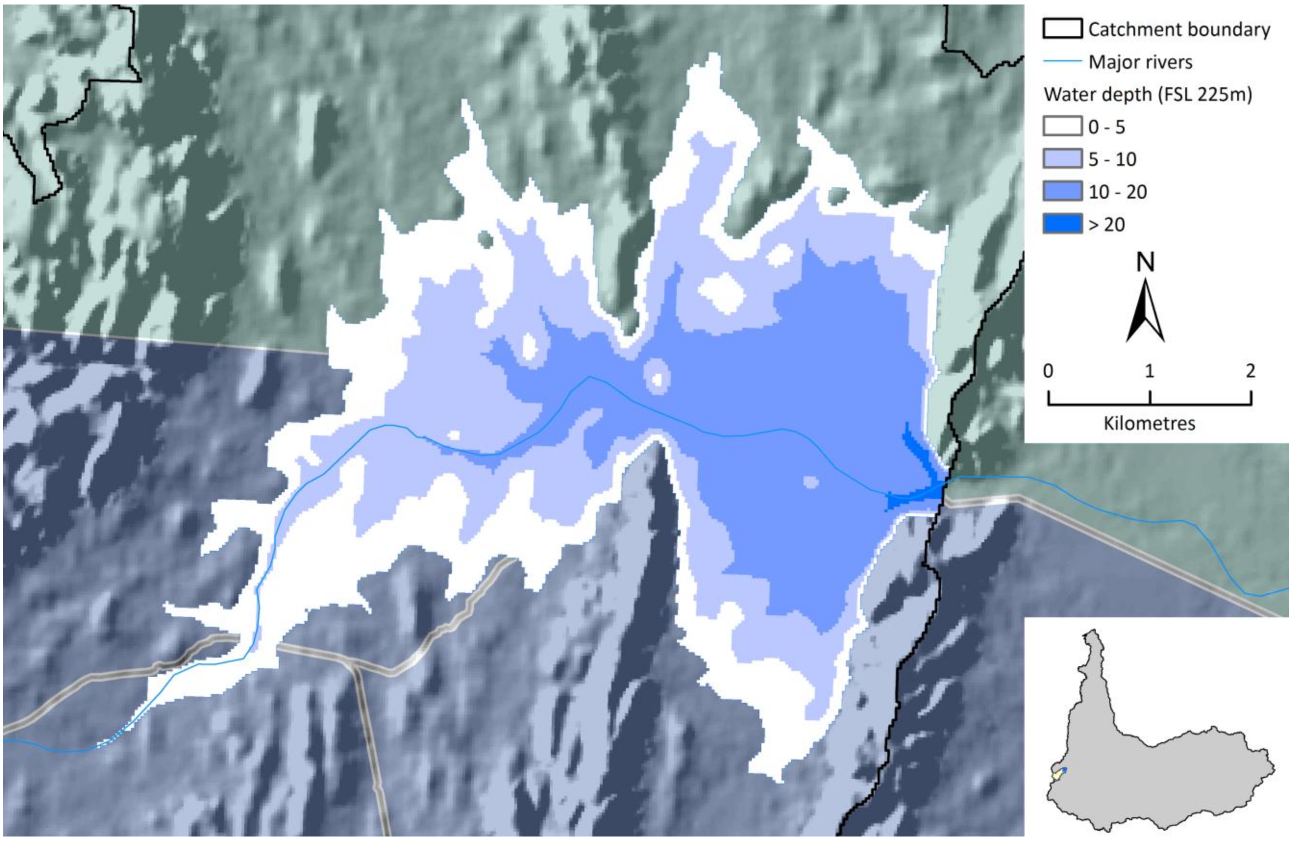
Low open-woodland and low woodland of Acacia cambagei over annual grasses. Occasional Atalaya hemiglauca, Hakea lorea subsp. lorea, Grevillea striata and Acacia excelsa. Low open-woodland of Corymbia capricornia, often with Eucalyptus leucophloia and Triodia spp. understorey.</td></tr>
<tr><td>Estimated cost</td><td colspan="4">$290 m to $490m</td></tr>
<tr><td>Estimated cost / ML of supply</td><td colspan="4">$42,230/ML (at 85% annual time reliability)</td></tr>
<tr><td>Potential benefit/cost</td><td colspan="4">Not assessed as yet</td></tr>
<tr><td>Summary comment</td><td colspan="4">This site is substantially wider than the Corella River site and although not requiring any saddle dams is likely to involve higher costs.

Additionally, the site has a substantially smaller catchment area and is expected to have lower yields.</td></tr>
</table>

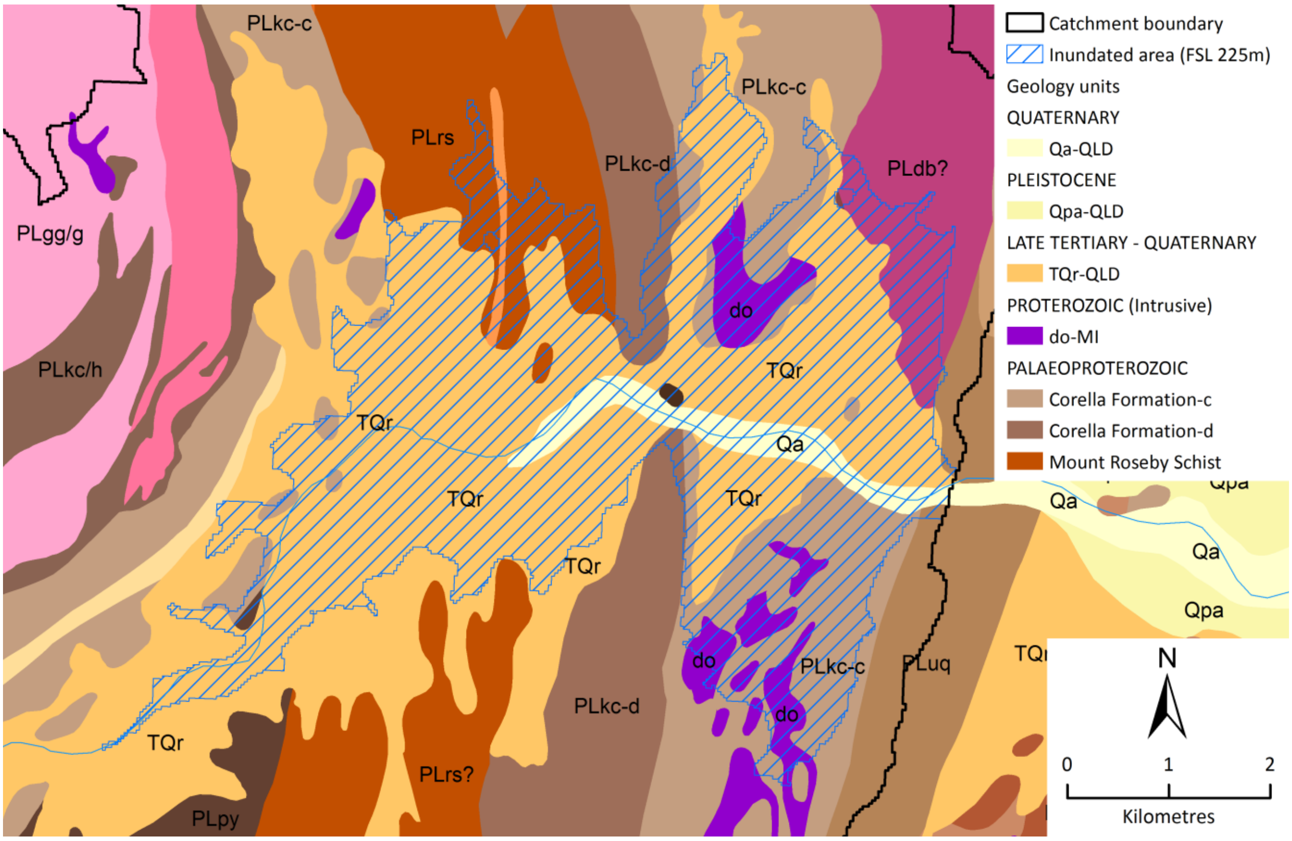
Apx Figure A.16 Cameron Creek potential dam site looking upstream



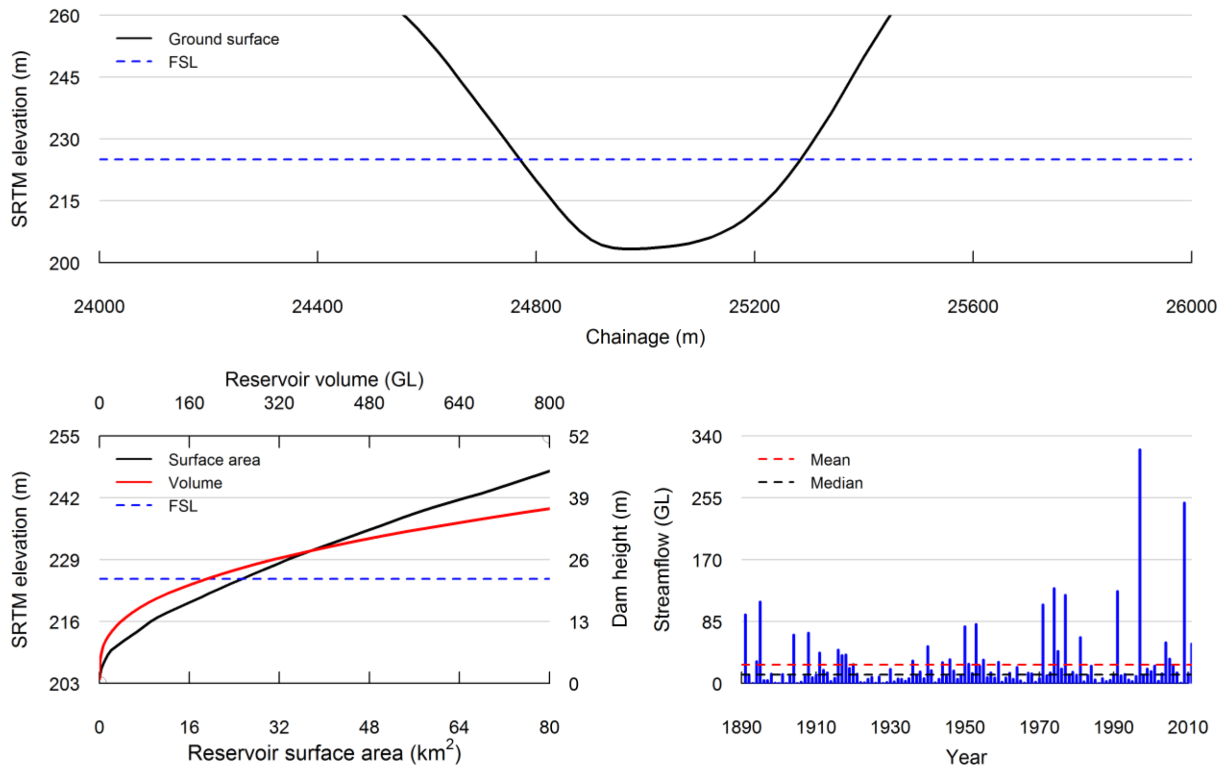
Apx Figure A.17 Location map of Cameron Creek dam, reservoir and catchment area



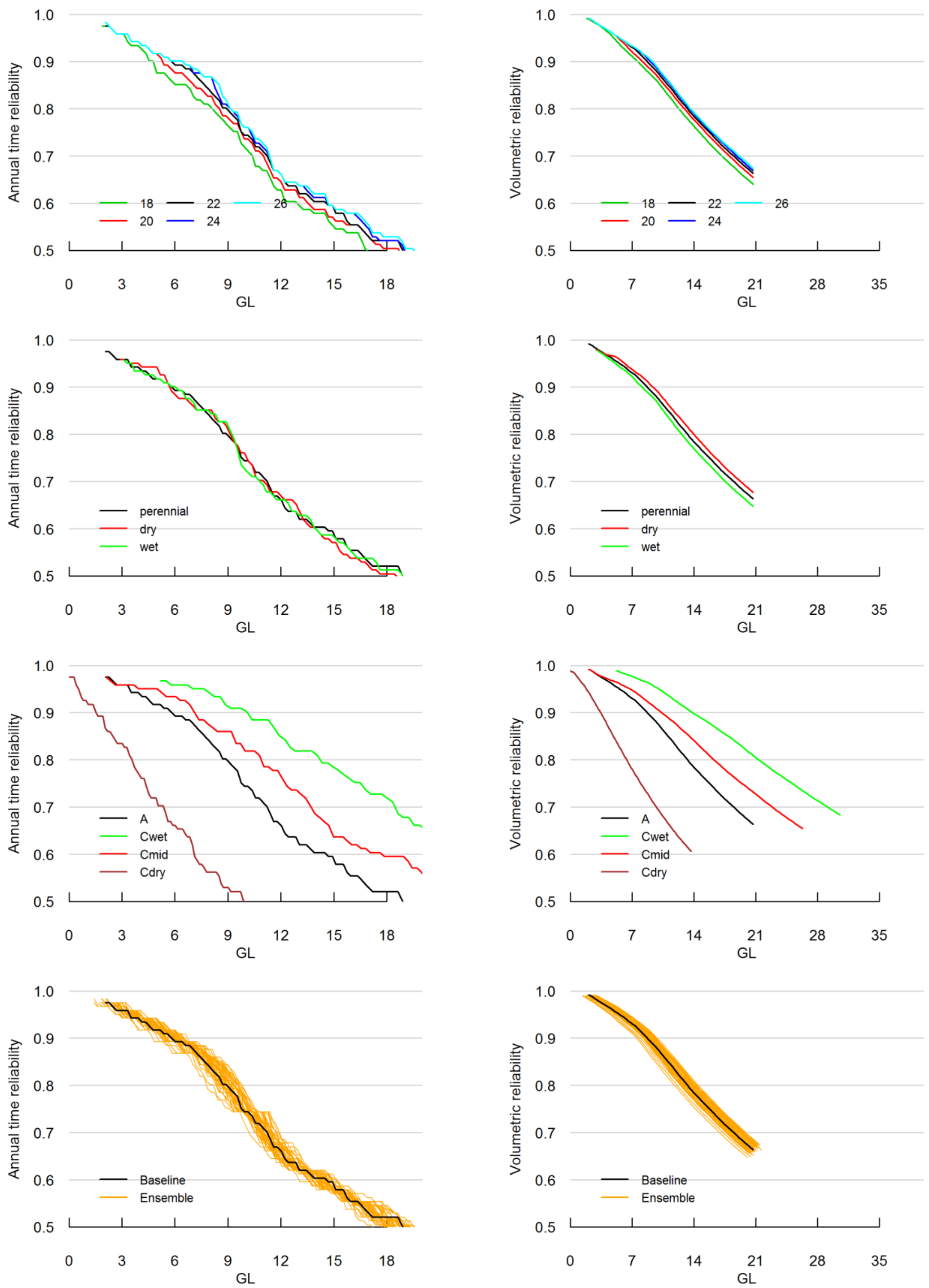
Apx Figure A.18 Cameron Creek dam inundated area



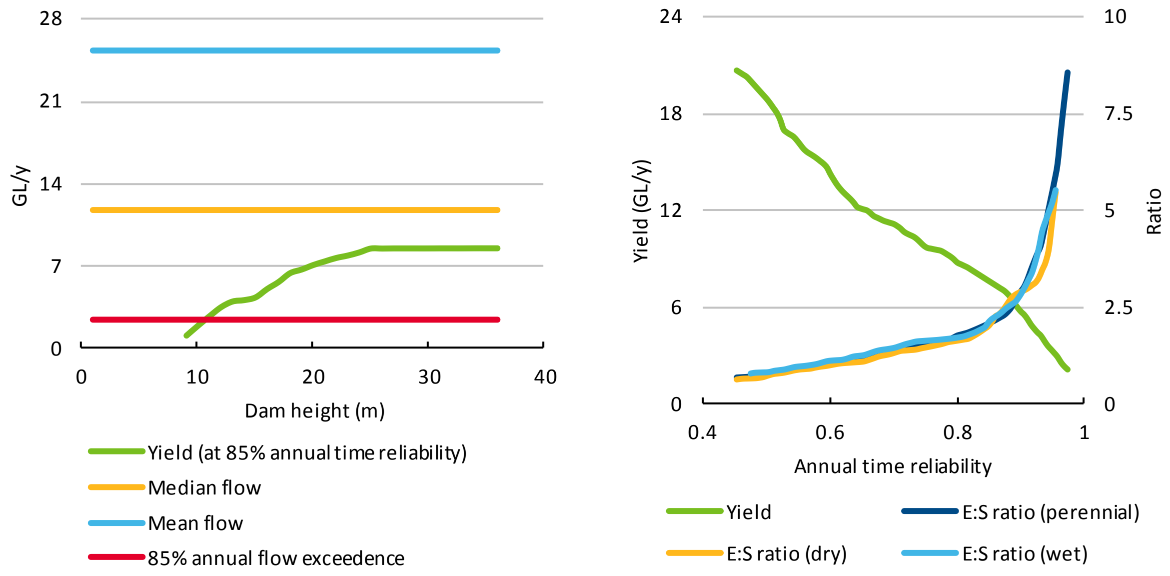
Apx Figure A.19 Cameron Creek dam underlying geology



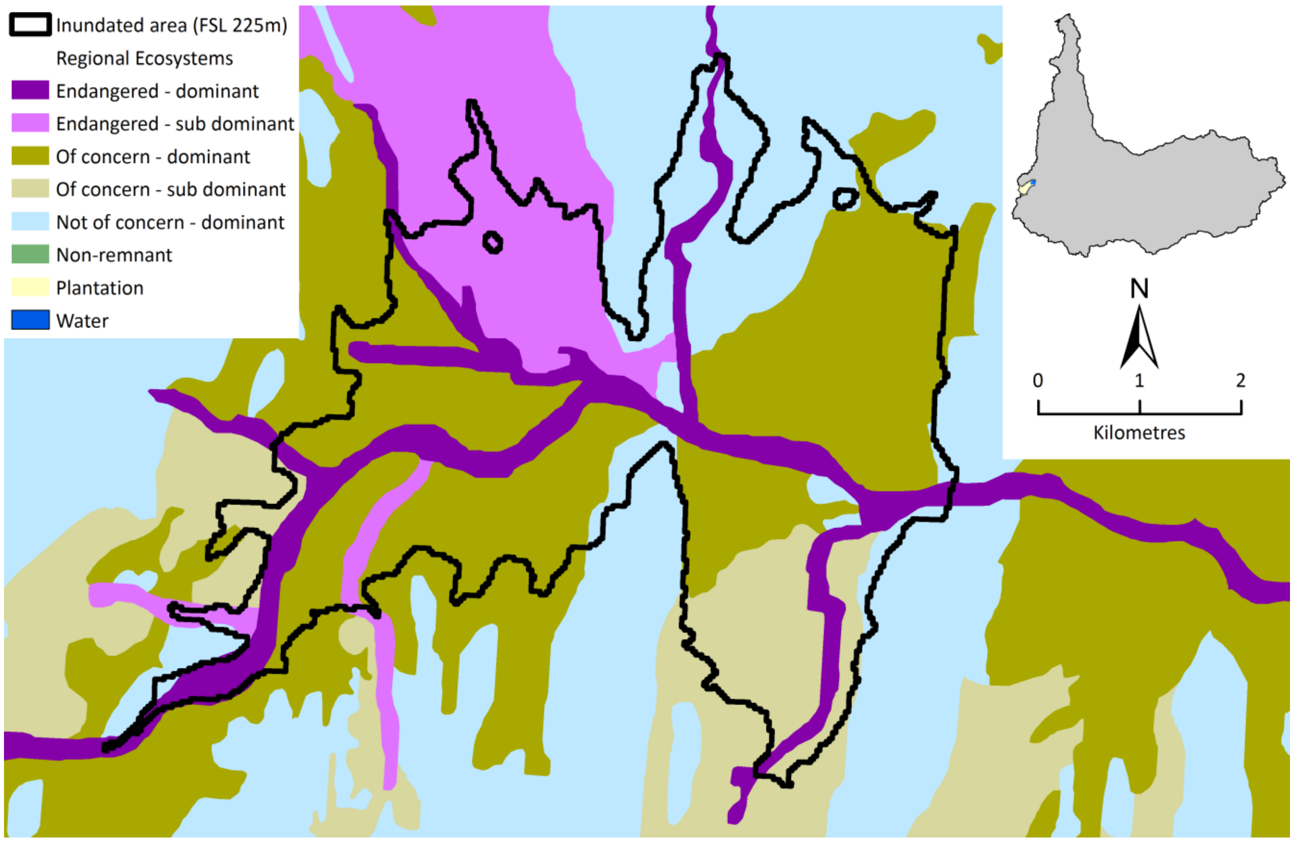
Apx Figure A.20 Cross section along main dam axis, volume surface area height relationship and annual streamflow Cameron Creek dam site



Apx Figure A.21 Cameron Creek dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 225 m FSL. Third row: YRR under Scenario C for 225 m FSL. Fourth row: YRR for baseline and ensemble model runs for 225 m FSL



Apx Figure A.22 a) Yield at 85% annual time reliability and streamflow at Cameron Creek dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Cameron Creek dam site for different annual time reliability for the selected dam height of 22 m



Apx Figure A.23 Cameron River dam regional ecosystems mapping

Chinaman Creek Dam dam site; near junction with Concurry River

PARAMETER	DESCRIPTION
Previous investigations	Chinaman Creek Dam was constructed by the Cloncurry Shire Council to augment the town water supply which was at the time drawn from the Cloncurry River bed sands. The dam was completed in September 1995. Supply to Cloncurry was further augmented in 2010 after a critical water supply situation developed because of growth in demand combined with severe drought conditions. The latest augmentation is a 900 ML/a capacity pipeline extension of the North West Queensland Pipeline which was developed to provide supply from Julius Dam to the Ernest Henry Mine located to the north of Cloncurry. Cost of the pipeline extension was $42.5 m.
Description of dam	The dam is sited on Chinaman Creek near the creek's junction with the Cloncurry River and is some 3 km south west of Cloncurry. Inflows from the dam catchment are supplemented by water harvesting from the Cloncurry River via a 1.5 m^3/s (130 ML/d) capacity pump station located in the dam spillway abutment. A photograph of the site is shown in Apx Figure A.24.
Regional geology	The dam and reservoir area are located within silicified quartzite, siltstone, basalt and schist of the Palaeoproterozoic age Malbon Group. These rocks have been intruded by a series of dolerite dykes and sills. Several major faults affect the project area. The most prominent is represented by a quartz-haematite reef and breccia complex trending sub-parallel and adjacent to the dam axis. This has given rise to the range of hills where the dam is located. There have been several episodes of alluvial deposition. Higher terraces related to a previous erosion surface flank the present drainage system and appear as isolated remnants. Recent alluvial terraces also adjoin the current drainage system and are also being actively eroded.
Site geology	The main dam foundation may be subdivided into a number of lithological zones. Upstream of the dam axis is a zone of meta-dolerite. This is deeply weathered and varies from coarse grained amphibolite to fine-grained dolerite. In sheared zones meta-dolerite forms chlorite schist. To the east and downstream of the meta-dolerite is a fault zone. On the abutments the fault zone is represented by massive quartz-haematite flanked by quartz-haematite breccia. These materials contain numerous open defects and voids. In the central zone between the abutments, quartz-haematite is less well developed and the dominant rock type is a chlorite – haematite schist. Foliation is sub-vertical. To the east the chlorite-haematite schist forms a sharp contact with partially silicified meta-basalt. The rock is foliated near the contact zone. The levee bank overlies deep alluvium. A cemented hardpan zone occurs at 2.5 to 3.5 m depth but none of the boreholes in this area intersect bedrock.
Reservoir rim stability and leakage potential	The rock on the reservoir rim is high strength and highly deformed. It is unlikely to become unstable at the current FSL. There is some potential for reservoir leakage through the quartz-haematite zones that cross the reservoir. Any leakage that does occur will depend on the orientation of these zones and the inter-connectedness of voids within the zones.
Structural arrangement	The dam comprises: • A 153 m long central concrete gravity section 13.7 m high incorporating a spillway with 90 m crest length. • A 211 5m long, 7 m maximum height embankment levee on the southern side to contain the storage; and • A 130 m long erodible fuse plug section within the levee section.
Availability of construction materials	Materials for the concrete gravity main dam were obtained from the riverbed sands and gravels of the Cloncurry River.
Catchment area	The Chinaman Creek catchment area at the dam site is 167 km^2. Catchment area of the Cloncurry River at the creek junction is approximately 5800 km^2.

PARAMETER	DESCRIPTION
Flow data	No recorded stream flow data is available for Chinaman Creek itself. Streamflow data is available for the Cloncurry River from streamflow gauging station 915203B at Cloncurry AMTD 327.6 km, catchment area 5859 km^2. Data is available from 1994 to date. Over this period - Maximum recorded annual flow was 1,986,000 ML Mean annual flow 441,000 ML Median annual flow 230,000 ML Minimum annual flow 11,000 ML
Capacity	At FSL 190 m, the dam storage capacity is 2750 ML.
Reservoir yield assessment	The existing supply is fully utilised for Cloncurry town water supply. Whilst the volume and/or reliability of supply could be marginally improved by increasing the capacity of the water harvesting system, any increase in supply would be marginal. A raising of FSL would involve high costs because of the considerable length of the levee embankment on the southern side of the storage.
Open water evaporation	
Potential use of supply	Any further development of Chinaman Creek Dam is likely to provide only a marginal increase in supply to meet urban or mining demands.
Impacts of inundation	NA
Estimated rates of reservoir sedimentation	(see table below)
Environmental considerations	Any additional environmental impacts arising from a further development of the dam are likely to be minimal. As an existing impoundment, this dam is subject to fish stocking. Pearce et al. (2001) conducted a pre-stocking fish survey of Chinaman Creek Dam in October 2000. Barramundi were first stocked into this dam in 2006 (M. Pearce pers. comm.). Subsequent post-stocking fish surveys in 2007 and 2010 have raised the number of fish species known from this impoundment to 15 species (plus red claw crayfish) with bony bream, banded grunter and rainbow fish numerically dominant (M. Pearce, DAFF unpublished data). A single sooty grunter (224 mm fork length) was caught in the 2000 survey. This species was illegally stocked into the impoundment as fingerlings in 1997. Pearce et al. (2001) claim that sooty grunter are known from the nearby Cloncurry River. No sooty grunter were located in this dam in the 2007 or 2010 surveys (M. Pearce, DAFF unpublished data). Many of the relevant environmental issues have already eventuated, although a rise in FSL may inundate parts of valuable ecosystems established at the old level. The dam is high in the catchment and is outside the known or likely distribution of fish species such as barramundi, freshwater sawfish or freshwater whipray. The dam captures a relatively small catchment area.
Estimated cost	No specific proposal to augment supply from the dam has been developed.

Estimated rates of reservoir sedimentation:

	Best case	Expected	Worst case
30 years (%)	1.53	6.56	21.75
100 years (%)	5.10	21.87	72.50
Years to fill	1960	457	138

Apx Figure A.24 Chinaman Creek dam looking upstream

Corella Dam (Lake Corella) on Corella River

PARAMETER	DESCRIPTION
Previous investigations	Corella Dam was constructed in 1956-7 to provide water supply to the Mary Kathleen Uranium township and mine. Since the cessation of mining in 1982, the dam has been owned by the State Government. Apart from recreation, no use has been made of the dam since 1982. Data on the dam including safety inspections and review reports are held by the Department of Energy and Water Supply (DEWS) Non - Commercial Assets group based in Rockhampton.
Description of proposal	Two options were considered by the Assessment: 1. To make use of the existing structure; or 2. Construct a new dam downstream of the existing structure. A photograph of the dam is shown in Apx Figure A.25. A location map and map showing the inundated area at FSL are shown in Apx Figure A.26 and Apx Figure A.27 respectively. The water impounded by Corella Dam is referred to as Lake Corella.
Regional geology	The embankment and spillway are underlain by rocks belonging to the Corella Formation of Palaeoproterozoic age. The original rocks consisted of fine grained sediments, limestone and evaporite. Metamorphism has changed these rocks to schist, slate, calc-silicate rock and granofels. Lithology in the Corella Formation is extremely heterogeneous, with significant and abrupt changes both laterally and vertically. At the site, the rock has been metamorphosed to the high grade granulite facies and has undergone several deformation events. As a result of metamorphism the original sedimentary rock has been altered to hard and high strength rock composed of quartz, feldspar, pyroxene, hornblende and calc-silicate minerals. Apx Figure A.28 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	Within the gorge where the dam is located, deformation of the high strength granofels has resulted in intense folding and faulting of the rock. A foliation is present that dips at a low angle downstream at an average strike of 030˚ M. Brecciated zones up to 12 m wide striking parallel to the foliation occur in the gorge. The brecciated zones have been healed by late phase scapolite (calc-silicate mineral), quartz or calcite. There are three principal joint directions striking 115˚M, 030˚M and 090˚M. Small faults with displacements up to 150 mm are also present striking at 070˚. The 115˚M set (presumed to be vertical) is the most common and is usually healed by scapolite. However, joint apertures of up to 200 mm were observed on the northern side of the gorge. The 030˚M set is parallel to the foliation and is mostly not healed but generally described as tight. However, joint apertures up to 150 mm were observed on the northern wall of the gorge. The 090˚M (presumed to be vertical) system is not well developed and is usually healed with scapolite. The fault system is either not healed or contains an infilling of calcite. Though individual planes are not conspicuous they are widespread and provide links between the major joints. Drilling at the dam showed that the jointing had produced a permeable rock mass but this was amenable to cement grouting. In the main spillway the rock consists of calc-silicate rock and schist. The calc-silicate rock is pink and green in colour (orthoclase feldspar and epidote), fine grained, slightly weathered to fresh and high to extremely high strength. Schist and calcareous rock outcrops at the downstream end of the spillway. The rock is differentially weathered where the carbonate has been removed from the rock mass. It is distinctly to slightly weathered and of high strength. The rock in the auxiliary spillway appears to be more weathered and erodible than the main spillway although it is still in the same geological formation. The foundation conditions for a possible new dam downstream of the existing dam (see option 2 below) are unknown. Given the heterogeneous lithology in the Corella Formation the foundation may be different from the existing dam.

PARAMETER	DESCRIPTION
Reservoir rim stability and leakage potential	The reservoir rim is composed of strong highly deformed rock. It is unlikely to become unstable at current or raised reservoir levels. The potential for leakage through the reservoir rim is low.
Proposed structural arrangement	**Option 1.** The existing dam comprises a 23 m high concrete faced rockfill embankment with a 1.5m high parapet wall on the embankment crest. Rockfill placement was by dumping and sluicing without compaction. A 75 -100 mm thick gunite concrete slab was placed on the upstream embankment face. The main spillway is a 34.8 m wide unlined cut through the right abutment with an auxiliary spillway through a saddle north east of the embankment with a crest level 2 m higher than the original main spillway control level. Supply to the town and mine was via a pump station located in the dam storage (now decommissioned). There is no river outlet through the dam embankment. Over the years, embankment settlement has led to numerous areas of cracking of the face slab, which has worsened as the slab reinforcing mesh has corroded. Seepage through the face as measured through a V- notch weir at the downstream toe has been as high as 300 l/s (26 ML/day). Repairs to the upstream face undertaken when the storage level has been low have reduced leakage but new areas of cracking progressively appear. For the existing dam to provide a reliable supply, action would need to be taken to: 1. Effectively reduce seepage losses through the dam Other than local repairs to the cracked face as storage levels permit, no proposal has been developed which would reduce leakage to minimum levels on a permanent basis. This could be most effectively achieved by constructing a new concrete face on the dam with sealed connection to a new plinth slab but this would require total dewatering of the upstream face. In that there is no outlet through the embankment, there is no control over storage level. Even if the storage level were lowered by a controlled progressive removal of the existing face slab and an upstream coffer dam constructed, the upstream face area would be inundated by even minor storage inflows. 2. Provide for supply from the dam storage Supply from the dam storage could be established by the installation of a floating pump station upstream of the dam embankment with pipeline delivery to the area of demand to minimise conveyance losses. Given the likelihood of continuing embankment settlement and of disruption during any reconstruction of the upstream face, Option 1 is not favoured. **Option 2.** The topography immediately downstream of the existing dam appears suitable for the development of a new dam, possibly to a slightly higher storage level than for the existing dam. A roller compacted concrete (RCC) dam with central overflow spillway is likely to be the most suitable type. Diversion of the leakage flow through the existing dam could be easily achieved during construction. Based on DRWG A3-78017, capacity of a raised storage would be as follows; FSL 300 m 15,500 ML. FSL 302 m 21,700 ML.
Availability of construction materials	A quarry for the production of RCC aggregate could be established in the granulite facies of the Corella Formation. Suitable sites should be available within 1 km of the dam. There do not appear to be any suitable alluvial materials within economic hauling distance of the dam.
Catchment area	Catchment area upstream of the dam is 334 km^2.

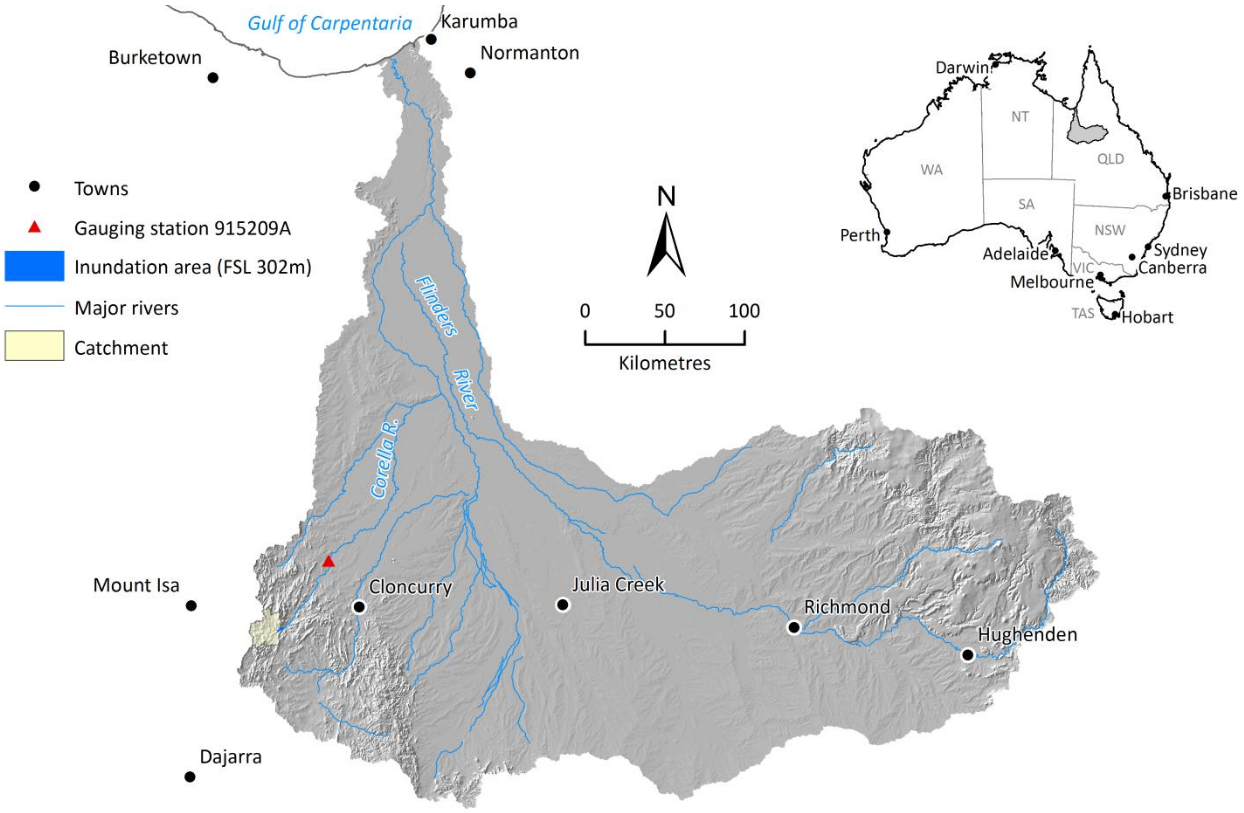
PARAMETER	DESCRIPTION
Flow data	Streamflow gauging station 915202A was installed to record dam storage levels from 1973 to 1983. Apart from the data available from this gauge station, flow data was collected from streamflow gauging station 915209A - Corella River at Main Road AMTD 142.7 km, 60 km downstream of the dam. Catchment area at this gauging station is 1687 km^2. Data was collected from November 1971 until September 1988 and was therefore affected (slightly) by the dam storage. Summary data is as follows; Maximum recorded annual flow was 390,000 ML Mean annual flow 86,200 ML Median annual flow 56,000 ML Minimum annual flow 4,000 ML
Capacity	Storage capacity of the existing dam is 10.5 ML after a lowering of the right abutment side main channel spillway in 2005-6 to improve spillway capacity (Apx Figure A.29). The yield assessment undertaken here was based on a new dam with a capacity of 20 GL.
Reservoir yield assessment	3.7 GL at 85% annual time reliability (Apx Figure A.30 and Apx Figure A.31). 3.5 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): %45 Ratio of evaporation to water supplied (at 85% annual time reliability): 0.8
Open water evaporation	Mean annual evaporation is estimated to be 5.5 mm d^{-1} using a bulk aerodynamic approach. Mean annual evaporation was estimated to be 5.0 mm d^{-1} using Morton's APE.
Impacts of inundation	Existing dam. Reconstruction of dam wall slightly downstream would have minimal impact.
Ecological and cultural considerations considered by previous studies	NA
Estimated rates of reservoir sedimentation	(see table below)
Water quality and stratification considerations	Corella Reservoir is predicted to experience extensive persistent thermal stratification during most of the year. The risk of blue-green algal blooms is high with Zsl:Zeu ~ 1-3 (typically 2) from September through April. The water column is predicted to be poorly mixed during the long stratification season and low dissolved oxygen with associated nutrient and metal releases from the sediments likely to be experienced in most years. Comparisons between simulated temperature stratification and the few existing historical data are in broad agreement in regards to temperature range and surface mixed layer depth.
Environmental considerations	Development of a new dam would, however, trigger a possible need for a fish transfer facility. Over 2000-2001, the Mt. Isa Fish Stocking Group stocked 5000 sooty grunter fingerlings into Lake Corella. A post-stocking survey in October 2000 (Pearce et al. 2001b) did not observe any sooty grunter present, though they may have been too small for capture at the time of that survey, having only been stocked as fingerlings 4 months previously. Post-stocking surveys have subsequently occurred in 2003, 2007 and 2010 and sooty grunter were located in all those surveys. A total of 9 fish species have now been caught in these post-stocking surveys in Lake Corella (M. Pearce, DAFF unpublished data), with bony bream and rainbowfish

Estimated rates of reservoir sedimentation:

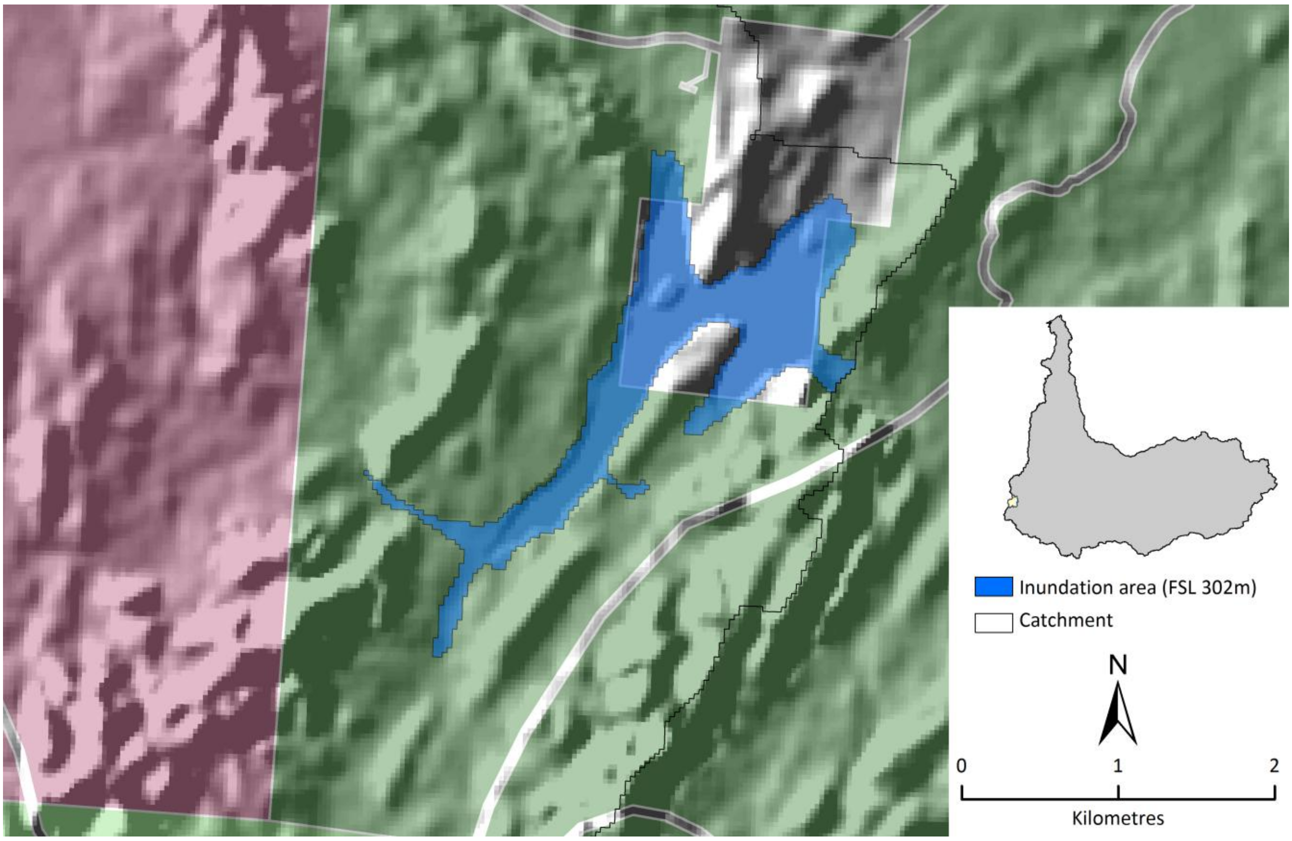
	Best case	Expected	Worst case
30 years (%)	0.38	1.64	5.42
100 years (%)	1.27	5.45	18.07
Years to infill	7863	1835	554

PARAMETER	DESCRIPTION
	numerically dominant. This dam already exists so many of the relevant environmental issues have already been experienced. The dam is a long distance upstream and thus captures only a small portion of catchment area. It is outside the known or likely distribution of species such as barramundi, freshwater sawfish or freshwater whipray. The values of the aquatic habitat upstream of the proposed dam wall site are not known. The proposal to increase the height of the original Corella Dam wall would flood a small area of non-remnant vegetation (Apx Figure A.32). In other areas, flood land would cover woodland and low woodlands of *Corymbia aparrerinja* and *C. terminalis*. *Acacia cambagei* and the ground tussock grasses (*Triodia longiceps*) would be also flooded. A small extent of open-woodland including *Eucalyptus leucophylla* or *E. leucophloia* would be also flooded.
Estimated cost	The cost of a new dam downstream of the existing dam has not been estimated but is likely to be between $200 m and $340 m.
Estimated cost / ML of supply	$60,020/ML (at 85% annual time reliability)
Potential benefit/cost	
Summary comment	The supply available from a rehabilitated Corella Dam or from a new dam immediately downstream of the existing dam is limited by the small catchment area upstream of the site. Additionally, the site is a considerable distance upstream of land areas potentially suitable for irrigation and transmission losses would be high.

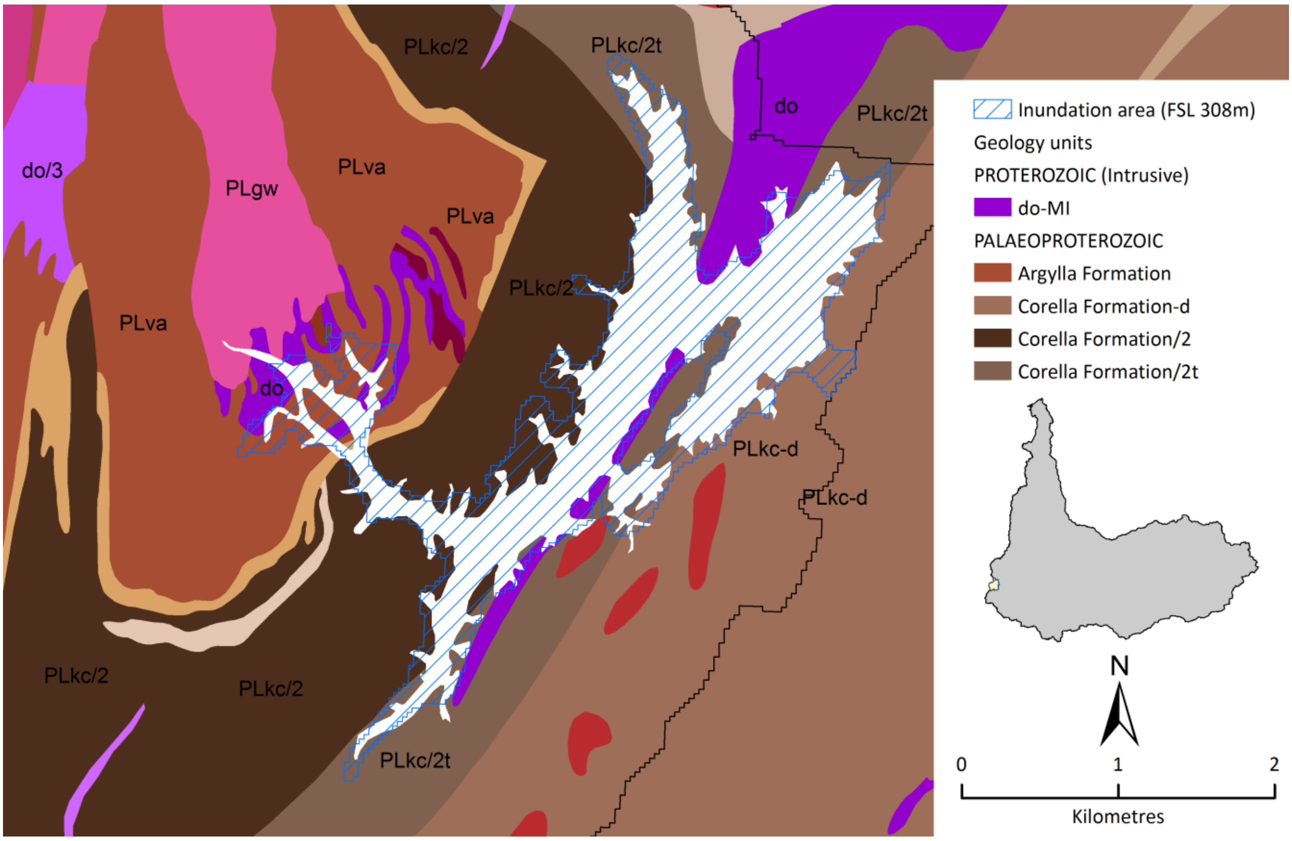
Apx Figure A.25 Corella River dam looking upstream



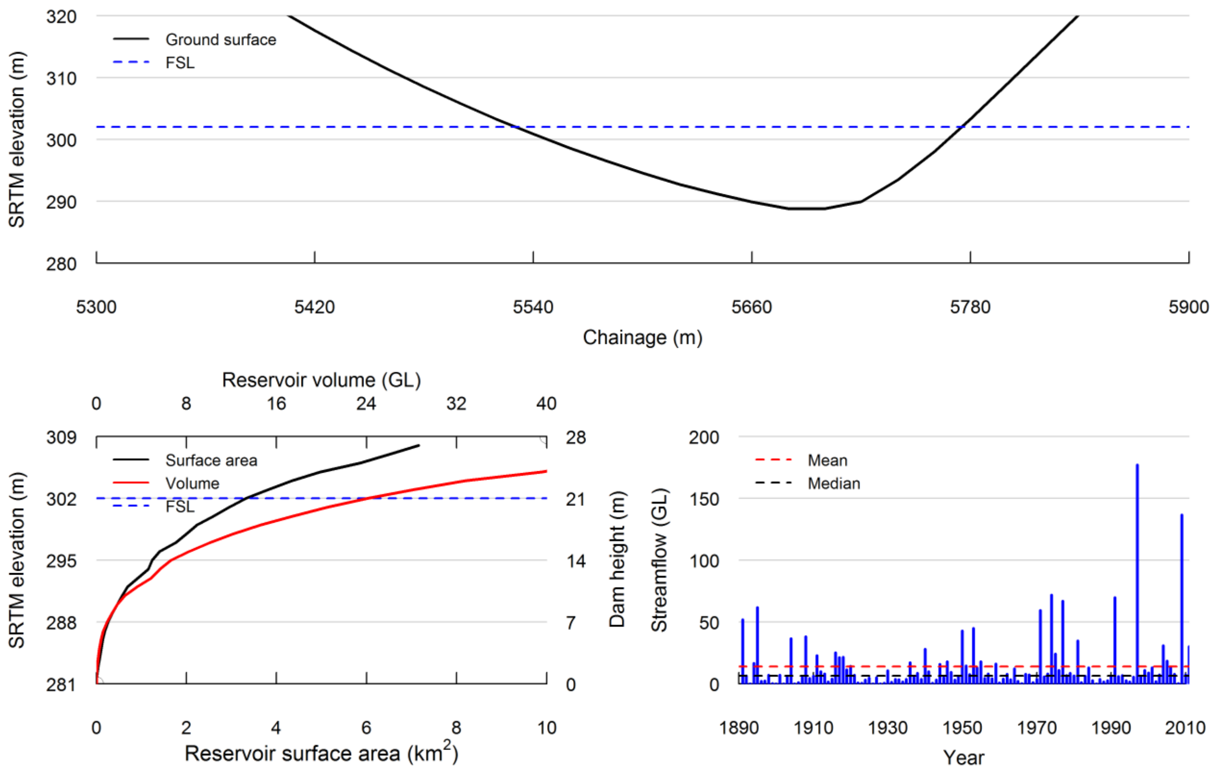
Apx Figure A.26 Location map of Corella River dam, reservoir and catchment area



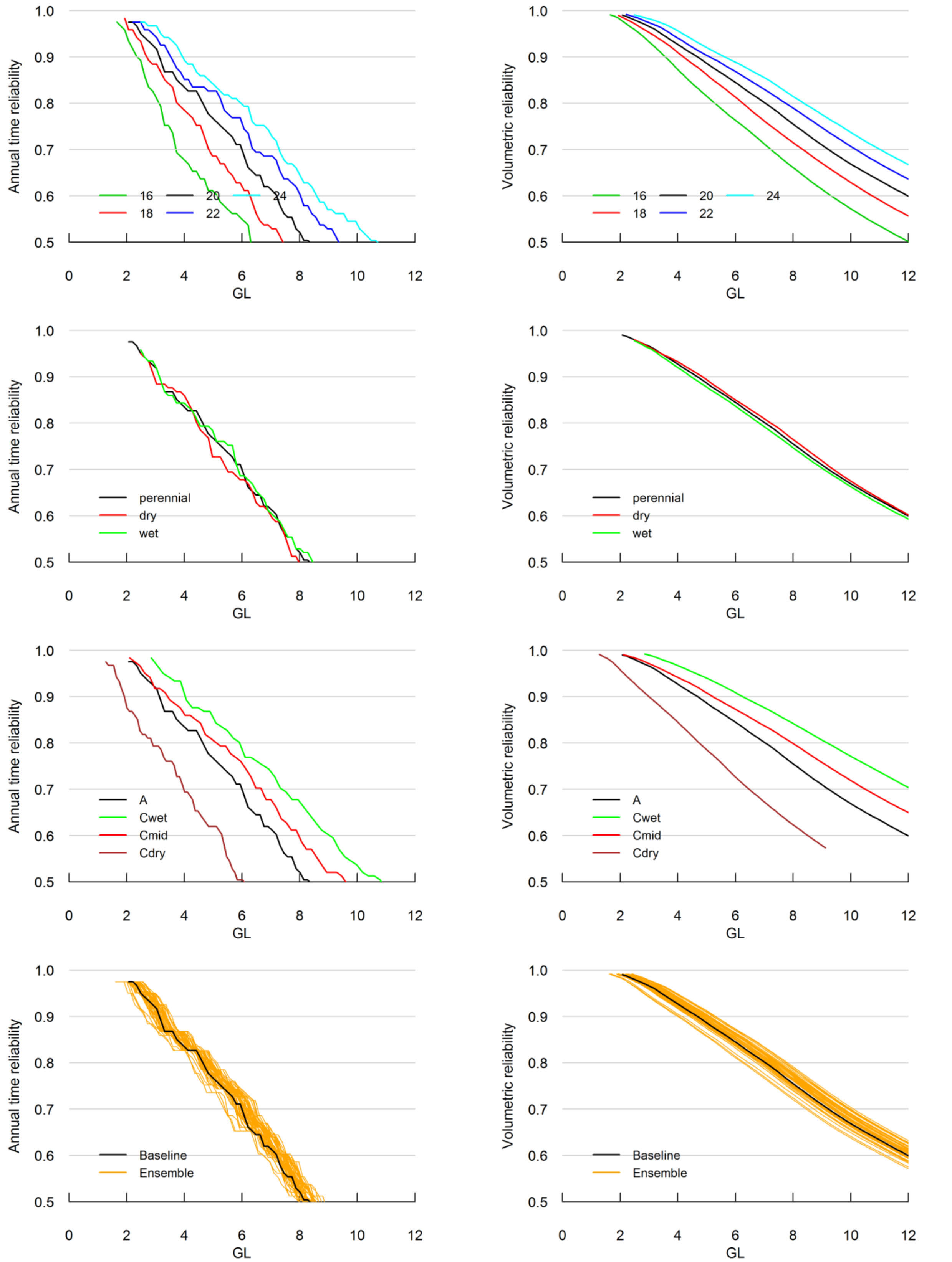
Apx Figure A.27 Corella River dam are of inundation and property boundaries (indicated by coloured shading)



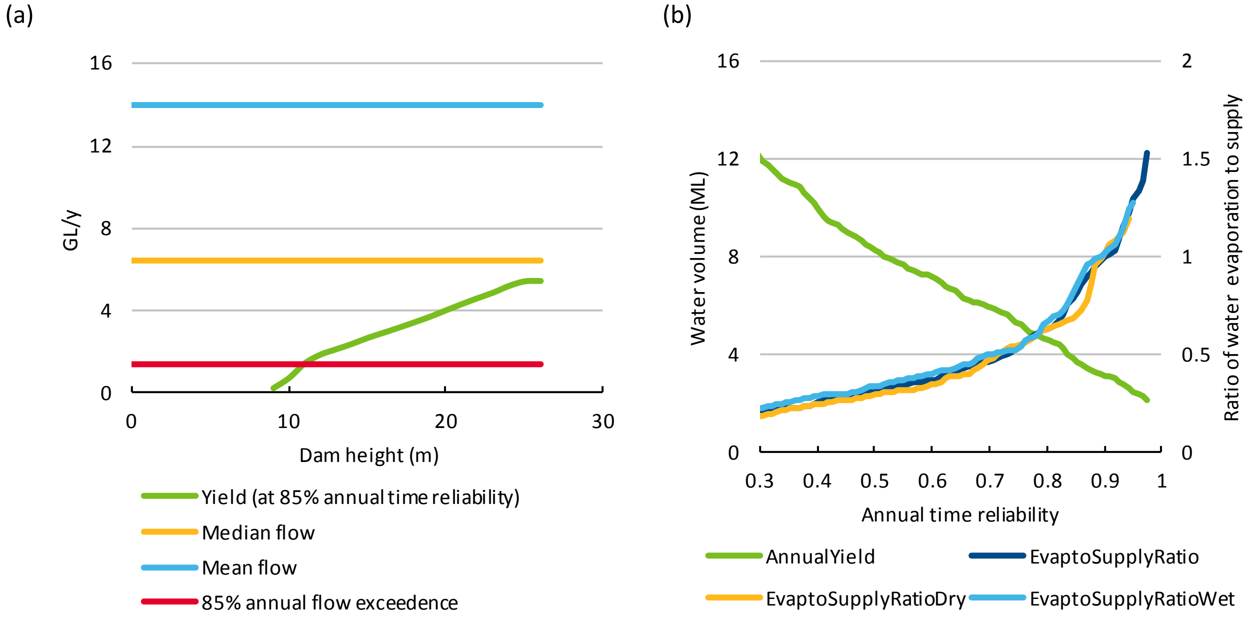
Apx Figure A.28 Corella River dam underlying geology



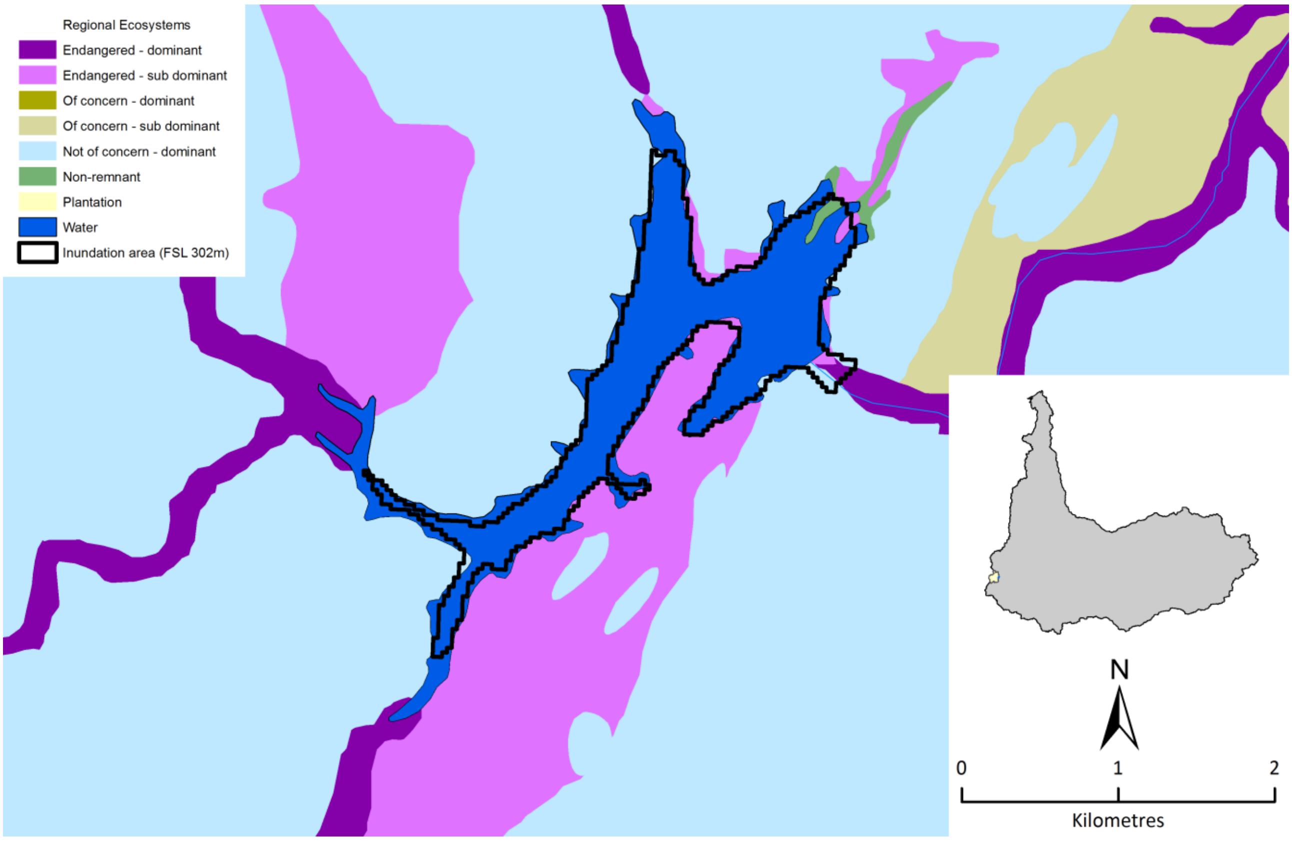
Apx Figure A.29 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Corella River dam site



Apx Figure A.30 Corella Dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 302 m FSL. Third row: YRR under Scenario C for 302 m FSL. Fourth row: YRR for baseline and ensemble model runs for 302 m FSL



Apx Figure A.31 a) Yield at 85% annual time reliability and streamflow at Corella Dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Corella Dam site for different annual time reliability for the selected dam height of 20 m



Apx Figure A.32 Corella River dam regional ecosystems mapping

Corella River dam site; 195.3 km

PARAMETER	DESCRIPTION
Previous investigations	A desktop study of this site was undertaken by the Queensland Department of Energy and Water Supply (DEWS) in 2012 as part of the North West Queensland Regional Water Supply Strategy development with the objective of increasing the availability of water supplies to meet urban and mining demands in the NW minerals province area.
Description of proposal	On stream dam downstream of the existing Corella Dam, releasing to stream for downstream extraction. A photograph of the site is shown in Apx Figure A.33. A location map and map showing the inundated area at FSL are shown in Apx Figure A.34 and Apx Figure A.35 respectively.
Regional geology	The dam is located within the Ballara-Corella River Fault Zone structure. The reservoir area is within calcareous sandstone, slate, schist, granofels and calc-silicate rocks of the Corella Formation and intrusive meta-dolerite. Apx Figure A.36 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	High strength rock composed of calc-silicate rock, gneiss and microgranite outcrop in the riverbed. Thin disconnected deposits of silty sand alluvium occur on the banks with rock outcrop at higher levels. To the west of the left abutment is a saddle area trending about north-northeast. Brecciated rock in this area suggests that this may represent a sheared zone along a fault. This fault is also recognised on the Marraba 1:100,000 geological map.
Reservoir rim stability and leakage potential	The reservoir rim is composed of strong, highly deformed rock. This is unlikely to become unstable when the reservoir is filled. The potential for leakage through the reservoir rim is low.
Proposed structural arrangement	Roller compacted concrete (RCC) dam with central over flow spillway with two embankment saddle dams was proposed by Department of Energy and Water supply (DEWS) initially. A concrete faced rockfill dam with a largely unlined spillway through the left or right bank saddle may be a more economical alternative.
Availability of construction materials	The reservoir contains a variety of strong rocks ranging from meta-dolerite to granofels. Quarry sites suitable for concrete aggregate should be available within 2 km of the site. The riverbed contains small deposits of alluvial sand-gravel mixtures downstream of the site that may be suitable for augmenting quarry sourced aggregate.
Catchment area	642 km^2
Flow data	Streamflow data is available from GS 915209A - Corella River at Main Road AMTD 142.7 km, 40.3 km downstream of the dam site. Catchment area at the streamflow gauging station is 1687 km^2, that is, 262% of that at the dam site. Data was collected at the gauging station from November 1971 until September 1988. Summary data is as follows; Maximum recorded annual flow was 390,000 ML Mean annual flow 86,200 ML Median annual flow 56,000 ML Minimum annual flow 4,000 ML
Capacity	101 GL at FSL 262 (Apx Figure A.37).

PARAMETER	DESCRIPTION
Reservoir yield assessment	9.1 GL at 85% annual time reliability (Apx Figure A.38 and Apx Figure A.39) 8 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 56% Ratio of evaporation to water supplied (at 85% annual time reliability): 1.3
Open water evaporation	Mean annual evaporation is estimated to be 5.7 mm d^{-1} using a bulk aerodynamic approach. Mean annual evaporation was estimated to be 5.1 mm d^{-1} using Morton's APE.
Impacts of inundation	The larger capacity storages may back up under the Barkly Highway bridge over the Corella River. Additionally, it is likely that part or all of the storage area might impact on mining exploration authorities.
Ecological and cultural considerations raised by previous studies	None previously undertaken.

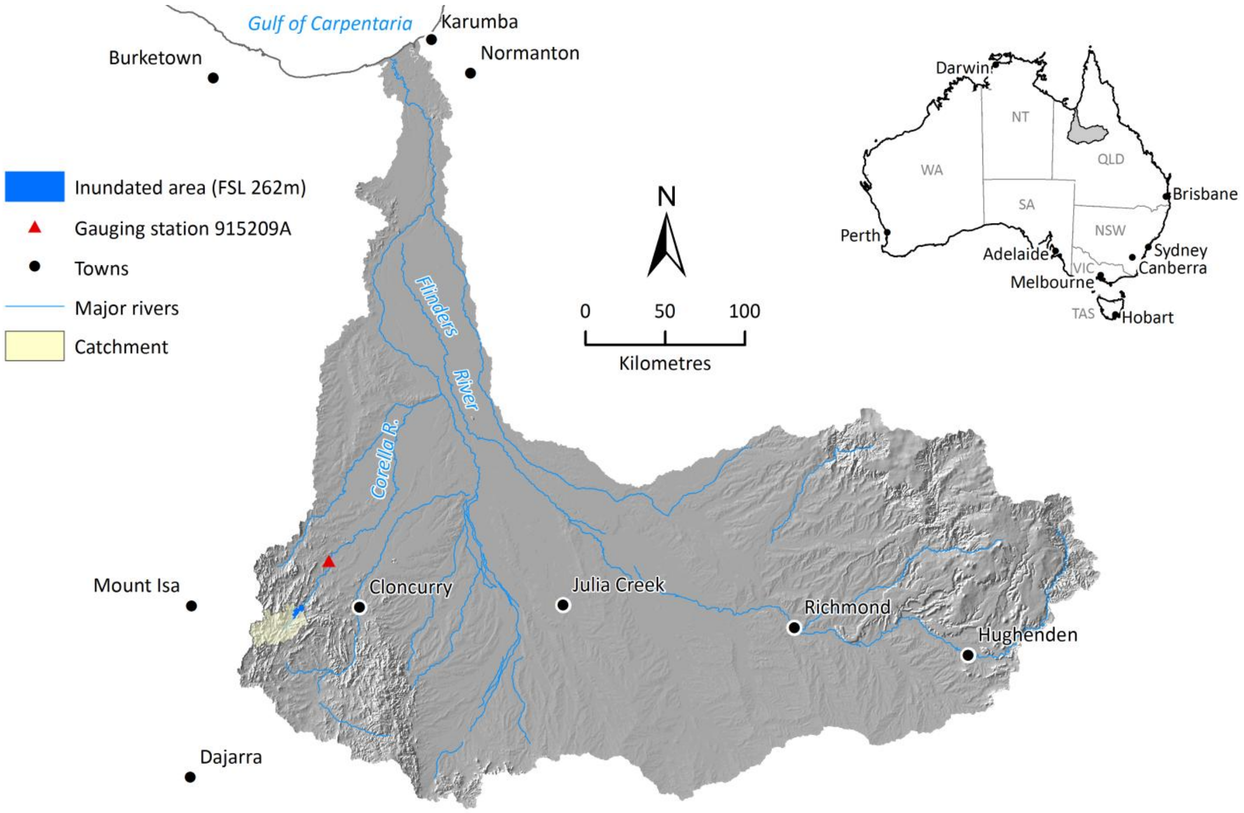
Estimated rates of reservoir sedimentation

	Best case	Expected	Worst case
30 years (%)	0.15	0.66	2.20
100 years (%)	0.52	2.21	7.33
Years to infill	19392	4525	1365

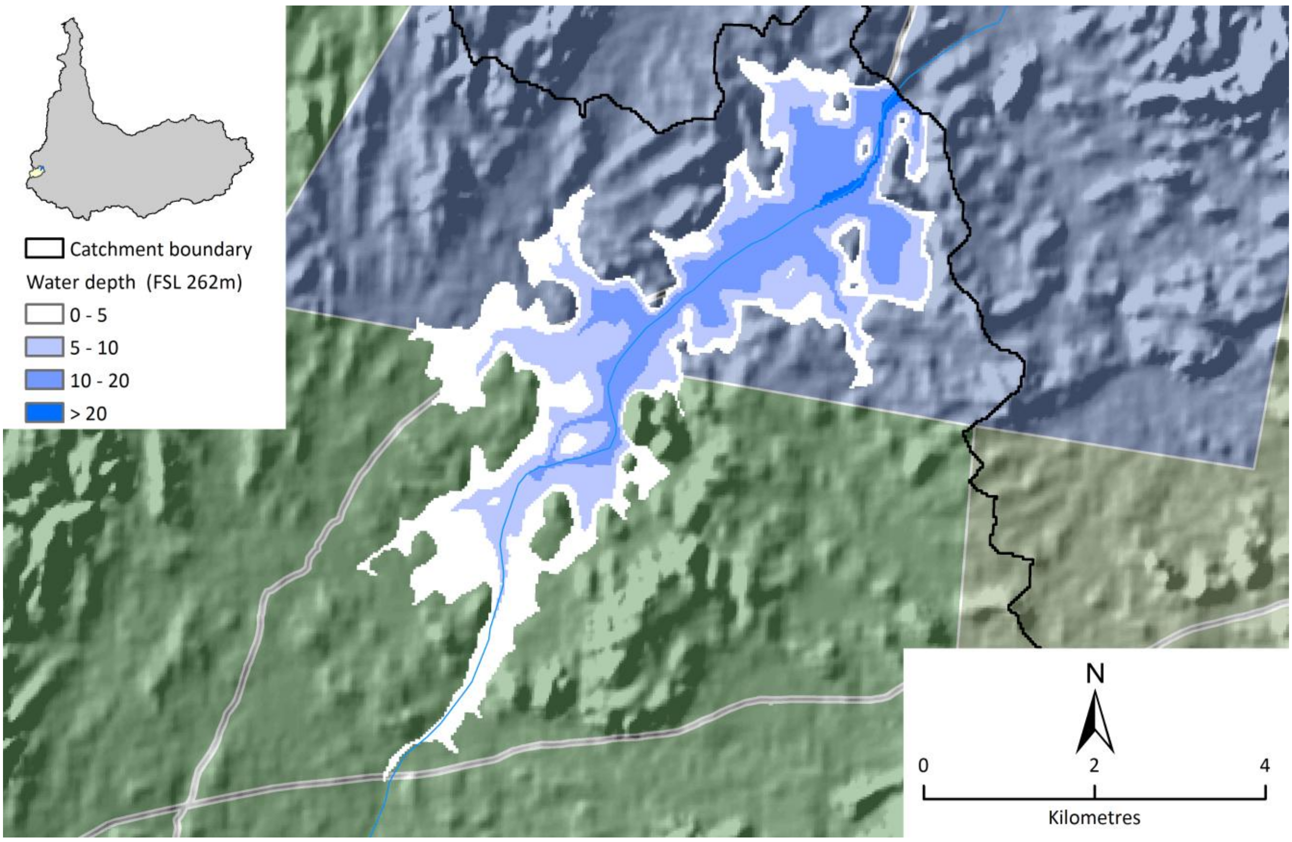
Water quality and stratification considerations	The proposed Corella River reservoir is predicted to experience persistent thermal stratification during most of the year. The risk of blue-green algal blooms is low-moderate with Zsl:Zeu ~ 2-3 during summer and ~ 3 during spring. The water column is predicted to be poorly mixed during extended periods of stratification each year and low dissolved oxygen with associated nutrient and metal releases from the sediments is likely to be experienced in most years.
Environmental considerations	This site is near Lake Corella, from which a total of 9 fish species are known (Malcolm Pearce, DAFF unpublished data). This site is a long distance upstream and is outside the known or likely distribution of species such as barramundi, freshwater sawfish or freshwater whipray. The dam captures a relatively small catchment area. The values of the aquatic habitat upstream of the proposed dam wall site are not known. The site covers a mix of regional ecosystems that are likely to be 'Endangered' and 'Of concern'. Apx Figure A.40 shows relative areas in each category. *Endangered Ecosystems* This site includes endangered vegetation ecosystems that follow the Corella River channel flow which would be lost under this option. The riparian communities are not specifically listed in the Queensland Herbarium mapping database of regional ecosystems. *Ecosystems Of Concern* The site covers woodland of *Corymbia aparrerinja* often with *C. terminalis*, *Eucalyptus leucophylla*, *E. camaldulensis*, *Lysiphyllum cunninghamii* and *Acacia cambagei* with a sparse ground layer of tussock grasses with *Triodia longiceps* in some places. *Melaleuca leucadendra* is also likely to occur along dominate creek lines where water is available.
Estimated cost	$200 m to $340m. Previous studies A preliminary desktop estimate by DEWS (2012) of the cost of a RCC dam with FSL 260m was $76.8 m This estimate was based on an assumed 3 m depth of excavation across the site to establish an adequate foundation. From the above site inspection it is now known that minimal excavation would be required across the river bed.

PARAMETER	DESCRIPTION
Estimated cost / ML of supply	$24,850/ML (at 85% annual time reliability)
Summary comment	The DEWS (2012) cost seems low given the remoteness of the site. Unlikely to be a viable option for irrigation development.

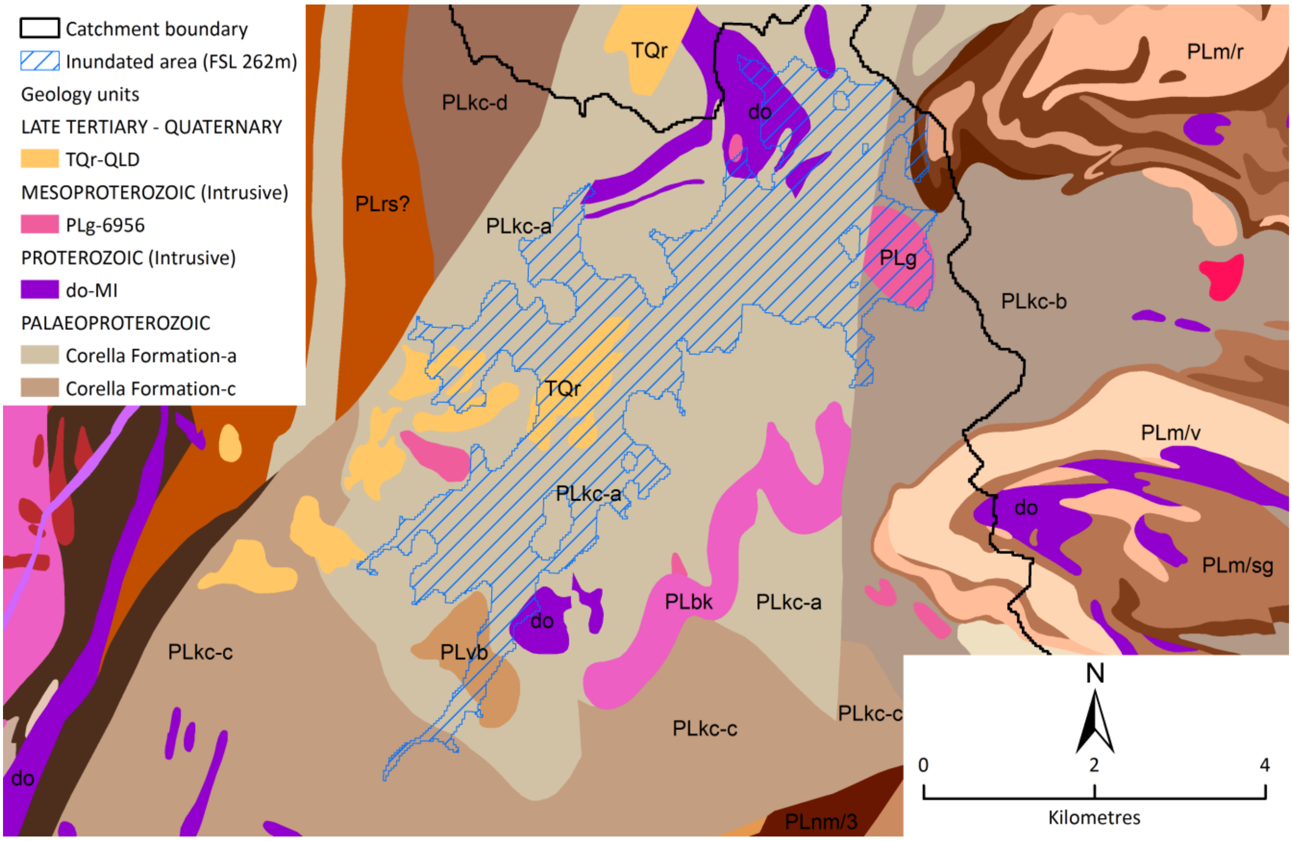
Apx Figure A.33 Corella River dam site looking downstream



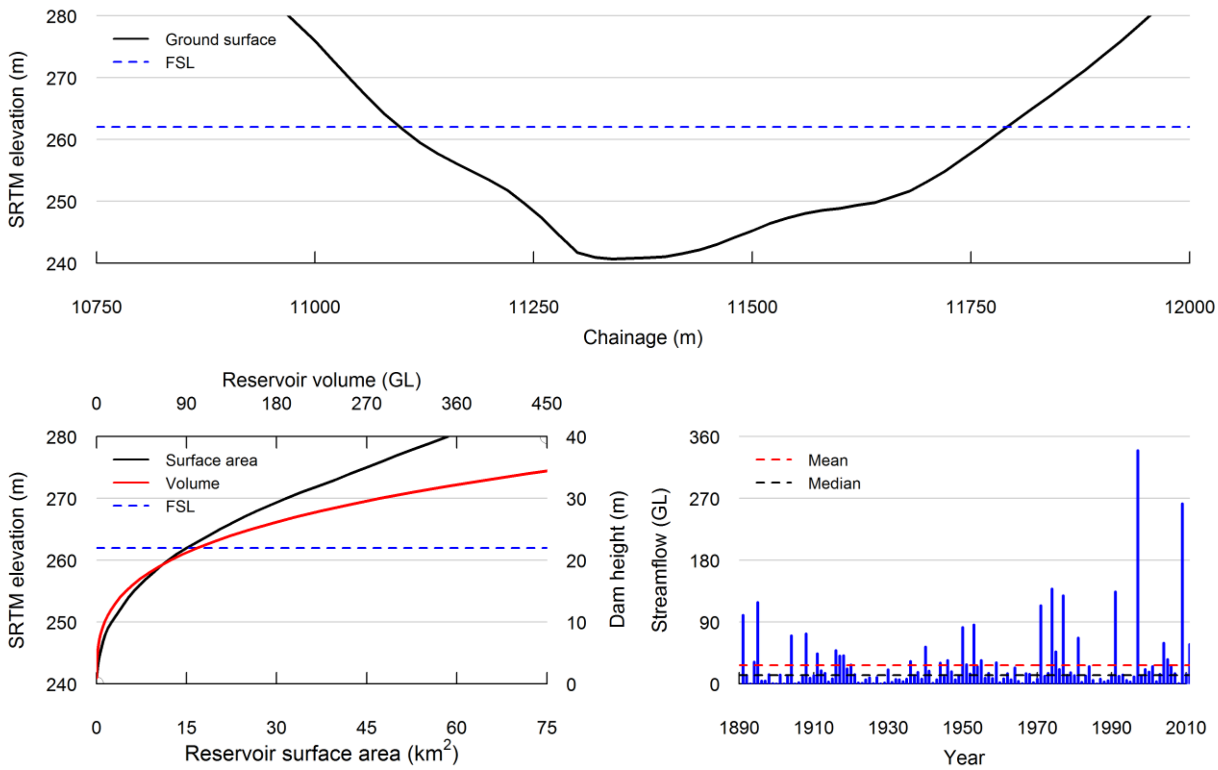
Apx Figure A.34 Location map of Corella River potential dam, reservoir and catchment area



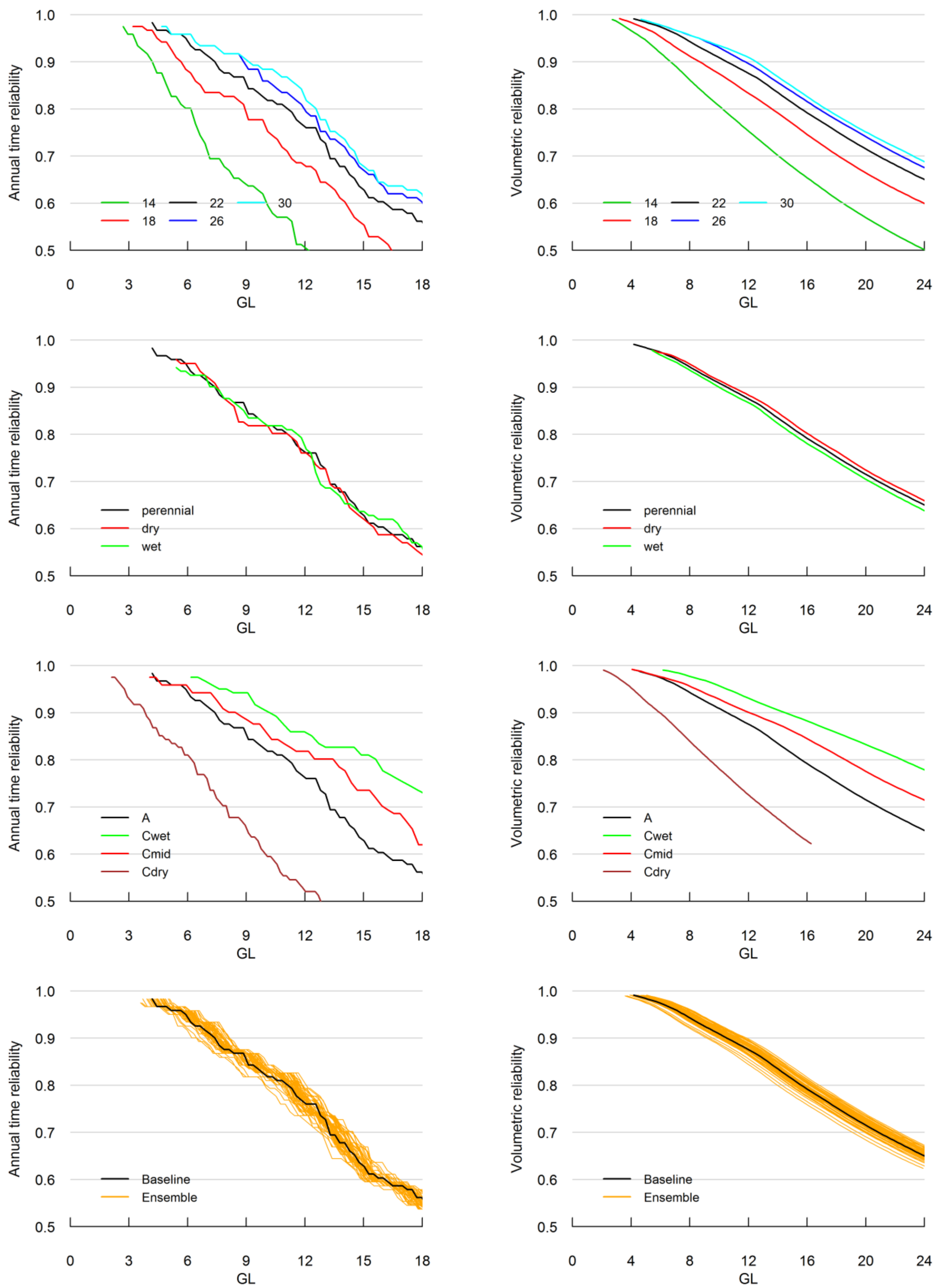
Apx Figure A.35 Corella River dam site inundated area



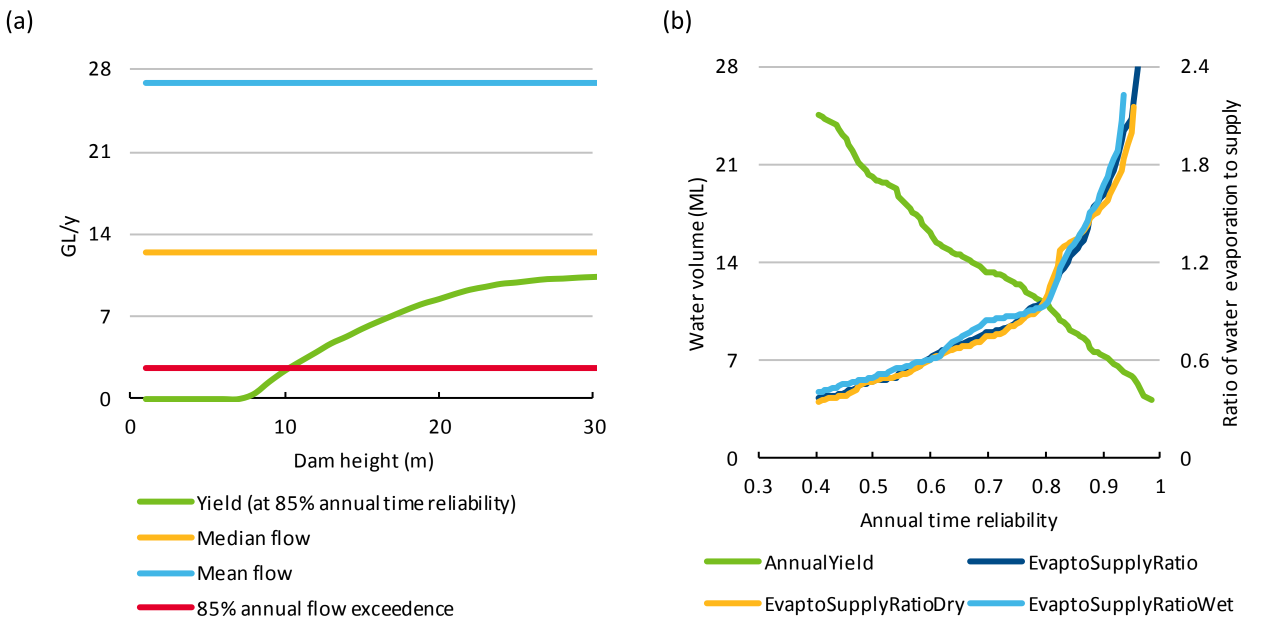
Apx Figure A.36 Corella River site dam underlying geology



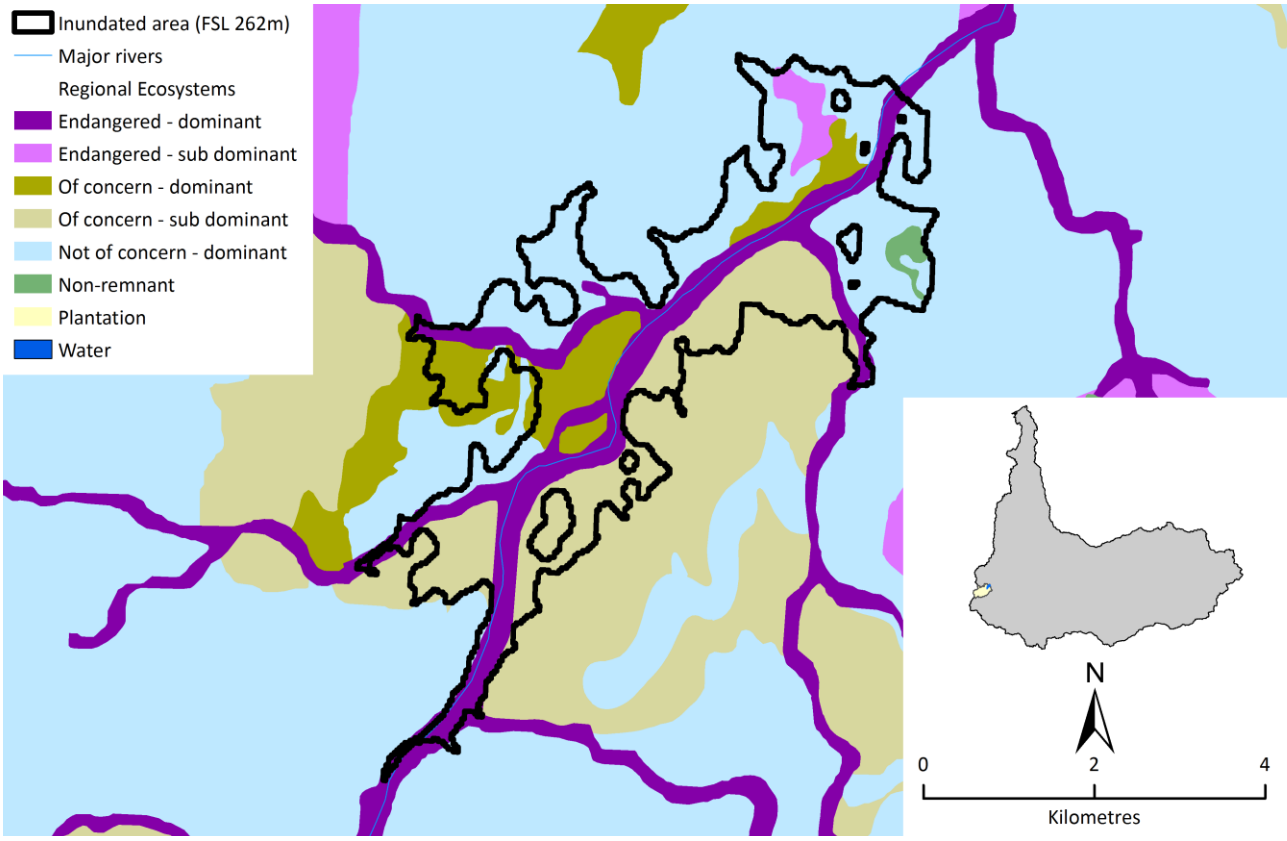
Apx Figure A.37 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Corella River dam site (cross-section does not show saddle dam requirements)



Apx Figure A.38 Corella River dam site performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 262 m FSL. Third row: YRR under Scenario C for 262 m FSL. Fourth row: YRR for baseline and ensemble model runs for 262 m FSL



Apx Figure A.39 a) Yield at 85% annual time reliability and streamflow at Corella River dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Corella River dam site for different annual time reliability for the selected dam height of 22 m



Apx Figure A.40 Corella River dam regional ecosystems

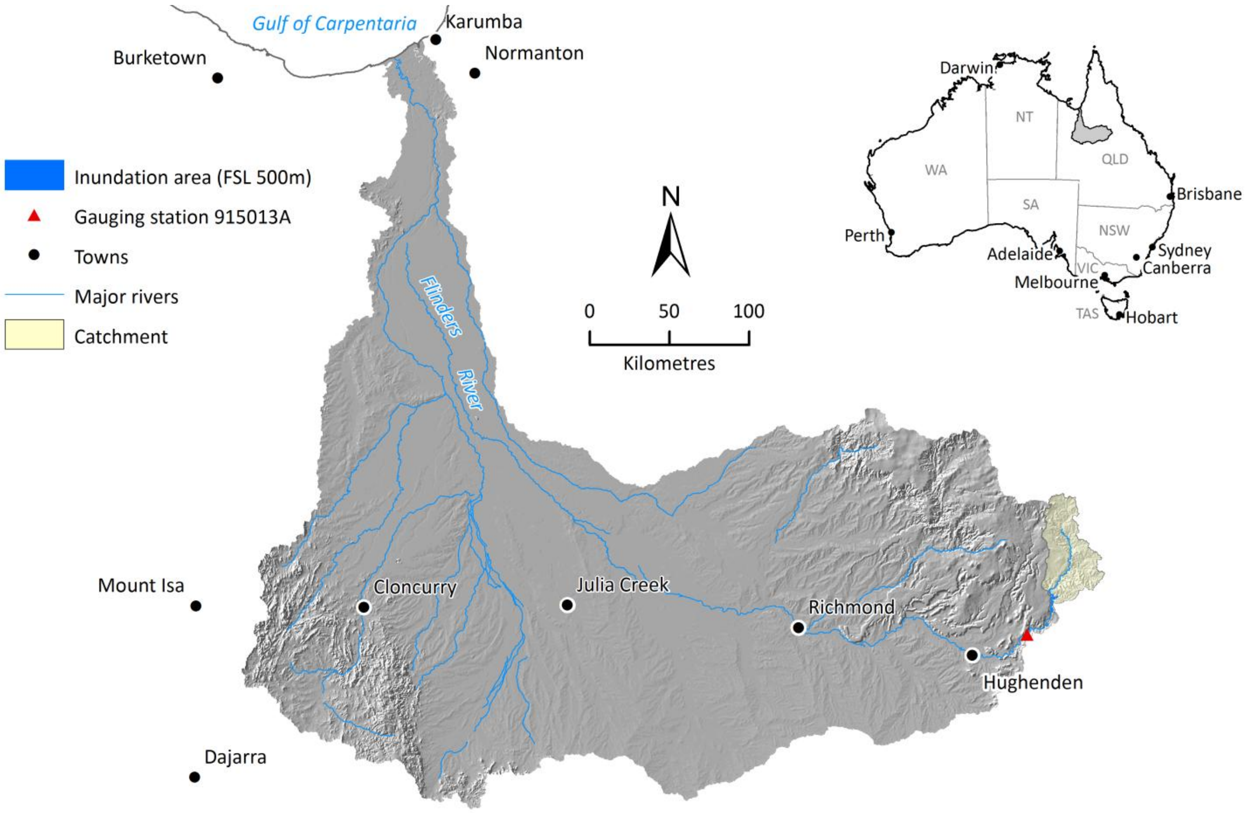
Flinders 856 km dam site on the Flinders River: 879 km

PARAMETER	DESCRIPTION
Previous investigations	DPI (1983). Upper Flinders River Irrigation Proposal (soils) Queensland Department of Primary Industries – Q83016. QWRC (1990). Appraisal Report on Potential for Irrigated Cotton Production – Hughenden Area, Betts Gorge Creek 18.1 km dam site, Flinders River 856km dam site, Porcupine Creek 69km dam site.
Description of proposal	This proposal was one of the three storage proposals in the Hughenden area (QWRC 1990) intended to provide supply for irrigated cotton production on lands adjacent to each of the storages. Previously the distance along the river was calculated as 856 km. Capacity to irrigate a total of 10,000 ha was sought to support development of a cotton gin in the area. A photograph of the site is shown in Apx Figure A.41. A location map and map showing the inundated area at FSL are shown in Apx Figure A.42**Error! Reference source not found.** and Apx Figure A.43 respectively.
Regional geology	The dam site is located within sedimentary rocks of the Great Artesian and Galilee Basins. In the reservoir area, rock at riverbed level consists of quartzose sandstone of the Blantyre Sandstone overlain by clayey sandstone of the Gilbert River Formation and mudstone of the Wallumbilla Formation. Basalt belonging to the Sturgeon Basalt Province forms plateaus above the river on each bank. The basalt plateau above the right bank is significantly lower than the plateau above the left abutment indicating a younger basalt flow. Mudstone in the Wallumbilla Formation may contain clay seams of low shear strength. Landslides may occur in steep slopes in this unit. Apx Figure A.44 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	There has been no site inspection or site investigation. The suitability of the site for the proposed roller compacted concrete (RCC) dam will depend on the extent of the sandstone units (Blantyre Sandstone and Gilbert River Formation). These will be suitable as a foundation for the RCC dam whereas the mudstone of the Wallumbilla Formation may not. This is because the mudstone may contain sub-horizontal clay seams of low shear strength. If the mudstone is restricted to the dam abutments, it may be possible to substitute embankment sections over these areas to ensure stability.
Reservoir rim stability and leakage potential	Reservoir rim stability will depend on the distribution of mudstone of the Wallumbilla Formation. If this unit underlies steep slopes there is a possibility that these slopes will become unstable when the reservoir fills. The Blantyre Sandstone is an important aquifer. The potential for leakage through this unit should be investigated at the feasibility stage.
Proposed structural arrangement	<u>Previous studies</u> A RCC dam with central overfall spillway was proposed. At FSL 500 m, the spillway crest would be 34 m above bed level and overall length of the dam in excess of 550 m. A provision was made in the estimate of cost for anchors to resist sliding on the sheared mudstone foundation. *(The use of anchors to establish primary stability for large dams is now not favoured)*
Availability of construction materials	No site inspections or investigations have been carried out. Sandstone of the Blantyre Sandstone or basalt of the Sturgeon Basalt may be suitable for production of RCC aggregate. The riverbed appears to contain deposits of alluvial sand that may be suitable for augmenting the crushed rock aggregate. Earthfill materials may be available from weathered sandstone upstream and within 1 km of the site.
Catchment area	Catchment area at the site is 1694 km^2.

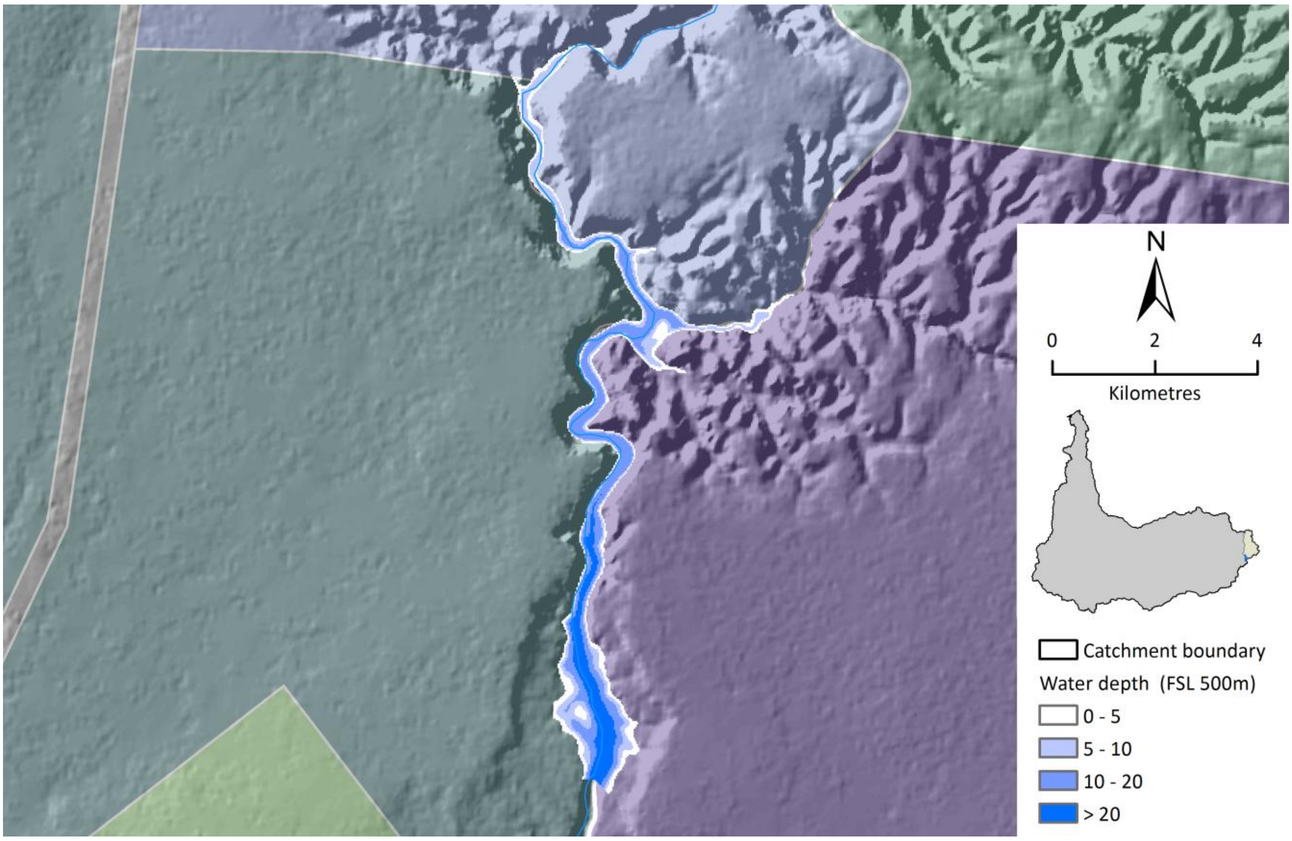
PARAMETER	DESCRIPTION
Flow data	The nearest gauging station to the site is streamflow gauging station. 915013A - Flinders River at Glendower AMTD 828.8 km (27 km downstream), which was operated from September 1972 until June 2011. Maximum recorded annual flow was 414,000 ML Mean annual flow 113,910 ML Median annual flow 75,000 ML Minimum annual flow 4,000 ML Catchment area at the gauging station site is 1958 km^2, that is 16% larger than at the dam site.
Reservoir capacity	89 GL at FSL 500 m (Apx Figure A.45).
Reservoir yield assessment at dam wall	39 GL at 85% annual time reliability (Apx Figure A.46). 39 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 17% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.2 Any leakage from the reservoir to groundwater aquifers would reduce the estimated yields as would any release requirements to meet downstream needs.
Open water evaporation	Mean annual evaporation is estimated to be 4.8 mm d^{-1} using a bulk aerodynamic approach. Mean annual evaporation was estimated to be 4.9 mm d^{-1} using Morton's APE.
Impacts of inundation	
Ecological and cultural considerations raised by previous studies	None had been undertaken
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>0.45</td><td>3.52</td><td>6.37</td></tr><tr><td>100 years (%)</td><td>1.5</td><td>11.75</td><td>21.24</td></tr><tr><td>Years to infill</td><td>6689</td><td>851</td><td>471</td></tr></table>
Water quality and stratification considerations	The Flinders 856 reservoir is predicted to experience persistent thermal stratification from mid-September to mid-May. Years with large relatively cold inflows exhibit a longer duration of persistent stratification. The risk of blue-green algal blooms is moderate with Zsl:Zeu from 2 to 3 from mid-September to March. The water column is predicted to be poorly mixed during extended periods of stratification each year and low dissolved oxygen with associated nutrient and metal releases from the sediments is likely to be experienced in most years.
Environmental considerations	Specific data are not available from this site. The dam location is likely to be above the distribution of freshwater sawfish but this would be subject to specific verification. The values of the aquatic habitat upstream of the proposed dam wall site are not known. The site is likely to cover "Of Concern" regional ecosystems (Apx Figure A.47). <u>*Ecosystems Of Concern*</u> This site is likely to support *Eucalyptus camaldulensis*, *E. coolabah* as a sparse canopy on channels, levees and floodplains. *Acacia harpophylla* or *A. cambagei* may be present as clumps or scattered trees. *Corymbia leichhardtii* is frequently present along with *E. exilipes*, *C. citriodora* and *Lophostemon suaveolens* sometimes occur as subdominants in the canopy. *Acacia spp*. may define the very sparse to sparse shrub layer. *Hannafordia shanesii* and *Seringia corollata* occur occasionally. *Themeda avenacea* frequently dominates the ground layer.
Estimated cost	$250 m to $410m (dam cost only) <u>Previous studies</u>

PARAMETER	DESCRIPTION
	Costs (assumed to be in 1989 $'s) were estimated as follows; Dam $51 m. Distribution works $23.8m Annual pumping costs $924,000. CPI escalation of these costs to 2012 $'s would result in costs as follows: Dam $89.1m Distribution works $45.8 m Annual pumping costs. $1,780,000. It is likely that construction costs, particularly in remote areas, have risen at a higher rate than the CPI index has risen over this period.
Estimated cost / ML of supply	$7110/ML (at 85% annual time reliability).
Potential benefit/cost	
Summary comment	Adjusting the previous cost by CPI is likely to understate current costs of dam. There have not been any on site investigations. Uncertainties as to actual costs are therefore higher than at other options under consideration.

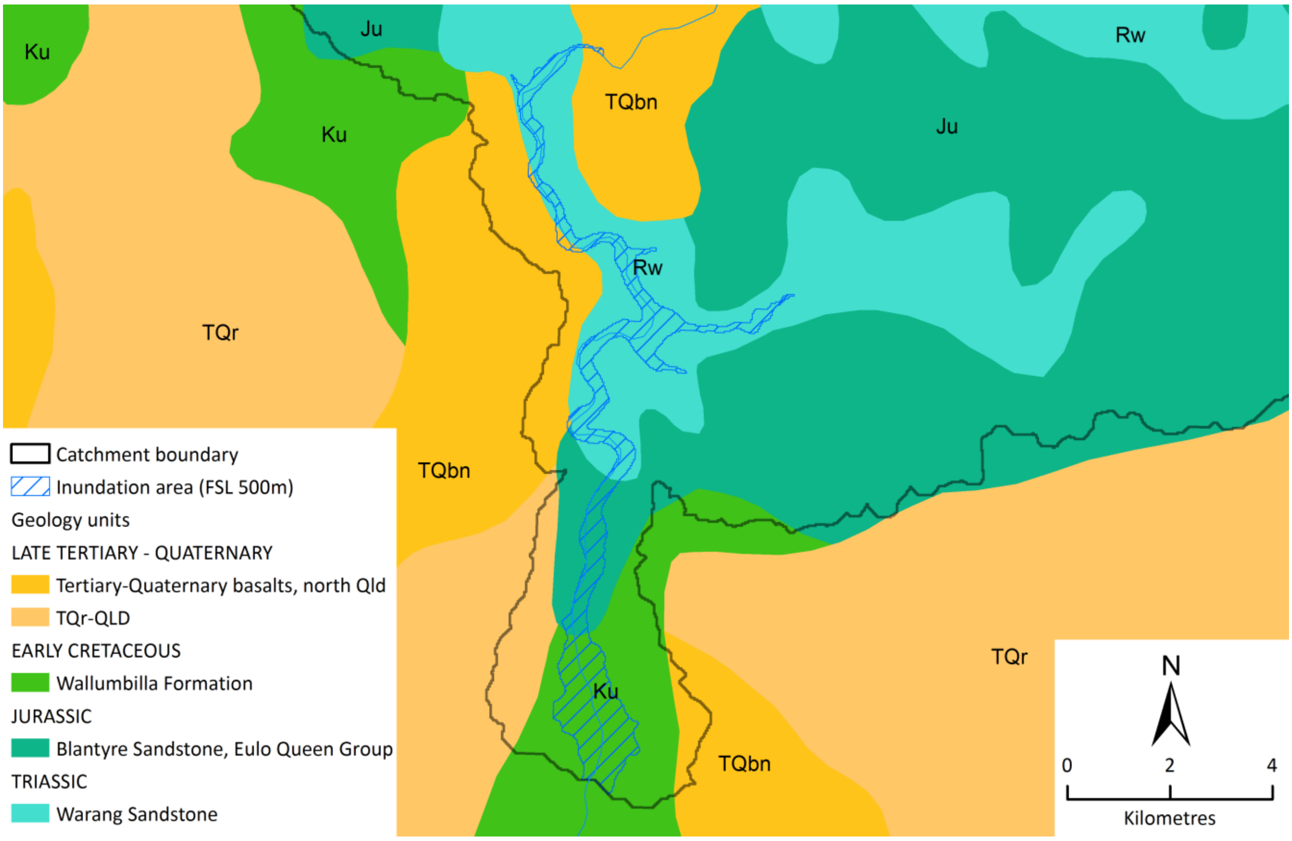
Apx Figure A.41 Flinders 856 dam site looking upstream



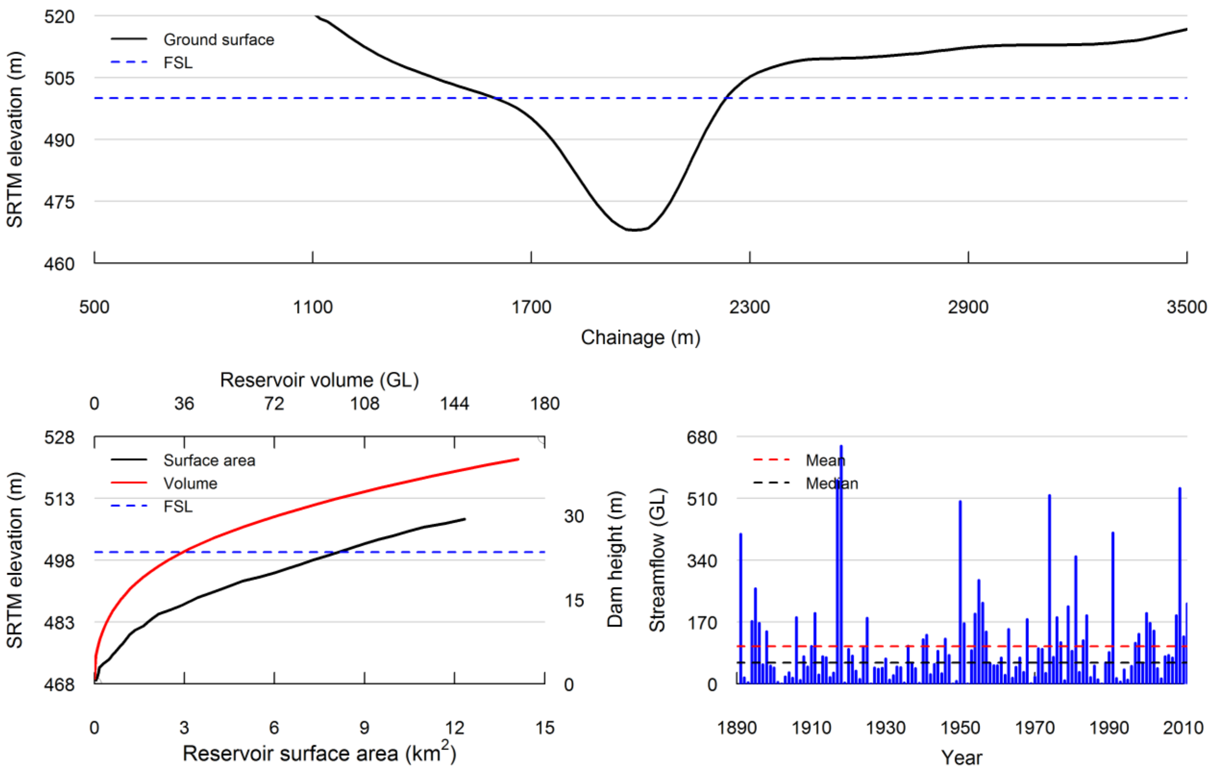
Apx Figure A.42 Location map of Flinders 856 dam site, reservoir and catchment area



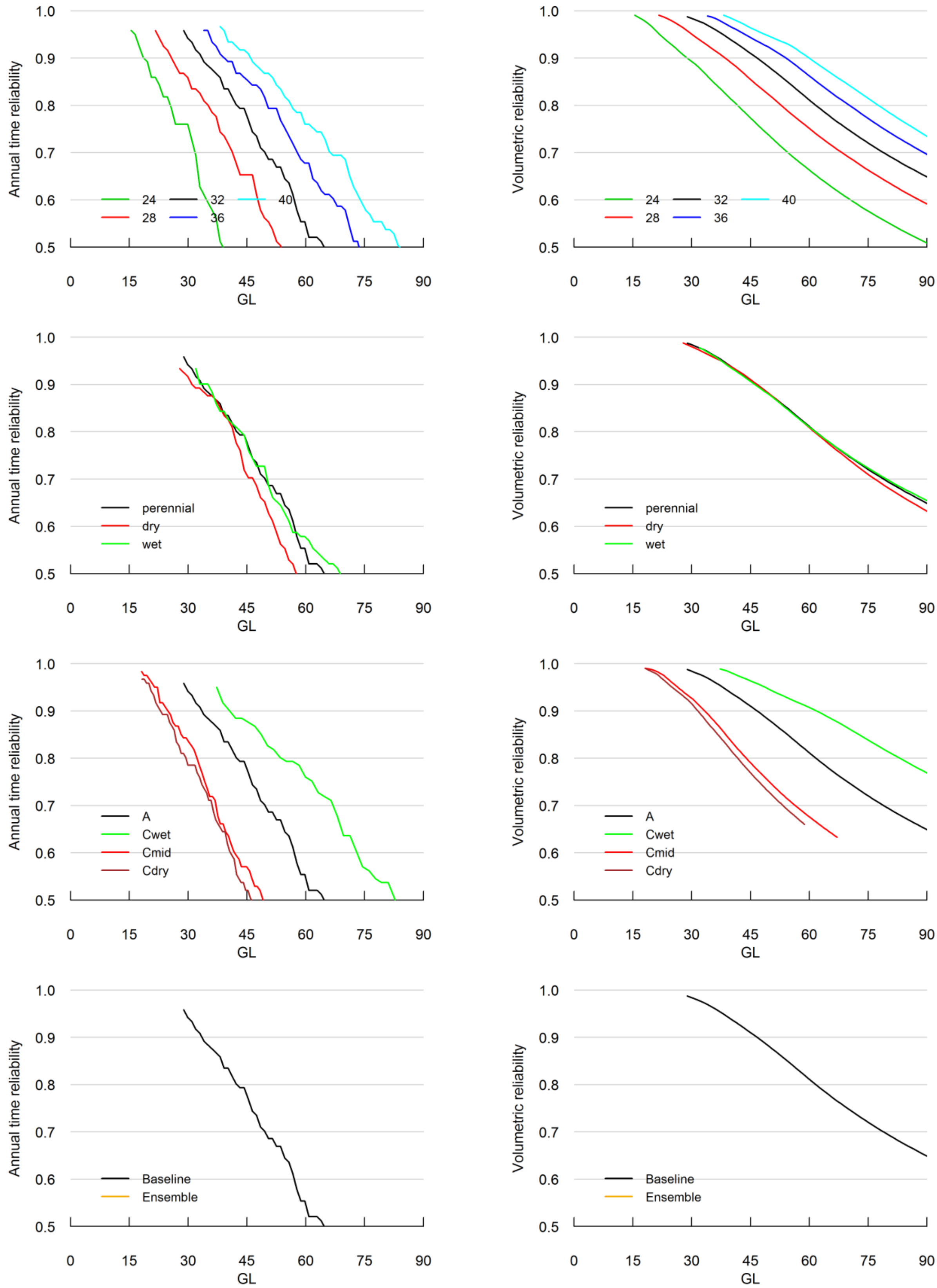
Apx Figure A.43 Flinders 856 site dam depth of inundation and property boundaries (indicated by coloured shading)



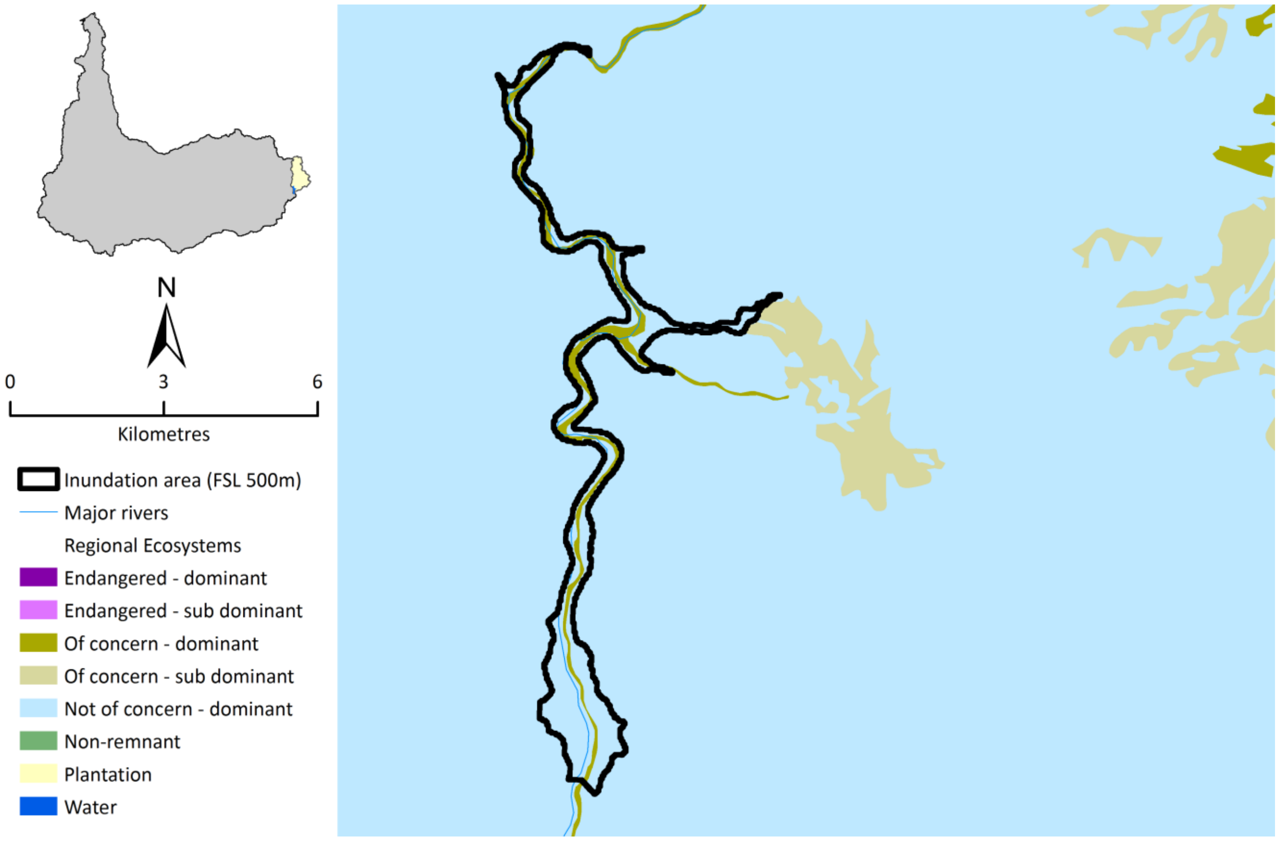
Apx Figure A.44 Flinders 856 site dam underlying geology



Apx Figure A.45 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Corella River dam site



Apx Figure A.46 Flinders 856 dam site performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 500 m FSL. Third row: YRR under Scenario C for 500 m FSL. Fourth row: Ensemble model runs unavailable for this site (see Lerat et al. 2013).



Apx Figure A.47 Flinders 856 dam regional ecosystems mapping

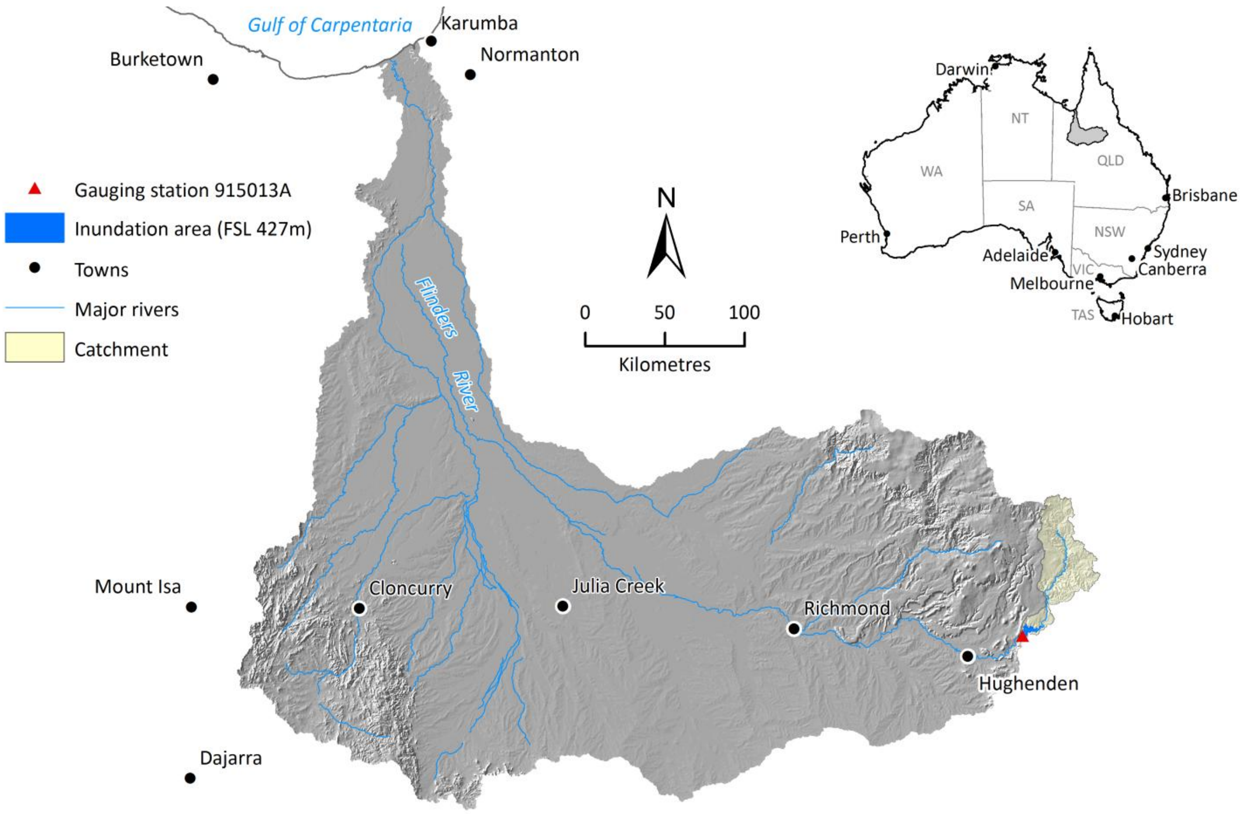
Glendower dam site on the Flinders River: 853.3 km

PARAMETER	DESCRIPTION
Previous investigations	QWRC (1982) Flinders River Dam Sites – 826km, 829km, 897km – Geology Appraisal Study. Poplawski and Ashkanasy (1984) Flinders River - Flood and Yield Study for Damsite at Glendower. Poplawski (1985) Flinders River - Sediment Study, Damsite at Glendower. Morwood (1983a) Preliminary Environmental Assessment of the Proposed Glendower Damsite on the Flinders River North Queensland. Morwood (1983b) Preliminary Archaeological Assessment of the Proposed Glendower Damsite on the Flinders River North Queensland. QWRC (1985a) Flinders River Damsite 828.5km –Investigations. Waye (1985b) Flinders River damsites 828.5km and 825.8km – Addendum to report on permeable sandstone which outcrops within reservoir area.
Description of proposal	<u>Previous investigations</u> An on river storage intended to provide supply for irrigation of land south east of Hughenden at 853.3 km (previously 828.5 km). A photograph of the site is shown in Apx Figure A.48. A location map and map showing the inundated area at FSL are shown in Apx Figure A.49 and Apx Figure A.50 respectively.
Regional geology	The Flinders River has incised into a sequence of rocks ranging from Jurassic to Cretaceous age mudstones of the Great Artesian Basin to Cainozoic age basalt of the Sturgeon Basalt Province. The oldest rocks are flinty mudstones of the Gilbert River Formation outcropping at the top of the proposed reservoir. These are overlain by clayey to silty mudstone of the Wallumbilla Formation that forms the foundation of the dam. The mudstone contains a prominent quartzose sandstone member of high permeability about 3 m thick. Regional dip of these units is less than 1° towards the southwest. The Wallumbilla Formation is unconformably overlain by the Glendower Formation of Tertiary age. It forms prominent cliffs and plateaus above the river. It consists of conglomerate and sandstone. Beds lack continuity with lensing out and changing texture or composition being common. The unit has been silicified and ferruginised in its upper layers to form a duricrust surface. Basalt of the Sturgeon Basalt Province forms a prominent plateau to the west and northwest of the sites. Four sets of alluvial terraces have been recognised and these are being actively eroded indicating recent rejuvenation of the drainage system. Apx Figure A.51 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	Investigations targeted the 828.5 km site. At this site the left abutment overlies a large landslide at least 20 m deep within mudstone. The landslide extends a significant distance upstream and downstream of the site where the river has eroded a steep slope below the resistant cap rock of the Glendower Formation. A highly permeable sandstone bed underlies mudstone at a depth of 28 m below riverbed level. This sandstone forms a sub-artesian aquifer about 1000 km^2 in area. It is about 13 m thick at the damsite and daylights in the reservoir area. Accordingly a reservoir will raise piezometric levels in the aquifer. Shear strength of sub-horizontal sheared zones in the mudstone is very low ($c' = 0$, $\phi' = 13°$ for normal stress less than 260 kPa). Also, the strength will be adversely affected by increased pore pressure resulting from the underlying sandstone aquifer. Landslides also occur on the left abutment at the 825.8 km site but these have not been investigated in detail.
Reservoir rim stability and leakage potential	Both dam sites are affected by unstable slopes upstream of the left abutment of the dam. These dormant landslides will almost certainly be re-activated by the creation of a reservoir. These could lead to blocking of the reservoir and also affect the dam and its intake or outlet works. Preliminary estimates of leakage through the sandstone aquifer daylighting in the reservoir

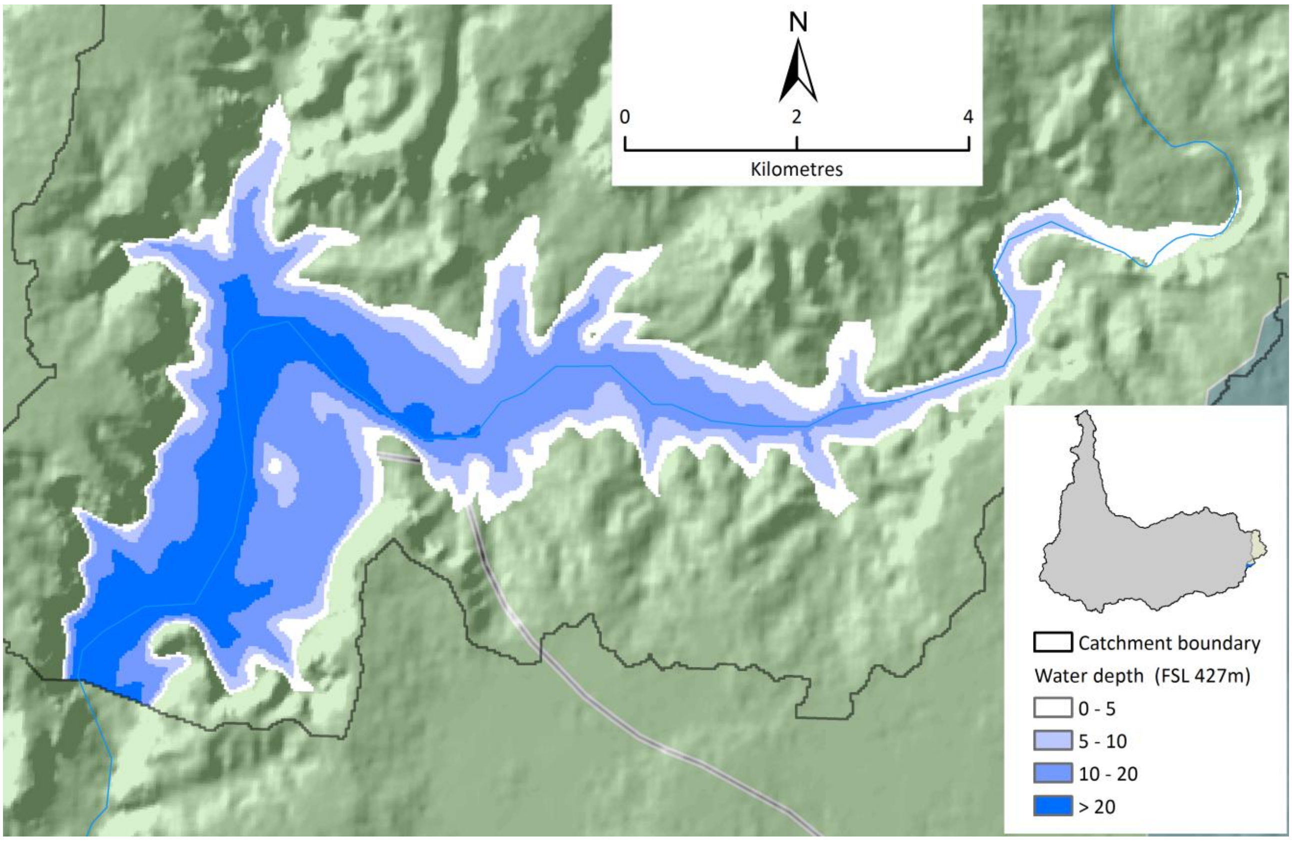
PARAMETER	DESCRIPTION
	range from 116 to 290 ML/year.
Proposed structural arrangement	After consideration of the alternative sites, the 828.5 km site was considered to be marginally more favourable and a proposal developed for this site as follows. The proposed dam is of roller compacted concrete (RCC) construction, total length of 800 m with an overflow spillway section, crest length 128 m. The spillway upstream and downstream faces, intake tower and outlet works were of conventional concrete construction. It is proposed that the structure would be founded on moderately weathered mudstone at depths ranging from 5-15 m below natural surface levels. Prestressed anchor cables were provided to ensure adequate sliding resistance. An estimate of a 0.01% Annual Exceedance Probability (AEP) flood was adopted as a design flood rather than the estimated PMF which would overtop the abutments by 4.62 m if it were to occur. *(Reliance on prestressed anchor cables for primary stability and sliding resistance may not meet current dam safety standards)*
Availability of construction materials	Potential quarry sites are located in basalt about 3 km west of the 828.5 km site and in sandstone about 1 km northwest of that site. The basalt was investigated by seismic refraction survey and trenching. This indicated slightly weathered basalt at a depth of about 2 m. Thickness of the deposit is unknown. In the sandstone (Glendower Formation) slightly weathered sandstone occurs at a depth of 1.5 to 5 m. Silty sand and sand within terraces and instream alluvial deposits could be used to augment quarry material to produce a suitable RCC aggregate.
Catchment area	The catchment area is 1912 km^2
Flow data	Flow data is available from streamflow gauging station 915013A Flinders River at Glendower AMTD 828.8 km, which was operated from September 1972 until June 2011. Maximum recorded annual flow was 414,000 ML Mean annual flow 113,910 ML Median annual flow 75,000 ML Minimum annual flow 4,000 ML Recorded mean annual flow was somewhat higher than the 93,700 ML estimated in 1982 – QWRC (1984).
Storage capacity	427 GL at FSL 427 (Apx Figure A.52)
Reservoir yield assessment at dam wall	57 GL at 85% annual time reliability (Apx Figure A.54 and Apx Figure A.55) 57 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 28% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.4 Previous studies QWRC (1984) details approaches taken to develop estimates of 'safe' yield using the short period of record using what information was available to calibrate a rainfall runoff model. For a storage of 200,000 ML capacity, 'safe' yield was assessed as being between 19,500 and 35,900 ML/a with a maximum period between overflows of 11 years. No reference is made to any environmental flow provisions or allowance for existing downstream entitlements, nor to likely yields at lower reliabilities of supply.
Open water evaporation	Mean annual evaporation is estimated to be 4.8 mm d^{-1} using a bulk aerodynamic approach. Mean annual evaporation was estimated to be 5.0 mm d^{-1} using Morton's APE.
Impacts of inundation on existing infrastructure	

PARAMETER	DESCRIPTION			
Ecological and cultural considerations raised by previous studies	Morwood (1983a,b) drew attention to the following issues: • 15km of riverine vegetation being impacted by the storage. • Impacted plant and fauna communities existing elsewhere in the region. • Inundation of a fossil locality considered not to be unique. • A proposed national park at the upper reaches of the reservoir. • Possible rising saline levels in the storage. • Possible insect and animal pest impacts in the irrigation area. • Social benefits such as recreation. • Of 22 Aboriginal sites, it was recommended that further studies be undertaken at 4 particular sites to obtain information on the way these sites were used. No allowance for fish transfer was made.			
Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)	0.16	1.24	2.25
	100 years (%)	0.53	4.14	7.49
	Years to infill	18969	2414	1335
Water quality and stratification considerations	Glendower reservoir is predicted to experience persistent thermal stratification from early/mid-September to mid-May/early June. Years with large relatively cold inflows exhibit a longer duration of persistent stratification. The risk of blue-green algal blooms is low with Zsl:Zeu > 3 at virtually all times on average. The water column is predicted to be poorly mixed during extended periods of stratification each year and low dissolved oxygen with associated nutrient and metal releases from the sediments is likely to be experienced in most years.			
Environmental considerations	Specific data on fish are not available from this site. The dam location is likely to be above the distribution of freshwater sawfish but this would be subject to specific verification. The values of the aquatic habitat upstream of the proposed dam wall site are not known. The location of this proposed dam site is unlikely to influence any regional ecosystems of significance to the region, though this will require detailed site survey to confirm the mapping (Apx Figure A.55).			
Estimated cost	$340 m to $560 m (cost of dam only) Previous studies QWRC (1985a) details an estimate of cost in 1984 prices. Cost of the dam was estimated to be between $85 and $97 m depending on the extent of stabilisation required on the left abutment. Up to a further $3m was expected to be required to control leakage in the sandstone beneath the dam foundation. Consumer Price Index adjustment of these costs to 2012 prices results in estimated costs ranging from $247 m to $280 m. Construction costs, particularly in remote areas have almost certainly increased at a higher rate than CPI over this period.			
Estimated cost / ML of supply	$6580/ML (at 85% annual time reliability).			
Potential benefit/cost	Very high value uses would need to be identified for this proposal to have positive economic benefits.			
Summary comment	Further consideration of this site would be highly dependent on more certain understanding of geological conditions and identification of structural details suitable to those conditions. Final costs could be higher than those estimated by the Assessment.			

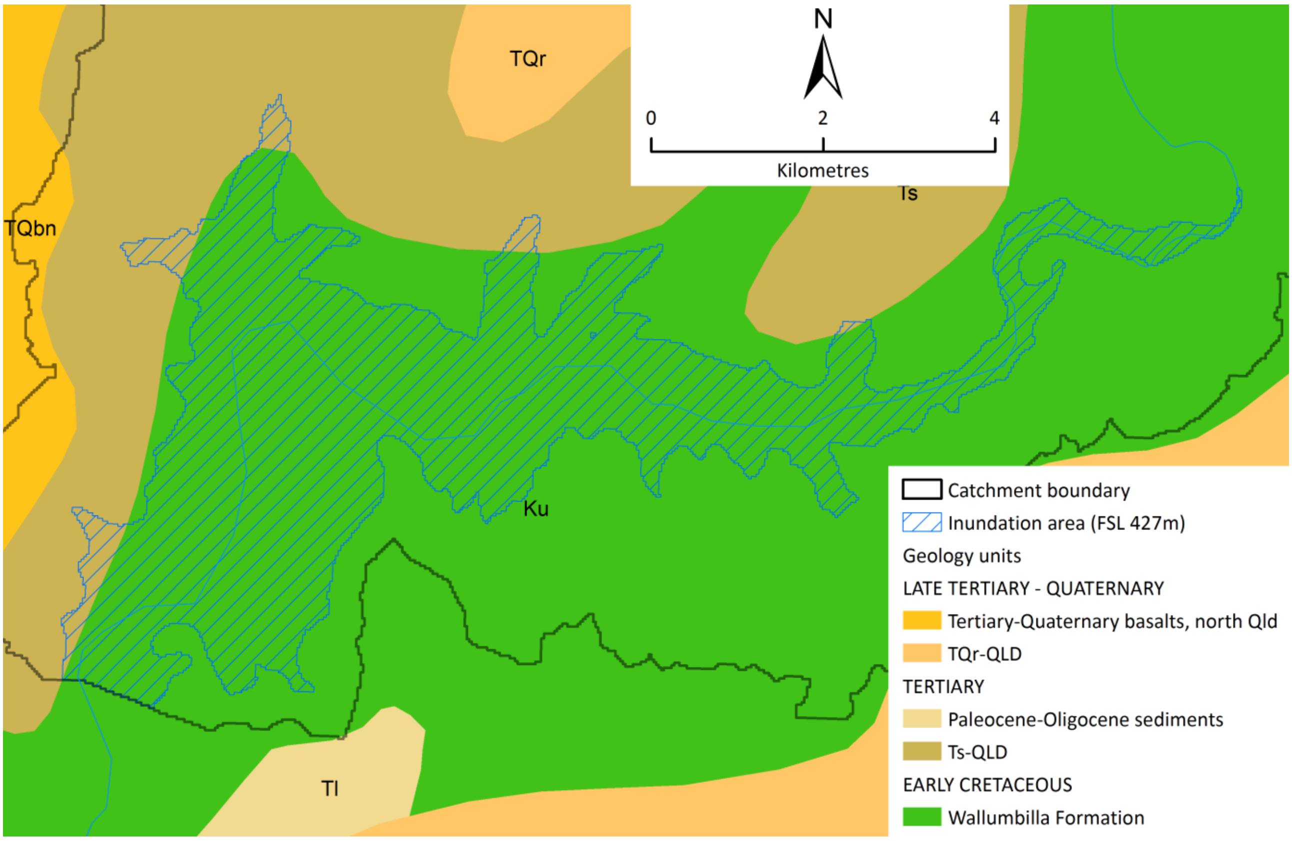
Apx Figure A.48 Glendower dam site looking upstream



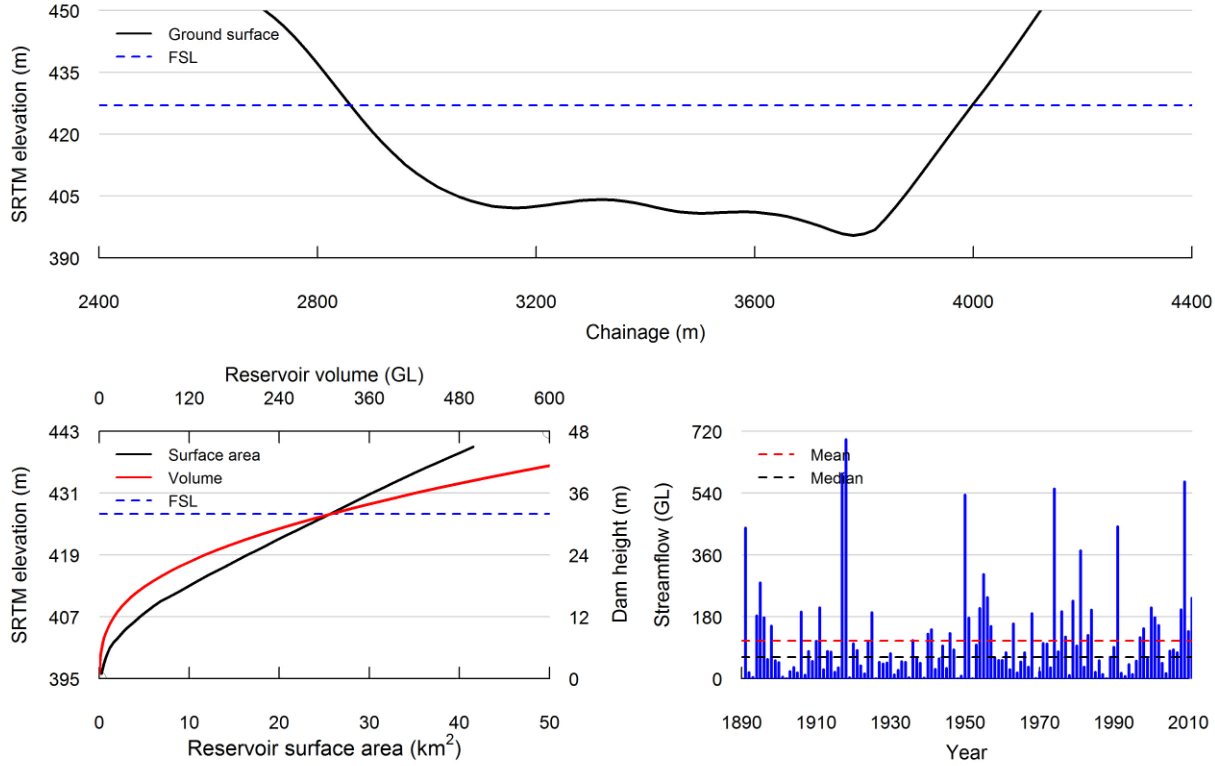
Apx Figure A.49 Location map of Glendower dam site, reservoir and catchment area



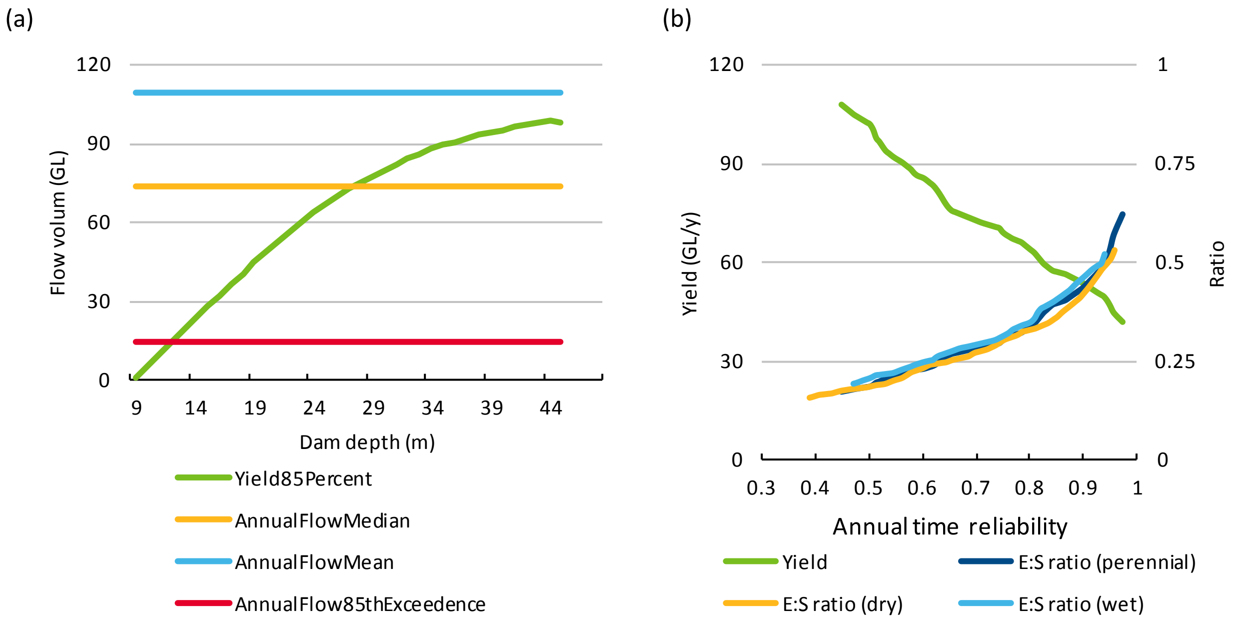
Apx Figure A.50 Glendower damsite depth of inundation and property boundaries (indicated by coloured shading)



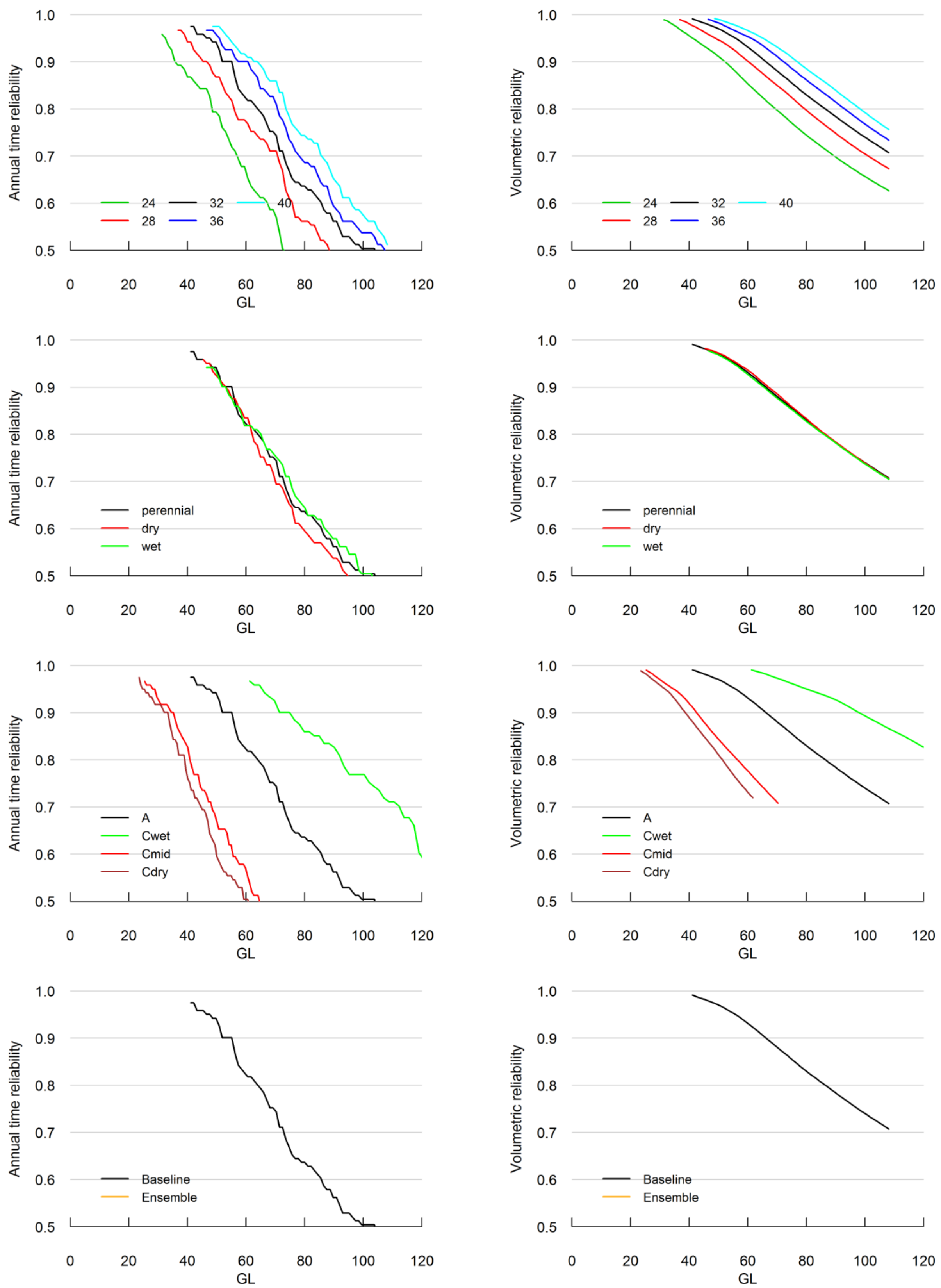
Apx Figure A.51 Glendower site dam underlying geology



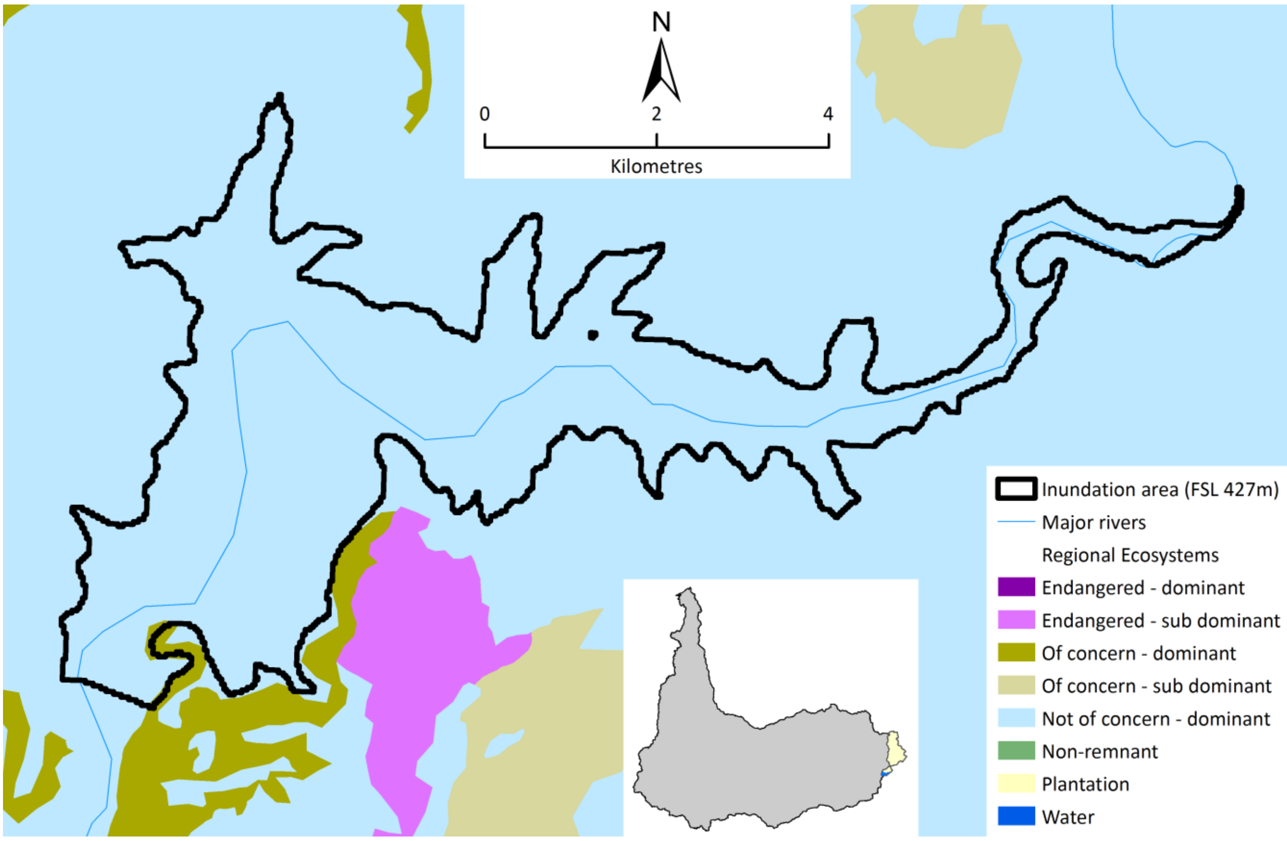
Apx Figure A.52 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Glendower dam site



Apx Figure A.53 a) Yield at 85% annual time reliability and streamflow at Glendower dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Glendower dam site for different annual time reliability for the selected dam height of 32 m



Apx Figure A.54 Glendower site dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 427 m FSL. Third row: YRR under Scenario C for 427 m FSL. Fourth row: ensemble model runs unable (see Lerat et al. 2013).



Apx Figure A.55 Glendower dam regional ecosystems mapping

Mount Beckford dam site on the Flinders River; 821.4 km

PARAMETER	DESCRIPTION
Previous investigations	Poplawski (1985) Flinders River - Sediment Study, Damsite at Glendower GHD (2000) Preliminary Investigation - Potential Irrigation Scheme at Hughenden. SMEC (2003a) Hughenden Irrigation Project – Mt Beckford Scheme. SMEC (2003b) Irrigation Project-Alstonvale, Final Report. NARG (2004) Hughenden Irrigation Project (Beckford Scheme) – Social and Economic Benefits Study.
Description of proposal	<u>Previous investigations</u> The proposed development involves construction of 'instream' dam on Flinders River at Mt Beckford. The dam would supply either of two potential irrigation schemes by means of open channels up to 35 km long from the dam site: • to the north-west in the vicinity of Porcupine/Galah and Coolibah Creeks. (SMEC 2003b) • across the Flinders Highway to the south west (SMEC 2003b). The dam site is just north of Flinders Highway about 15 km east of Hughenden. For the north west proposal, water would be diverted from the dam to Porcupine Creek where a diversion weir would divert water via a canal to the proposed irrigation area. A photograph of the site is shown in Apx Figure A.56. A location map and map showing the inundated area at FSL are shown in Apx Figure A.57 and Apx Figure A.58 respectively.
Regional geology and topography	The site lies between plateaus formed by Mt Beckford to the north and The Sentinal outcrop to the south. The Flinders River meanders within a floodplain between the plateaus. Rock below the valley is mudstone belonging to the Wallumbilla Formation, part of the Rolling Downs Group of Early Cretaceous age. The upper surface of the plateaus is covered by a relatively thin layer of basalt (< 30 m). The basalt formerly flowed down a river valley but the topography is now inverted because of the more resistant nature of the basalt. Apx Figure A.59 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	No site investigation has been carried out. A roller compacted concrete (RCC) dam was proposed by SMEC (2003a). Excavation of alluvium 8 to 12 m deep across the river bed to expose the mudstone bedrock is expected to be necessary at the dam site. The mudstone would be expected to have very low shear strength similar to the Glendower site. The abutments of the dam will have to be assessed for slope stability. At the Glendower site in similar rock, landslides 20 m deep occurred on one of the abutments adjacent to steep upper slopes. The landslides are caused by valley stress relief inducing shearing along sub-horizontal bedding planes in the mudstone. SMEC proposed that the proposed irrigation canals be excavated into natural soils and mudstone with high density polyethelene (HDPE) liners to control breakdown of the mudstone during wetting and drying conditions.
Reservoir rim stability and leakage potential	The reservoir will inundate the lower slopes of Mt Beckford and The Sentinal where steep slopes have formed in mudstone under the resistant basalt cap rock. The stability of these slopes should be assessed at the feasibility stage. There is a low potential for leakage from the reservoir rim.
Proposed structural arrangement	The proposed structure type assessed by SMEC as suitable for the dam site included: • RCC dam structure with central spillway section. • Earth embankments: constructed from local mudstone, with rock riprap and sheet pile cut offs. • Weir structure: concrete sill and piers with radial gates, overhead roadway, and sheet pile cut off. • Canals: Cut into natural soil and mudstone with HDPE liner.

PARAMETER	DESCRIPTION
	The dam would require a 2000m long river embankment between the western end of Mt Arthur and the south-eastern ridge of Mt Beckford, approximately 30 to 35m high and a 2000m long western embankment 20 to 25m high across Eight Mile Creek.
Availability of construction materials	There has been no investigation for construction materials at the site. Basalt is a possible source of aggregate in combination with river sands and gravels from the riverbed.
Flow data	Mean annual discharge Flinders River at Hughenden is estimated to be 132,000 ML/a.
Storage capacity	245 GL at FSL 364 (Apx Figure A.60)
Reservoir yield assessment	45 GL at 85% annual time reliability (Apx Figure A.61 and Apx Figure A.62). 44 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 39% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.6 Previous studies The potential supply yield at 85% annual reliability was estimated by DERM (July 2009) using the water resource plan (WRP) hydrologic model. Distribution losses of 20% were assumed between the storage and on farm areas. 124 GL storage Yield 32,000 ML/a 247 GL storage Yield 38,000 ML/a **Note:** 1. The yield estimates undertaken by the Assessment were substantially lower than estimates made by SMEC (2003a,b). 2. For the above yield estimates, no specific provisions were made to meet Environmental Flow Objectives or to meet downstream entitlements. 3. Both cases would have significant impacts on flow statistics in the reach downstream of the dam site, particularly to the Porcupine Creek junction. Impacts would reduce progressively further downstream and would be minimal at the end of system. 4. Provision of environmental flows is likely to have a considerable impact on the above yield estimates. 5. The yield estimates may be sensitive to actual conveyance losses.
Open water evaporation	Mean annual evaporation is estimated to be 5.1 mm d^{-1} using a bulk aerodynamic approach. Mean annual evaporation was estimated to be 5.0 mm d^{-1} using Morton's APE.
Impacts of inundation on existing infrastructure	Only a small number of properties would be affected by inundation or potential land resumption as part of the proposed dam. Cummins et al. (2004b) examined various scenarios of development and identified two properties that would likely require partial resumption, namely Monavale Station and Hughenden Station.
Ecological and cultural considerations raised by previous studies	There has not been any specific study of environmental issues arising from this proposal. A 15 to 20% rise in workforce and population was projected to occur due to additional employment generated during construction of the scheme and associated farm establishment in the area. (Cummins et al. 2004a). New recreation and tourism benefits are likely to be generated with a lake in close proximity to the regional centre of Hughenden. These include swimming, boating, fish stocking, water skiing, walking tracks, camping, picnic areas, local tourism development and increased tourist numbers. The dam would likely become a regional resource attracting tourists and recreational usage from people in surrounding regions.
Estimated rates of reservoir sedimentation	
Water quality and stratification	Mt Beckford reservoir is predicted to experience persistent thermal stratification from early

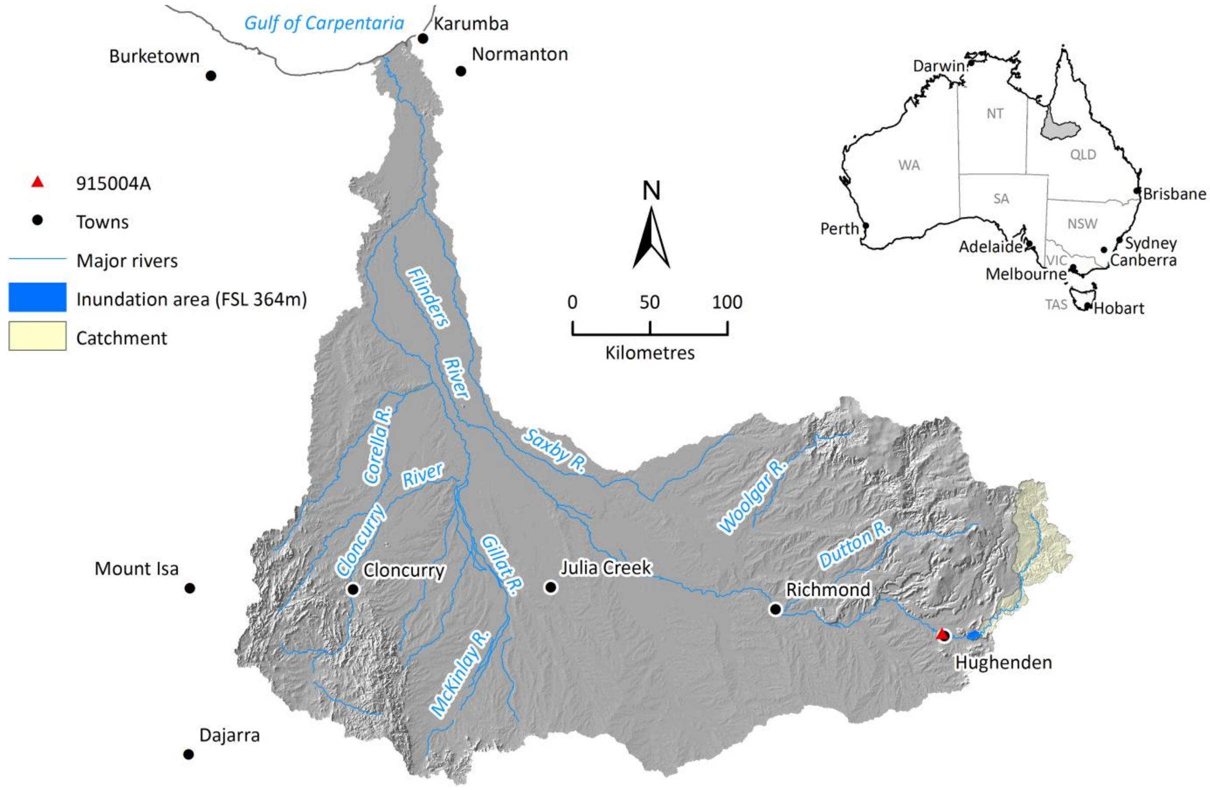
Estimated rates of reservoir sedimentation:

	Best case	Expected	Worst case
30 years (%)	0.20	1.76	2.80
100 years (%)	0.66	5.87	9.33
Years to infill	15222	1705	1072

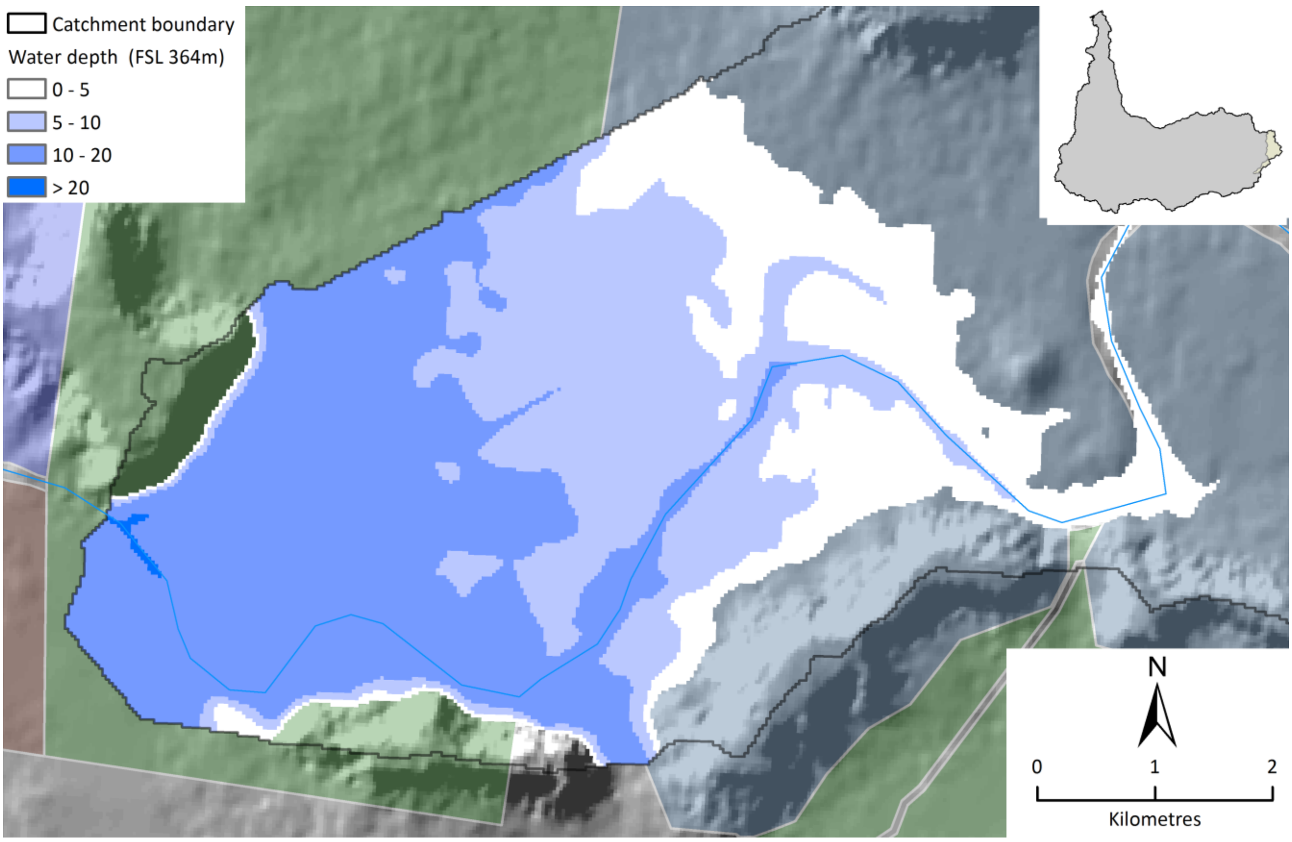
PARAMETER	DESCRIPTION
considerations	October to mid-late April each year. Summer inflow events are likely to cause full water column mixing for short periods (up to 1 week) each year. The risk of blue-green algal blooms is low to moderate with Zsl:Zeu ≤ 3 from late January - early March and > 3 at other times. The water column is predicted to mix annually during winter and in summer in half of years as a result of inflows. The duration of stratification and weak mixing behaviour suggests this storage will be moderately susceptible to low dissolved oxygen conditions and associated water quality issues. In some years summer inflows may resupply some oxygen to deeper waters and reduce some symptoms of low dissolved oxygen.
Environmental considerations	Common to most dams, issues which would need to be addressed include, • Riverine ecology and particularly, the impact of any alteration to the flow regime. • Sediment transport and deposition. • Fish passage requirements. • Creation of mosquito habitat. • Land suitability and salinity risk in proposed irrigation areas. • Heritage impacts. A 1985 study by the Queensland Water Resources Commission (Poplawski 1985) of sediment transport at the Glendower damsite (approx 28 km upstream) concluded that the total sediment transport in an average streamflow year would be 130 ML which would have a significant impact on the storage over a 100 year period. The possible deposition of sediment within the storage area and its impact on upstream flood levels was not assessed. Specific data are not available from this site. The dam location is likely to be above the distribution of freshwater sawfish but this would be subject to specific verification. The values of the aquatic habitat upstream of the proposed dam wall site are not known. The site covers a mix of regional "Of concern" ecosystems compring about half the proposed surface area (Apx Figure A.63). <u>*Ecosystems Of Concern*</u> The riparian vegetation zone is likely to include fringing woodland to open-forest of *Eucalyptus camaldulensis*, *E. tereticornis*, *Melaleuca fluviatilis*, *M. leucadendra*, *Casuarina cunninghamiana, Corymbia tessellaris*. A distinct sub-canopy can occur and contain *Ficus spp., Lophostemon spp.* and *Pleiogynium timorense* as well as juvenile canopy species. The shrub layer varies from none to mid-dense stands of *Ficus opposita*, *Melaleuca spp.* and *Acacia crassicarpa*. Dense ground cover includes *Heteropogon contortus* and *Themeda triandra* as well as a range of other graminoid and forb species.
Estimated cost	$405 m to $675 m (cost of dam only). <u>Previous studies</u> SMEC (2003a,b) reported the following costs: **North West irrigation area**. 124 GL storage $ 72.9 million 247 GL storage $ 87.1 million. **South West irrigation area**. 124 GL storage $82.2 million. 247 GL storage $96.4 million No schedules of estimated quantities or of assumed unit rates were provided. **NB:** These estimates appear to be based on very preliminary information and do not appear to reflect the significant uncertainties associated with the proposal. Assuming these estimates were prepared in June 2002 prices, significant price escalation would apply to June 2012 prices. The Consumer Price Index variation suggests a 30% escalation over this period. Cost escalation in the construction sector particularly in remote areas is probably significantly

PARAMETER	DESCRIPTION
	higher.
Estimated cost / ML of supply	$9900/ML at 85% annual time reliability (does not include transmission/distribution losses or take into account environmental and downstream entitlements).
Potential benefit/cost	Previous investigations SMEC (2003a,b) undertook a financial analysis assuming that a State contribution to the project of $10 million would be made, that land would be acquired for the irrigation area at a cost of $250/ha and sold as irrigation farms (with a water allocation of 4 ML/ha) at a price of $3,750 /ha. The consultant's financial analysis concluded that financial viability was likely to be better for the lower dam development and that the SW proposal was more likely to be viable than the NW proposal. Positive returns were indicated for lower discount rates. SMEC (2003a,b) commented that the results were sensitive to construction costs. The lower yields now estimated to be available; the impact of environmental flow requirements and uncertainties associated with this proposal would have major impacts on project viability as would the rate of take up of irrigation farms.
Summary comment	The Mt Beckford proposals involve major uncertainties as follows: • Foundation conditions across the river bed and their adequacy to support a major gated spillway structure. • Foundation conditions along the two major embankments required to contain the storage. • The likely significant impact of sedimentation on the proposed Flinders River storage. • Geotechnical conditions in the storage area particularly on the south bank near The Sentinel and along the distribution channels. Hence the previous cost estimates do not appear to adequately reflect the uncertainties associated with this site.

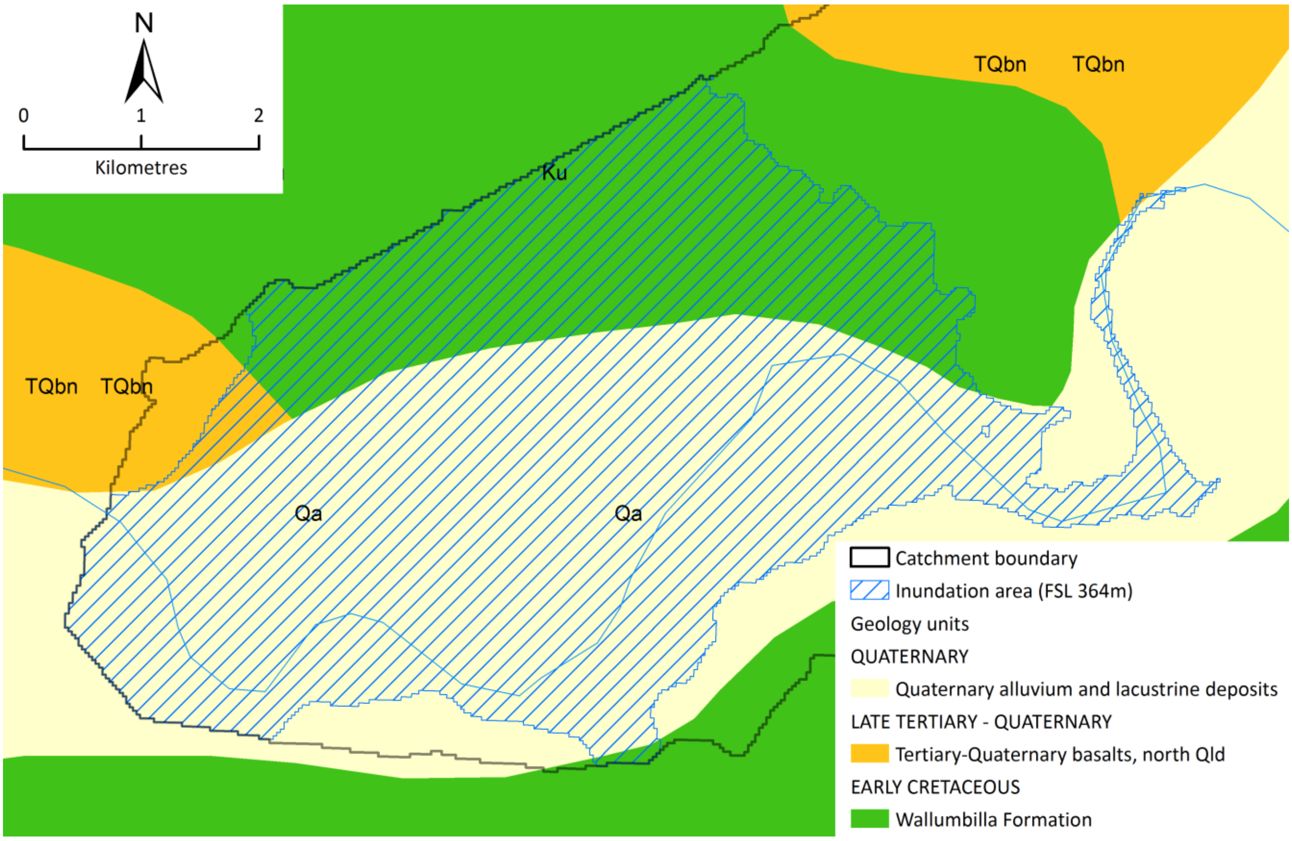
Apx Figure A.56 Mount Beckford dam site looking downstream



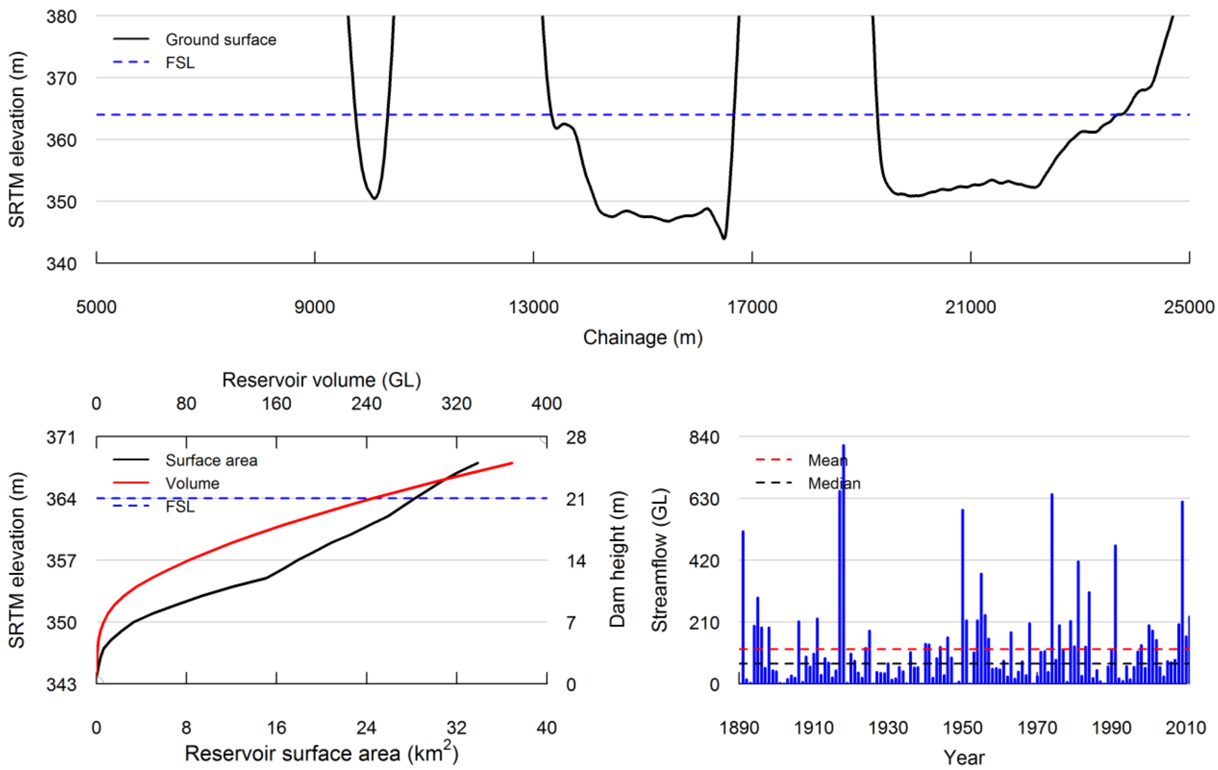
Apx Figure A.57 Location map of Mount Beckford dam site, reservoir and catchment area



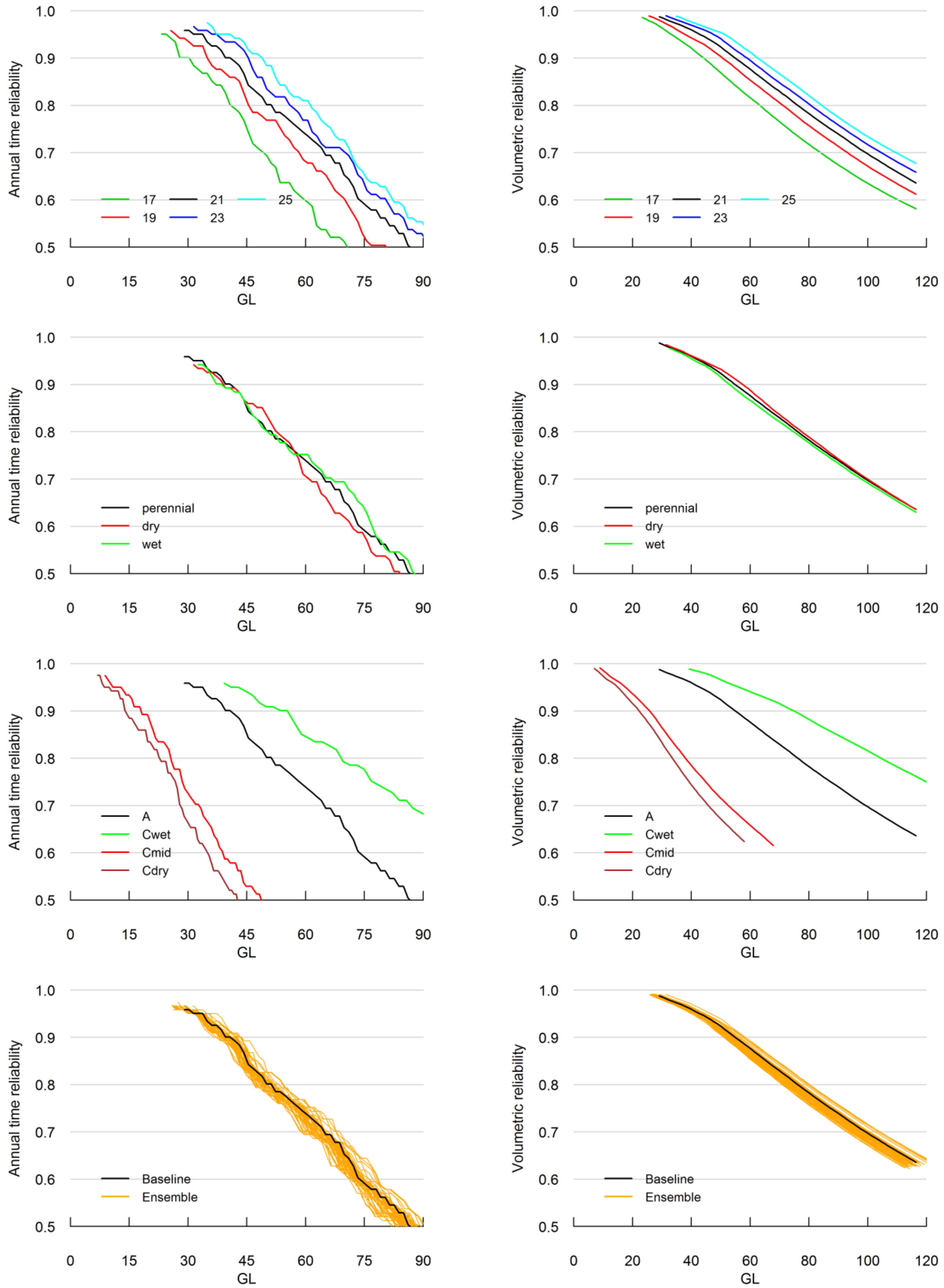
Apx Figure A.58 Mount Beckford dam site depth of inundation and property boundaries (indicated by coloured shading)



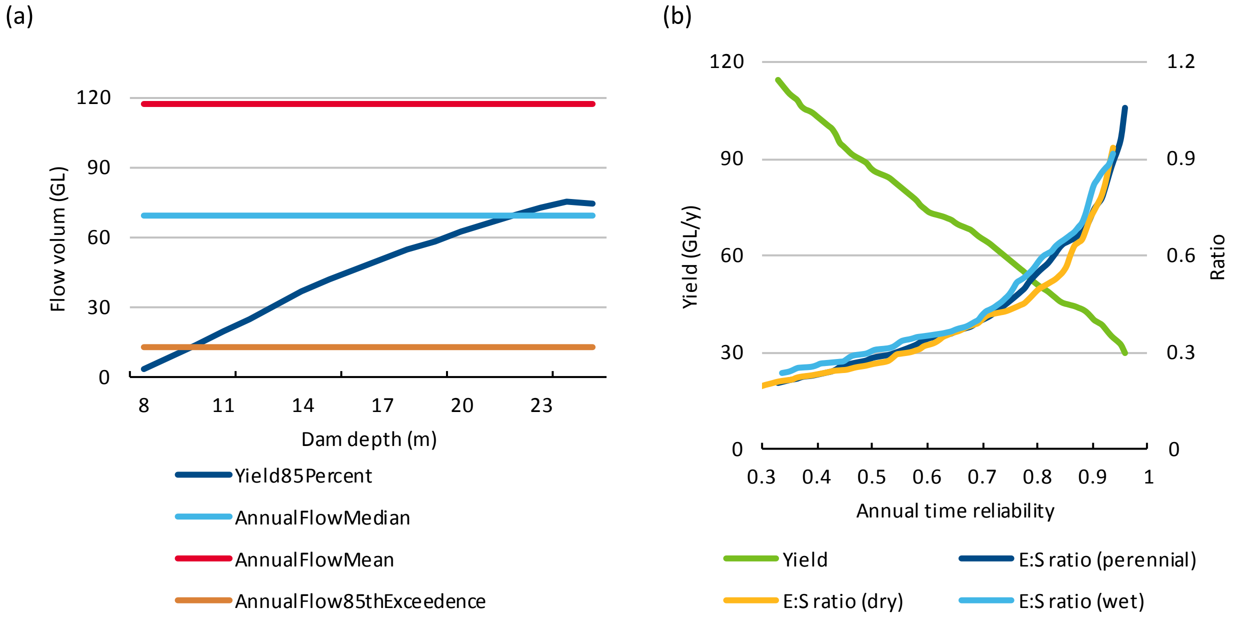
Apx Figure A.59 Mount Beckford dam site underlying geology



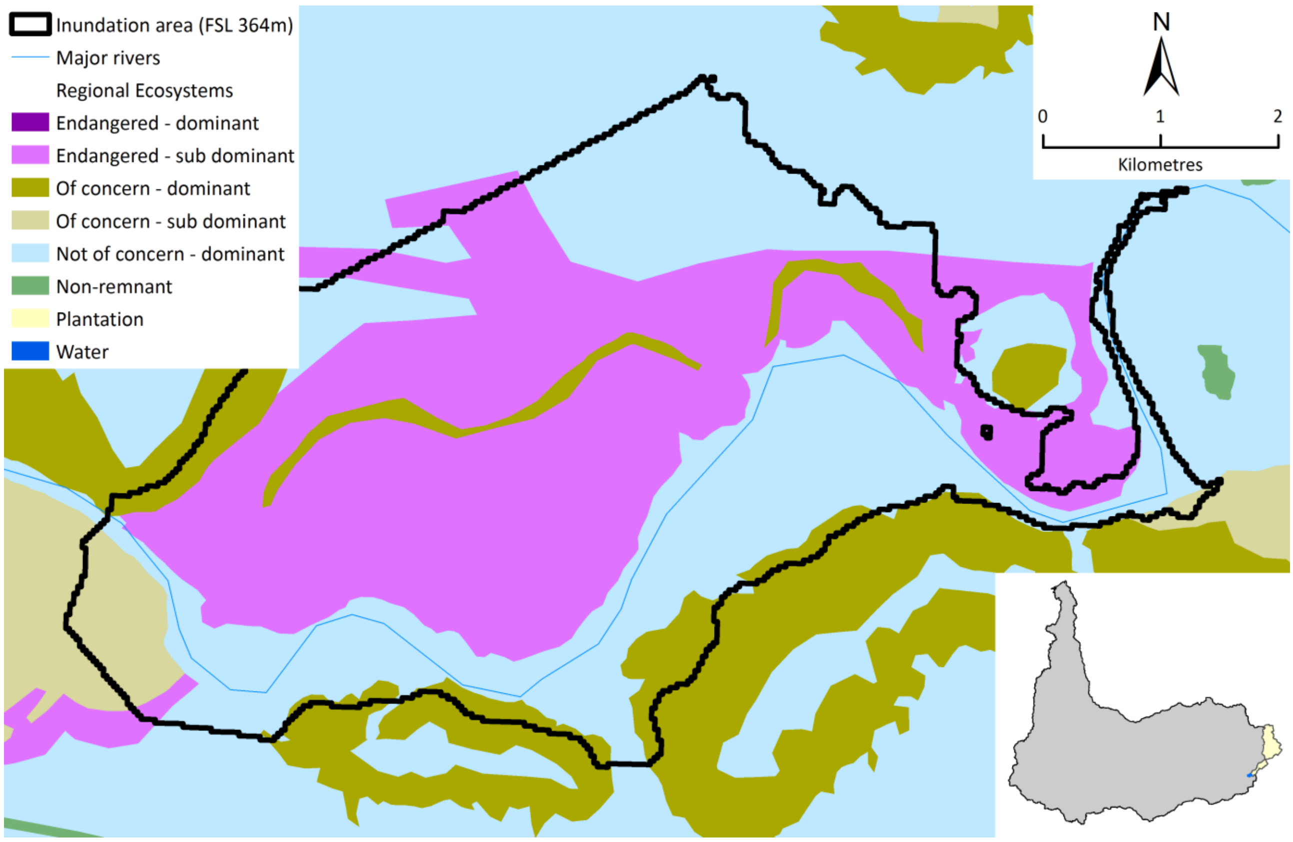
Apx Figure A.60 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Mount Beckford dam site



Apx Figure A.61 Mount Beckford dam site performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 364 m FSL. Third row: YRR under Scenario C for 364 m FSL. Fourth row: YRR for baseline and ensemble model runs for 364 m FSL



Apx Figure A.62 a) Yield at 85% annual time reliability and streamflow at Mount Beckford dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Mount Beckford dam site for different annual time reliability for the selected dam height of 21 m



Apx Figure A.63 Mount Beckford dam regional ecosystems mapping

Mount Oxley dam site on the Flinders River; 926.2 km

PARAMETER	DESCRIPTION
Previous investigations	These sites were, in addition to the Glendower site at AMTD 826 km, investigated as potential sources of water supply to irrigate land in the Hughenden area. QWRC (1982) Flinders River Damsites, 826 km, 829 km, 897 km, Geology Appraisal Study. QWRC (1983) Flinders River – Basin 915, Yield Analysis for Damsites at 826 km, 897 km & 904 km.
Description of proposal	On stream storage dam releasing supply to the river channel for downstream extraction. A location map and map showing the inundated area at FSL are shown in Apx Figure A.64 and Apx Figure A.65 respectively.
Regional geology	The site and reservoir area are located within the Cape River beds consisting of quartzite, schist and gneiss of Proterozoic to Early Palaeozoic age. The Cape River beds are overlain by Cainozoic age Sturgeon Basalt that forms a plateau on both sides of the river above the dissected terrain of the Cape River beds. Apx Figure A.66 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	This site has not been inspected and no investigations been carried out.
Reservoir rim stability and leakage potential	There is potential for instability at the unconformity between basalt and Cape River beds. If the reservoir level is above the unconformity this potential should be investigated at the feasibility stage. Similarly, the unconformity is a potential leakage path if it is below reservoir level.
Proposed structural arrangement	No details of the proposal have been located.
Availability of construction materials	No information is available for this site.
Catchment area	The catchment area is 690 km^2.
Flow data	The closest streamflow gauging station to these sites is gauging station 915013 at AMTD 828.8 km (Glendower) which operated from September 1958 to June 2011. Catchment area at the G.S. is 2,110 km^2, nearly 2.8 times that at the dam sites. Summary flow data is as follows. Maximum recorded annual flow was 414,000 ML Mean annual flow 113,910 ML Median annual flow 75,000 ML Minimum annual flow 4,000 ML.
Reservoir capacity	45 GL at 589 FSL (Apx Figure A.67)
Reservoir yield assessment	22 GL at 85% annual time reliability (Apx Figure A.68 and Apx Figure A.69) 21 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 17% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.2 Previous studies QWRC (1983) draws attention to the likely high seepage losses as porous sandstones are exposed over much of the storage area for the alternative 897 km site. Seepage losses were expected to be exceedingly high initially but to reduce over time as siltation occurred over the area. After an initial siltation period, monthly seepage losses were assumed for a range of storage

<table>
<tr><th>PARAMETER</th><th>DESCRIPTION</th></tr>
<tr><td></td><td>depths as given in Table 4-5 of QWRC (1983).

Analyses indicated that at the hydrologic limit of the site, after the initial period of high seepage losses, the a safe yield was likely to be of the order of 18,000 ML/a from a storage capacity of 110,000 ML capacity.

At the alternative 904 km site, seepage losses were expected to be much smaller (25 mm per month was applied).

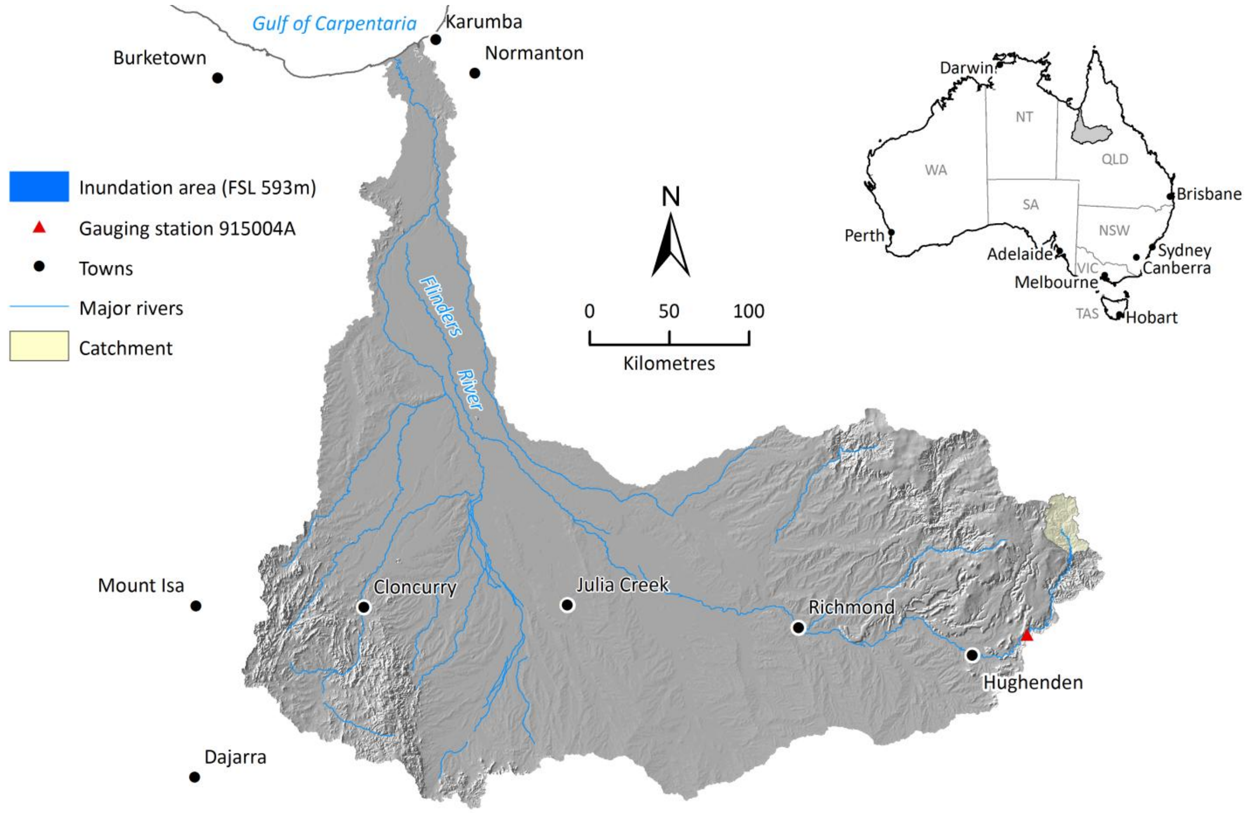
A safe yield of 21,000 ML/a was estimated to be available from a storage of 60,000 ML capacity. However, conveyance losses to the Hughenden area would be very high.

QWRC (1983) emphasises that the yield estimates are preliminary and that an upgraded rating of the Glendower gauging station was critical to more certain estimates being derived.</td></tr>
<tr><td>Open water evaporation</td><td>Mean annual evaporation is estimated to be 4.6 mm d^{-1} using a bulk aerodynamic approach. Mean annual evaporation was estimated to be 4.9 mm d^{-1} using Morton’s APE.</td></tr>
<tr><td>Impacts of inundation on existing infrastructure</td><td>None</td></tr>
<tr><td>Ecological and cultural considerations raised by previous studies</td><td>No assessment has been located.</td></tr>
<tr><td>Estimated rates of reservoir sedimentation</td><td><table>
<tr><th></th><th>Best case</th><th>Expected</th><th>Worst case</th></tr>
<tr><td>30 years (%)</td><td>0.05</td><td>0.38</td><td>0.68</td></tr>
<tr><td>100 years (%)</td><td>0.16</td><td>1.26</td><td>2.28</td></tr>
<tr><td>Years to infill</td><td>62242</td><td>7922</td><td>4381</td></tr>
</table></td></tr>
<tr><td>Water quality and stratification considerations</td><td>Mt Oxley reservoir is predicted to be strongly stratified during most of the year. The large water column depth combined with occasional winter inflows can produce temperature changes of > 15 °C. Full mixing is only likely to occur during a brief winter overturn period each year. The risk of blue-green algal blooms is moderate-high with Zsl:Zeu between 2 and 3 from mid-September to mid-April. The water column is predicted to mix briefly once each year during winter. The very long duration of stratification and weak mixing behaviour suggests this storage is highly susceptible to anoxic conditions and associated water quality issues.</td></tr>
<tr><td>Environmental considerations</td><td>Specific data are not available from this site. The dam location is above the distribution of all but a few fish species that all breed within freshwater. The dam captures a relatively small catchment area. The values of the aquatic habitat upstream of the proposed dam wall site are not known but there are perennial springs within the Flinders River upstream of this location, providing a relatively rare habitat type in this catchment.

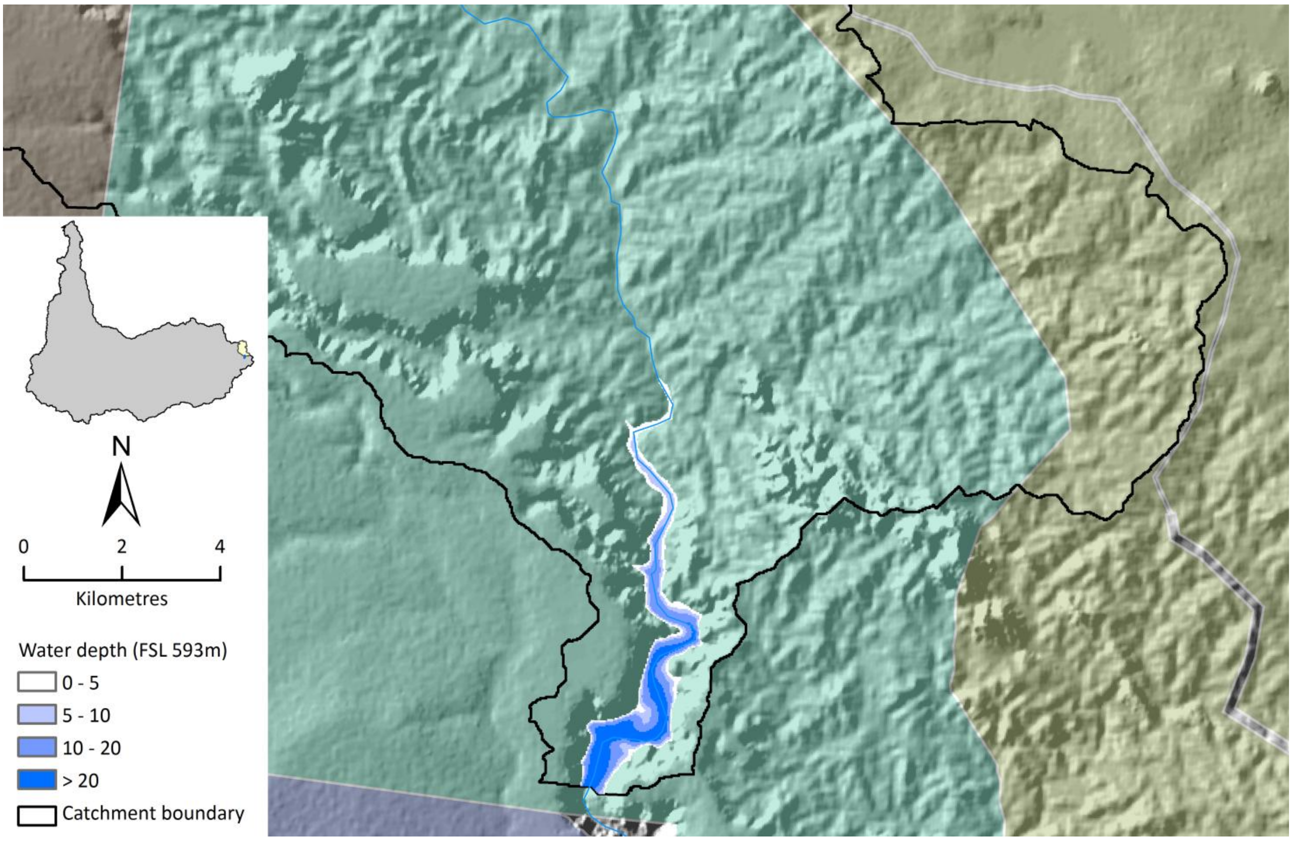
This site covers a stretch of riparian vegetation along a tributary of the Flinders River that is likely to be of “Of concern” (Apx Figure A.70).

<u>Ecosystems Of Concern</u>

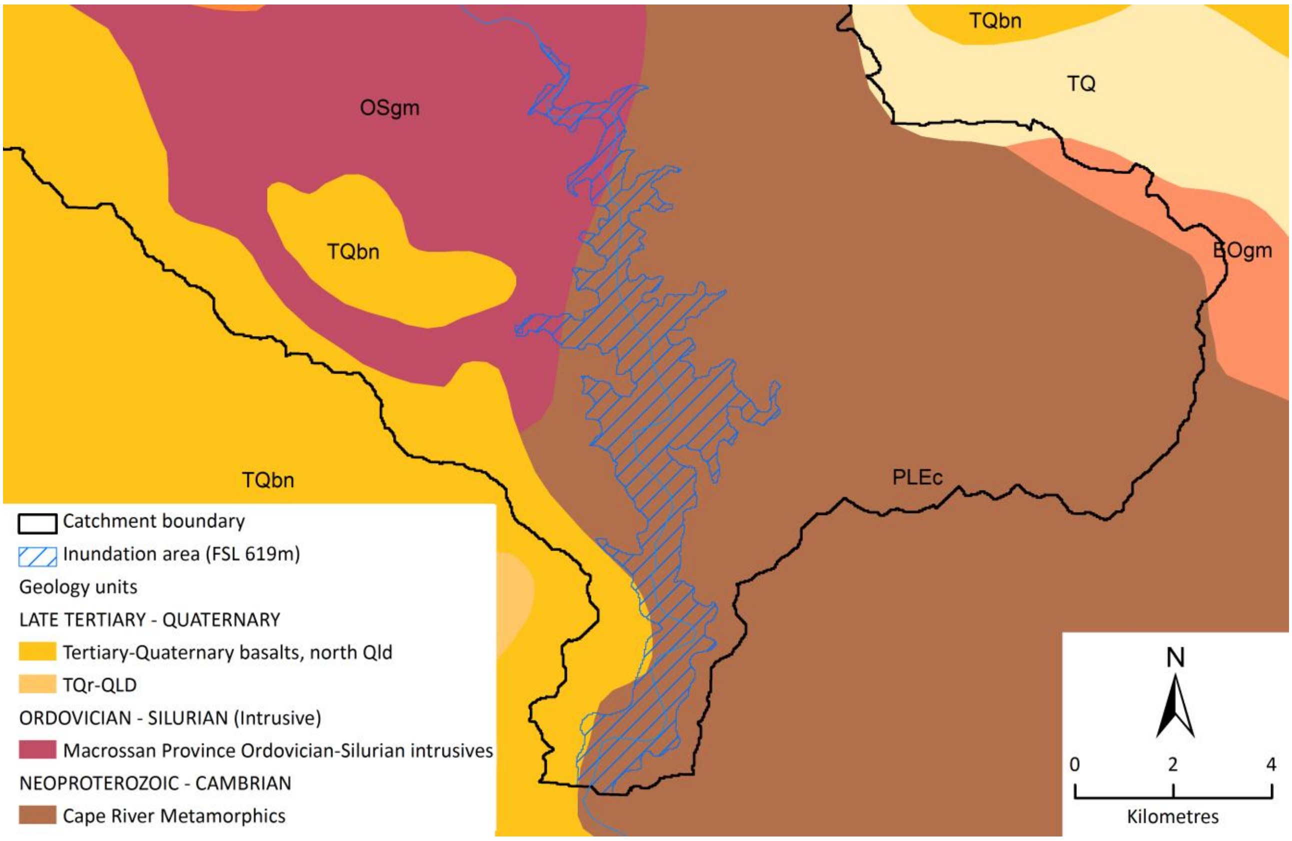
Regional ecosystems within this dam site include fringing woodland to open-forest of Eucalyptus camaldulensis, E. tereticornis, Melaleuca fluviatilis, M. leucadendra, Casuarina cunninghamiana, Corymbia tessellaris. A distinct sub-canopy can occur and contain Ficus spp., Lophostemon spp. and Pleiogynium timorense. The shrub layer varies from none to mid-dense and contains Ficus opposita, Melaleuca spp. and Acacia crassicarpa. The dense ground cover commonly includes Heteropogon contortus and Themeda triandra as well as a range of other graminoid and forb species.</td></tr>
<tr><td>Estimated cost</td><td>$200 m to $340 m (cost of dam only)</td></tr>
<tr><td>Estimated cost / ML of supply</td><td>$10,300/ML (at 85% annual time reliability)</td></tr>
<tr><td>Summary comment</td><td>Given the much smaller catchment area and distance upstream of lands which might potentially be irrigated, this site would not appear to offer any potential advantage over the various other sites further downstream in the Flinders River Basin.</td></tr>
</table>



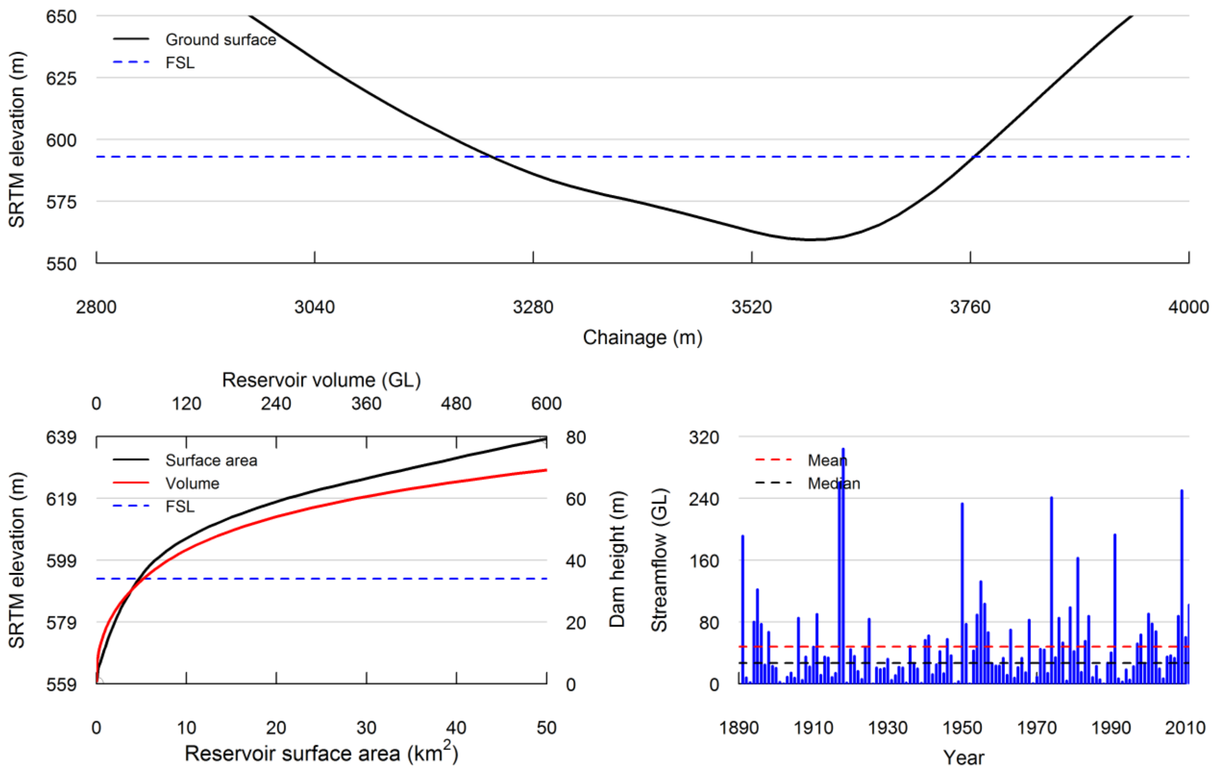
Apx Figure A.64 Location map Mount Oxley dam site, reservoir and catchment area



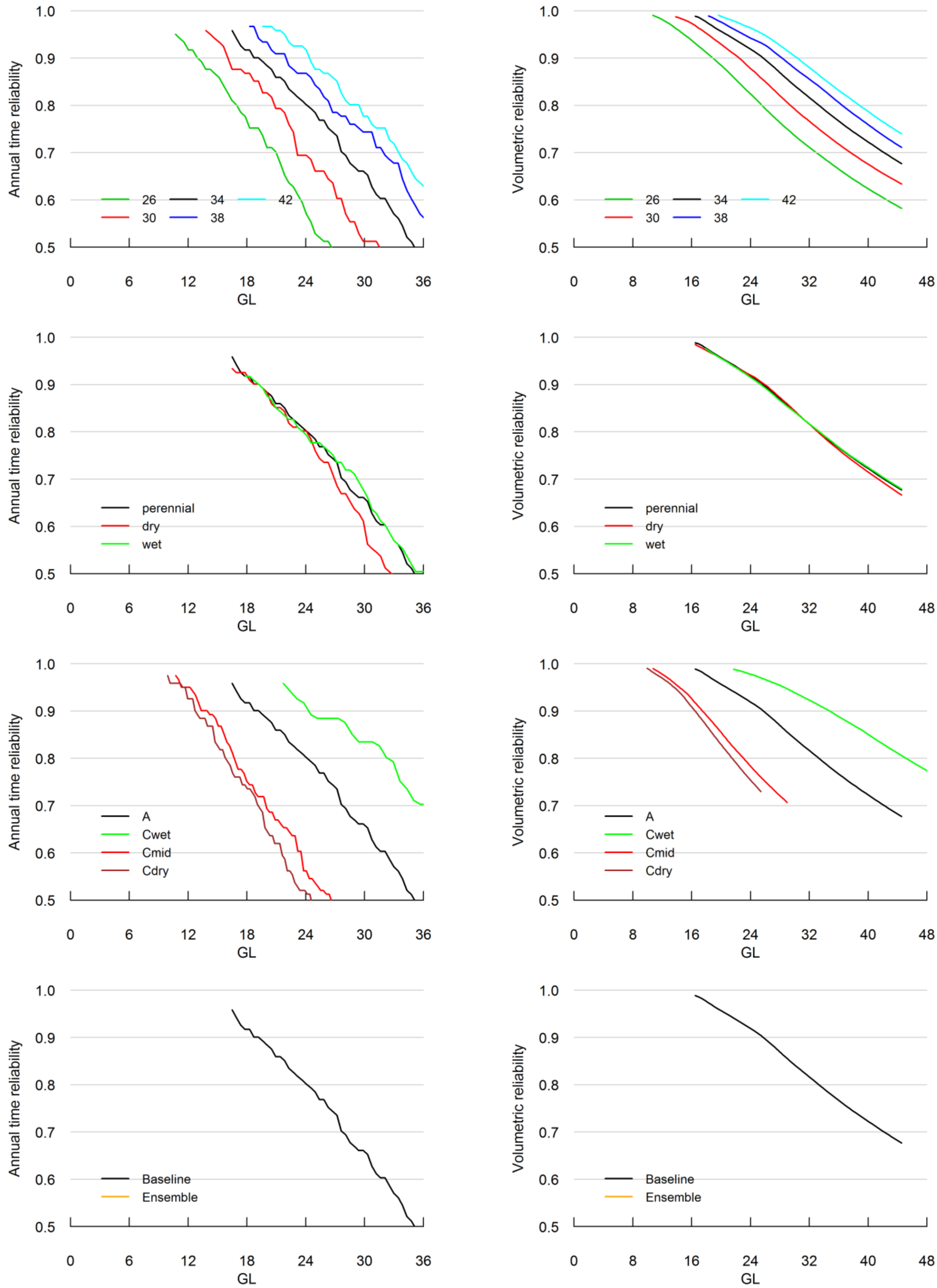
Apx Figure A.65 Mount Oxley potential dam depth of inundation and property boundaries (indicated by coloured shading)



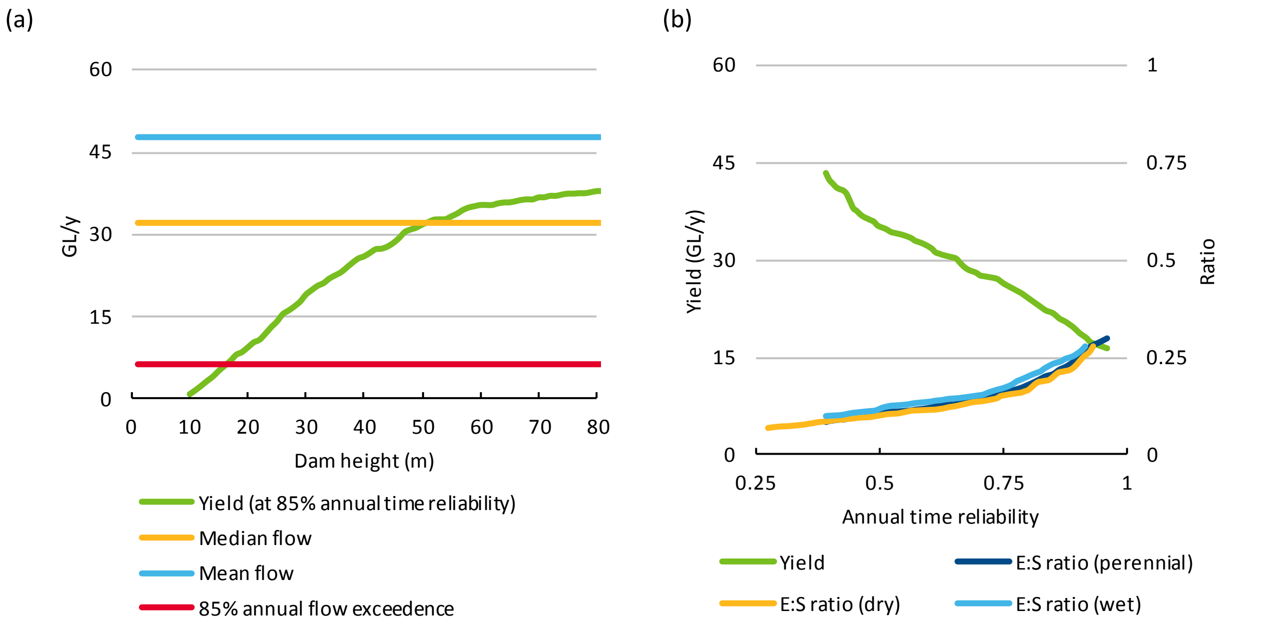
Apx Figure A.66 Mount Oxley site dam underlying geology



Apx Figure A.67 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Mount Oxley dam site



Apx Figure A.68 Mount Oxley potential dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 593 m FSL. Third row: YRR under Scenario C for 593 m FSL. Fourth row: Ensemble model runs unavailable for this site (see Lerat et al. 2013).



Apx Figure A.69 a) Yield at 85% annual time reliability and streamflow at Mount Oxley dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Mount Oxley dam site for different annual time reliability for the selected dam height of 34 m

Apx Figure A.70 Mount Oxley potential dam regional ecosystems mapping

Richmond dam site on the Flinders River; 628.3 km

PARAMETER	DESCRIPTION
Previous investigations	Maunsell McIntyre (1998) Flinders River Dam (AMTD 600 km) Pre-Feasibility Report, Maunsell McIntyre, July 1998. Land Resource Assessment, Graham Spackman and Associates Pty. Ltd., Earthtech (1998) Geotechnical Investigation Flinders River Dam, Earthtech Consultants, November 1998. ACTFR (1998) Richmond Dam and Irrigation Development Proposal -Ecological Issues, Australian Centre for Tropical Freshwater Research, July 1998. NAC (1998) Cultural Heritage Desk Top Study, Northern Archaeology Consultancies Pty. Ltd., May1998.
Description of proposal	The proposal developed by consultants Maunsell McIntyre (1998) involved a dam on the Flinders River some 15 km downstream of Richmond (to avoid flooding the town) to provide supply via a series of diversion weirs, pump stations and diversion channels to an irrigation area to the south of the Flinders River. A 13 m high dam wall (ie. FSL 203 m) was selected so as to minimise the impact of flood storage on Richmond. Should this proposal proceed further the impact of flood storage on Richmond will need to be specifically assessed. A photograph of the site is shown in Apx Figure A.71. A location map and map showing the inundated area at FSL are shown in Apx Figure A.72 and Apx Figure A.73 respectively.
Regional geology and topography	Rock at the site consists of sedimentary rocks belonging to the Rolling Downs Group of Early Cretaceous Age. The formations present include the Toolebuc Limestone outcropping on the north bank of the river and the Allaru Mudstone outcropping on the south bank. The formations dip very gently (<1˚) to the southwest so the Toolebuc Limestone underlies the Allaru Mudstone on the south bank. Alluvium of the Flinders River flood channels and floodplain underlies the central part of the dam and forms its left abutment. The Allaru Mudstone is dominantly argillaceous so the topography on the south bank is gently undulating except where eroded adjacent to the river. The topography on the north bank is more dissected where the limestone beds outcrop.
Site geology	The site has been investigated by drilling of five boreholes although some of these are offset from the adopted axis by up to 500 m because of a subsequent axis realignment. The drilling indicates up to 13 m of alluvium overlying low strength shale and mudstone in the riverbed. The alluvium is dominantly clayey but does contain sand layers particularly in the upper 4-5 m. A persistent sand layer appears to overlie rock from 10-13 m depth. On the north bank limestone occurs at a depth of 2.7 m. The limestone is medium strength, thinly laminated and is underlain by mudstone and claystone containing sub-horizontal laminations. The south bank is an alluvial terrace. Approximately 12 m of clayey alluvium containing lenses of sand overlies mudstone of low strength. Apx Figure A.74 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams
Reservoir rim stability and leakage potential	Slopes on the reservoir rim are very gentle and stability of the reservoir rim is not an issue. The left abutment and left (south) side of the reservoir is an alluvial terrace consisting of clay containing lenses of sand. The leakage potential of the sand lenses into the adjoining O'Connell Creek catchment would require investigation at the feasibility stage. The leakage potential on the right (north) side of the reservoir is low.
Proposed structural arrangement	The proposed dam comprises: • a 5 km long earthfill embankment between ridges forming a narrowing of the flood plain with the higher embankment sections across the alluvial sections including an inclined chimney and blanket drains and cement bentonite cut off. Wave protection by a compacted soil cement zone rather than by rip rap was proposed; • a central gated spillway also with a cement bentonite cut off including 13 of 13m wide by 13m high radial gates intended to pass the 1:1,000 year flood;

PARAMETER	DESCRIPTION
	• a 800 m long erodible fuse plug embankment on the southern side of the reservoir some 4 km upstream of the dam embankment. Given that the spillway structure and retaining walls between the spillway and embankment sections would be founded on alluvial materials, the consultant assumed that deep piles would be required to minimise any differential settlements. Maunsell McIntyre (1998) proposed that releases would be made from the dam to a downstream weir and pump station delivering supply by channel to a balancing weir storage on O'Connell Creek. Supply would then be delivered by a channel and pipeline system to an irrigation area between Richmond and Maxwelton.
Availability of construction materials	No investigations for construction materials have been carried out. Based on a consideration of the regional geology, earthfill materials are likely to be available in the immediate area. Deposits of silty sand occur at the junction of Stawell River and Alexander Creek about 10 km west of the site. Basalt is available from a deposit about 25 km east of Richmond. Platy limestone and calcareous shale, which have been used as road base, may be available from outcrop of Toolebuc Limestone to the north of Flinders River. These materials may be suitable for erosion protection.
Catchment areas	The catchment area is 17,724 km^2.
Flow data	Streamflow gauging station 915008A is located on the Flinders River some 13 km upstream of the dam site with daily data from 1971 to date. Flow data from this station is as follows; Maximum annual flow volume 3,166,700 ML Mean annual flow volume 530,300 ML Median annual flow volume 293,000 ML Minimum annual flow volume 0 ML
Storage capacity	200 GL at FSL 203 (Apx Figure A.67). This is considerably lower than previous estimates of storage volume of 620 GL. While it is likely that there may be a higher error associated with the SRTM at this site than other sites due to riparian vegetation, it is thought unlikely that this error would constitute a volume difference of > ±25% in the SRTM estimate.
Reservoir yield assessment	30 GL at 85% annual time reliability (Apx Figure A.76 and Apx Figure A.77). 20 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 66% Ratio of evaporation to water supplied (at 85% annual time reliability): 1.9
Open water evaporation	Mean annual evaporation was estimated to be 5.8 mm d^{-1} using a bulk aerodynamic approach. Mean annual evaporation was estimated to be 5.2 mm d^{-1} using Morton's APET.
Potential use of supply	<u>Previous studies</u> Maunsell McIntyre (1998) reported that a minimum irrigated cotton area of 7500 ha would be required to support development of a local ginning facility and that at an irrigation rate of 7.2 ML/a, a supply of 54,000 ML/a would be required. Peak monthly demand would be 22,500 ML requiring the irrigation supply system to have a delivery capacity of 11 m^3/s.
Impacts of inundation	Relocations would be required as follows: • A major realignment of the Richmond – Woolgar road would be necessary. An alignment along the northern side of the storage would require 37 km of new road construction including new bridges across the Flinders River to the east of the town and across the Dutton River.

PARAMETER	DESCRIPTION
	• New access to the Silver Hills and Valley Downs properties. • Relocation of the SWER power supply to Silver Hills, Valley Downs and to Boree Park. • Relocation of the gauging station, property pumps and fences.
Ecological and cultural considerations raised by previous studies	This site was the subject of a brief field visit by staff from the Australian Centre for Tropical Freshwater Research in 1998 (Tait 1998a). Major issues identified in that report were: • Impact on vegetation and habitat, particularly in the riparian zone. • Weed invasion in shallow storage areas and in storage drawdown areas. • Fish movement requirements. • Creation of a mosquito habitat. • Inundation of a landfill site. • Habitat impacts due to agricultural development. • Downstream impacts due to agricultural development. NAC (1998) identified a number of indigenous and European cultural heritage issues that would need to be addressed. It was also noted that the potential storage area is extremely fossiliferous.

Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)	1.94	17.33	27.57
	100 years (%)	6.47	57.76	91.91
	Years to infill	1546	173	109

Water quality and stratification considerations	Flinders Reservoir is predicted to experience very limited persistent thermal stratification during most of the year. The risk of blue-green algal blooms is low on average with Zsl:Zeu ≥ 3 during most of the year. The water column is predicted to be well mixed during most of each year and low dissolved oxygen is unlikely to be experienced in most years.
Environmental impacts	Importantly, sediment volumes entering the storage are more likely to be deposited in the upper sections of the storage as flow velocities progressively reduce. If this were the case, increased flood levels could have serious impacts in the Richmond town area. This site is within the known range of barramundi and the predicted range of freshwater sawfish, albeit close to their upstream limit, so fish passage will be an issue. Being the most downstream potential dam site on the main channel of the Flinders River, this site captures the largest catchment area of any of the potential dam sites in the Flinders catchment. Nearly all of the proposed site covers a mix of 'Of concern' regional ecosystems (Apx Figure A.78). *Ecosystem Of Concern* Woodland of *Corymbia aparrerinja* often with *C. terminalis*, *Eucalyptus leucophylla*, *E. camaldulensis*, *Lysiphyllum cunninghamii* and *Acacia cambagei* with a sparse ground layer of tussock grasses with *Triodia longiceps* in some places. *Melaleuca leucadendra* is also likely to occur along dominate creek lines where water is available.
Estimated costs	$340 m to $560 m (cost of dam only) Previous studies Maunsell McIntyre (1998) reported on their cost estimates for the dam including relocations, diversion weirs and balancing storage, pump stations and for the channel supply infrastructure in the irrigation area. Preliminary schedules of quantities and unit rates were included. Summary costs (assumed to be in 1998 $'s) were as follows:

PARAMETER	DESCRIPTION

Development option	Component	Preliminary estimate of cost ($million)
FSL 200.0m	Dam	153.4
	Diversion weirs and balance storage	2.4
	Pump station	4.0
	Irrigation infrastructure	35.4
Total estimated cost		**195.2**
FSL 202.5m	Dam	171.6
	Diversion weirs and balance storage	2.4
	Pump station	4.0
	Irrigation infrastructure	35.4
Total estimated cost		**213.4**

Based on CPI variations, cost escalation since 1998 to today's costs would be at least 52%.

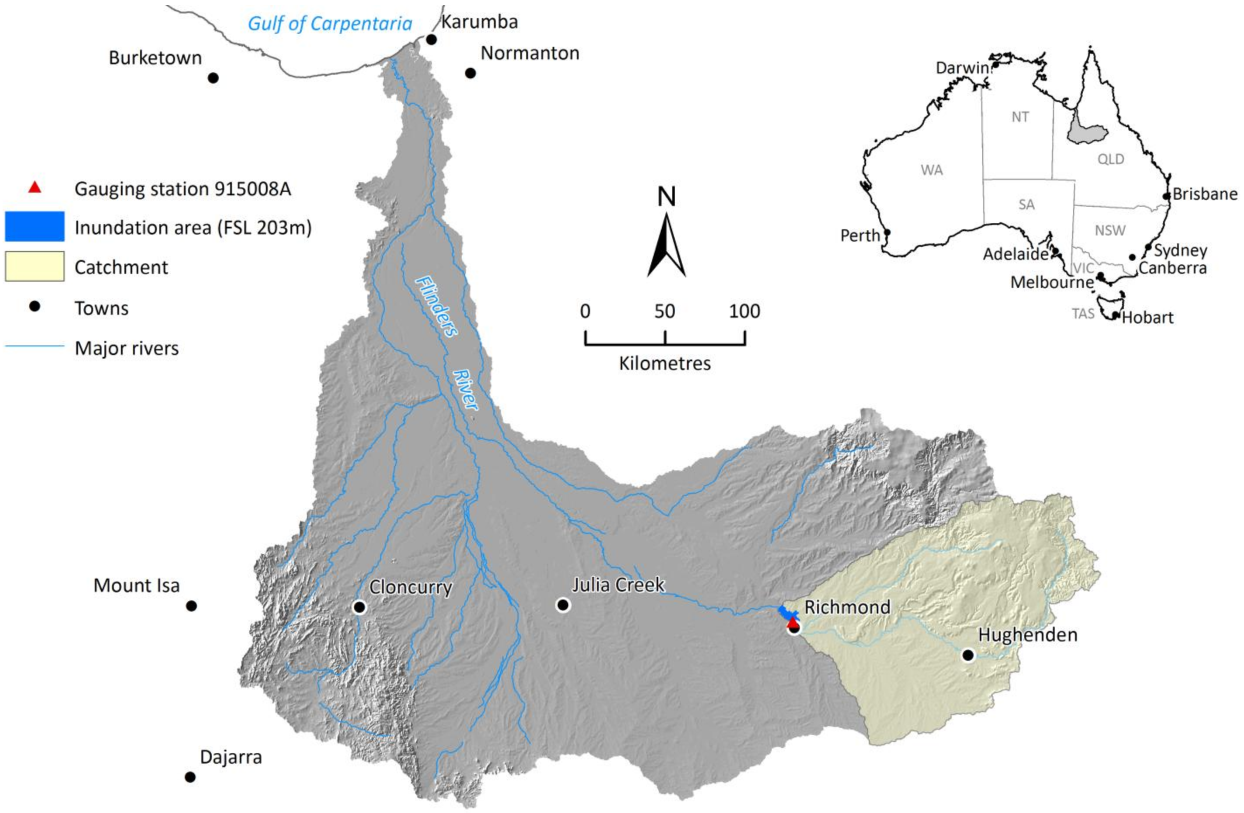
Cost escalation in the construction sector is probably higher.

Additionally, it should be noted that the above estimates are based on minimal data and although a 25% contingency allowance was made by the consultants, project uncertainties and risks are such that final costs could be considerably higher.

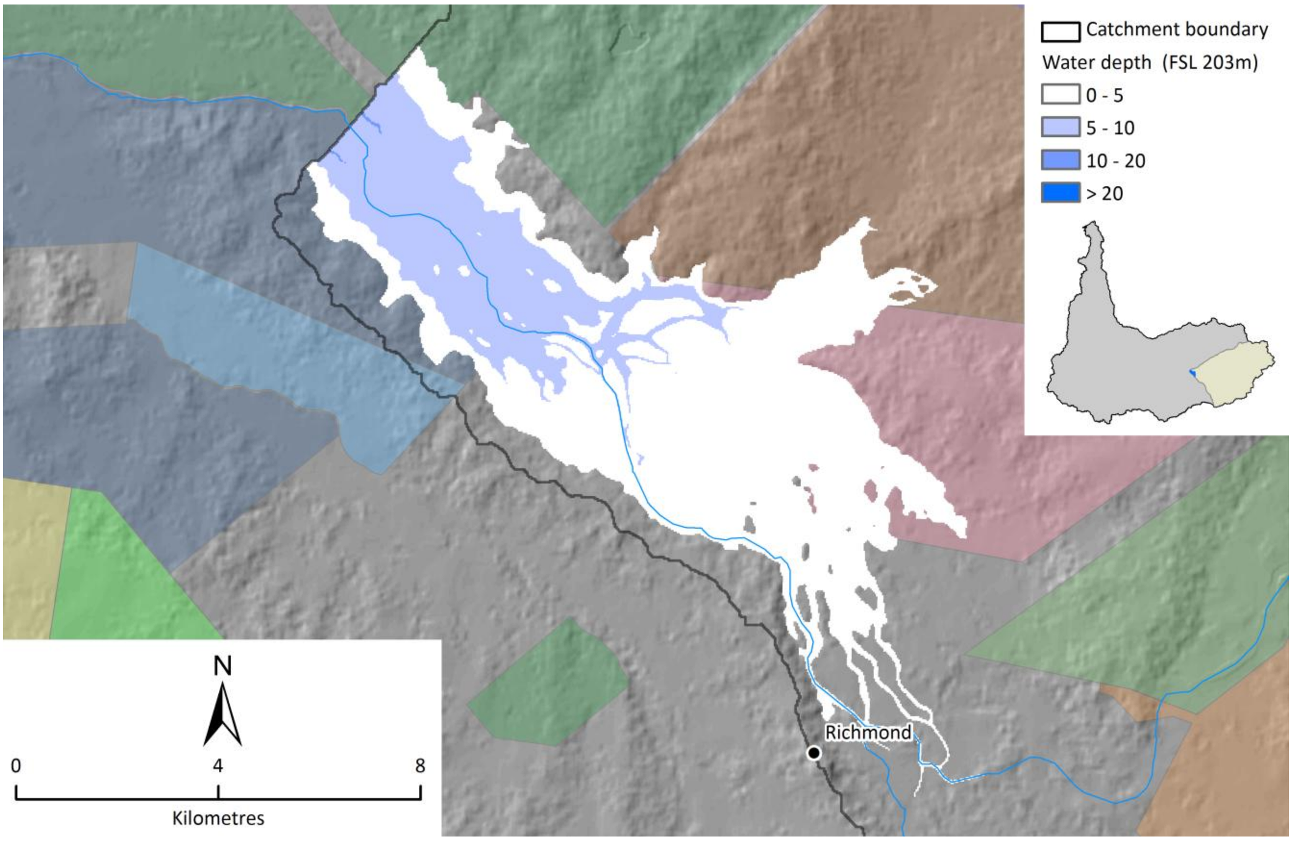
PARAMETER	DESCRIPTION
Estimated cost / ML of supply	$12,410/ML at 85% annual time reliability (does not consider transmission/distribution losses or take into account environmental and downstream entitlements).
Potential benefit/cost	<u>Previous studies</u> Maunsell McIntyre (1998) reported on a project cost/benefit analysis undertaken over a 30 year period assuming a discount rate of 6%. Capital and operating costs for the project were considered for gross margins for cotton production ranging from $681 to $1,500/ha. Residual values for each component of the works at the end of the 30 year analysis period were assessed based on an assumed life of each of the components. For the cases with the residual values included, Benefit /Cost ratios were just in excess of 1.0 for gross margin values approaching $1,500/ha. For all other cases examined, Benefit/Cost ratios were less than 1.0.
Other water resource development options	Given the high cost of an on river dam, Maunsell McIntyre (1998) undertook a simple analysis of a typical ring tank water harvesting option with a 5,500 ML/a capacity. Based on an assumed yield of 3,000 ML/a, it was concluded that the cost of supply from such a facility would be $1,500 ML/a. Reliability of supply and operating costs were not discussed.
Summary comment	The Richmond dam proposal would clearly involve very high costs because of: • The width of the site. • Absence of sound foundations at reasonable depth.

PARAMETER	DESCRIPTION
	• A significant number of environmental issues would need to be addressed. Additionally major uncertainties include: • Storage yield when environmental and downstream entitlements are taken into account. • The risk of storage sedimentation and increased flooding at Richmond. • The risk of scour damage during periods of spillway discharge.

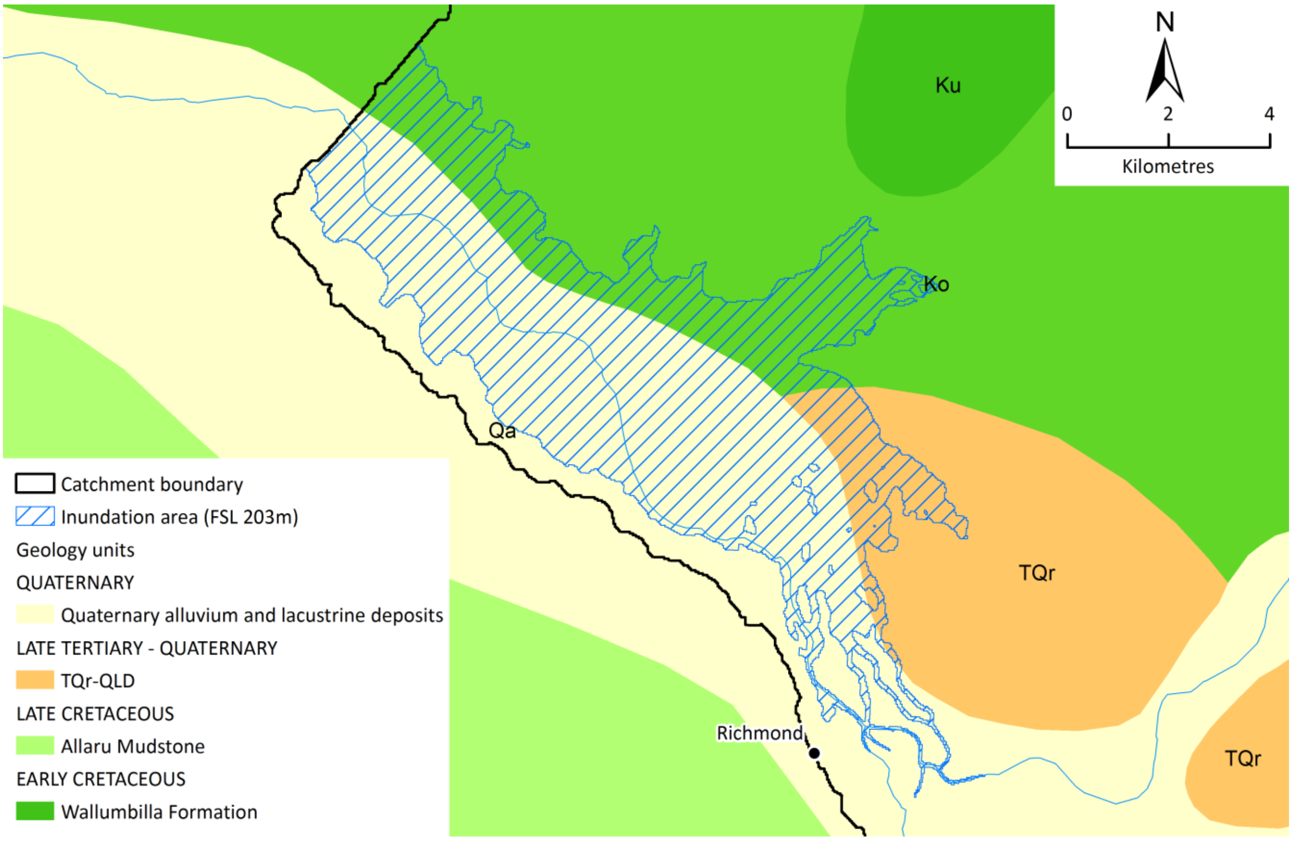
Apx Figure A.71 Looking north across Flinders River near Richmond potential dam site



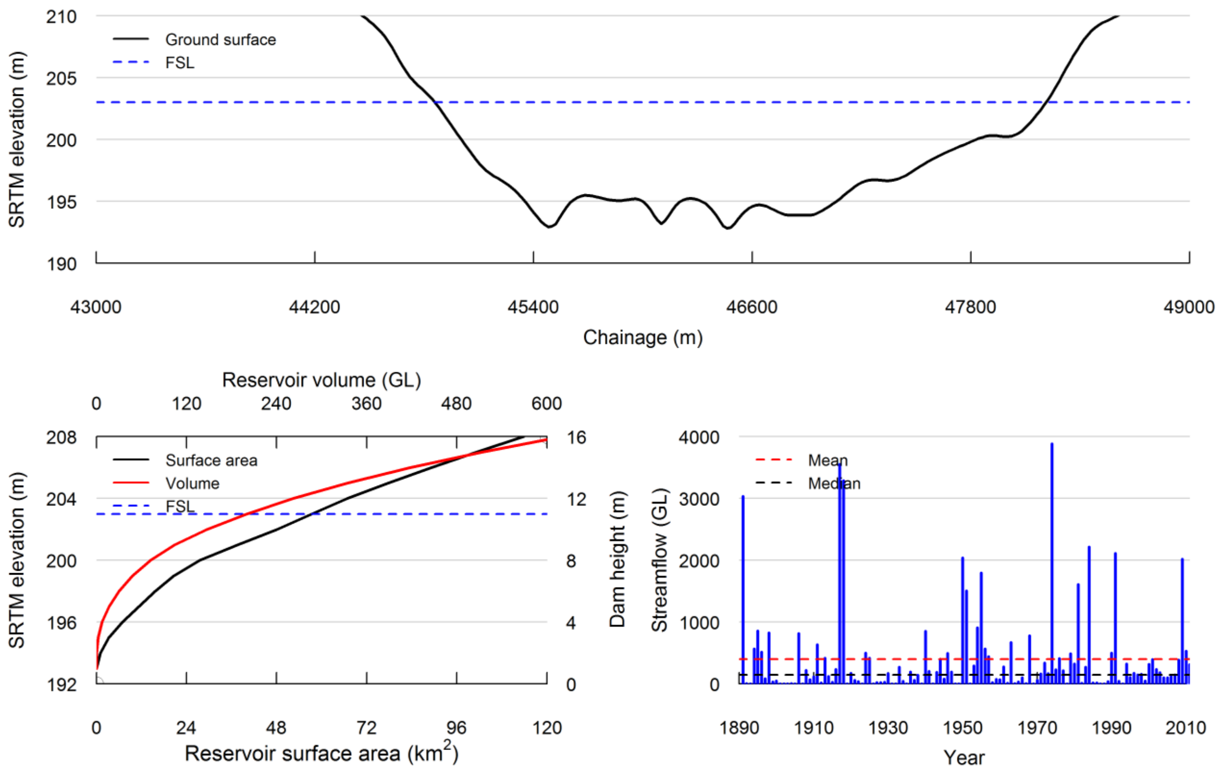
Apx Figure A.72 Location map of Richmond potential dam, reservoir and catchment area



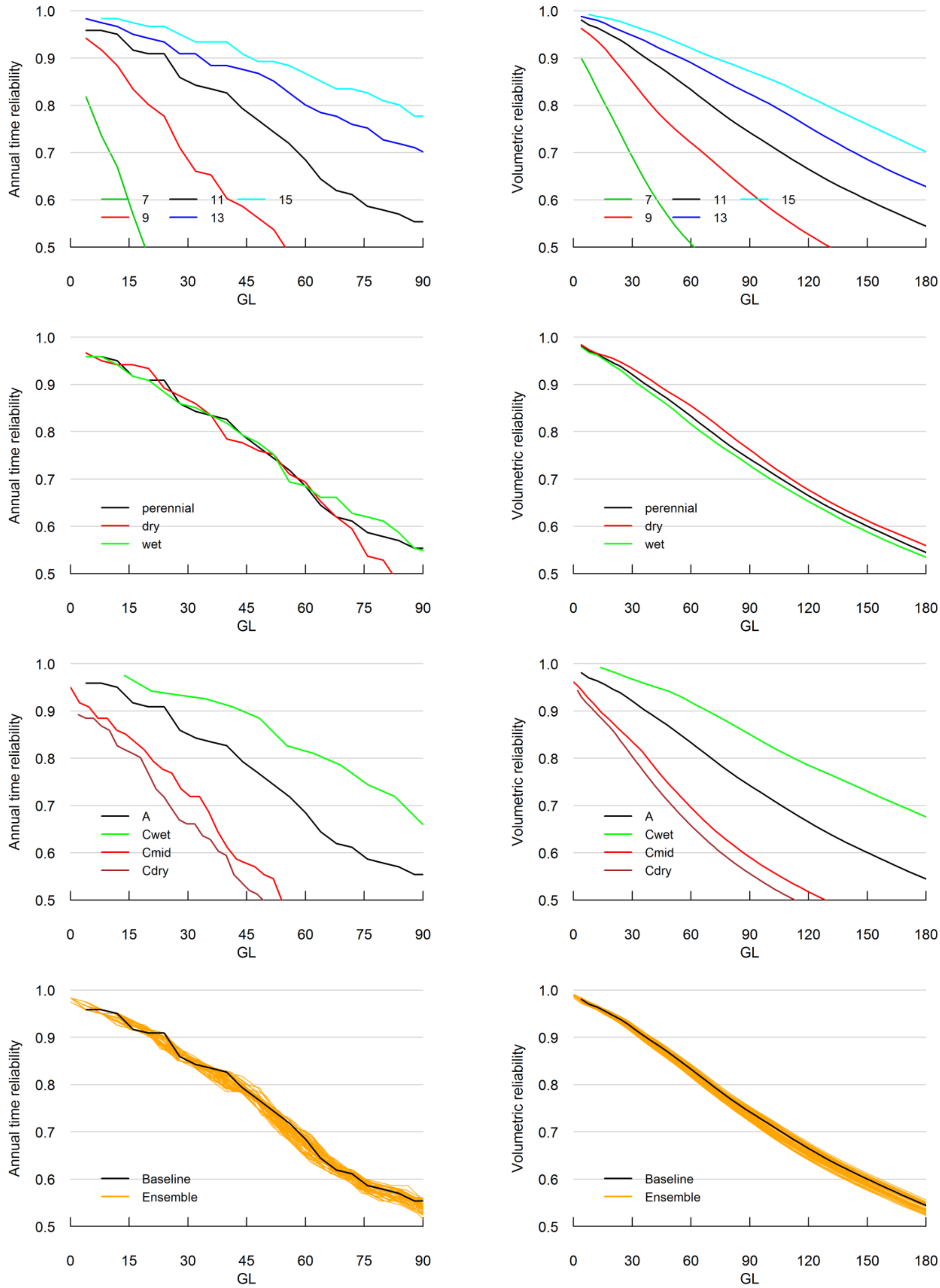
Apx Figure A.73 Richmond potential dam depth of inundation and property boundaries (indicated by coloured shading)



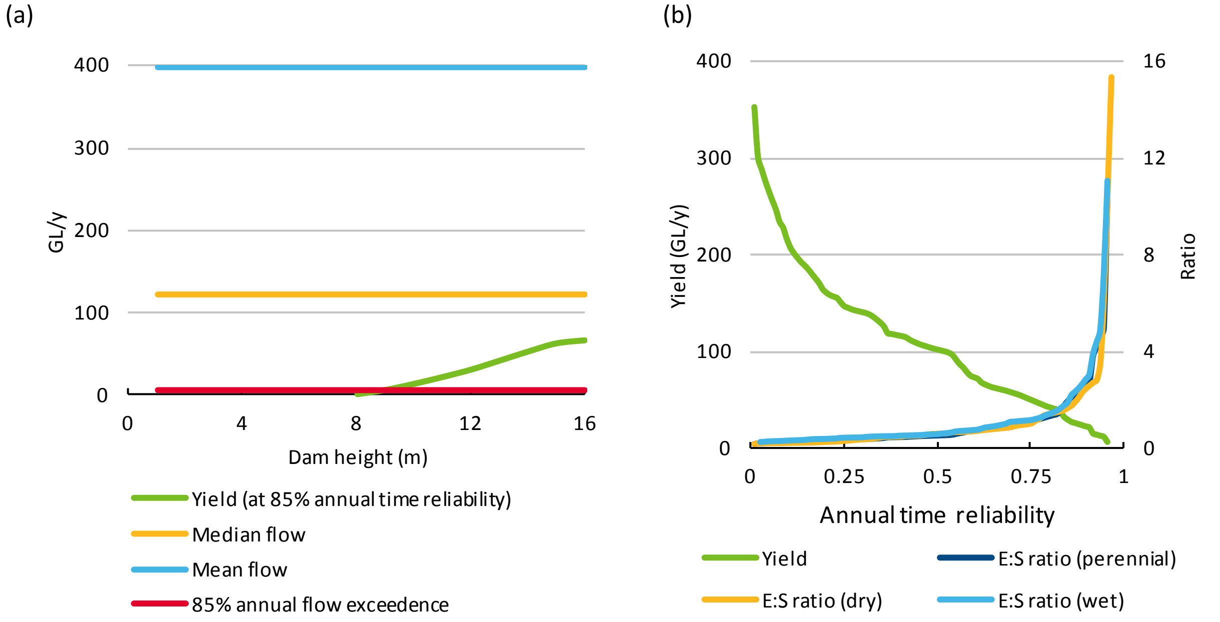
Apx Figure A.74 Richmond potential dam underlying geology



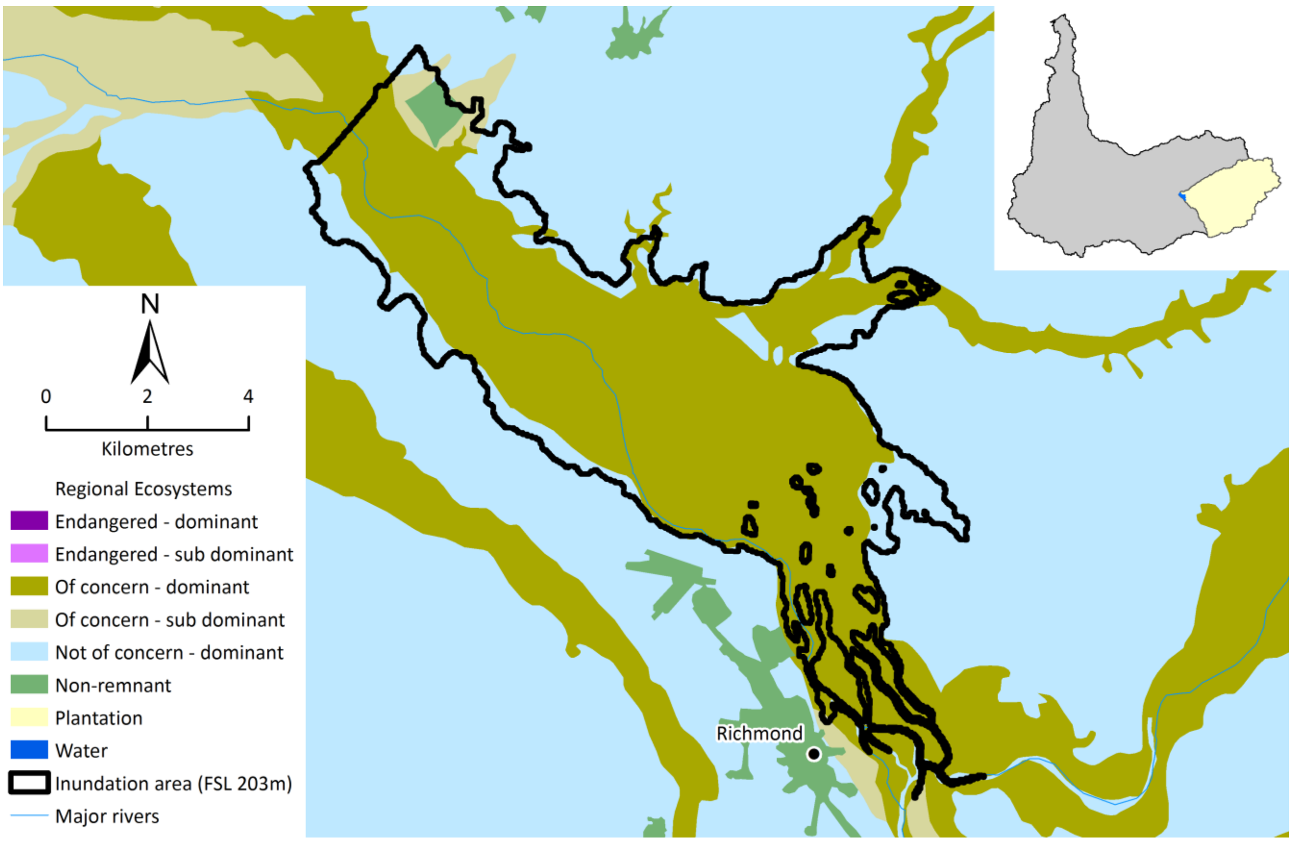
Apx Figure A.75 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Richmond potential dam site



Apx Figure A.76 Richmond dam potential dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 203 m FSL. Third row: YRR under Scenario C for 203 m FSL. Fourth row: YRR for baseline and ensemble model runs for 203 m FSL



Apx Figure A.77 a) Yield at 85% annual time reliability and streamflow at Richmond dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Richmond dam site for different annual time reliability for the selected dam height of 11 m



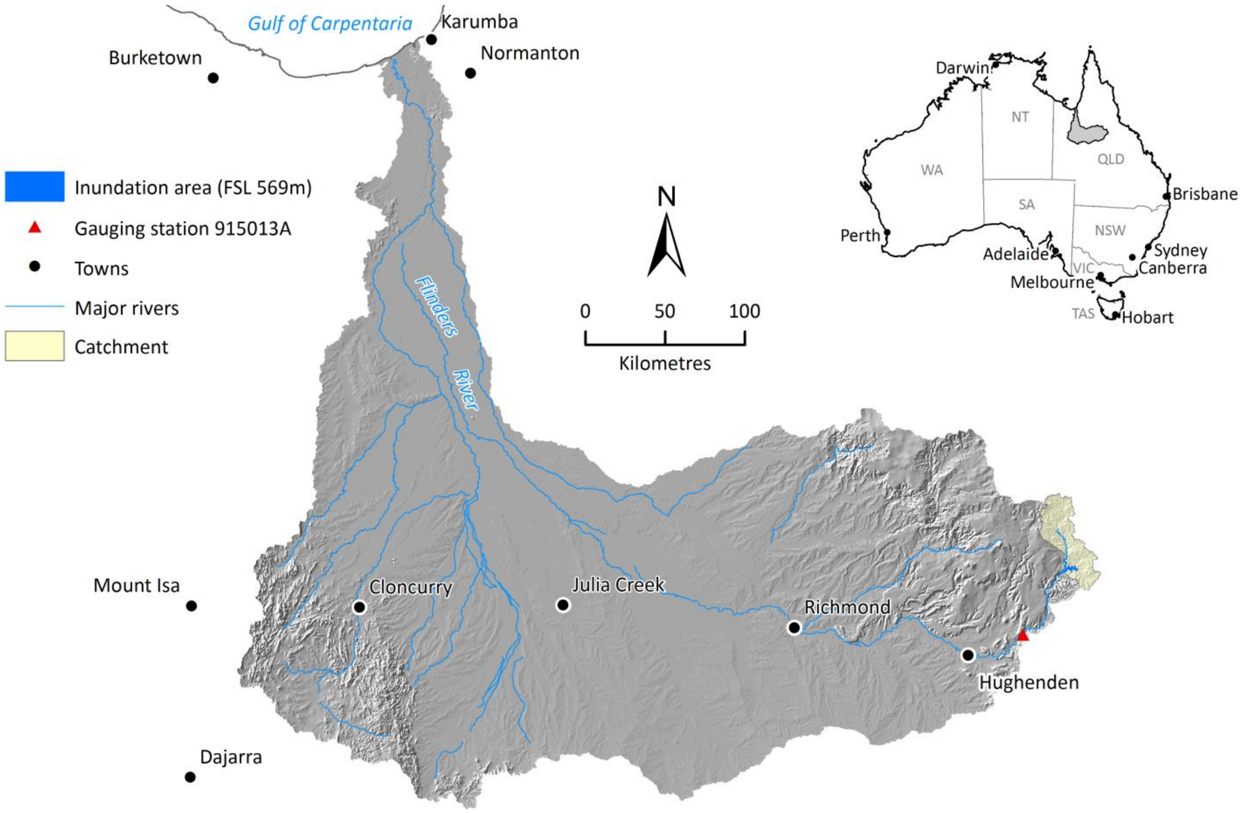
Apx Figure A.78 Richmond potential dam regional ecosystems mapping

White Mountains dam site on the Flinders River: 916.9 km

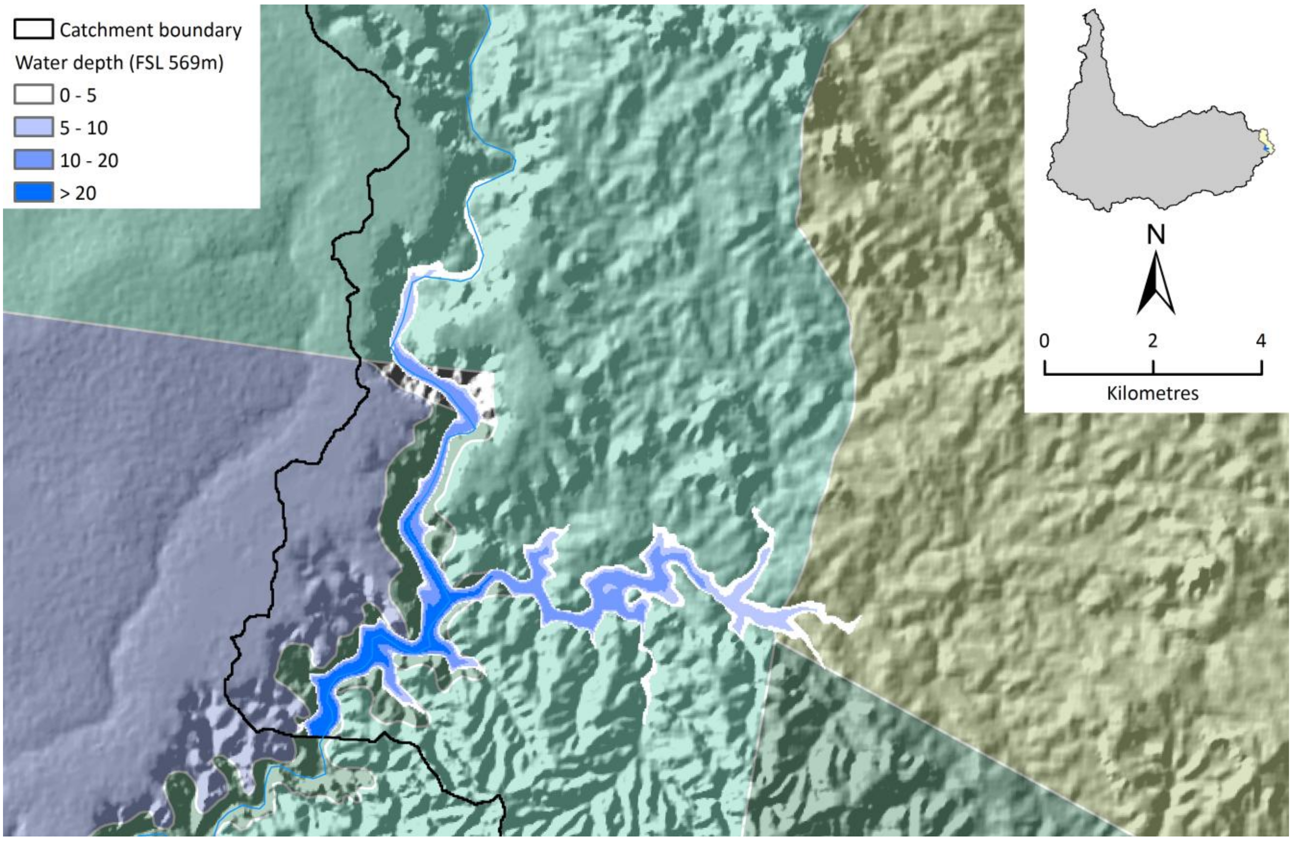
PARAMETER	DESCRIPTION
Previous investigations	These sites were, in addition to the Glendower site at AMTD 826 km, investigated as potential sources of supply to irrigate lands in the Hughenden area. 1. QRC (1982) Flinders River Damsites, 826 km, 829 km, 897 km, Geology Appraisal Study. 2. QRC (1983) Flinders River – Basin 915, Yield Analysis for Damsites at 826 km, 897 km & 904 km.
Description of proposal	On stream storage dam releasing supply to the river channel for downstream extraction. A location map and map showing the inundated area at FSL are shown in Apx Figure A.79 and Apx Figure A.80 respectively.
Regional geology	The site and reservoir area lie within the Warang Sandstone. This unit is part of the Galilee Basin and consists predominantly of white to grey, quartzose to sub-labile sandstone with siltstone and mudstone interbeds. The Warang Sandstone is the main rock unit in the spectacular dissected topography of the White Mountains National Park which encompasses this site. The Warang Sandstone is overlain by Cainozoic age Sturgeon Basalt that forms a plateau to the west of the reservoir area. Apx Figure A.81 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	No investigations have been carried out. The following account is based on a site inspection. On the right abutment a basalt plateau forms an escarpment 10 to 30 m high. Below this is a series of benches and bluffs that fall steeply to a colluvial slope and then to the sandy riverbed. The steep bluffs are composed of sandstone and thin siltstone beds occur on the flatter benches. The left abutment rises steeply above a colluvial slope to a sandstone escarpment. The top of the left abutment is marked by prominent joint bound blocks trending parallel to the river. The joints are open and slope failure by block toppling is common. Open joints also occur on the sandstone bluffs of the right abutment. The sandstone dips to the south at a shallow angle. There is a possibility that the slope instability observed on the abutments is caused by the sandstone overlying a mudstone unit near riverbed level that is much lower strength. Stress relief caused by erosion has possibly allowed movement to occur within the mudstone thereby causing rotation and toppling of the overlying sandstone blocks.
Reservoir rim stability and leakage potential	The sandstone cliffs immediately upstream of the axis on the left abutment appear to be affected by block rotation and toppling. The stability of these should be investigated at the feasibility stage. The Warang Sandstone that underlies the reservoir is an aquifer in the Great Artesian Basin and its leakage potential should be investigated at the feasibility stage.
Proposed structural arrangement	No details of the proposal have been located. For the purposes of the Assessment a 50m high dam wall was selected.
Availability of construction materials	Potential sources of aggregate for a roller compacted concrete structure are the low to medium strength sandstones and the basalt. Sources of both these materials are likely to be found within 2 km of the site. Shallow deposits of coarse grained sand in the riverbed may be suitable to augment these materials. There are unlikely to be any sources of low permeability earthfill materials near the site.
Catchment area	Catchment area at the dam site is 1084 km^2
Flow data	The closest streamflow gauging station to these sites is 915013A at AMTD 828.8 km (Glendower) which operated from September 1972 to June 2011. Catchment area at 915013A is 2110 km^2, approximately double that at the dam sites. Summary flow data at 915013A is as follows.

PARAMETER	DESCRIPTION			
	Maximum recorded annual flow was 414,000 ML Mean annual flow 113,910 ML Median annual flow 75,000 ML Minimum annual flow 4,000 ML.			
Capacity	324 GL at FSL 582 (Apx Figure A.82).			
Reservoir yield assessment	34GL at 85% annual time reliability (Apx Figure A.83 and Apx Figure A.84). 32GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 21% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.3 QWC (1983) draws attention to the likely high seepage losses as porous sandstones are exposed over much of the storage area. Seepage losses were expected to be exceedingly high initially but to reduce over time as siltation occurred over the area. After an initial siltation period, monthly seepage losses were assumed for a range of storage depths as given in Table 4-5 of QWC (1983).			
Open water evaporation	Mean annual evaporation is estimated to be 4.6 mm d-1 using bulk aerodynamic formulae. Mean annual evaporation was estimated to be 4.9 mm d^{-1} using Morton's APE.			
Impacts of inundation to existing infrastructure	None identified			
Ecological and cultural considerations raised by previous studies	No assessment has been located.			
Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)	0.08	0.63	1.13
	100 years (%)	0.27	2.09	3.78
	Years to infill	37,500	4750	2650
Water quality and stratification considerations	White Mountains Reservoir is predicted to be strongly stratified with winter deep-mixing occurring each year and a characteristic temperature difference of 7 - 10 °C. Summer inflows have a large effect on the bottom temperature. The risk of blue-green algal blooms is low with Zsl:Zeu always ≥ 3, on average. The very long duration of stratification and weak mixing behaviour suggest this storage is susceptible to anoxic conditions and associated water quality issues. Summer inflows may play a significant role resupplying oxygen near the bottom and thereby reduce the severity of oxygen depletion and associated metal and nutrient release from the sediments.			
Environmental considerations	Specific data were not available for this site. The dam location is above the distribution of all but a few fish species that all breed within freshwater. The dam captures a relatively small catchment area. The values of the aquatic habitat upstream of the proposed dam wall site are not known but there are perennial springs within the Flinders River upstream of this location, providing a relatively rare habitat type in this catchment. Although not inundating the nearby White Mountains National Park itself, some of the values of that park may be within the inundation area. This site covers a narrow stretch of riparian vegetation along a Flinders River tributary that is likely to be of "Of concern". This dam is located near to The White Mountains National Park which is included on the Register of National Estate (Apx Figure A.85). *Ecosystem Of Concern* The riparian vegetation zone includes fringing woodland to open-forest of *Eucalyptus camaldulensis*, *E. tereticornis*, *Melaleuca fluviatilis*, *M. leucadendra*, *Casuarina cunninghamiana, Corymbia tessellaris*. A distinct subcanopy can occur and contain *Ficus spp., Lophostemon spp.* and *Pleiogynium timorense* as well as juvenile canopy species. The shrub layer varies from none to mid-dense stands of *Ficus opposita*, *Melaleuca spp.* and *Acacia*			

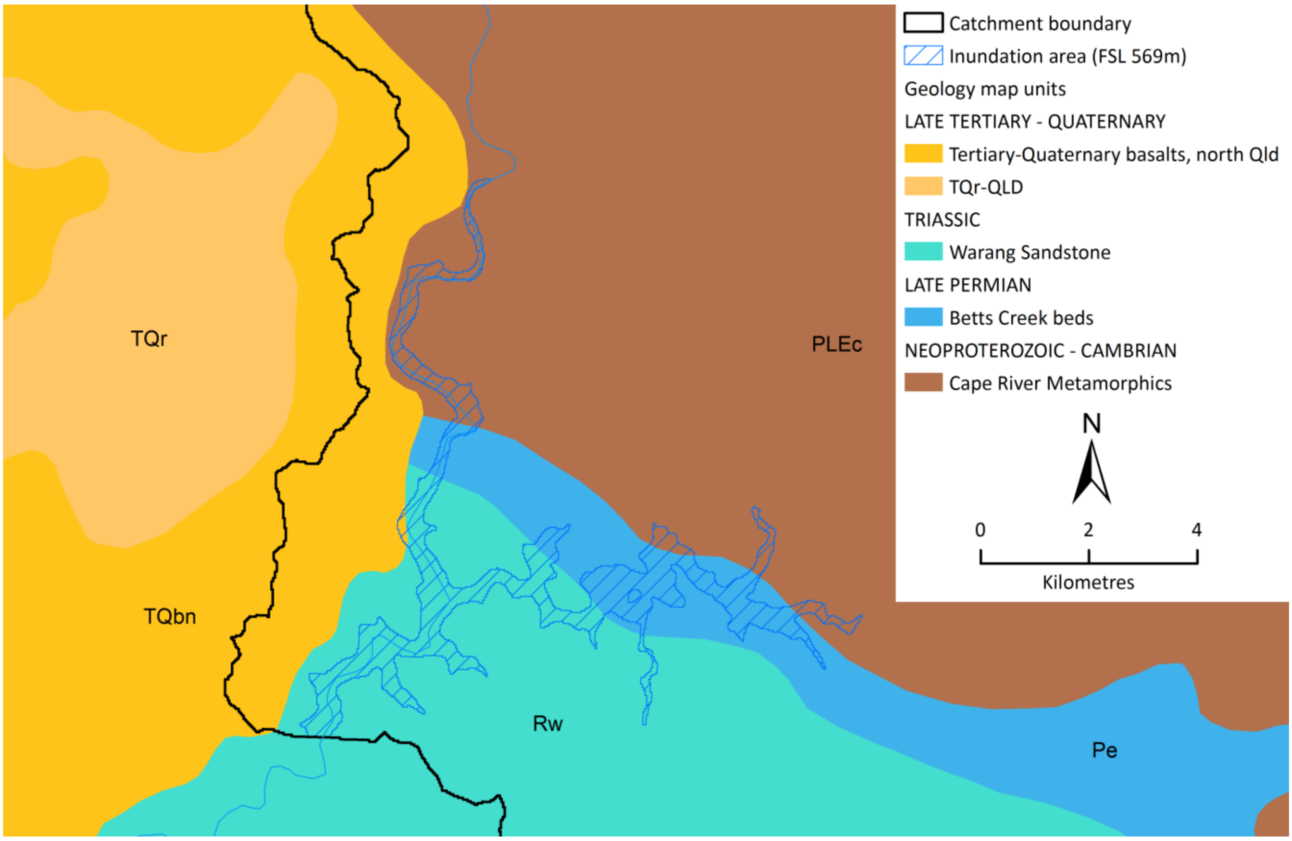
PARAMETER	DESCRIPTION
	crassicarpa. Dense ground cover includes *Heteropogon contortus* and *Themeda triandra* as well as a range of other graminoid and forb species.
Estimated cost	$200 m to $340 m (cost of dam only) No previous estimate of cost has been located.
Estimated cost / ML of supply	$6720/ML at 85% annual time reliability (does not include transmission/distribution losses or take into account environmental and downstream entitlements)..
Potential benefit/cost	No previous assessment identified.
Summary comment	Given the much smaller catchment area and distance upstream of lands which might potentially be irrigated, these sites would not appear to offer any potential advantage over the various other sites further downstream in the Flinders catchment.



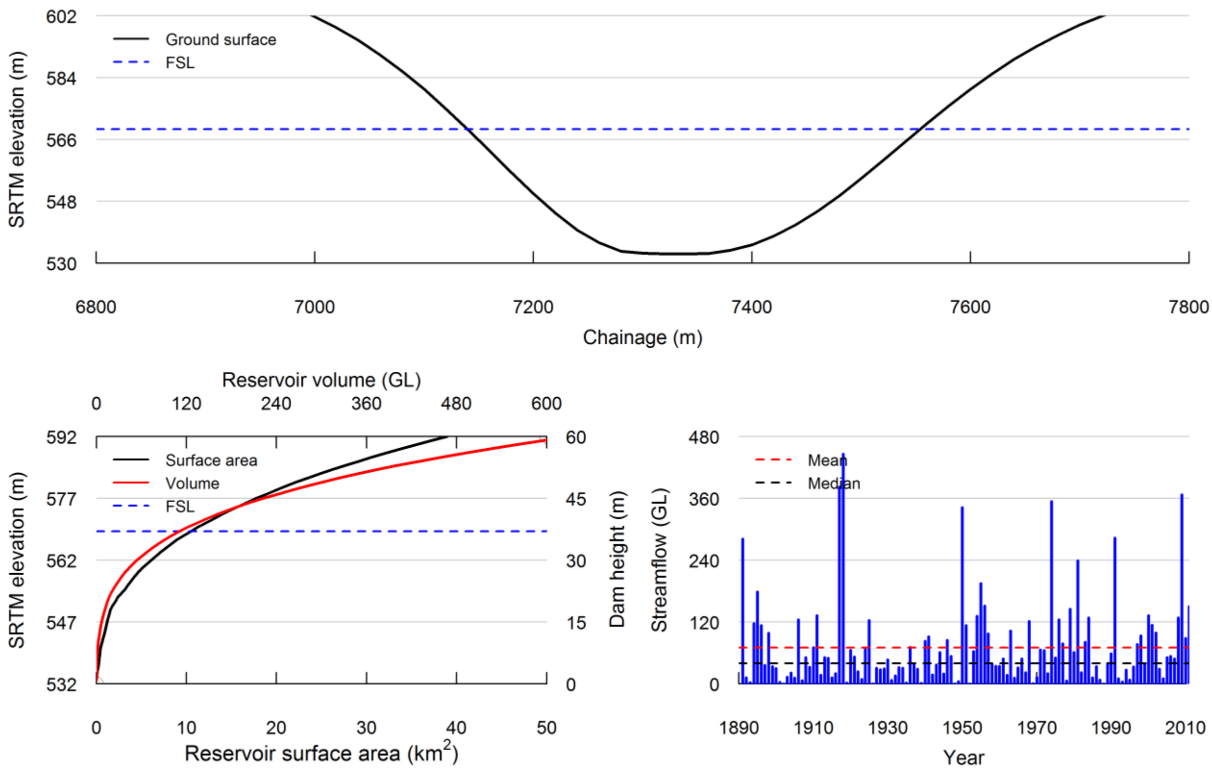
Apx Figure A.79 Location map of White Mountains potential dam, reservoir and catchment area



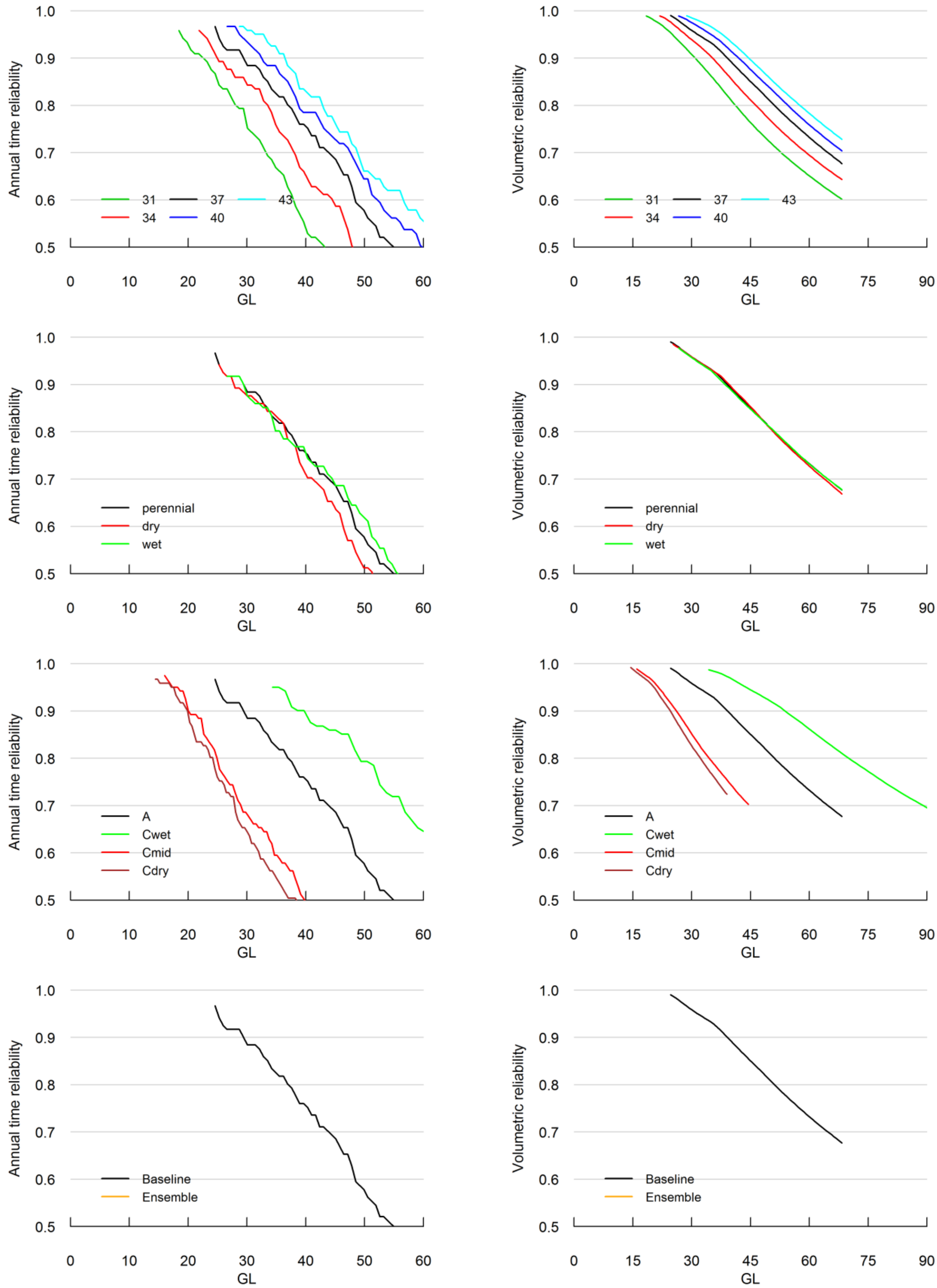
Apx Figure A.80 White Mountains potential dam depth of inundation and property boundaries (indicated by coloured shading)



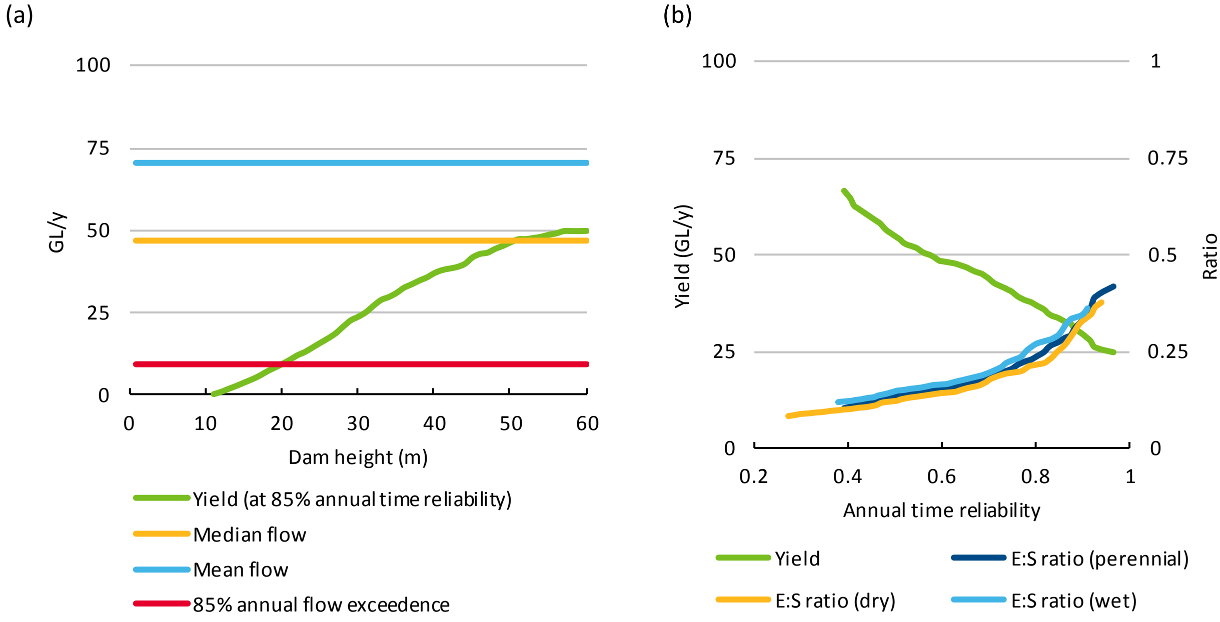
Apx Figure A.81 White Mountains dam site underlying geology



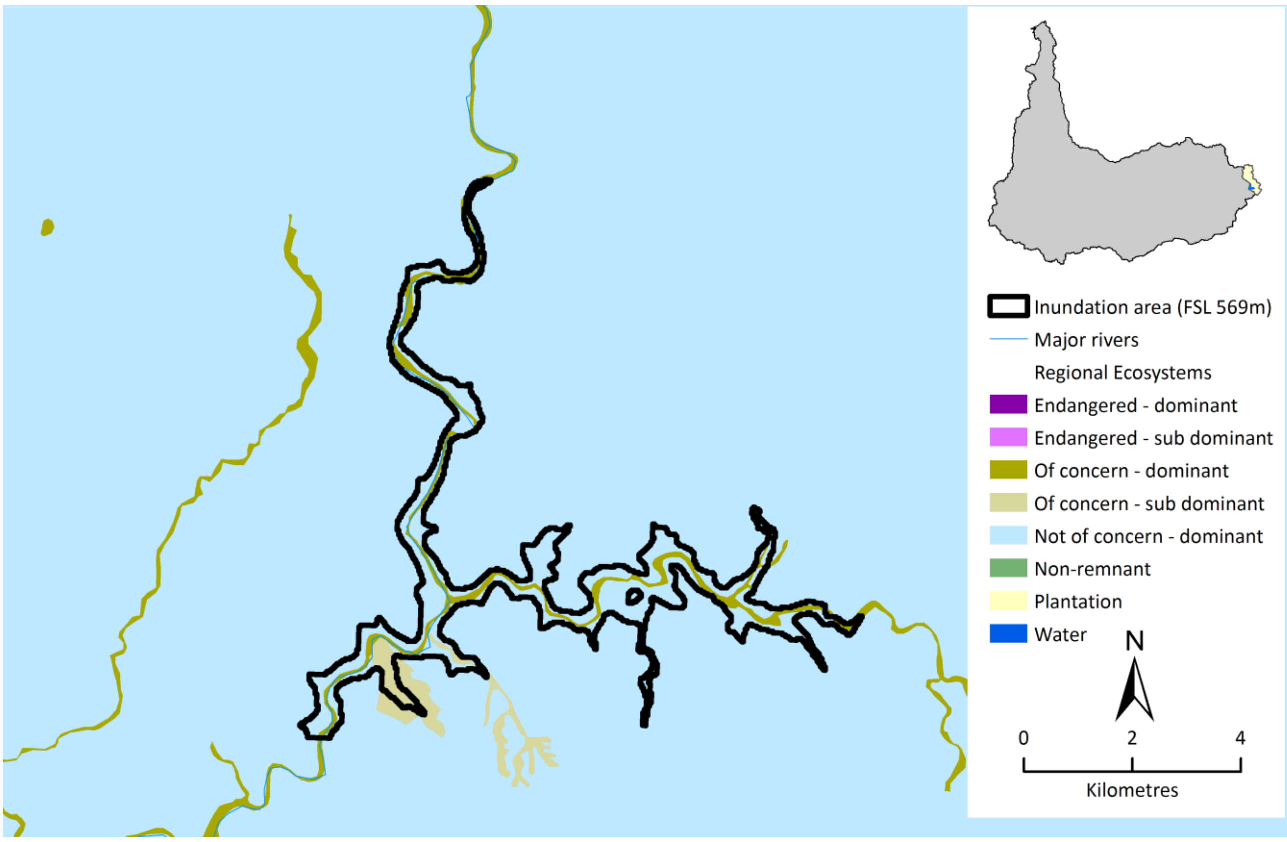
Apx Figure A.82 Cross section along main dam axis, volume surface area height relationship and annual streamflow at White Mountains dam site



Apx Figure A.83 White Mountains potential dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 569 m FSL. Third row: YRR under Scenario C for 569 m FSL. Fourth row: Ensemble model runs unavailable for this site (see Lerat et al. 2013).



Apx Figure A.84 a) Yield at 85% annual time reliability and streamflow at White Mountains dam site for different dam heights; (b) Yield and evaporation : water supply ratio at White Mountains dam site for different annual time reliability for the selected dam height of 37 m



Apx Figure A.85 White Mountain potential dam regional ecosystems mapping

Appendix B Non short-listed potential dams in the Gilbert Catchment

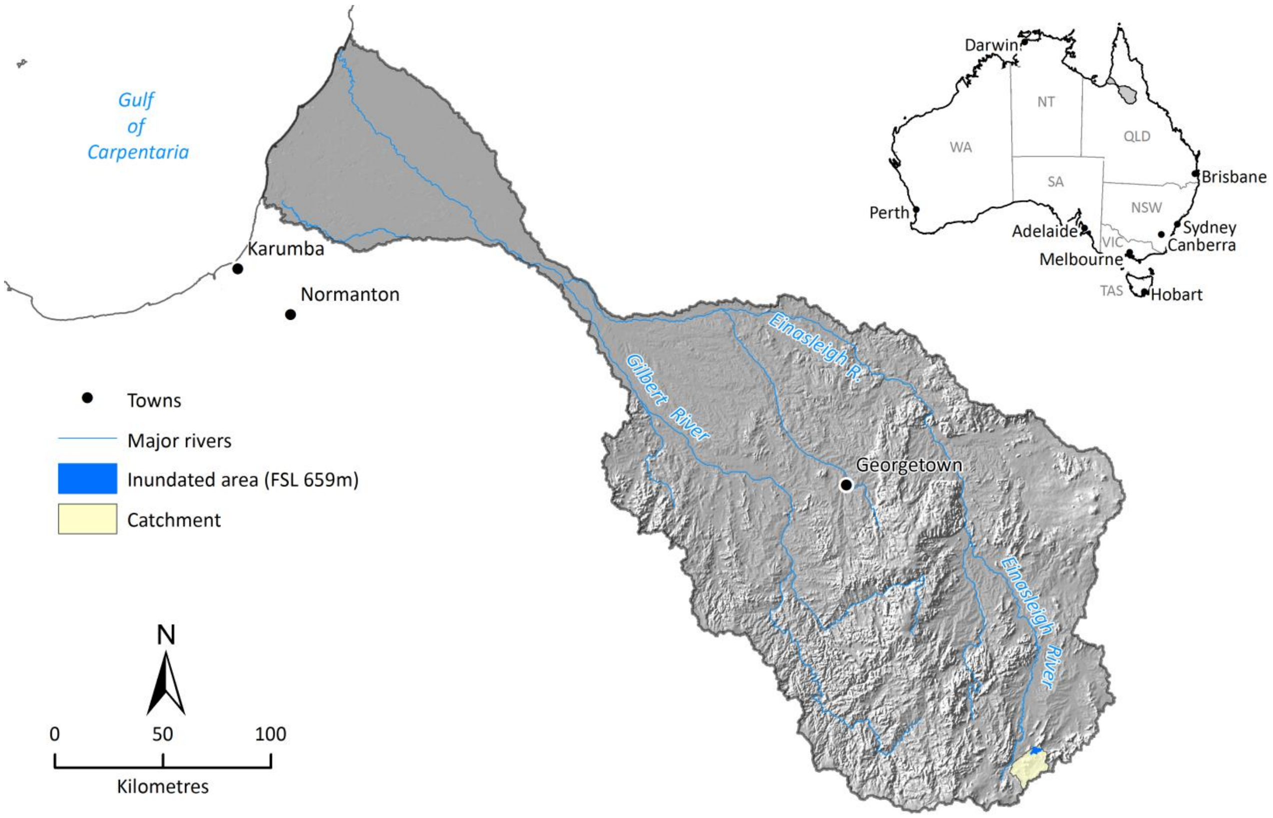
This appendix provides summary tables for the four (non-short-listed) potential dams identified in the Gilbert catchment.

Bundock Creek dam site; 47.9 km

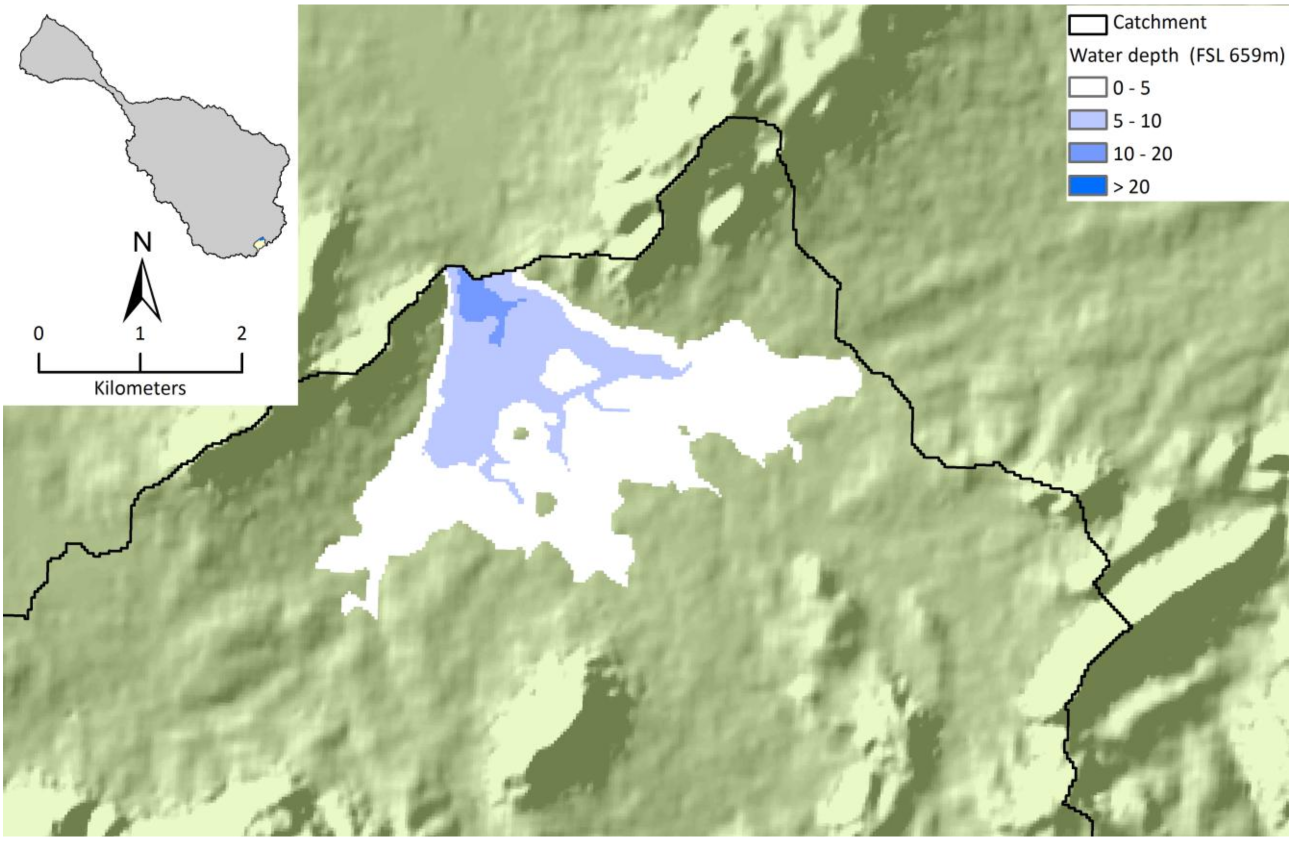
PARAMETER	DESCRIPTION
Previous investigations	DNR (1998) Engineering Assessment of Storage Options. DNR (1999a) Feasibility Study for Dams and Weirs on Bundock Creek and Gilbert River- State Water Projects. DNR (1999b) Preliminary Geotechnical Assessment of Dam and Weir Sites on Bundock Creek and Gilbert River – State Water Projects, DNR, July 1999 and October 1999. DNRME (2004). Agricultural Land and Water Assessment Report, Gulf and Mitchell Water Resource Planning.
Description of proposal	Small dam on Bundock Creek, 14 m high plus freeboard, FSL 659 m. A location map and map showing the inundated area at FSL are shown in Apx Figure B.1 and Apx Figure B.2 respectively. Potentially including a gravity open cut channel diversion from the Einasleigh River to the upper reaches of Lava Creek (a tributary of Bundock Creek) to increase the effective catchment area.
Regional geology	The site on Bundock Creek occurs where the creek has eroded through a northeast trending ridge of the Balcooma Metavolcanic Group of Late Cambrian to Early Ordovician age. These originally rhyolitic volcanic rocks have been metamorphosed to gneiss and granofels. These rocks are similar in appearance to granite but contain metamorphic minerals such as garnet. The high grade metamorphism was caused by cycles of tectonism from Early Ordovician to Early Silurian. Most of the reservoir area is within alluvium overlying gneiss or granite. Arenite, shale and limestone of the Bundock Creek Group are faulted against the granite to the south of the dam site. Bundock Creek adjoins the Einasleigh River to the west. Geologically recent (260ka) basalt flows down the Einasleigh River floodplain have resulted in a muted topography in this area with few water storage sites. Apx Figure B.3 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	The site has been investigated by seismic refraction survey. No drilling has been carried out. The left abutment consists of high strength foliated gneiss rising from the floodplain at a slope of about 20˚. Rock outcrop and bouldery float is common. The floodplain in the valley section is about 500 m wide with the creek flowing through the middle of the valley. The right abutment slopes at about 10˚.Rock outcrop is distinctly weathered and low to medium strength. Seismic profiling indicates up to 14 m of material with an intermediate seismic velocity (700-1400 m/s) with the deeper section on the right side of the floodplain. The nature of this material is unknown but it probably represents both alluvium and weathered rock.
Reservoir rim stability and	Apart from the dam abutments, terrain within the reservoir is gently undulating and the

PARAMETER	DESCRIPTION			
leakage potential	potential for slope instability is low. There is a low potential for reservoir leakage.			
Proposed structural arrangement	Previous investigations DNR (1999a) reported that the site is suitable for an earth and rockfill dam (170,000 m^3 volume of fill required) but notes that a RCC dam would have a centrally located spillway. Fig. 3 of DNR (1999a) indicates that the embankment would be some 800 m long. An unlined spillway approx. 120 m wide cut through the left abutment was proposed for the embankment dam Outlet works would be located in the left abutment.			
Availability of construction materials	No materials investigations have been carried out. There are potential quarry sites adjoining the reservoir area to the east and west of the dam site and within 2 km of it. The rock is probably gneiss and would be suitable for both RCC and concrete. Sand supplies may be limited. There are small bars of sandy gravel in the creek bed but exploration will be required to confirm quantities. The reservoir area probably contains significant deposits of clay if required.			
Catchment areas	The catchment area is 205 km^2.			
Flow data	The nearest streamflow gauging station to the site is 917108A, which was open from 1968 to1988, and has a catchment area 1,572 km^2. Mean annual flow at this location was 190,000 ML/a (120 ML/a /km^2 of catchment area), the median annual flow is 60,000 ML/a. Based on catchment area scaling, total mean annual flow upstream of the dam and diversion is likely to be approx. 45-50,000 ML/a.			
Capacity	30 GL at FSL 659m (Apx Figure B.4).			
Reservoir yield assessment	8.8 GL at 85% annual time reliability (Apx Figure B.5 and Apx Figure B.6) 8.6 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 39% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.7			
Open water evaporation	Mean annual evaporation is estimated to be 4.4 mm d^{-1} using bulk aerodynamic formulae. Mean annual evaporation was estimated to be 4.6 mm d^{-1} using Morton's APE.			
Impacts of inundation on existing infrastructure	Inundated area appears to be largely grazing land.			
Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)	0.23	1.64	3.26
	100 years (%)	0.76	5.46	10.86
	Years to infill	13087	1832	921
Water quality and stratification considerations	Bundock reservoir is predicted to experience persistent thermal stratification with a top-to-bottom temperature change of 10-12 °C during most of the simulation. The risk of blue-green algal blooms is very high with Zsl:Zeu ≤ 2 at virtually all times. The water column is predicted to mix briefly during late June - early July with the onset of persistent seasonal stratification typically no later than mid-August. The very long duration of stratification and weak mixing behaviour suggests this storage is susceptible to experiencing profound anoxic conditions and associated water quality issues.			
Ecological and cultural considerations raised by previous studies	No specific assessment had been made.			

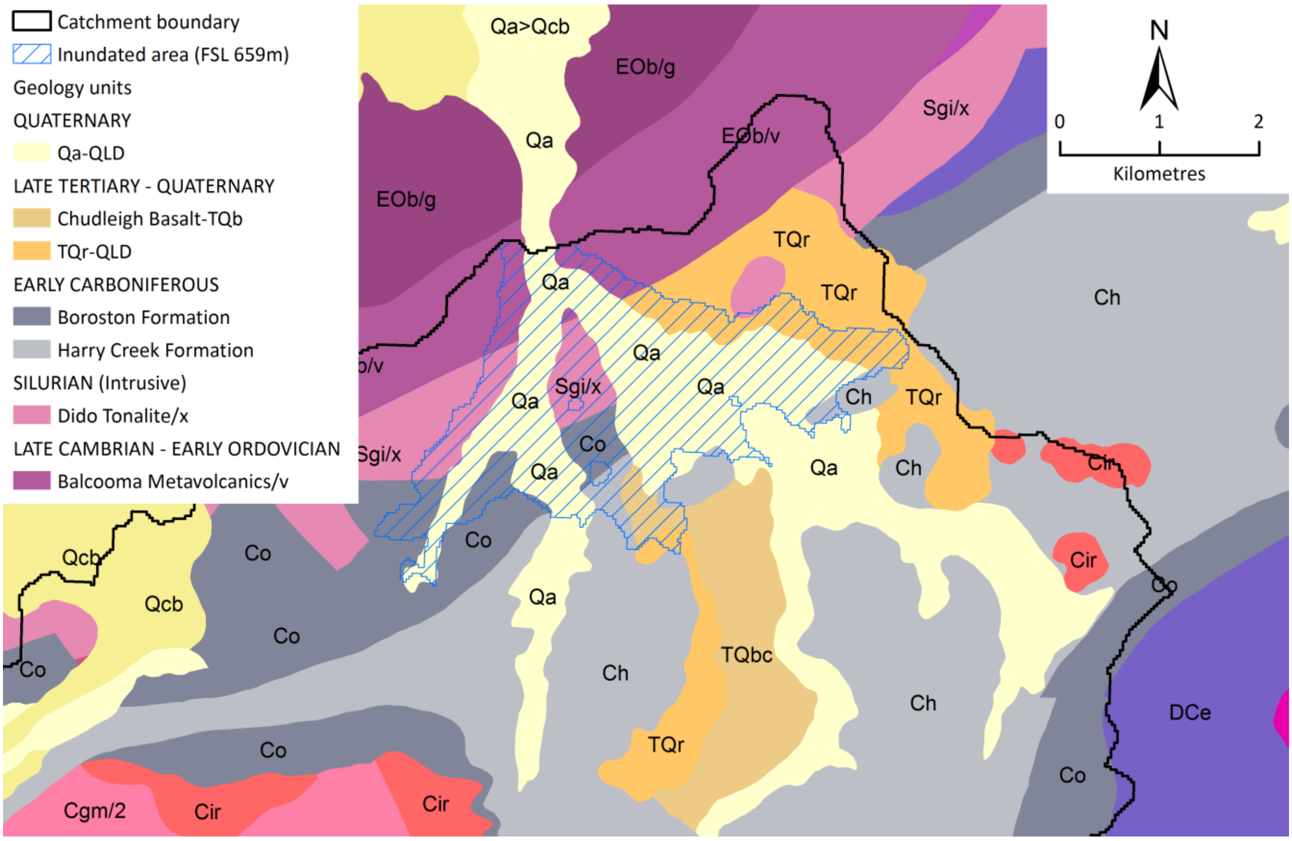
PARAMETER	DESCRIPTION
Environmental considerations	As the potential dam is very far upstream in the Einasleigh sub-catchment, the proposed dam site captures a very small catchment area and would have little impact upon fish movement. The values of the aquatic habitat upstream of the proposed dam wall site are not known but despite the short length of river, some waterholes may be present. Vallance et al. (2000) found just two fish species – spangled perch and chequered rainbowfish – both typical of upstream locations, at the one site they surveyed in upper Bundock Creek. Other fish species found in this region include Bony bream, catfish, sooty grunter, and freshwater turtles (Waltham et al., 2013). The site is likely to cover 'Of Concern' regional ecosystems. Apx Figure B.7 shows relative area of ecosystems Of Concern. *Ecosystems Of Concern* About half of the inundated area is likely to be within a regional ecosystem Of Concern. The site covers open-woodland to woodland of *Eucalyptus brownii*, *E. crebra*, *Corymbia dallachiana*, *E. leptophleba*, *E. camaldulensis*. The site contains open sub-canopy that can contain *E. brownii*, *Atalaya hemiglauca* and *Grevillea striata*. The shrub layer varies from absent to mid-dense and can include canopy species, *Eremophila mitchellii*, *Carissa lanceolata* and *Acacia victoriae*. Ground layer varies from open to dense and can contain a variety of species including *Heteropogon contortus*, *Themeda triandra*, *Chrysopogon fallax* and *Bothriochloa spp*. Fringing open-forest to low woodland containing any combination of *Melaleuca argentea*, *M. fluviatilis* or *M. leucadendra*, *Eucalyptus camaldulensis*, *Casuarina cunninghamiana*, *Lophostemon grandiflorus*, Corymbia spp. In eastern areas *E. tereticornis* may replace *E. camaldulensis*. There can be an open sub-canopy, which can include canopy species, *M. linariifolia*, *M. bracteata*, *Lysiphyllum sp*., *Ficus opposita* and *Acacia spp*. Low woodlands of *M. bracteata* with emergent *Eucalyptus spp*. can also occur. The shrub layer can vary from none to scattered juvenile canopy spp., *Acacia holosericea* and *Planchonia careya*. The ground layer on the steep banks can be grassy and include *Heteropogon spp*., *Arundinella spp*., *Eragrostis spp*. and *Cyperus spp*. but its presence is seasonally dependent.
Estimated cost	$200 m to $340m (cost of dam only). Previous studies DNR (1999a) reports an estimated cost of $22 m which appears to be for the dam only. CPI adjustment to 2012 prices indicates a cost of $33 m. This cost appears to be exceedingly low given the remoteness of the site and the project uncertainties. No details of the possible Einasleigh River diversion or an estimated cost for it were located.
Estimated cost / ML of supply	$25,590/ML at 85% annual time reliability (does not include transmission/distribution losses)
Summary comment	This dam site is very remote and even with diversions from the Einasleigh River (diversion channel and associated infrastructure not costed in this analysis) it would be very expensive and given the small storage capacity of the reservoir would still only generate small yields (ie. < 30 GL).



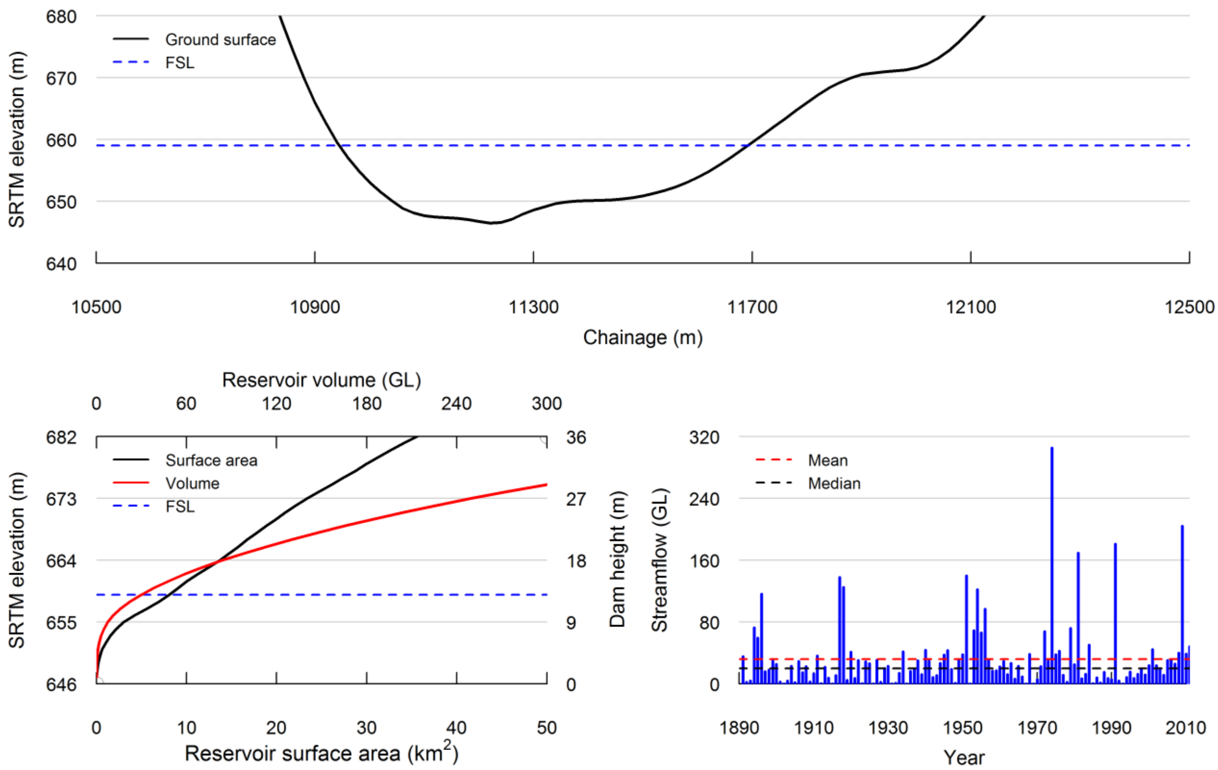
Apx Figure B.1 Location map of Bundock Creek dam, reservoir and catchment area



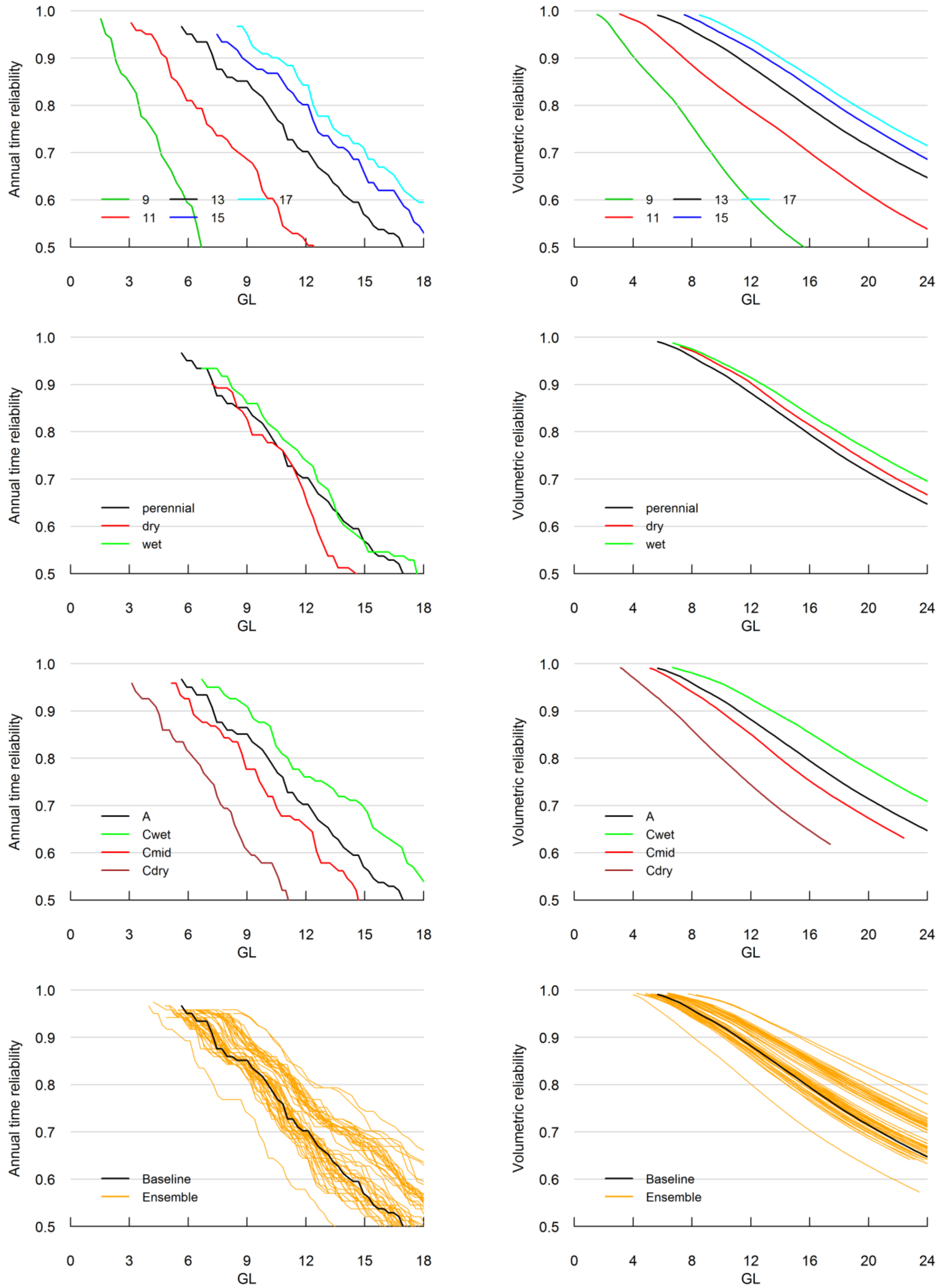
Apx Figure B.2 Bundock Creek dam depth of inundation and property boundaries (indicated by coloured shading)



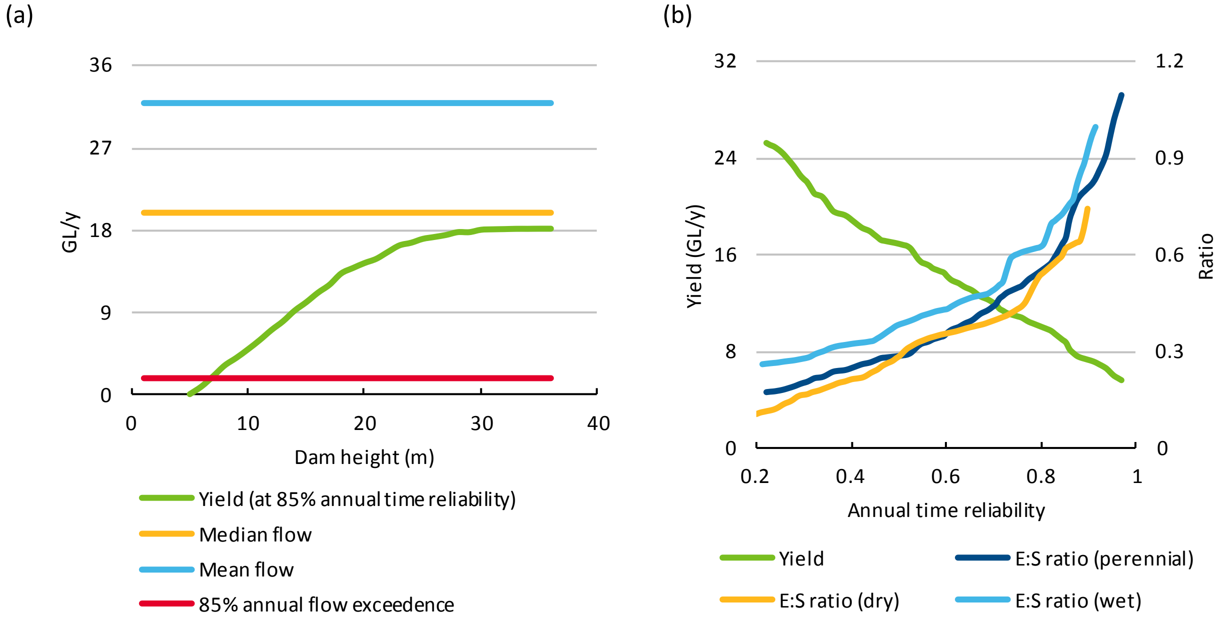
Apx Figure B.3 Bundock Creek dam underlying geology



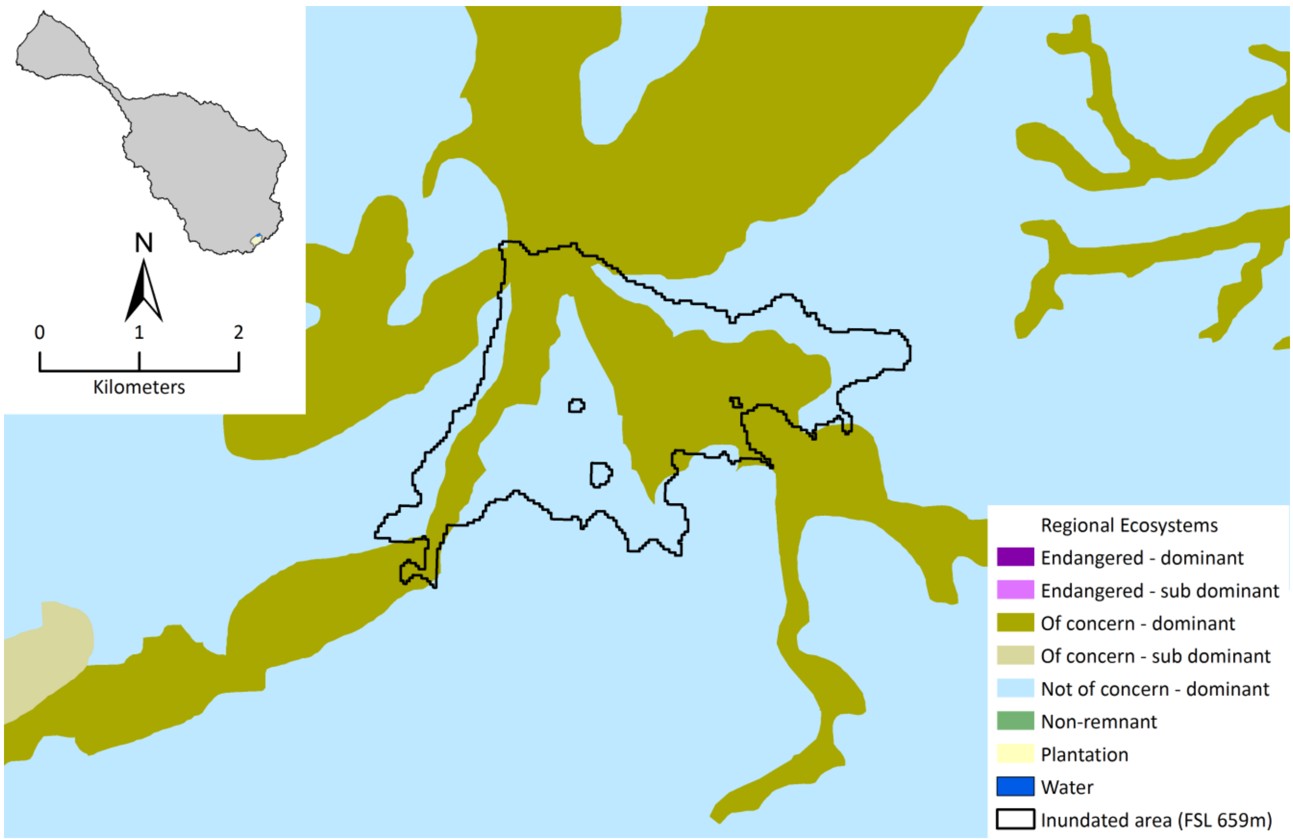
Apx Figure B.4 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Bundock Creek dam site



Apx Figure B.5 Bundock Creek dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 659 m FSL. Third row: YRR under Scenario C for 659 m FSL. Fourth row: YRR for baseline and ensemble model runs for 659 m FSL



Apx Figure B.6 a) Yield at 85% annual time reliability and streamflow at Bundock Creek dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Bundock Creek dam site for different annual time reliability for the selected dam height of 30 m



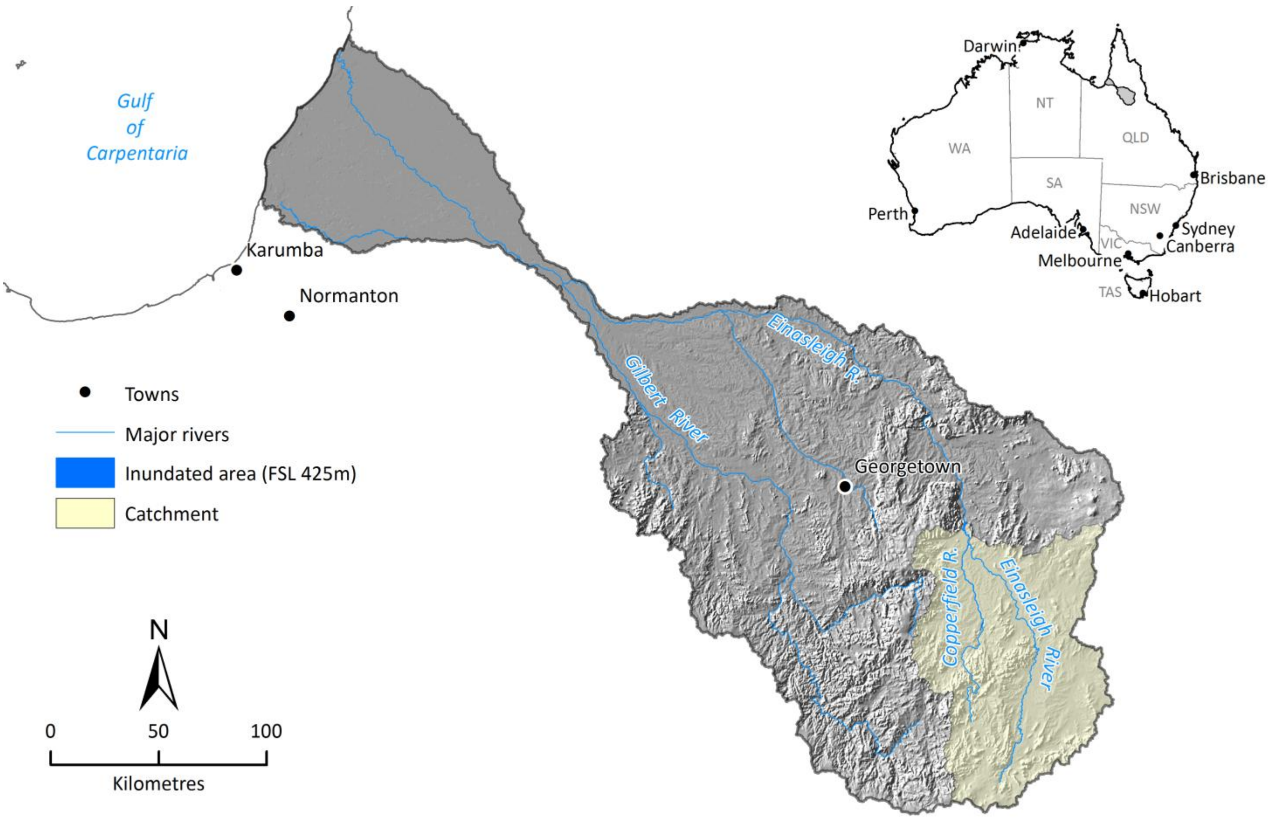
Apx Figure B.7 Bundock Creek dam regional ecosystems mapping

Mount Alder dam site on t Einasleigh River; 285.0 km

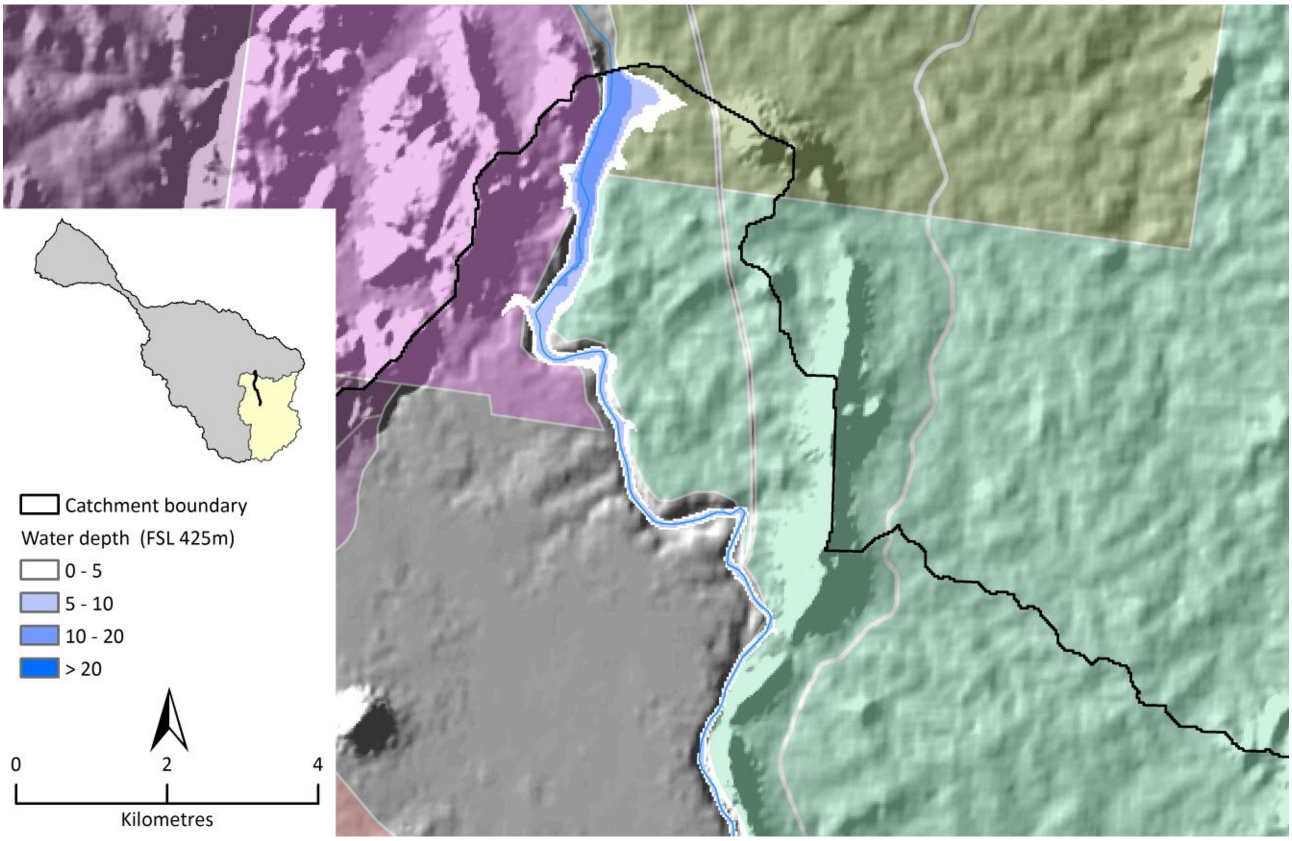
PARAMETER	DESCRIPTION
Previous investigations	DNR (1998). Potential dam sites at Mt Alder and at Mt Noble are referred to in Table 1 of a report Gulf Region Study – Engineering Assessment of Storage Options (Phase 2). Apart from the reference to this potential dam in Table 1 of (DNR 1998), no other data on this site could be located.
Description of proposal	On river dam providing supply for irrigation. The height of the dam spillway was selected to be 20 m above bed level (FSL 425). A higher dam wall would require saddle dams. A photograph taken at the site is shown in Apx Figure B.8. A location map and map showing the inundated area at FSL are shown in Apx Figure B.8 and Apx Figure B.9 respectively.
Regional geology	The Einasleigh River flows in a northerly direction through an undulating plain underlain by biotite gneiss and schist of the Einasleigh Metamorphics (Palaeo-proterozoic) and granitic rocks of the Puppy Camp Granodiorite (Silurian). To the west is rugged hilly terrain underlain by rhyolitic ignimbrite of the Eveleigh Volcanic Sub-Group (Carboniferous). To the east are linear ridges formed by intrusions of microgranite (Carboniferous). Mt Alder is a prominent hill in one of these ridges. The former Einasleigh River floodplain was covered in part by basalt lava flows in the Quaternary (260 ka). These flows may underlie more recent alluvium in the river channel and may themselves be underlain by older alluvium. A former course of the Einasleigh River or one of its tributaries appears to have been blocked, possibly by basalt, upstream of Mt Alder. The stream formerly flowed through the rhyolitic ignimbrite to the west of the river and now forms an abandoned stream valley. Apx Figure B.10 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	No investigations have been carried out at the site. The following comments are based on a brief site inspection as part of the Assessment. The dam site is bound to the west by rugged terrain underlain by rhyolitic ignimbrite and to the east by microgranite at Mt Alder. The footprint of the proposed dam is mainly underlain by granodiorite. Remnants of basalt lava flows may be present at higher levels. The right abutment ridge is relatively narrow and open joints closer to the river channel suggest that excavation to a significant depth would be required to achieve a sound foundation for a roller compacted concrete (RCC) dam.
Reservoir rim stability and leakage potential	The reservoir rim is mostly bound by gently undulating topography of the Einasleigh Metamorphics. The slopes formed in these materials are unlikely to become unstable when the reservoir is filled. At the FSL proposed here the potential for leakage is low.
Proposed structural arrangement	A RCC dam with central overflow spillway appears to be the most suitable type at this site.
Availability of construction materials	No investigations have been carried out. Quarry sites, suitable for production of RCC aggregate appear to be available within 2 km of the site in either ignimbrite or microgranite. Sand deposits occur within the river channel upstream of the site and would probably be suitable for augmenting the crushed aggregate.
Catchment area	The catchment area is 8641 km^2
Flow data	Streamflow data is available from GS 917109 Einasleigh River at Lake Cawana AMTD 206 km some 69km downstream of the site. Over the period, 1968-1988, recorded flows were; Maximum recorded annual flow 8,411,000 ML (January 1974) Mean annual flow 1,415,000 ML Median annual flow 500,000 ML Minimum annual flow 54,000 ML. Flows at the Mt Alder site would be substantially less than the above flows because of the

PARAMETER	DESCRIPTION			
	smaller catchment area at the dam site.			
Capacity	31 GL at FSL 425 (Apx Figure B.11).			
Reservoir yield assessment	37 GL at 85% annual time reliability (Apx Figure B.12 and Apx Figure B.13) 44 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 12% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.1			
Open water evaporation	Mean annual evaporation is estimated to be 4.6 mm d^{-1}. Mean annual evaporation was estimated to be 5.0 mm d^{-1} using Morton's APE.			
Impacts of inundation on existing infrastructure	The potential storage area appears to be predominantly grazing country. No infrastructure identified.			
Estimated rates of reservoir sedimentation		Best case	Expected	Worst case
	30 years (%)	6.34	49.81	90.05
	100 years (%)	21.13	100	100
	Years to infill	473	60	33
Ecological and cultural considerations raised by previous studies	No previous assessments have been identified.			
Water quality and stratification considerations	Mt Alder reservoir is predicted to experience persistent thermal stratification with a top-to-bottom temperature change of approximately 5 °C during spring and post-runoff summer periods each year. Summer inflow events are likely to cause full water column mixing for short periods (up to 1 week) each year. The risk of blue-green algal blooms is very high with Zsl:Zeu ≤ 3 from August through April and 1-2 during much of this period. The water column is predicted to mix twice each year. The duration of stratification and weak mixing behaviour suggests this storage is moderately susceptible to low dissolved oxygen conditions and associated water quality issues. However, summer inflows may resupply some oxygen to deeper waters and reduce some symptoms of low dissolved oxygen.			
Environmental impacts	This potential dam site has a large catchment area, and the Einasleigh River reach on which its sits has numerous large permanent waterholes. A dam in this location would provide a barrier to the upstream and downstream migration of numerous fish species and would therefore require a fish transfer facility. Further investigation is required to assess the impact of this potential dam on fish passage. A major part of the storage site is likely to cover dominant 'Of Concern' regional ecosystems. Apx Figure B.14 shows the relative areas ecosystems Of Concern that could be affected. *Ecosystems Of Concern - Dominant* This region contains grasslands of *Dichanthium spp*., *Astrebla spp*. and *Iseilema spp*., isolated trees of *Eucalyptus microneura* (Georgetown box), *E. coolabah* (coolibah), *Grevillea striata* (beefwood), *Lysiphyllum sp*., *E. tereticornis* (bluegum), *E. leptophleba* (Molloy red box), *E. moluccana* (gum-topped box), *E. platyphylla* (poplar gum). Major vegetation communities include: grasslands of *Dichanthium sp*. The region contains palustrine wetlands (e.g. vegetated swamp), and swamps.			
Estimated cost	$250 m to $410 m (cost of dam only) No previous estimate of cost has been located.			
Estimated cost / ML of supply	$7510/ML at 85% annual time reliability (does not include transmission/distribution losses or take into account environmental and downstream entitlements).			
Summary comment	Because of the steep bed slopes and confined nature of the area, the storage characteristics at this site are less favourable than at the downstream Mt Noble sites or at the Dagworth site. On this basis, this option does not appear to warrant any further consideration.			

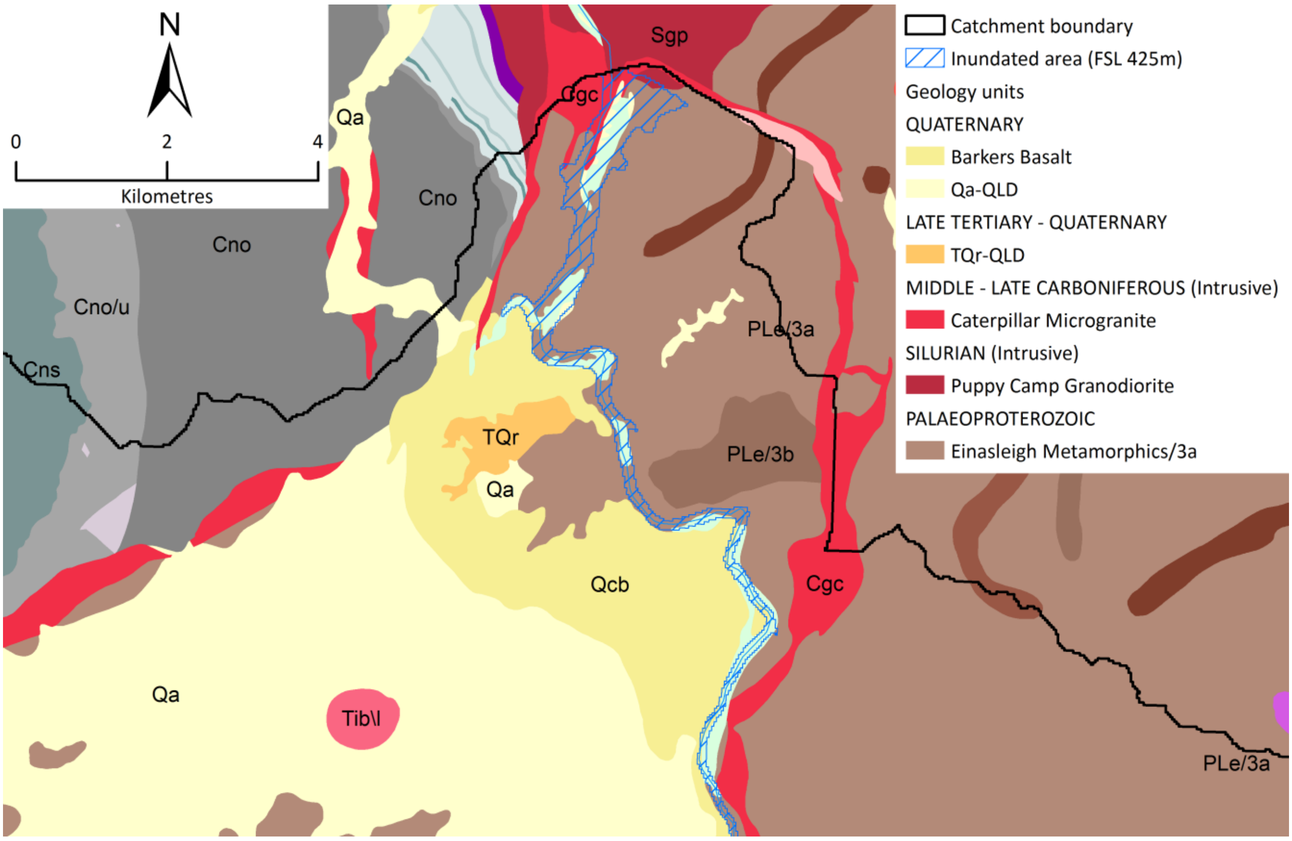
Einasleigh River looking downstream from the right abutment of the Mount Alder dam



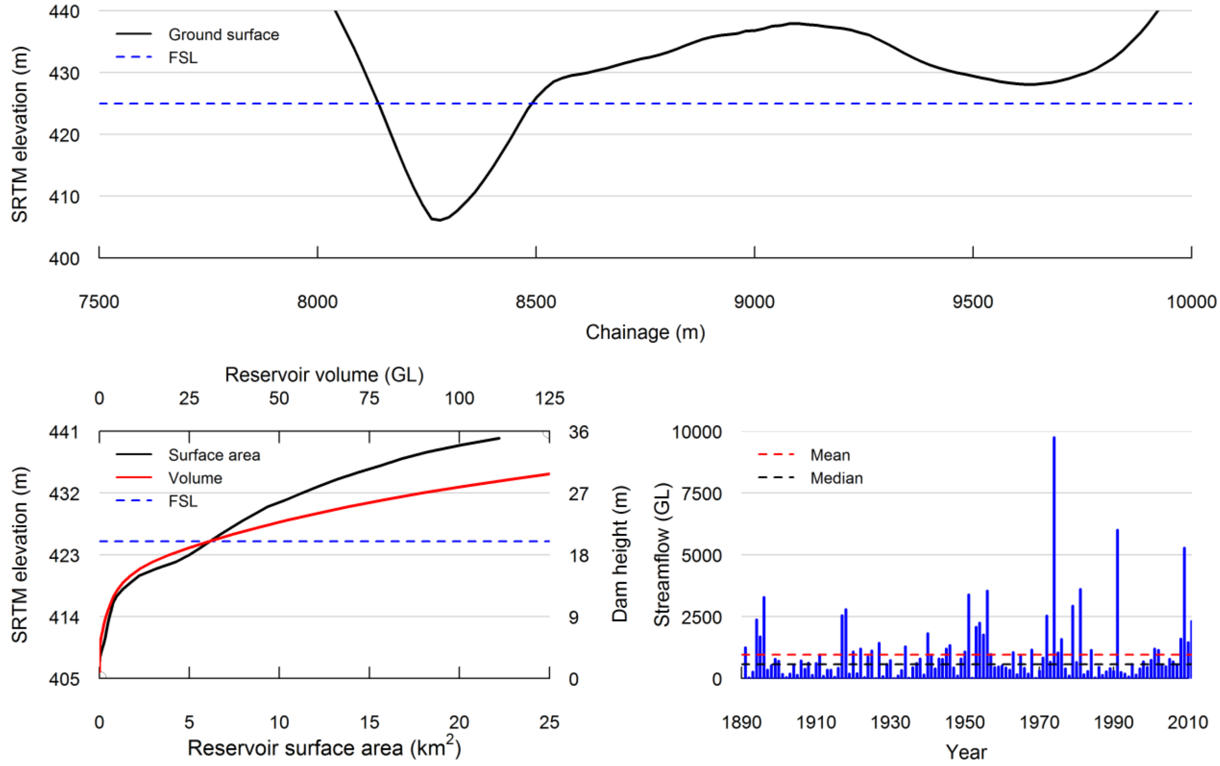
Apx Figure B.8 Location map of Mount Alder dam, reservoir and catchment area



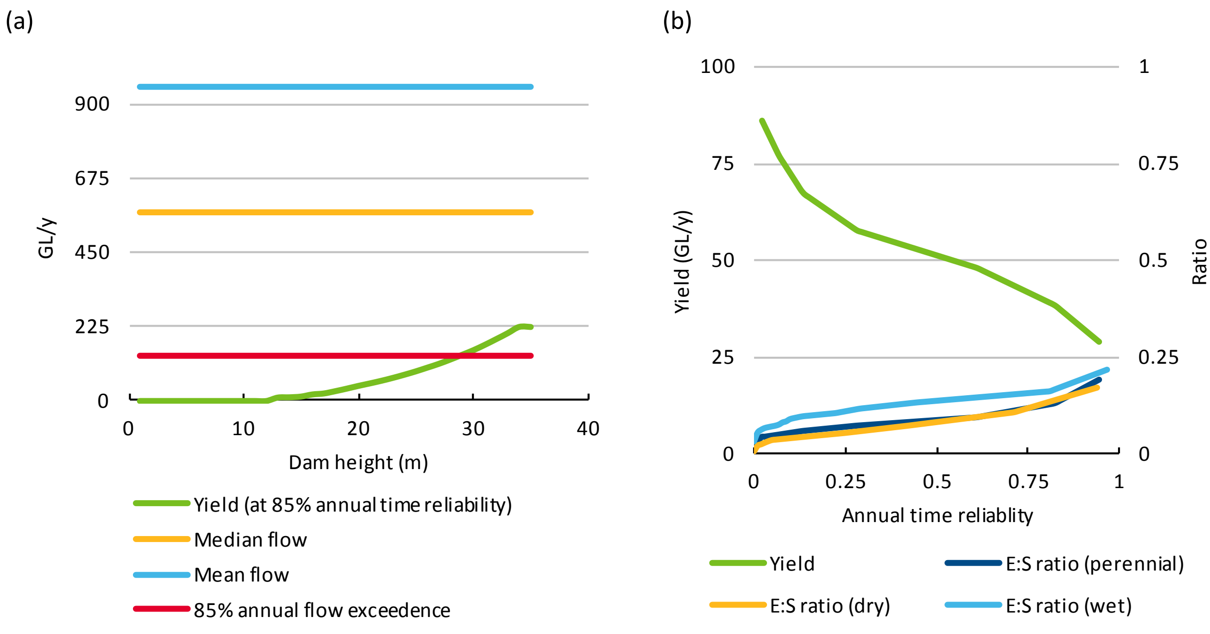
Apx Figure B.9 Mount Alder potential dam site depth of inundation and property boundaries (indicated by coloured shading)



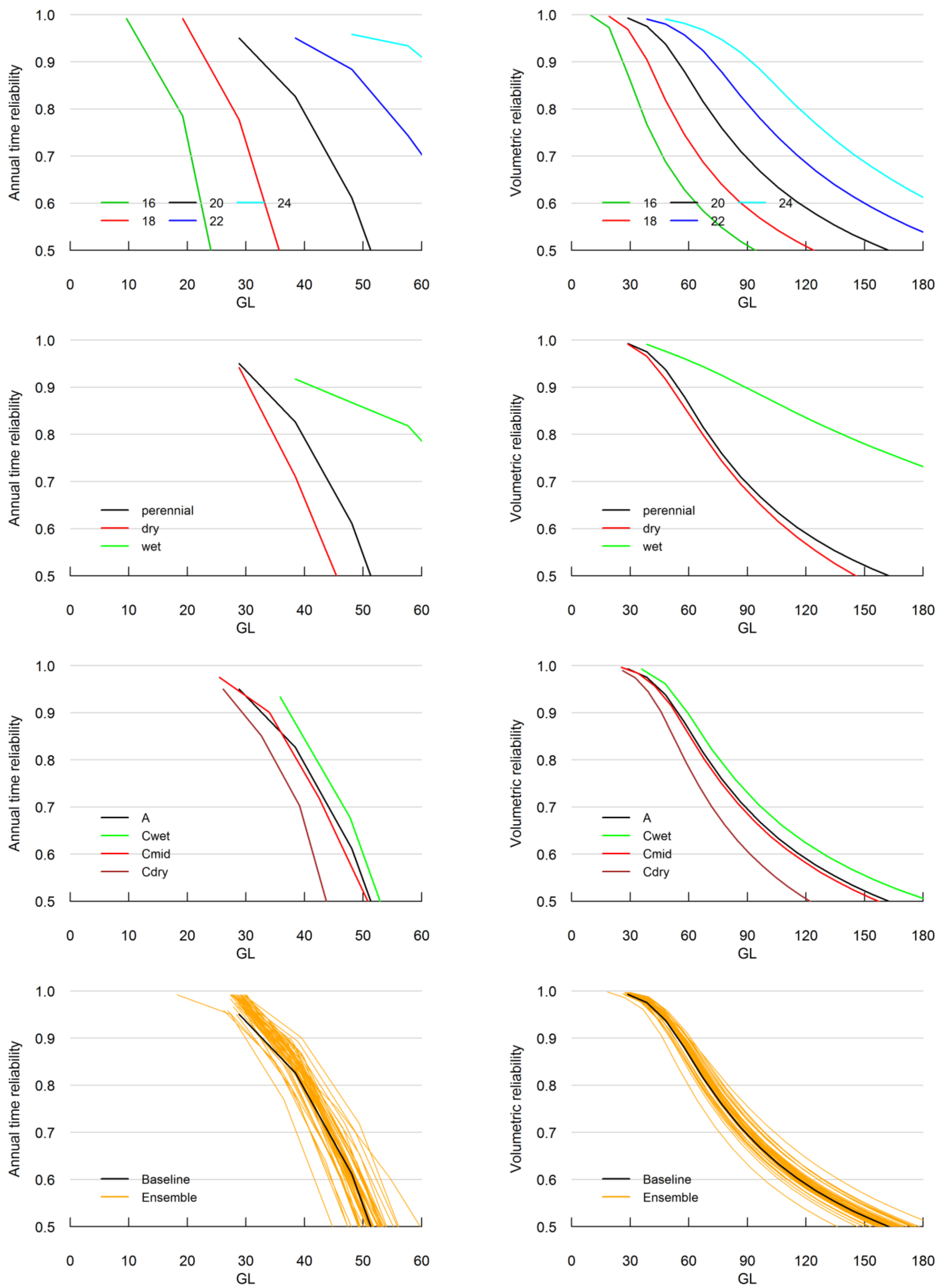
Apx Figure B.10 Mount Alder potential dam underlying geology



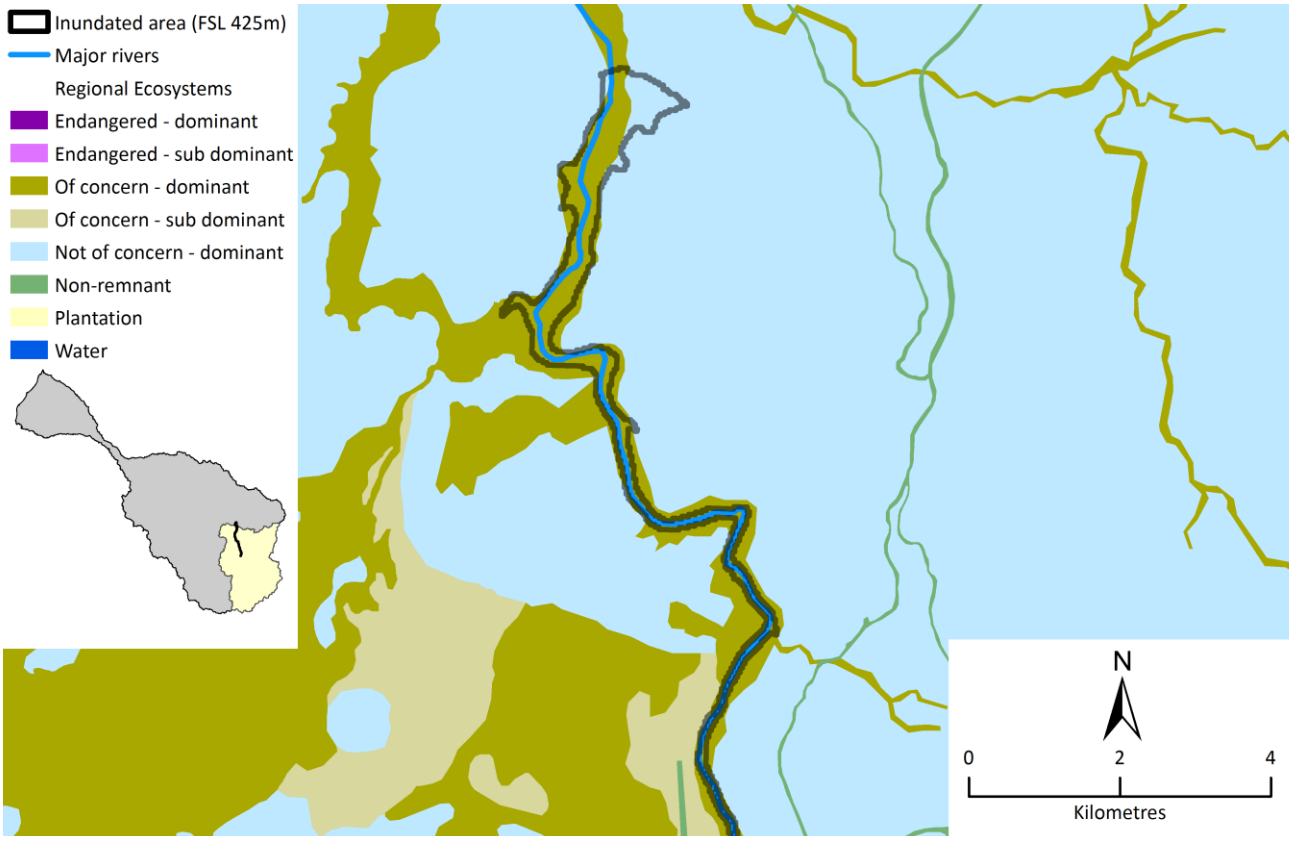
Apx Figure B.11 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Mount Alder potential dam site



Apx Figure B.12 a) Yield at 85% annual time reliability and streamflow at Mount Alder dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Mount Alder dam site for different annual time reliability for the selected dam height of 20 m



Apx Figure B.13 Mount Alder potential dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 425 m FSL. Third row: YRR under Scenario C for 425 m FSL. Fourth row: YRR for baseline and ensemble model runs for 425 m FSL



Apx Figure B.14 Mount Alder dam regional ecosystems mapping

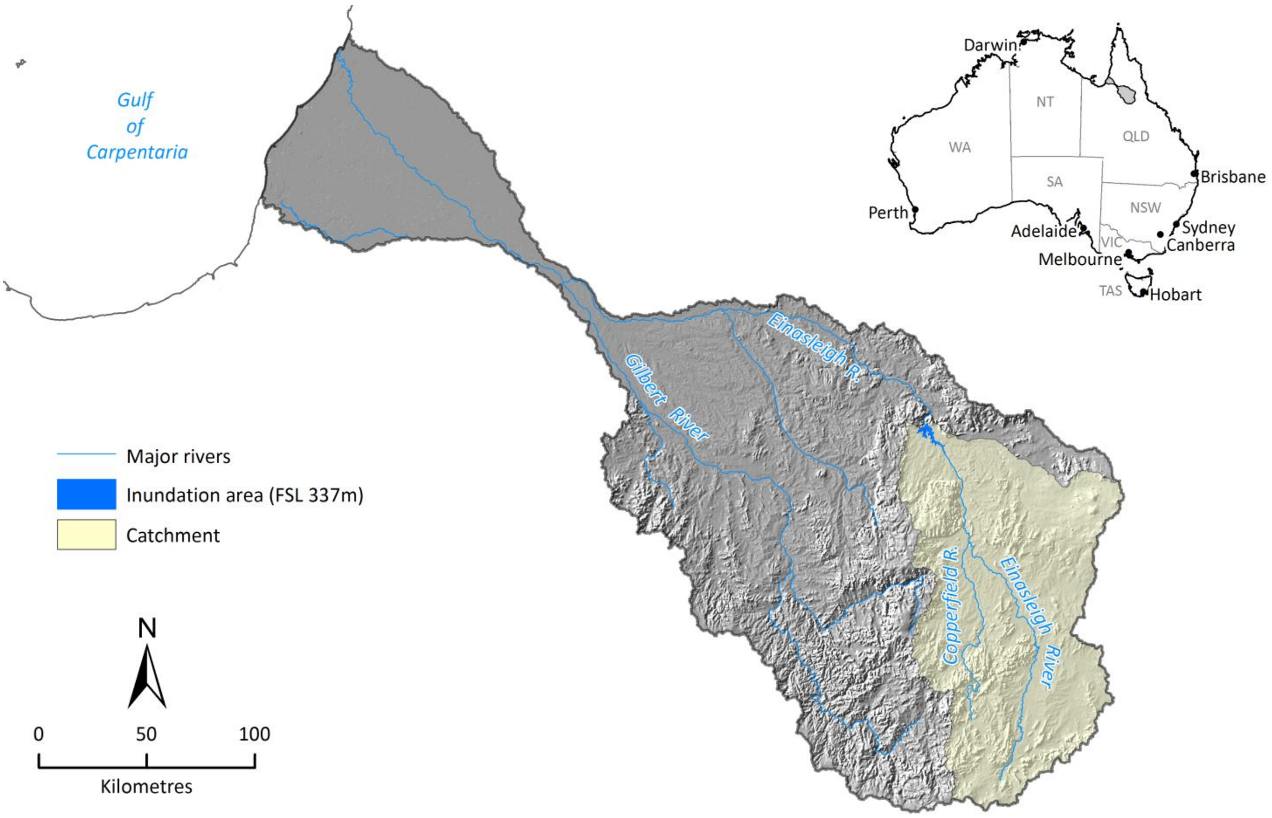
Mount Noble dam site on the Einasleigh River; 232.4 km

PARAMETER	DESCRIPTION
Previous investigations	DNR (1998) Potential dam sites at Mt Alder and at Mt Noble are referred to in Table 1 of a report Gulf Region Study – Engineering Assessment of Storage Options (Phase 2). Apart from the reference to this potential dam in Table 1 of the above report (DNR 1998), no other data on this site could be located.
Description of proposal	On river dam to provide irrigation supplies to lands adjacent to Cowana Lake. Three potential sites at Mount Noble were identified. At all three sites basalt has filled the former river channel, and this poses some risks for dam foundations. Although the geology appears to be most favourable at the downstream site, the storage characteristics of the upstream site are superior to the middle and downstream sites. Hence a modest storage was investigated at the upstream site. At the upstream site the height of the dam spillway was selected to be 25 m above bed level (FSL 342 m). This height was selected as higher FSL would require saddle dams and the dam storage would potentially be affected by the basalt to the east of the right abutment. See geological descriptions below. A photograph of the Mount Noble location is shown in Apx Figure B.15. A location map and map showing the inundated area at FSL are shown in Apx Figure B.16 and Apx Figure B.17 respectively.
Regional geology	In this area the northwest course of the Einasleigh River has been diverted to a northeast direction by a range of hills formed from the resistant rhyolitic ignimbrite of the Nammarong Volcanic Sub-Group (Carboniferous) and microgranite of the Elizabeth Creek Granite (Carboniferous). Upstream of the range the ignimbrite has been intruded by granitic rocks of the Mount Noble Granite (Carboniferous). The Mount Noble Granite forms strongly undulating topography having lower relief than the ignimbrite and microgranite. Downstream of the range, the ignimbrite is faulted against mica schist and gneiss of the Einasleigh Metamorphics (Palaeo-Proterozoic). In this area the river resumes its northwest course. During the Quaternary period, basalt flows from the east (Undara Basalt, 190 ka) flowed into the Einasleigh River valley and down the river channel. These flows diverted the course of the river channel downstream of the range. In the vicinity of the dam sites basalt has filled the former river channel and adjoining floodplain areas. Subsequent erosion by the river has left the basalt as disconnected outliers adjoining the current river channel. Upstream of the dam sites, Cawana Lake and smaller ephemeral lakes have formed where former tributary streams have been blocked by the lava flow. Apx Figure B.18 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	No investigations have been carried out at the sites and the following comments are based on a brief site inspection. As a general comment both the coarse grained granite and microgranite would form a suitable dam foundation after removal of loose, stress relieved and weathered rock. The basalt poses some risks for a dam foundation and would require thorough investigation. This is because the basalt probably overlies old alluvium and/or weathered rock. Also the basalt may have been deposited in a number of lava flow events. The top of each flow may be marked by permeable vesicular layers and soil. The upstream site has coarse grained granite outcropping in the riverbed and on the abutments. Basalt occurs to the east of the right abutment in a former alluvial channel. This area may require construction of a saddle dam. The middle site has coarse grained granite outcropping in the riverbed and both upper abutment areas. Adjoining the river channel for about 500 m on each bank are the remnants of the Undara Basalt. The downstream site is almost wholly within microgranite with rock outcropping in the river bed and on the abutments. Basalt appears to be confined to a narrow zone less than 100 m wide on the right bank
Reservoir rim stability and	Materials forming the reservoir rim include strongly undulating topography in granite, gently undulating metamorphic terrain and relatively flat basaltic terrain. None of these materials

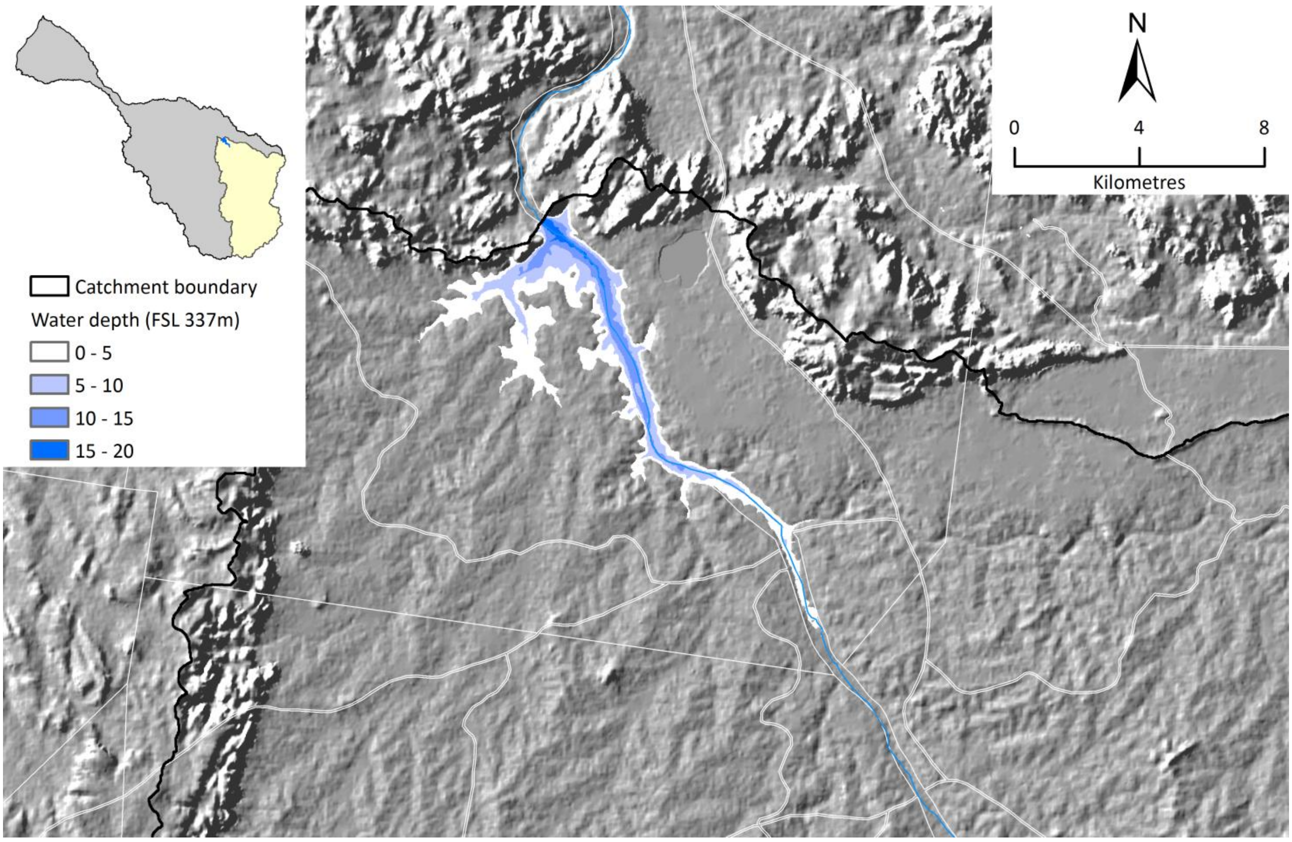
PARAMETER	DESCRIPTION
leakage potential	are likely to be unstable when the reservoir fills. There is potential for leakage from the reservoir into the Undara basalt and possibly into Cawana Lake. The basalt extends for a distance of 9 km from the upstream damsite along the right bank. This should be investigated at the feasibility stage.
Proposed structural arrangement	A RCC dam with central overflow spillway appears to be the most suitable type at this site.
Availability of construction materials	No investigations have been carried out at the site. Quarry sites within granite, microgranite or basalt appear to be available within 2 km of the damsites. There are only small deposits of sand within the river adjoining the damsites. Larger deposits are located about 8km downstream and 6 km upstream.
Catchment area	The catchment area is 12,383 km^2
Flow data	Flow data is available from GS 917109 Einasleigh River at Lake Cawana AMTD 206 km for the period 1968-1988. Over the period, Maximum recorded annual flow 8,411,000 ML (January 1974) Mean annual flow 1,415,000 ML Median annual flow 500,000 ML Minimum annual flow 54,000 ML
Capacity	103 GL at FSL 337 m (Apx Figure B.19)
Reservoir yield assessment	113 GL at 85% annual time reliability (Apx Figure B.20 and Apx Figure B.21). 130 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability):13 % Ratio of evaporation to water supplied (at 85% annual time reliability): 0.1
Open water evaporation	Mean annual evaporation is estimated to be 4.7 mm d^{-1} Using bulk aerodynamic formulae. Mean annual evaporation was estimated to be 5.2 mm d^{-1} using Morton's APE.
Impacts of inundation on existing infrastructure	The storage area appears to be predominantly grazing country.
Ecological and cultural considerations raised by previous studies	Not previous assessments have been identified.
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>0.66</td><td>4.26</td><td>9.41</td></tr><tr><td>100 years (%)</td><td>2.21</td><td>14.19</td><td>31.35</td></tr><tr><td>Years to infill</td><td>4531</td><td>705</td><td>319</td></tr></table>
Water quality and stratification considerations	The Mount Noble reservoir is predicted to experience weak to moderate persistent thermal stratification during spring and summer each year. The stratification appears to be sensitive to inflow and summer mixing is common. Summer inflow events are likely to cause full water column mixing for short periods (up to 1 week) each year. The risk of blue-green algal blooms is high with Zsl:Zeu ≤ 3 from virtually all year on average. The relatively rapid warming of the deeper waters suggests inflows will play a significant role in the dissolved oxygen dynamics of this storage. The duration of stratification and mixing behaviour suggests this storage is low to moderately susceptible to low dissolved oxygen conditions and associated water quality issues.
Environmental considerations	This potential dam site has a large catchment area and the Einasleigh River reach on which its sits has numerous large permanent waterholes. Anecdotal evidence suggests this location may be within the distribution of barramundi and possibly freshwater sawfish but this would

PARAMETER	DESCRIPTION
	require further investigation. The site is likely to cover only a small proportion of ecosystems of "Of Concern", and larger proportions of "Non-Remnant" and "Not of Concern" regional ecosystems (Apx Figure B.22). *Ecosystem Of Concern* The region supports riverine wetlands (sometimes ephemeral), fringed by grasses and sedges or with a fringing woodland which can contain *Eucalyptus camaldulensis* or *E. tereticornis* or *Melaleuca fluviatilis*. Major vegetation communities including palustrine wetland (e.g. vegetated swamp), wetlands (sometimes ephemeral), often with a fringing woodland which can contain *Eucalyptus camaldulensis* or *E. tereticornis*, *Eucalyptus platyphylla*, *E. leptophleba*. Fringing vegetation can also includes a sub-canopy layer which can contain *Melaleuca spp*. Alternatively the fringing woodland species can occur as emergent *Casuarina spp*.. Ground layer species present include *Marsilea hirsuta*, *Schoenoplectus spp*. and *Eleocharis spp*. This unit may have areas of grassland included.
Estimated cost	$340 m to $560 m (cost of dam only) No previous cost estimates have been located.
Estimated cost / ML of supply	$3322/ML at 85% annual time reliability (does not include transmission/distribution losses or take into account environmental and downstream entitlements).
Summary comment	Of the three Mount Noble sites, the most downstream site appears to be geologically the most suitable for a dam, particularly for a higher dam. However, the upstream site has much better storage characteristics. At the upstream site the basalt to the east of the right abutment would require thorough investigation.

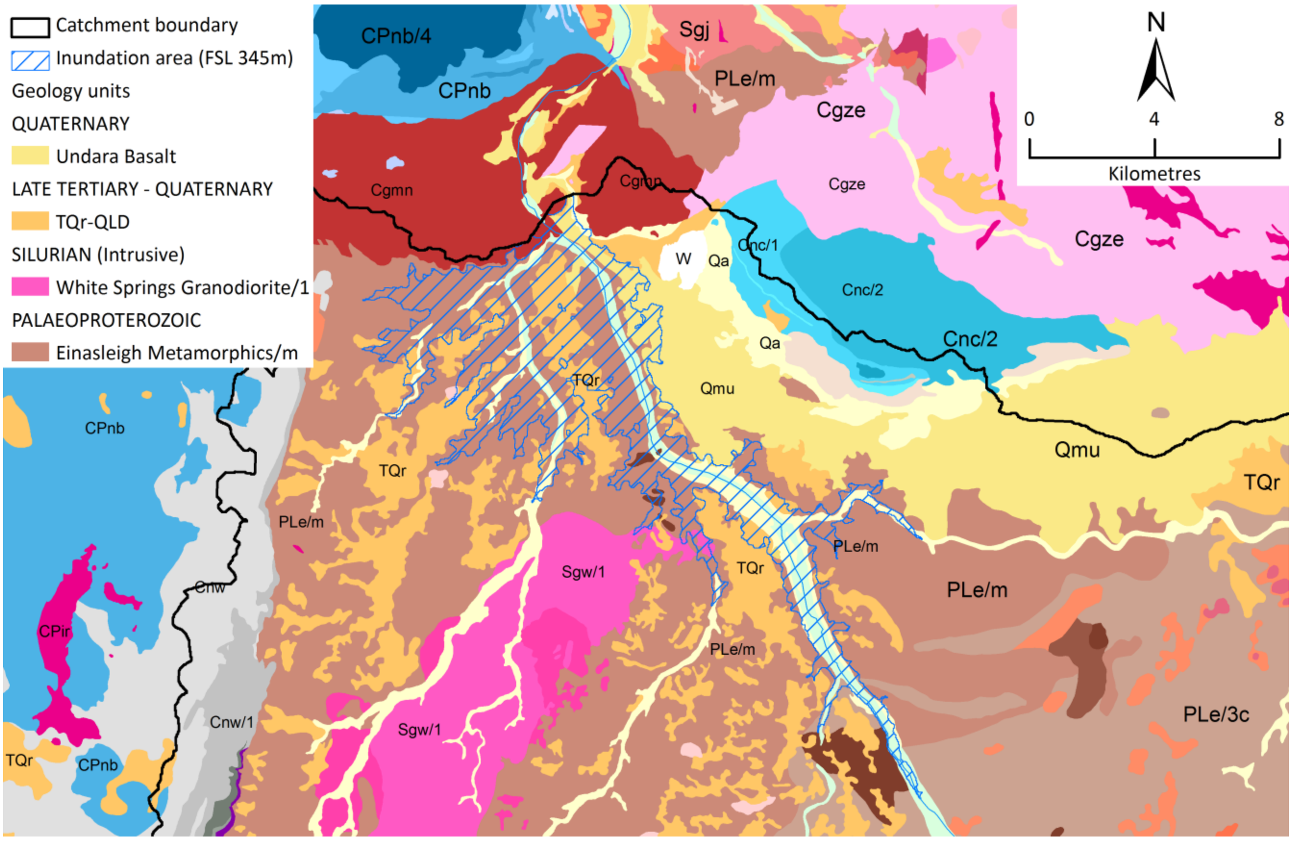
Apx Figure B.15 Mount Noble downstream potential dam site, looking upstream



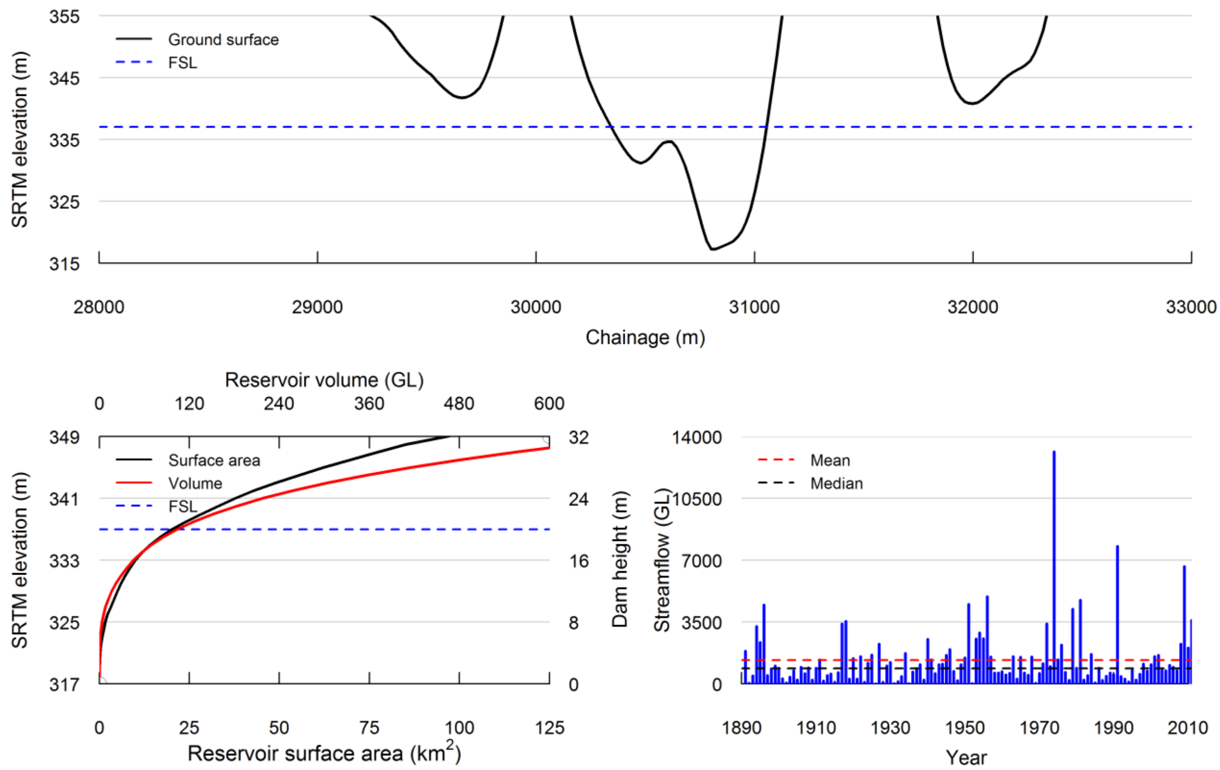
Apx Figure B.16 Location map of Mount Noble upstream dam, reservoir and catchment area



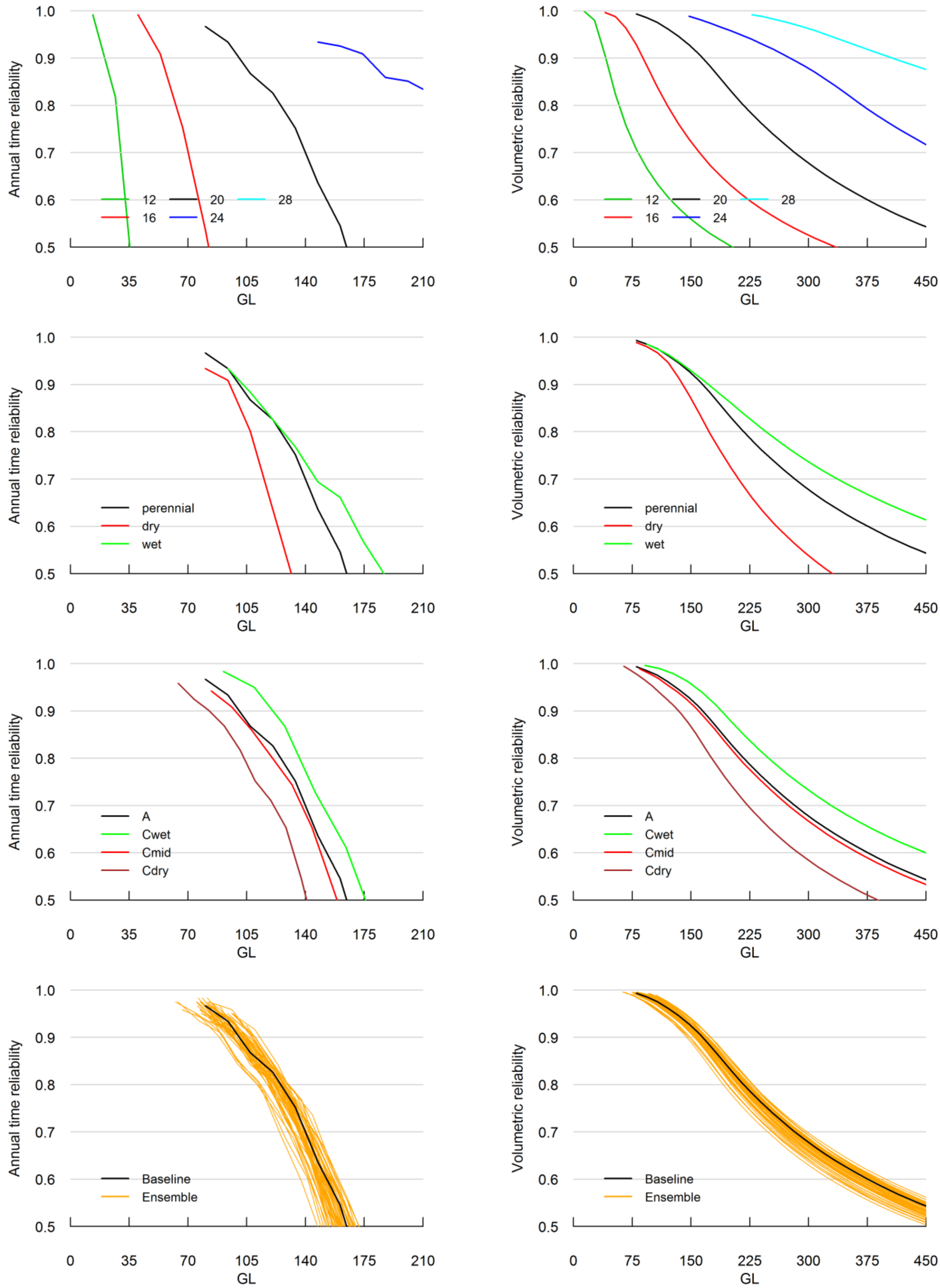
Apx Figure B.17 Mount Noble upstream dam depth of inundation and property boundaries (indicated by coloured shading)



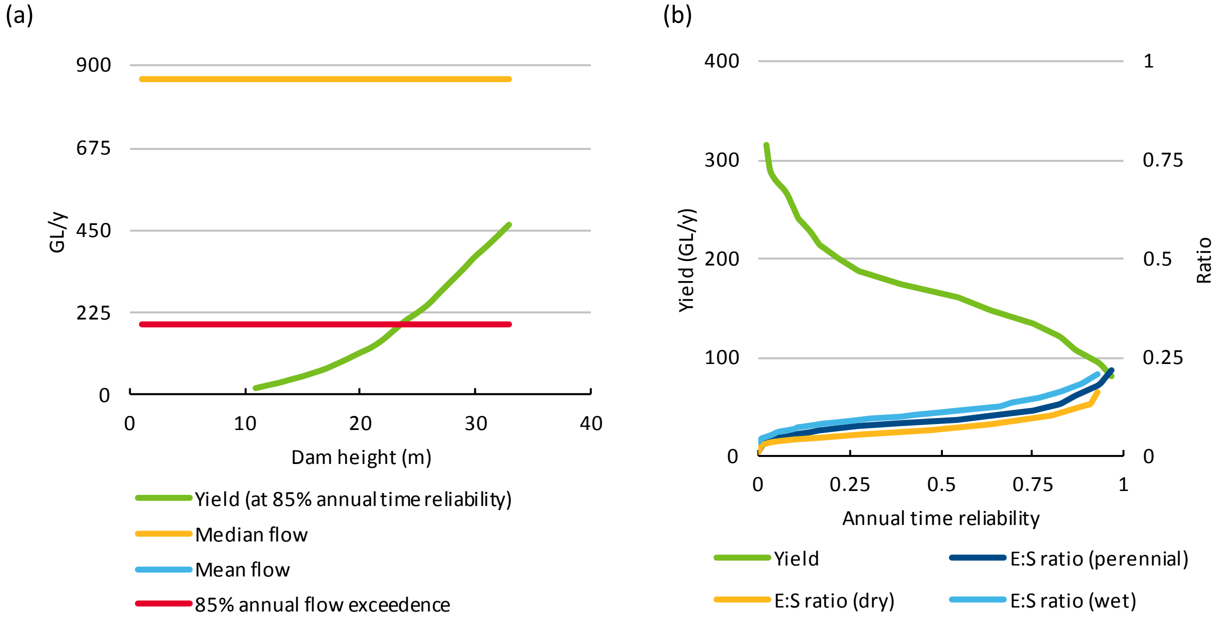
Apx Figure B.18 Mount Noble upstream potential dam underlying geology



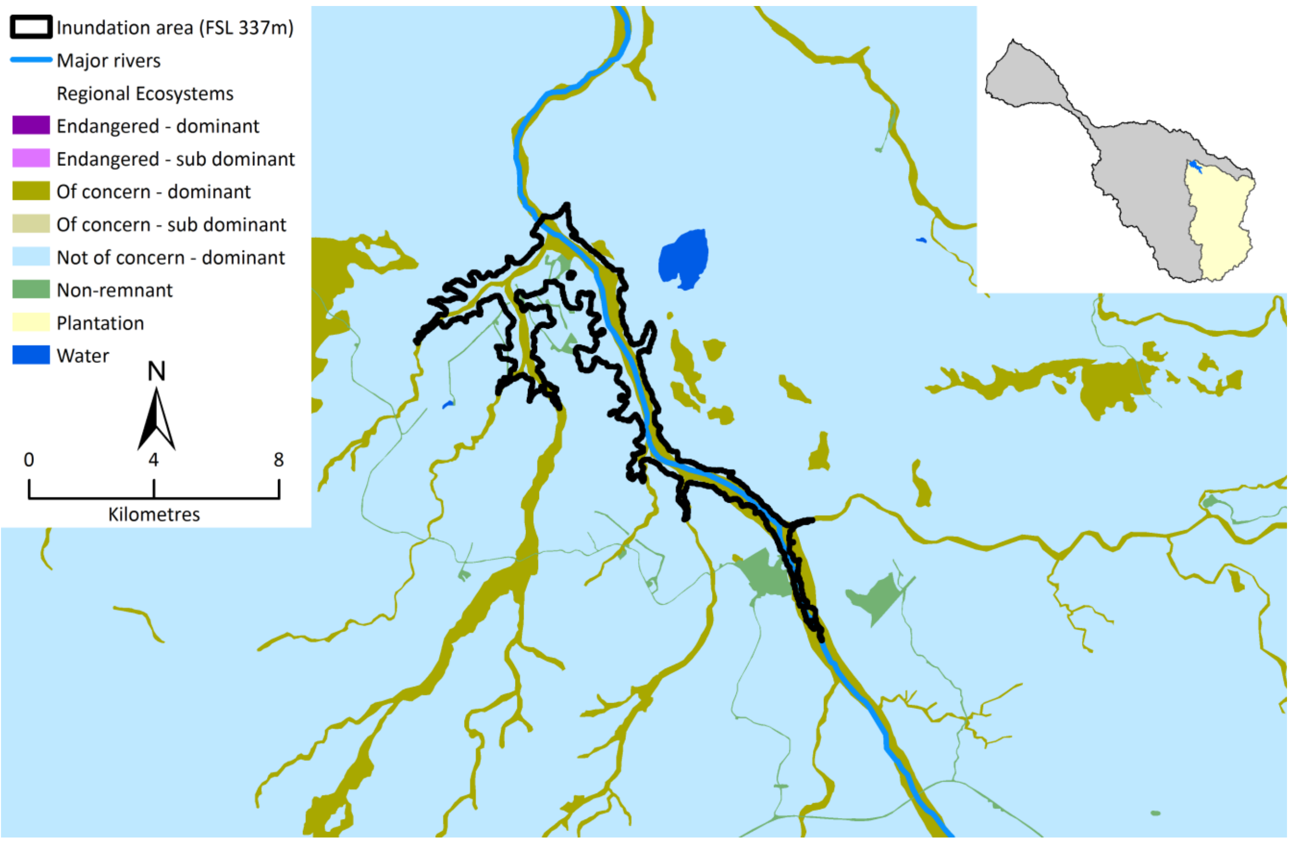
Apx Figure B.19 Cross section along main dam axis, volume surface area height relationship and annual streamflow at Mount Noble upstream potential dam site



Apx Figure B.20 Mount Noble potential dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 337 m FSL. Third row: YRR under Scenario C for 337 m FSL. Fourth row: YRR for baseline and ensemble model runs for 337 m FSL



Apx Figure B.21 a) Yield at 85% annual time reliability and streamflow at Mount Noble dam site for different dam heights; (b) Yield and evaporation : water supply ratio at Mount Noble dam site for different annual time reliability for the selected dam height of 20 m



Apx Figure B.22 Mount Noble dam upstream regional ecosystems mapping

North Head (upstream) dam site on Gilbert River; 433.2 km

PARAMETER	DESCRIPTION
Previous investigations	DNR (1998) Engineering Assessment of Storage Options. DNR (1999a) Feasibility Study for Dams and Weirs on Bundock Creek and Gilbert River- State Water Projects. DNR (1999b) Preliminary Geotechnical Assessment of Dam and Weir Sites on Bundock Creek and Gilbert River – State Water Projects.DNRME (2004). Agricultural Land and Water Assessment Report, Gulf and Mitchell Water Resource Planning, May 2004.
Description of proposal	An on stream dam located on the Gilbert River. Two potential sites exist, an upstream and a downstream site. The upstream site was selected for analysis here due to geological challenges with the downstream site. The height of the dam spillway was selected to be 30 m above bed level (FSL 344) as this is similar to the original proposal. A location map and map showing the inundated area at FSL are shown in Apx Figure B.23 and Apx Figure B.24 respectively.
Regional geology	The rock in the area is part of the Etheridge Group of Proterozoic Age. The two major formations here are the Dead Horse Meta-basalt and the Lane Creek Formation. The Dead Horse Meta-basalt represents basaltic flows and their pyroclastic equivalents that have been metamorphosed up to amphibolite facies. The Lane Creek Formation consists of cleaved mudstone and siltstone. Metamorphic grade increases to the east causing the rock to become phyllitic and then schistose in character. Both of these units are overlain by the Hampstead Sandstone of Jurassic age. This unit forms spectacular mesa and gorge country in the region. Apx Figure B.25 shows the geology underlying the dam wall and inundation area. Where the catchment boundary and inundated area join illustrates the location of the main dam wall and saddle dams.
Site geology	The upstream site has been investigated by seismic refraction survey. Rock at the site consists of meta-basalt or meta-dolerite of the Dead Horse Meta-basalt. The rock is extremely high strength when fresh or slightly weathered. The left abutment is underlain by meta-dolerite with a thin soil cover. The riverbed contains thin pockets of sand and gravel between pinnacled outcrops of fresh meta-dolerite. Terrace alluvium consisting of gravel and cobbles underlies the right abutment. About 500 m from the stream channel the soil changes from alluvial to residual in character. The total depth to rock as indicated by seismic refraction survey, ranges from 10 to 18 m on the right abutment but is less than 2 m on the left abutment. No investigations have been carried out at the downstream site. Based on a brief site inspection, the riverbed section consists of sand and gravel overlying cleaved mudstone of the Lane Creek Formation. The abutments consist of steep sandstone and conglomerate cliffs belonging to the Hampstead Sandstone. The unconformity between the two formations is exposed at the base of the cliffs. The rock in the cliffs has separated along joint planes. Vertical joints adjoining the river have opened up to 1 m because of rotation of the blocks on the weak mudstone below. If this site is considered, abutment stability should be investigated at the feasibility stage.
Reservoir rim stability and leakage potential	At the upstream site, the reservoir rim is within terrain mostly underlain by the Dead Horse Meta-basalt, Lane Creek Formation and Hampstead Sandstone. There is potential for instability where the reservoir level overlaps the unconformity between the Lane Creek Formation and the Hampstead Sandstone. However, at this site, the locations where this occurs are remote from the dam and there are unlikely to be adverse consequences if slope failure does occur. At the downstream site, there is a significant potential for instability close to the main dam and the consequences of this should be investigated at the feasibility stage. The potential for reservoir leakage from the upstream site is low. There may be some seepage into the permeable Hampstead Sandstone but this occurs in the upper reaches of the reservoir and is likely to be insignificant. The potential for leakage from the downstream site is high. Near the main dam, joints in the sandstone have opened up and are infilled with sand and gravel. The consequences of this

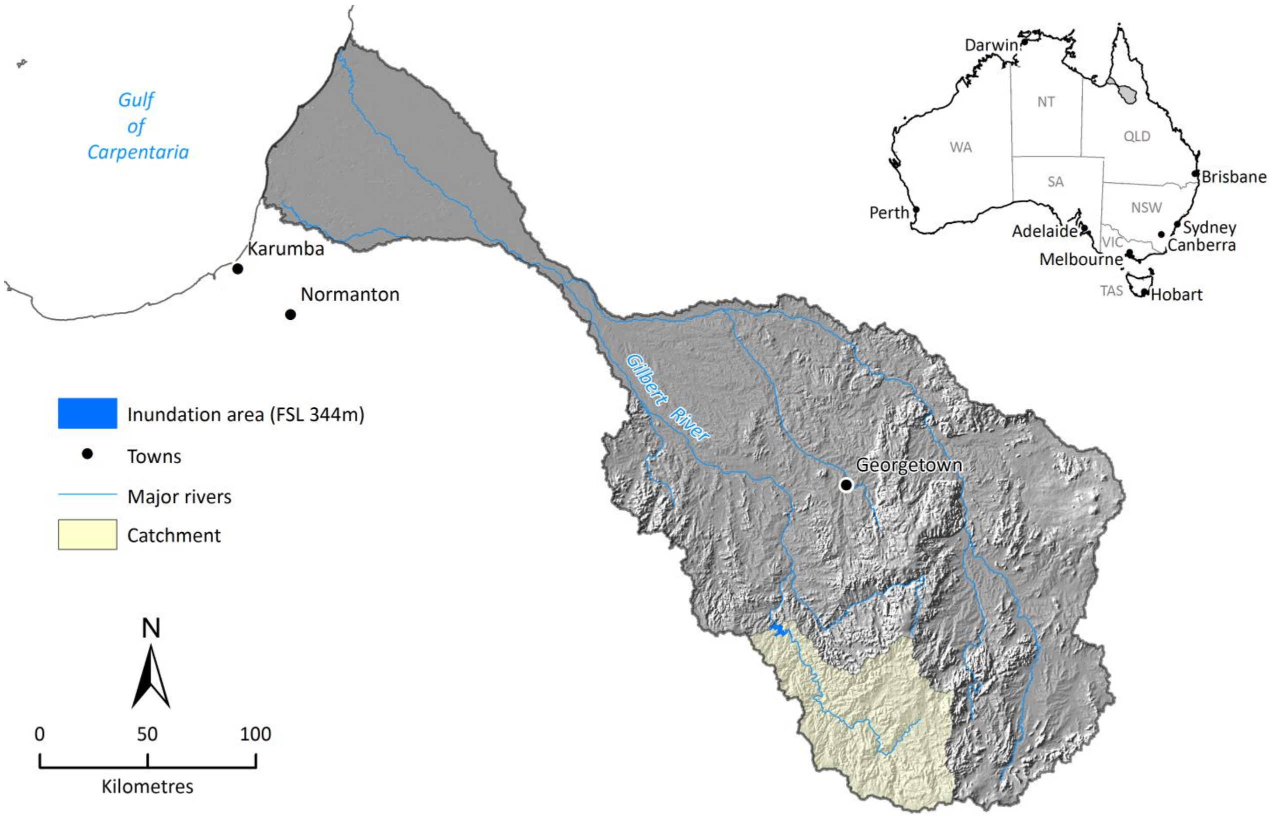
PARAMETER	DESCRIPTION
	leakage should be investigated at the feasibility stage.
Proposed structural arrangement	DNR (1999a) reported that the site is suitable for an earth and rockfill dam (1,610,000 m^3 volume of fill required) but notes that a RCC dam would have a centrally located spillway. Fig. 3 of DNR (1999a) indicates that the embankment would be some 850 m long. An unlined spillway approximately 100 m wide cut through the left abutment returning flow to the river bed some 200 to 300 m downstream of the embankment toe was proposed. Outlet works would be located in the left abutment. Access to the site would be via the existing road from North Head homestead.
Availability of construction materials	No site investigations have been carried out. There are several sites upstream of the dam adjoining the left bank of Elizabeth Creek that appear suitable for development of a quarry for concrete and RCC aggregate. The stream bed upstream of the site contains large quantities of sand and gravel. The alluvial terrace on the right bank is an alternative source for concrete and RCC aggregate. It is unlikely that there are sources of material suitable for an earth core close to the damsite.
Catchment area	The catchment area is 4680 km^2
Flow data	The nearest streamflow gauging station to the site is 917006A, Gilbert River at Percy Junction AMTD 447.4 km (approximately 50 km upstream of the dam site), catchment area 3,317 km^2.- with record from 1970 to 1988. Mean annual flow over the period of record at this location was 468,000 ML (140 ML/a /km^2 of catchment area), - median annual flow was 170,000 ML.
Capacity	136 GL at FSL 344 m (Apx Figure B.26).
Reservoir yield assessment	108 GL at 85% annual time reliability (Apx Figure B.27 and Apx Figure B.28). 112 GL at 95% monthly time reliability Evaporation as percentage of regulated flow (at 85% annual time reliability): 12% Ratio of evaporation to water supplied (at 85% annual time reliability): 0.1
Open water evaporation	Mean annual evaporation is estimated to be 4.9 mm d^{-1}. Mean annual evaporation was estimated to be 4.7 mm d^{-1} using Morton's APE.
Impacts of inundation on existing infrastructure	The potential storage area appears to be grazing country.
Ecological and cultural considerations raised by previous studies	No specific assessments have been found.

Estimated rates of reservoir sedimentation

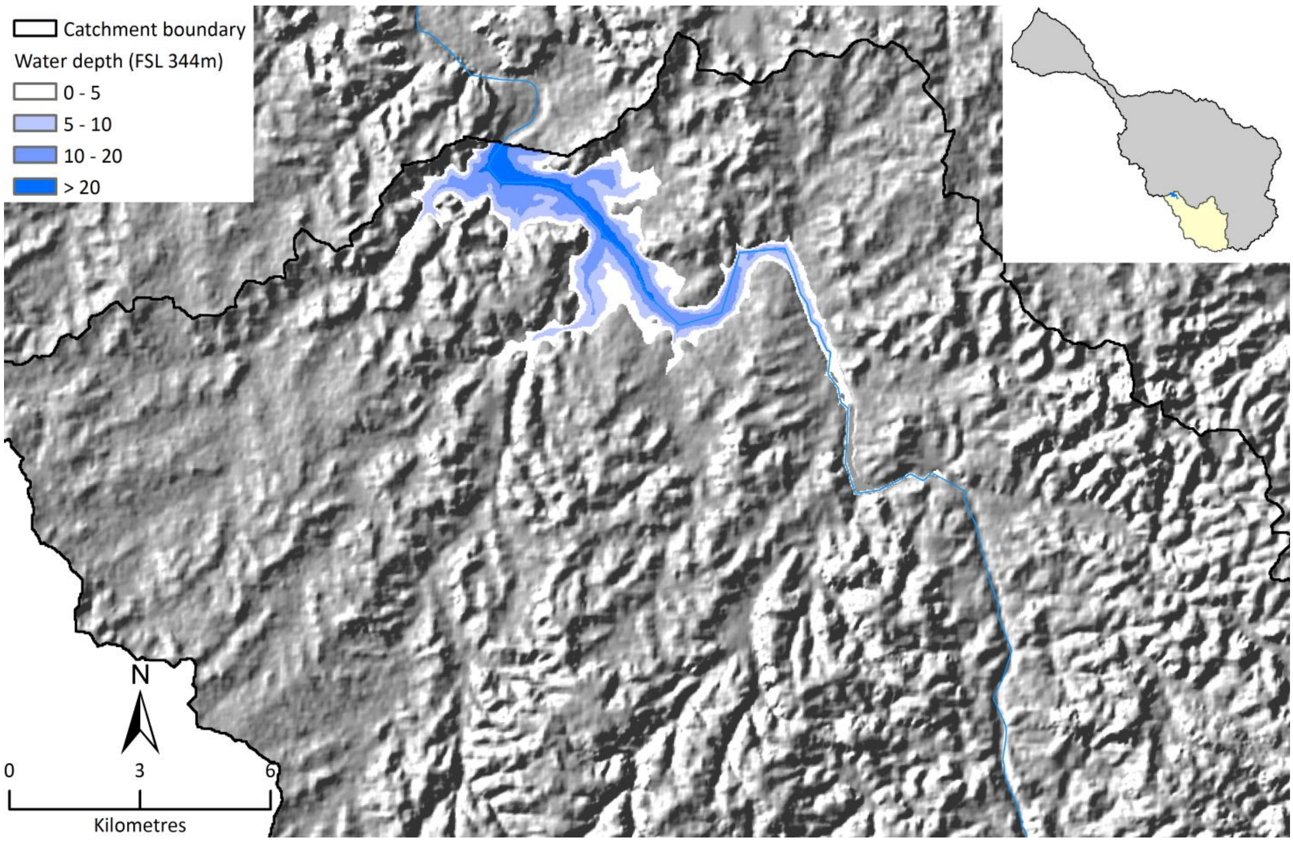
	Best case	Expected	Worst case
30 years (%)	0.13	0.69	1.83
100 years (%)	0.43	2.30	6.10
Years to infill	23279	4345	1639

PARAMETER	DESCRIPTION
Water quality and stratification considerations	The North Head reservoir is predicted to be strongly stratified during the entire year. Inflows entering the bottom of the reservoir help to maintain a strong temperature difference of roughly 10 °C. Some stratification appears to persist even through winter. Although the water column is not predicted to mix completely each year, winter surface layer depths are sufficiently deep to keep Zsl:Zeu > 3 from May through August. The risk of blue-green algal blooms is moderate-high with Zsl:Zeu between 2 and 3 from September through April. The very long duration of stratification and weak mixing behaviour suggests this storage is highly susceptible to anoxic conditions and associated water quality issues. However, the role of inflows resupplying oxygen at depth is likely to be important and may reduce the severity of oxygen depletion and associated metal and nutrient release from the sediments.

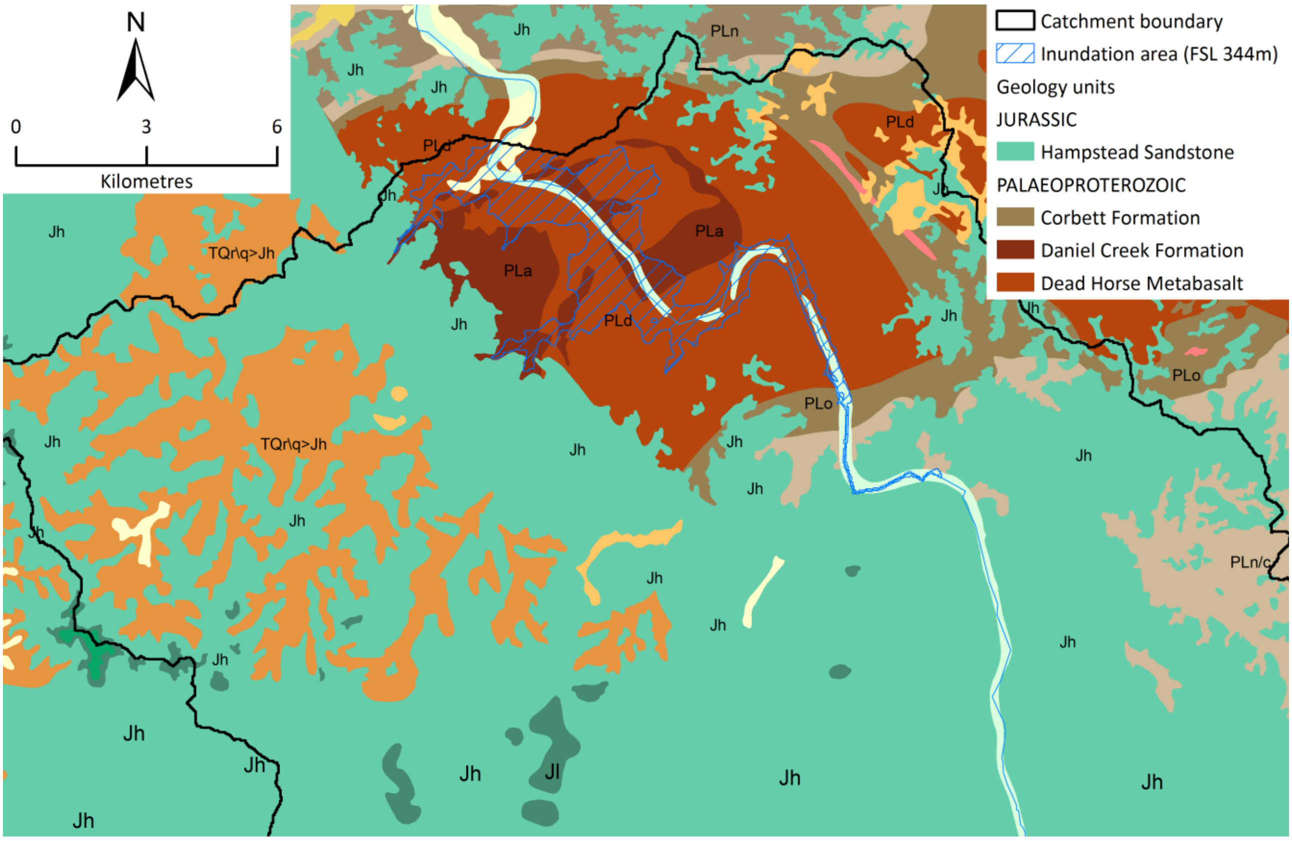
PARAMETER	DESCRIPTION
Environmental considerations	This potential dam site captures a large catchment area. This site on the Gilbert River hosts much less instream habitat than similarly-located dam options on the Einasleigh River. Anecdotal evidence suggests this location may be within the distribution of barramundi and possibly freshwater sawfish. A dam in this location may therefore require a fish transfer facility. The site is likely to cover a relatively small proportion of ecosystems "Of Concern" along the river. Apx Figure B.29shows the distribution of these and areas of less concern at the site. *Ecosystems Of Concern* Riverine wetland with sandy river beds sometimes with patches of ephemeral grassland, herbland or sedgeland, which can include *Heteropogon contortus*, *Bothriochloa spp*., and *Ammannia multiflora*. There can be clumps of shrubs (or isolated emergents), which can include *Lophostemon grandiflorus*, *Melaleuca spp*., *Eucalyptus camaldulensis* and *Casuarina cunninghamiana*. Proposed site also supports fringing open-forest to low woodland containing combination of *Melaleuca argentea*, *M. fluviatilis*, *M. leucadendra*, *Eucalyptus camaldulensis*, *Casuarina cunninghamiana*, *Lophostemon grandiflorus*, *Corymbia spp*. In eastern areas *E. tereticornis* may replace *E. camaldulensis*. There can be an open sub-canopy, which can include canopy species *M. linariifolia*, *M. bracteata*, *Lysiphyllum sp*., *Ficus opposita* and *Acacia spp*. Low woodlands of *M. bracteata* with emergent *Eucalyptus spp*. also occur. The shrub layer can vary from none to scattered juvenile canopy spp., *Acacia holosericea* and/or other Acacia spp. and *Planchonia careya*. The ground layer on the steep banks is grassy and includes *Heteropogon spp*., *Arundinella spp*., *Eragrostis spp*. and *Cyperus spp*. but its presence is seasonally dependent.
Estimated cost	$290 m to $490 m (dam cost only) Previous costs DNR (1999a) reported an estimated cost of $47.4 m. CPI adjustment to 2012 prices indicates a cost of $71.1 m. This cost appears to be exceedingly low compared with recent dam project costs, particularly given the remoteness of the site and the project uncertainties.
Estimated cost / ML of supply	$3013/ML at 85% annual time reliability (does not include transmission/distribution losses or take into account environmental and downstream entitlements).
Summary comment	This site is located a long way upstream of soils suitable for irrigation and it is expected that large conveyance losses would occur between the dam and the irrigation area. Hence the estimated cost / ML at the point of extraction is expected to be considerably larger than that stated above.



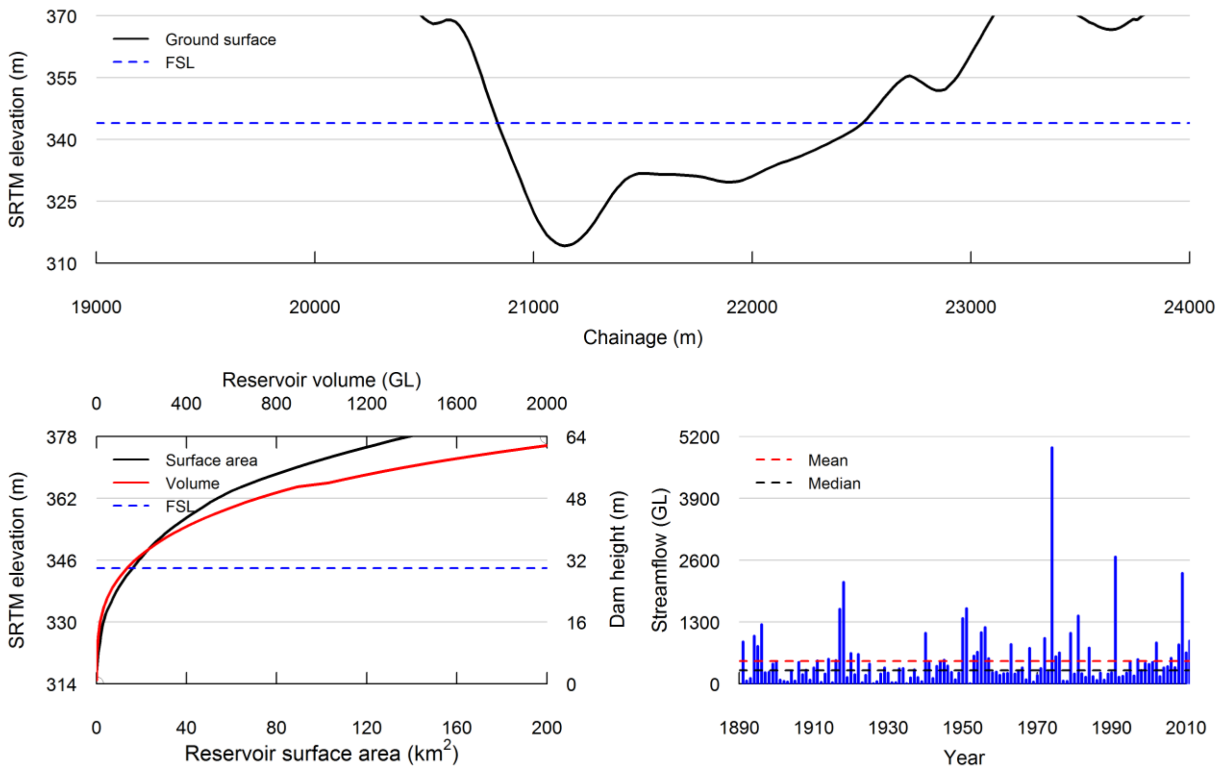
Apx Figure B.23 Location map of North Head upstream potential dam, reservoir and catchment area



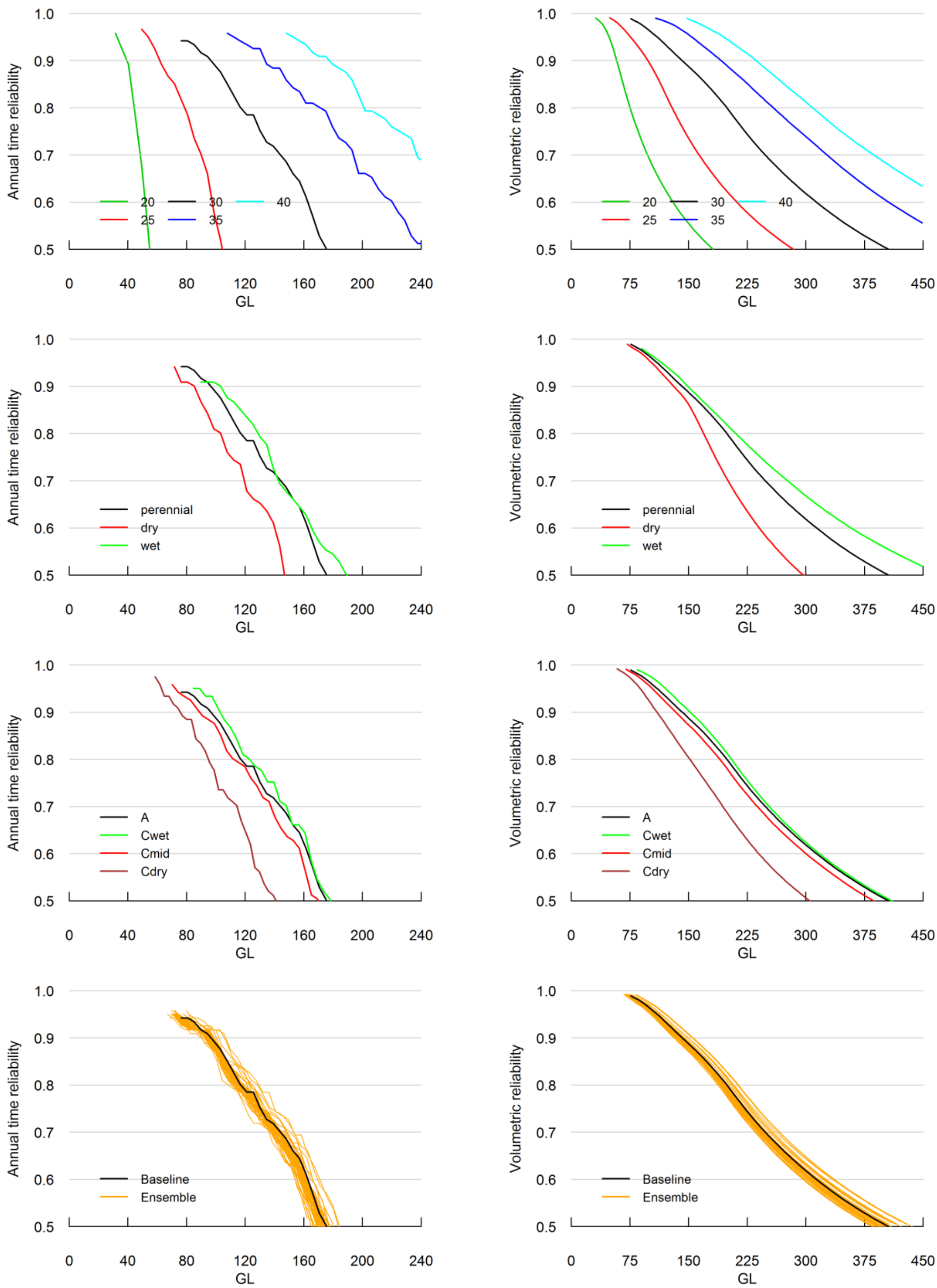
Apx Figure B.24 North Head upstream potential dam depth of inundation and property boundaries



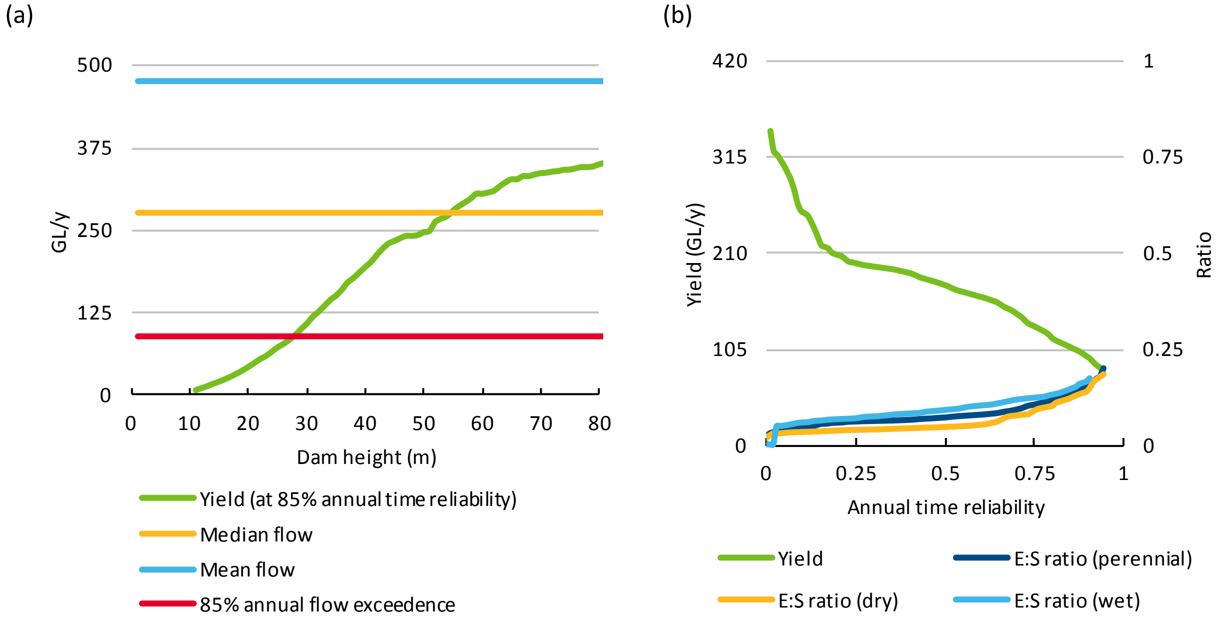
Apx Figure B.25 North Head upstream potential dam underlying geology



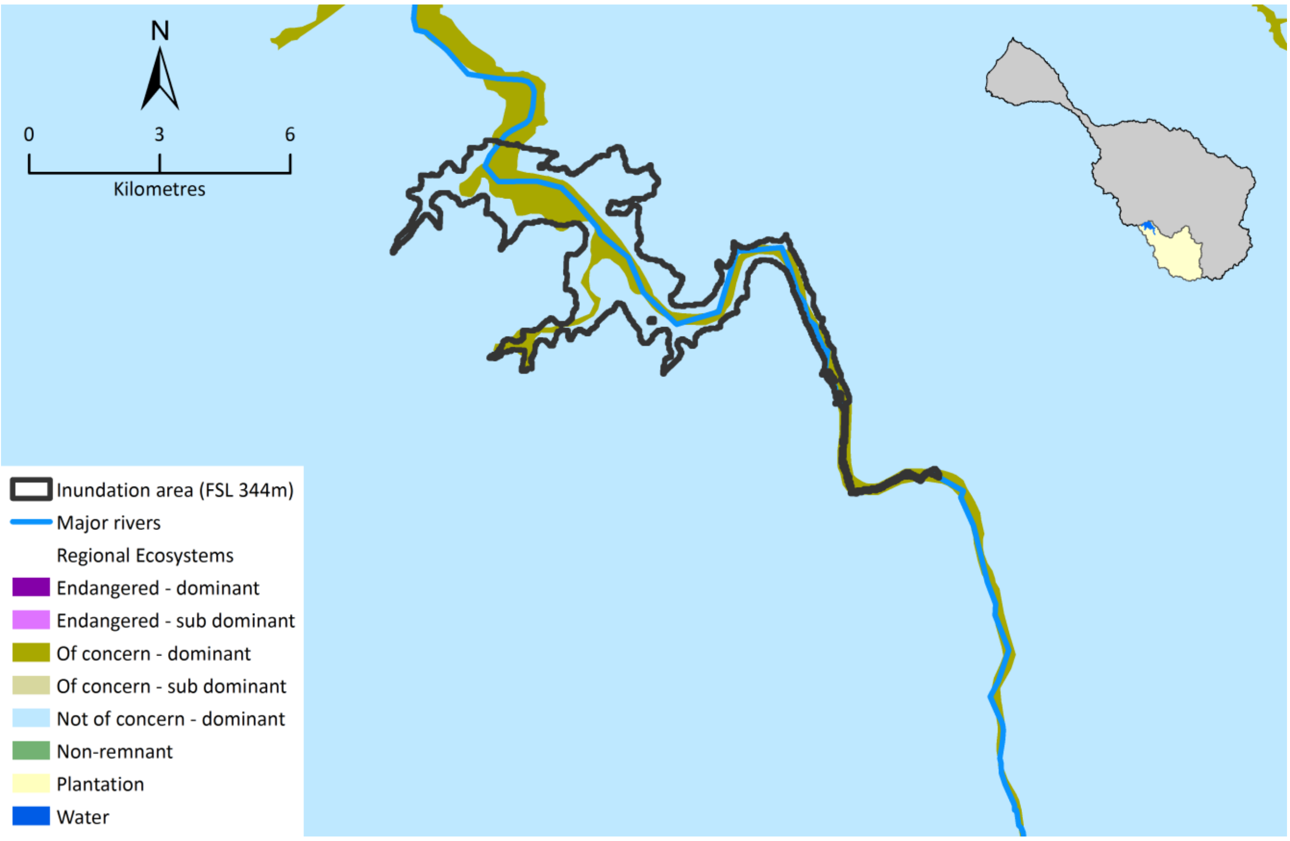
Apx Figure B.26 Cross section along main dam axis, volume surface area height relationship and annual streamflow at North Head upstream potential dam site



Apx Figure B.27 North Head upstream potential dam performance metrics. Perennial demand pattern unless otherwise stated. Top row: YRR for different FSL. Second row: YRR for different demand patterns for 344 m FSL. Third row: YRR under Scenario C for 344 m FSL. Fourth row: YRR for baseline and ensemble model runs for 344 m FSL



Apx Figure B.28 a) Yield at 85% annual time reliability and streamflow at North Head dam site for different dam heights; (b) Yield and evaporation : water supply ratio at North Head dam site for different annual time reliability for the selected dam height of 30 m



Apx Figure B.29 North Head (upstream) dam regional ecosystems mapping

Appendix C Flinders short-listed dam costings

This appendix provides detailed costings for the three short-listed dams in the Flinders catchment.

Cave Hill dam

Table C.1 Cave Hill dam, Cloncurry River – Direct Construction Costs

DIRECT CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
General	Environmental management	Lump sum			600,000
	Cultural heritage management	Lump sum			500,000
	Community consultation	Lump sum			150,000
Mobilisation and Demobilisation	Establishment of workforce accommodation	Lump sum			5,000,000
	Establishment of survey control	Lump sum			200,000
	Establish construction power supply	Lump sum			1,000,000
	Establish communications	Lump sum			200,000
	Mobilisation of major plant	Lump sum			2,000,000
	Demobilisation of major plant	Lump sum			500,000
	Demobilisation of workforce accommodation	Lump sum			2,000,000
	Clear site and 20% of storage area	ha	670	500	335,000
	Mobilise/demobilise site laboratory	Lump sum			250,000
Access	Develop access road from Flinders Highway	km	7	400,000	2,800,000

Table C.2 Cave Hill dam, Cloncurry River – Construction Costs

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
Material Sources	Remove quarry overburden	Lump sum			100,000
	Develop quarry	Lump sum			200,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Access road to quarry	km	2	400,000	800,000
	Access road to sand gravel sources	km	1.5	400,000	600,000
Diversion and Care of River	Excavate right abutment trench for diversion conduit	m^3	3,900	60	234,000
	Excavation for coffer dams	m^3	22,400	20	448,000
	Place embankment fill to coffer dams	m^3	62,100	30	1,863,000
	Dewatering	Lump sum			300,000
	Divert stream	Lump sum			100,000
	Removal of coffer dams	cu m	39,700	20	781,000
Foundations	Excavation of OTR from river bed	m^3	75,000	15	1,125,000
	Excavation of rock from abutments	m^3	71,000	25	1,755,000
	Foundation clean up and treatment	m^2	6,670	100	667,000
Seepage Control Abutments	Drill and grout holes	m	7,510	100	751,000
	Supply and install standpipes	no	760	120	91,000
	Hook ups and pressure tests	no	760	320	243,000
	Pressure grouting	bags	24,000	35	840,000
Cross River Section	Slurry trench cut off	sq m	1,820	1,000	1,820,000
Embankment Construction	Place Zone 1 material	m^3	118,000	20	2,360,000
	Place Zone 2 filters	m^3	141,000	15	2,115,000
	Place Zone 3 material	m^3	435,000	25	10,875,000
	Place Zone 3B material to US face	m^3	42,300	40	1,692,000
	Place weighting zone material	m^3	48,600	10	486,000
	Embankment instrumentation	Lump Sum			400,000
Outlet Works	Intake tower concrete	m^3	345	800	276,000
	Intake tower reinforcement	tonne	20	7,000	140,000
	Intake tower guides and seals	tonne	10	20,000	200,000
	Trash racks	tonne	10	14,000	140,000
	Selective withdrawal	tonne	8	12,000	96,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	baulks				
	Bulkhead gate	tonne	3	10,000	30,000
	Hoist crane, install and commission	Lump sum			300,000
	Ladders and platforms	tonne	5	14,000	70,000
	Access bridge deck	m²	180	5,000	900,000
	Bridge pier and abutment concrete	m³	70	800	56,000
	Supply and install 2.0m diameter by 12plate CL pipe	tonne	60	10,000	600,000
	Outlet conduit concrete encasement	m³	2,650	350	927,000
	Outlet conduit concrete reinforcement	tonne	105	6,000	630,000
	Outlet works drill holes for anchor bars	m	500	60	30,000
	Supply and install anchor bars	tonne	5	6,000	30,000
	Concrete to outlet works floor and walls	m³	200	800	160,000
	Reinforcement to outlet works	tonne	12	6,000	72,000
	Outlet works pipework	Lump sum			100,000
	Butterfly valves and actuators	no	2	200,000	400,000
	Fixed cone regulating valves	no	2	400,000	800,000
	Electrical installations	Lump sum			350,000
Fish Transfer Facility	Concrete to intake channels, hopper chamber and valve pit	m³	700	500	350,000
	Reinforcement to intake channels, hopper chamber and valve pit	tonne	35	6,000	210,000
	Fish attraction pipework, valves and diffusers	Lump sum			1,000,000
	Fish traps	Lump sum			1,000,000
	Fish lift hopper	no	2	500,000	1,000,000
	Hopper tracks	Lump sum			2,000,000
	Overhead crane at crest	Lump sum			1,000,000
	Monitoring and control equipment	Lump sum			350,000
	Electrical and mechanical	Lump sum			200,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	installations				
	Fish lift commissioning	Lump sum			200,000
Spillway	Excavation for spillway channel	m^3	655,000	25	16,375,000
	Foundation treatment and clean up	m^2	32,500	60	1,950,000
	Drill and grout holes	m	1,896	100	190,000
	Supply and install standpipes	no	196	120	24,000
	Hook ups and pressure tests	no	196	320	63,000
	Pressure grouting	bags	3,800	35	133,000
	Drill for anchor bars to crest and apron	m	15,800	60	948,000
	Supply and install anchor bars	tonne	158	6,000	948,000
	Concrete to spillway crest	m^3	4,260	450	1,917,000
	Concrete to spillway apron	m^3	10,920	380	4,150,000
	Concrete to training walls	m^3	1,400	500	700,000
	Reinforcement to aprons and walls	tonne	490	6,000	2,940,000
Spillway Chute and Drop Structure	Excavation	m^3	530,400	20	10,608,000
	Trim drop face	m^2	1,300	100	130,000
	Concrete control sill	m^3	705	380	268,000
	Drill for anchor bars to face and apron	m	2,960	60	178,000
	Supply and install anchor bars	tonne	30	6,000	180,000
	Shotcrete to face	m^3	400	800	320,000
	Conventional concrete to apron	m^3	1,410	380	536,000
	Reinforcement	tonne	95	6,000	570,000
	Rip rap	m^3	1,410	40	56,000
LB Saddle dam	Foundation excavation	m^3	22,100	20	442,000
	Place Zone 1fill material	m^3	17,400	20	348,000
	Place Zone 2 fill material	m^3	26,100	15	392,000
RB Saddle dam	Foundation excavation	m^3	93,800	20	1,876,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Drill and grout holes	m	3,420	100	342,000
	Supply and install standpipes	no	570	120	68,000
	Hook ups and pressure tests	no	570	320	182,000
	Pressure grouting	bags	6,840	35	239,000
	Foundation clean up and treatment	m^2	7,240	100	724,000
	Place Zone 1 material	m^3	72,900	20	1,458,000
	Place Zone 2 material	m^3	61,000	15	915,000
	Place Zone 3 material US and DS	m^3	236,000	25	5,900,000
	Place Zone 3B material US	m^3	30,500	35	1,067,000
Total Direct Construction Costs (TDC)					126,550,000

Table C.3 Cave Hill dam, Cloncurry River – On Site Overheads

ON SITE OVERHEADS		UNIT	QUANTITY	RATE	AMOUNT
On Site Overheads	Project and field staff	Lump sum	3% of TDC		3,796,500
	Staff recruitment and training	Lump sum	0.6% of TDC		759,300
	Camp operations	Lump sum	3.5% of TDC		4,429,250
	Site office expenses	Lump sum	0.6% of TDC		759,300
	Site water and power expenses	Lump sum	0.1% of TDC		126,550
	Site communication, IT expenses	Lump sum	0.45% of TDC		569,475
	Site cleaning, rubbish removal	Lump sum	0.04% of TDC		50,620
	Project control testing	Lump sum			900,000
	Misc. travel expenses	Lump sum	0.2% of TDC		253,100
	Insurances, public liability	Lump sum	3.4% OF TDC		4,302,700
Total On Site Overheads (OSO)					15,946,795
TDC and OSO Costs					142,496,795
Profit and Off Site Overheads (10% of TDC and OSO)					14,249,680
Total Out Turn Costs (TOC)					156,746,475

Table C.4 Cave Hill dam, Cloncurry River – Owner Costs

OWNER COSTS		UNIT	QUANTITY	RATE	AMOUNT
Investigation and Design	Preliminary design	Lump sum	0.5% of TDC		632,750
	Geotechnical and materials	Lump sum	2.0% of TDC		2,531,000
	Hydraulic model study	Lump sum			500,000
	Detailed design and documentation	Lump sum	2.5%of TDC		3,163,750
Acquisition and Approvals	Environmental assessment and approvals	Lump sum			4,000,000
	Cultural heritage	Lump sum			2,000,000
	Native title	Lump sum			1,000,000
	Storage area acquisition	ha	8,000	1,000	8,000,000
	Access relocations storage area	Lump sum			2,500,000
	Surveys and legals	Lump sum			2,000,000
Permanent Onsite Buildings and Services					2,000,000
Principal's Insurances (1.1% of TOC)					1,724,211
Owners Management and Supervision (0.15% of TOC)					235,120
Total Owners Costs					30,286,831
Total Project Costs (TPC)					187,033,305
Risk Adjustment					61,720,991
TOTAL CAPITAL COST					$249 million

O’Connell Creek offstream storage

Table C.5 O’Connell Creek Off Stream Storage – Direct Construction Costs

DIRECT CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
General	Environmental management	Lump sum			600,000
	Cultural heritage management	Lump sum			500,000
	Community consultation	Lump sum			150,000
Mobilisation and Demobilisation	Establishment of workforce accommodation	Lump sum			5,000,000
	Establishment of survey control	Lump sum			200,000
	Establish construction power supply	Lump sum			1,000,000
	Establish communications	Lump sum			200,000
	Mobilisation of major plant	Lump sum			2,000,000
	Demobilisation of major plant	Lump sum			500,000
	Demobilisation of workforce accommodation	Lump sum			2,000,000
	Clear site and 20% of storage area	ha	670	500	335,000
	Mobilise/demobilise site laboratory	Lump sum			250,000
Access	Develop access road from Flinders Highway	km	7	400,000	2,800,000

Table C.6 O’Connell Creek Off Stream Storage – Construction Costs

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
Flinders River Diversion Weir	Clearing	ha	8	2,000	16,000
	Coffer dams	Lump sum			250,000
	Diversion and care of river	Lump sum			500,000
	Dewatering	Lump sum			200,000
	Excavation	m^3	15,000	10	150,000
	Sheet piling supply to site	tonnes	530	18,000	9,450,000
	Sheet piling driving	m^2	4,350	350	1,522,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Concrete to crest slab 1	m³	225	600	135,000
	Concrete to crest slab 2	m³	900	550	495,000
	Concrete to crest slab 3	m³	300	600	180,000
	Concrete to crest slab 4	m³	450	700	315,000
	Concrete to wing walls	m³	940	850	799,000
	Concrete to training walls	m³	240	850	204,000
	Concrete to piers	m³	1,050	950	997,000
	Reinforcement	tonnes	205	6,500	1,332,000
	Guides and seals	tonnes	8	20,000	160,000
	Hoist deck	m²	325	1,000	325,000
	Access deck	m²	325	1,000	325,000
	Vertical lift gates 5 off 13m wide 5.8 m high	tonnes	100	14,000	1,400,000
	Gate hoists	Lump sum			500,000
	Mechanical and electrical	Lump sum			300,000
	Fish ladder concrete	Lump sum	120	1,500	180,000
	Reinforcement	tonnes	6	7,000	42,000
	Baffles	item	80	500	40,000
	Cover gratings	Lump sum			20,000
	Backfill to wing walls	m³	3,430	40	137,000
	Mattress erosion protection	m²	1,500	80	120,000
	Block weirs	Lump sum			400,000
	Control building	Lump sum			500,000
Diversion Channel (150 m³/s Capacity)	Clearing	ha	34	1,250	42,000
	Fencing	km	4.8	20,000	96,000
	Bulk excavation and disposal	m³	2,017,000	10	20,170,000
	Berm road surfacing	m³	3,240	80	259,000
	Berm drains	no	30	20,000	600,000
	Sheet piling cut off	tonne	81	1,800	146,000
	Drive steel sheet piling	m²	675	400	270,000
	Concrete to control structure floor	m³	1,400	400	960,000
	Concrete to US and DS head walls	m³	720	550	396,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Concrete to conduit surrounds	m³	1,615	500	808,000
	Concrete to inlet walls	m³	235	750	176,000
	Concrete to deck piers and corbels	m³	1,050	700	735,000
	Concrete to dissipator floor and walls	m³	510	600	306,000
	Reinforcement	tonnes	220	6,000	1,320,000
	Road and service decks	m²	430	4,000	1,720,000
	Guardrails	m	270	500	135,000
	Trash racks	tonnes	30	14,000	420,000
	Gate guides and seals	Lump sum			300,000
	Vertical lift gates and hoists	no	3	250,000	750,000
	Bulkhead gate	Lump sum			100,000
	Miscellaneous metalwork	Lump sum			100,000
	M and E equipment	Lump sum			250,000
	Backfill behind walls to channel batters	m³	7,680	50	384,000
	Rip rap erosion protection	m³	1,300	60	78,000
O'Connell Creek Embankment Foundation Preparation	Clear and grub	ha	24	1,250	29,000
	Stripping-	m³	116,000	6	696,000
	Cut-off excavation	m³	84,000	8	672,000
	Backfill cut-off	m³	63,000	15	945,000
	Bentonite slurry cut-off wall	m²	10,400	600	6,240,000
	Pressure relief wells @ 50m centres	no	60	5,000	300,000
	Toe drainage collection system	m	3,500	60	210,000
Embankment	Earth-fill	m³	724,000	12	8,690,000
	U/S weighting zone fill	m³	82,200	8	658,000
	D/S weighting zone fill	m³	42,400	8	339,000
	Chimney filter and drainage blanket	m³	211,700	40	8,470,000
	U/S slope protection	m³	133,700	45	6,020,000
	D/S slope protection	m³	26,700	90	2,400,000
	Gravel pavement	m³	5,250	80	420,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Instrumentation	Item			400,000
Spillway Over Embankment	Excavate embankment for spillway chute	m^3	95,000	15	1,425,000
	Excavate for discharge channel	m^3	10,000	10	100,000
	Trim and compact bank	m^2	25,000	5	125,000
	Under drainage system	m	2,000	100	200,000
	Drill for anchor bars crest and apron slabs	m	19,500	30	580,000
	Supply and install anchor bars	tonnes	95	6,000	570,000
	Concrete crest structure	m^3	4,290	450	1,930,000
	Concrete floor slabs	m^3	7,425	500	3,712,000
	Concrete retaining walls	m^3	1,536	900	1,380,000
	Reinforcement	tonnes	75	6,000	450,000
	Waterstops	m	3,000	180	540,000
	Backfill to retaining walls	m^3	5,400	50	270,000
	Rip rap protection to discharge channel	m^3	9,000	60	540,000
Outlet Works	Excavation including inlet and outlet channel	m^3	144,000	10	1,440,000
	Nom 1.8m diameter MSCL outlet conduit	tonnes	37.5	8,000	300,000
	Concrete surround to conduit	m^3	215	800	172,000
	Movement joints	no	9	5,000	45,000
	Intake tower concrete	m^3	115	1,000	115,000
	Intake tower reinforcement	tonnes	6	7,000	42,000
	Trash rack/guides	Item			120,000
	Bulkhead gate /guides	Item			160,000
	Hoist equipment	Item			250,000
	Access bridge deck	m^2	100	6,000	600,000
	Valve pit concrete	m^3	200	800	160,000
	Valve pit reinforcement	tonnes	10	6,000	6,000
	Pipe specials	Lump sum			50,000
	Guard valves	no	2	200,000	400,000
	Regulating valves	no	2	350,000	700,000
	M and E items	Lump sum			100,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
Total Direct Construction Costs (TDC)					120,021,000

Table C.7 O'Connell Creek Off Stream Storage – On Site Overheads

ON SITE OVERHEADS		UNIT	QUANTITY	RATE	AMOUNT
On Site Overheads	Project and field staff	Lump sum	3.5% of TDC		4,200,735
	Staff recruitment and training	Lump sum	0.6% of TDC		720,126
	Camp operations	Lump sum	3.5% of TDC		4,200,735
	Site office expenses	Lump sum	0.8% of TDC		960,168
	Site water and power expenses	Lump sum	0.25%of TDC		300,053
	Site communication, IT expenses	Lump sum	0.6% of TDC		720,126
	Site cleaning, rubbish removal	Lump sum	0.04% of TDC		48,008
	Project control testing	Lump sum			1,000,000
	Misc. travel expenses	Lump sum	0.2% of TDC		240,042
	Insurances, public liability	Lump sum	4.0% OF TDC		4,800,840
Total On Site Overheads (OSO)					17,190,833
TDC and OSO costs					137,211,833
Profit and Off Site Overheads (10% of TDC and OSO)					13,721,183
Total Out Turn Costs (TOC)					150,933,016

Table C.8 O'Connell Creek Off Stream Storage – Owners Costs

OWNERS COSTS		UNIT	QUANTITY	RATE	AMOUNT
Investigation and Design	Preliminary design	Lump sum	0.5% of TDC		600,105
	Geotechnical and materials	Lump sum	3.0 % of TDC		3,600,630
	Hydraulic model study	Lump sum			200,000
	Detailed design and documentation	Lump sum	3.0%of TDC		3,600,630
Acquisition and Approvals	Environmental assessment and approvals	Lump sum			600,000
	Cultural heritage	Lump sum			250,000
	Native title	Lump sum			150,000

OWNERS COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Diversion channel acquisition	ha	35	2,000	70,000
	Storage area acquisition	ha	4,600	1,000	4,600,000
	Surveys and legals	Lump sum			300,000
Impacts	Road relocations at diversion channel	Lump sum			250,000
	Flinders highway raising	Lump sum			1,000,000
	Railway raising	Lump sum			2,000,000
Permanent Onsite Buildings and Services		Lump sum			2,000,000
Principal's Insurances (1.1% of TOC)		Lump sum			1,660,263
Owners Management and Supervision (0.15% of TOC)		Lump sum			226,400
Total Owners Costs					21,108,028
Total Project Costs (TPC)					172,041,044
Risk Adjustment					56,773,544
TOTAL CAPITAL COST					$229 million

Porcupine Creek dam

Table C.9 Porcupine Creek dam – Direct Construction Costs

DIRECT CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
General	Environmental management	Lump sum			300,000
	Cultural heritage management	Lump sum			250,000
	Community consultation	Lump sum			100,000
Mobilisation and Demobilisation	Establishment of workforce accommodation	Lump sum			3,000,000
	Establishment of survey control	Lump sum			150,000
	Establish construction (and permanent) power supply	Lump sum			3,500,000
	Establish communications	Lump sum			200,000
	Mobilisation of major plant	Lump sum			1,800,000
	Demobilisation of major plant	Lump sum			450,000
	Demobilisation of workforce accommodation	Lump sum			1,200,000
	Clear site and 50% of storage area	ha	330	2,500	825,000
	Mobilise/demobilise site laboratory	Lump sum			100,000
Access	Access road to site from Kennedy Development Road	km	0.5	500,000	250,000
	Establish site access roads	Lump sum			1,000,000
	Rehabilitation of roads on construction completion	Lump sum			250,000

Table C.10 Porcupine Creek dam – Construction Costs

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
Material Sources	Remove quarry overburden	Lump sum			100,000
	Develop quarry	Lump sum			200,000
	Access road to quarry	km	2	400,000	800,000
	Access road to sand gravel sources	km	1.5	400,000	600,000
Diversion and Care of River	Excavate right abutment for diversion conduit bench	m^3	17,000	30	510,000
	Excavation for US and DS coffer dams	m^3	4,000	20	80,000
	Place material for coffer dams	m^3	13,000	30	390,000
	Dewatering	Lump sum			100,000
	Divert stream	Lump sum			150,000
	Removal of coffer dams	m^3	9,000	20	180,000
Foundations	Excavate sand from river bed	m^3	24,000	15	360,000
	Excavate rock from abutments	m^3	53,600	30	1,608,000
	Detailed excavation	m^3	15,000	120	1,800,000
	Detailed clean up	m^2	26,000	90	2,340,000
	Dental concrete	m^3	200	400	80,000
Foundation Grouting	Concrete to grouting plinth	m^3	1,660	450	720,000
	Reinforcement to grout plinth	tonne	13.6	5,000	68,000
	Drill and grout holes	m	12,920	100	1,290,000
	Supply and install standpipes	no	595	150	89,000
	Hook ups and pressure tests	no	905	320	290,000
	Pressure grouting	bags	25,000	30	750,000
Right Bank Gravel Layer Treatment	Trim abutment over slab contact area	m^3	1,200	50	60,000
	Anchor bars to abutment	m	200	100	20,000
	Place concrete blanket slab	m^3	600	20600	360,000
	Reinforcement to blanket slab	tonne	7.2	5,000	36,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
RCC Dam	Mobilise RCC placement plant	Lump sum			2,800,000
	Demobilise RCC placement plant	Lump sum			820,000
	Trial mixes	Lump sum			280,000
	RCC backfill to river bed below dam wall and apron to EL 376	m^3	19,200	210	4,030,000
	Conventional concrete to faces	m^3	8,020	440	3,529,000
	RCC concrete to dam wall	m^3	197,600	230	45,448,000
	Gallery floor units and precast slabs	m	270	2,500	675,000
	Conventional concrete to spillway crest	m^3	2,640	575	1,520,000
	Reinforcement to spillway crest	tonne	50	6,500	325,000
	Conventional concrete to spillway crest	m^3	3,600	350	1,260,000
	Reinforcement to spillway apron	tonne	145	6,000	870,000
	Conventional concrete to end sill and splitter piers	m^3	165	600	100,000
	Reinforcement to end sill and splitter piers	tonne	10	7,000	70,000
	Drill anchor bar holes for apron	m	4,500	60	270,000
	Anchor bars to spillway apron	tonne	45	6,000	270,000
	Conventional concrete to training walls	m^3	935	600	560,000
	Reinforcement to training walls	tonne	15	6,000	90,000
	Drill drainage holes	m	3,000	100	300,000
	Water stops	m	2,800	40	110,000
	Backfill on abutments	m^3	10,000	20	200,000
	Instrumentation HW/TW recorders etc	Lump sum			200,000
	Miscellaneous metalwork	Lump sum			50,000
Outlet Works	Intake tower concrete	m^3	250	800	200,000
	Intake tower reinforcement	tonne	15	7,000	105,000
	Intake tower guides and seals	tonne	10	14,000	140,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Trash racks	tonne	10	14,000	140,000
	Selective withdrawal baulks	tonne	8	12,000	96,000
	Bulkhead gate	tonne	2	10,000	20,000
	Hoist crane, install and commission	Lump sum			400,000
	Ladders and platforms	tonne	5	14,000	70,000
	Supply and install DN 1200 12mm plate CL pipe	tonne	12.5	12,000	150,000
	Outlet conduit concrete encasement	m³	400	350	140,000
	Outlet conduit concrete reinforcement	tonne	18	6,000	100,000
	Outlet works drill holes for anchor bars	m	500	60	30,000
	Supply and install anchor bars	tonne	5	6,000	30,000
	Concrete to outlet works floor and walls	m³	150	800	120,000
	Reinforcement to outlet works	tonne	8	7,000	56,000
	Outlet works pipework	Lump sum			100,000
	Butterfly valves and actuators	no	2	200,000	300,000
	Fixed cone 750mm diameter regulating valves	no	2	300,000	600,000
	Electrical installations	Lump sum			300,000
Fish Management	Fish habitat improvements	Lump sum			250,000
Permanent Downstream River Crossing		Lump sum			1,500,000
Total Direct Construction Costs (TDC)					94,980,000

Table C.11 Porcupine Creek dam – On Site Overheads

ON SITE OVERHEADS		UNIT	QUANTITY	RATE	AMOUNT
On Site Overheads	Project and field staff	Lump sum	3% of TDC		2,849,400
	Staff recruitment and training	Lump sum	0.6% of TDC		569,880
	Camp operations	Lump sum	3.5% of TDC		3,324,300
	Site office expenses	Lump sum	0.6% of TDC		569,880
	Site water and power expenses	Lump sum	0.1% of TDC		94,980

ON SITE OVERHEADS		UNIT	QUANTITY	RATE	AMOUNT
	Site communication, IT expenses	Lump sum	0.45% of TDC		427,410
	Site cleaning, rubbish removal	Lump sum	0.04% of TDC		37,992
	Project control testing	Lump sum			500,000
	Misc. travel expenses	Lump sum	0.2% of TDC		189,960
	Insurances, public liability	Lump sum	3.4% OF TDC		3,229,320
Total On Site Overheads (OSO)					11,793,122
TDC and OSO Costs					106,773,122
Profit and Off Site Overheads (10% of TDC and OSO)					10,677,312
Total Out Turn Costs (TOC)					117,450,434

Table C.12 Porcupine Creek dam – Owner Costs

OWNER COSTS		UNIT	QUANTITY	RATE	AMOUNT
Investigation and Design	Preliminary design	Lump sum	0.5% of TDC		474,900
	Geotechnical and materials	Lump sum	2.0% of TDC		1,899,600
	Hydraulic model study	Lump sum			400,000
	Detailed design and documentation	Lump sum	2.5%of TDC		2,374,500
Acquisition and Approvals	Environmental assessment and approvals	Lump sum			3,000,000
	Cultural heritage	Lump sum			1,250,000
	Native title	Lump sum			750,000
	Storage area acquisition	ha	400	1,000	400,000
	Surveys and legals	Lump sum			1,500,000
Permanent Onsite Buildings and Services		Lump sum			1,500,000
Principal's Insurances (1.1% of TOC)		Lump sum			1,291,955
Owners Management and Supervision (0.15% of TOC)		Lump sum			176,176
Total Owners Costs					15,017,130
Total Project Costs (TPC)					132,467,565
Risk Adjustment					46,363,648
TOTAL CAPITAL COST					$179 million

Appendix D Gilbert short-listed dam costing

This appendix provides detailed costings for the three short-listed dams in the Gilbert catchment

Dagworth dam

Table D.1 Dagworth dam, Einasleigh River – Direct Construction Costs

DIRECT CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
General	Environmental management	Lump sum			500,000
	Cultural heritage management	Lump sum			400,000
	Community consultation	Lump sum			100,000
Mobilisation and Demobilisation	Establishment of workforce accommodation	Lump sum			5,000,000
	Establishment of survey control	Lump sum			300,000
	Establish construction (and permanent) power supply	Lump sum			8,000,000
	Establish communications	Lump sum			400,000
	Mobilisation of major plant	Lump sum			3,500,000
	Demobilisation of major plant	Lump sum			1,000,000
	Demobilisation of workforce accommodation	Lump sum			2,000,000
	Clear site and 50% of storage area	ha	3,000	2,000	6,000,000
	Mobilise/demobilise site laboratory	Lump sum			150,000
Access	Access road to site from Gulf Development Road	km	60	750,000	45,000,000
	Establish site access roads	Lump sum			1,500,000
	Rehabilitation of roads on construction completion	Lump sum			500,000

Table D.2 Dagworth dam, Einasleigh River – Construction Costs

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
Material Sources	Remove quarry overburden	Lump sum			200,000
	Develop quarry	Lump sum			400,000
	Access road to quarry	km	2	400,000	800,000
	Access road to sand gravel sources	km	2	400,000	800,000
Diversion and Care of River	Excavate LB diversion channel (rock)	m^3	80,400	30	2,412,000
	Excavation for coffer dams	m^3	33,600	10	336,000
	Place material for coffer dams	m^3	114,000	15	1,710,000
	Dewatering	Lump sum			300,000
	Divert river	Lump sum			500,000
	Removal of coffer dams	m^3	80,000	10	800,000
Foundations Cross River Section	Excavate sand from river bed	m^3	60,000	8	480,000
	Excavate rock from abutments	m^3	70,000	30	2,100,000
	Detailed excavation	m^3	5,000	160	800,000
	Detailed clean up	m^3	28,500	80	2,280,000
	Dental concrete	m^3	1,000	400	400,000
Foundation Grouting Cross River Section	Concrete to grouting plinth	m^3	2,350	450	1,058,000
	Reinforcement to grout plinth	tonne	95	5,000	475,000
	Drill grout holes	m	18,600	100	1,860,000
	Supply and install standpipes	no	750	150	113,000
	Hook ups and pressure tests	no	750	320	240,000
	Pressure grouting	bags	36,000	35	1,260,000
RCC Dam River Section	Mobilise RCC placement plant	Lump sum			3,500,000
	De mobilise RCC placement plant	Lump sum			1,000,000
	Trial mixes	Lump sum			300,000
	RCC backfill to river bed below dam spillway and apron	m^3	32,100	200	6,420,000
	Conventional concrete to faces	m^3	14,900	430	6,407,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	RCC concrete to dam wall	m³	408,500	210	85,785,000
	Gallery floor units and precast slabs	m	520	2,500	1,300,000
	Conventional concrete to spillway crest	m³	15,500	500	7,750,000
	Reinforcement to spillway crest	tonne	110	6,500	715,000
	Conventional concrete to spillway crest	m³	8,400	340	2,856,000
	Reinforcement to spillway apron	tonne	340	6,000	2,040,000
	Conventional concrete to end sill and splitter piers	m³	1,120	600	670,000
	Reinforcement to end sill and splitter piers	tonne	65	7,000	455,000
	Anchor bars to spillway apron	m	8,400	60	504,000
	Conventional concrete to training walls	m³	840	600	504,000
	Reinforcement to training walls	tonne	40	6,000	240,000
	Drill drainage holes	m	8,500	100	850,000
	Water stops	m	650	40	26,000
	Backfill on abutments	m³	15,000	30	450,000
	Instrumentation HW/TW recorders etc	Lump sum			200,000
	Miscellaneous metalwork	Lump sum			100,000
Outlet Works	Intake tower concrete	m³	790	800	632,000
	Intake tower reinforcement	tonne	32	7,000	224,000
	Intake tower guides and seals	tonne	20	14,000	280,000
	Trash racks	tonne	20	14,000	280,000
	Selective withdrawal baulks	tonne	16	12,000	192,000
	Bulkhead gate	tonne	12	12,000	144,000
	Hoist crane, install and commission	Lump sum			350,000
	Ladders and platforms	tonne	8	14,000	112,000
	Supply and install outlet conduit 2.4m 12 pl	tonne	30	10,000	300,000
	Concrete to outlet works	m³	300	1,000	300,000
	Reinforcement to outlet	tonne	15	6,000	90,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	works				
	Outlet works pipework	Lump sum			400,000
	Butterfly valves and actuators	no	2	350,000	700,000
	Fixed cone regulating valves	no	2	450,000	900,000
	Outlet works hoist crane	Lump sum			350,000
	Miscellaneous metalwork	Lump sum			100,000
	Electrical installations	Lump sum			450,000
Fish Transfer Facility	Concrete to intake channels, hopper chamber and valve pit	m³	700	750	525,000
	Reinforcement to intake channels, hopper chamber and valve pit	tonne	53	6,000	210,000
	Fish attraction pipework, valves and diffusers	Lump sum			1,000,000
	Fish traps	Lump sum			1,000,000
	Fish lift hopper	no	2	500,000	1,000,000
	Hopper tracks	Lump sum			800,000
	Overhead crane at crest	Lump sum			1,000,000
	Monitoring equipment	Lump sum			350,000
	Electrical and mechanical installations	Lump sum			200,000
	Fish lift commissioning	Lump sum			300,000
Right Bank Saddle Dam	Foundation excavation	m³	77,000	20	1,540,000
	Drill and grout holes	m	7520	100	752,000
	Supply and install standpipes	no	415	120	50,000
	Hook ups and pressure tests	no	415	320	133,000
	Pressure grouting	bags			525,000
	Foundation clean up and treatment	m²			1,850,000
	Place Zone 1 material	m³			1,466,000
	Place Zone 2A material US and DS	m³			768,000
	Place Zone 3 material US	m³			1,008,000
	Place Zone 3B upstream face	m³			616,000
	Place downstream Zone 2B material	m³			1,757,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Mass concrete spillway section	m³			11,375,000
	Reinforced concrete apron	m³			2,590,000
	Reinforcement to apron	tonne			180,000
	Drill holes for anchors	m			648,000
	Anchor bars to apron	tonne			600,000
	Mass concrete retaining wall top of bank river sect	m³			383,000
Permanent Downstream Access Crossing		Lump sum			2,000,000
Total Direct Construction Costs		Lump sum			256,176,000

Table D.3 Dagworth dam, Einasleigh River – On Site Overheads

ON SITE OVERHEADS		UNIT	QUANTITY	RATE	AMOUNT
On Site Overheads	Project and field staff	Lump sum	3% of TDC		7,685,280
	Staff recruitment and training	Lump sum	0.6% of TDC		1,537,056
	Camp operations	Lump sum	3.5% of TDC		8,966,160
	Site office expenses	Lump sum	0.6% of TDC		1,537,056
	Site water and power expenses	Lump sum	0.1% of TDC		256,176
	Site communication, IT expenses	Lump sum	0.45% of TDC		1,152,792
	Site cleaning, rubbish removal	Lump sum	0.04% of TDC		102,470
	Project control testing	Lump sum			1,000,000
	Misc. travel expenses	Lump sum	0.2% of TDC		512,352
	Insurances, public liability	Lump sum	3.4% OF TDC		8,709,984
Total On Site Overheads (OSO)					31,459,326
TDC and OSO Costs					287,635,326
Profit and Off Site Overheads (10% of TDC and OSO)					28,763,533
Total Out Turn Costs (TOC)					316,398,859

Table D.4 Dagworth dam, Einasleigh River – Owner Costs

OWNER COSTS		UNIT	QUANTITY	RATE	AMOUNT
Investigation and Design	Preliminary design	Lump sum	0.5% of TDC		1,280,880
	Geotechnical and materials	Lump sum	2.0% of TDC		5,123,520
	Hydraulic model study	Lump sum			750,000
	Detailed design and documentation	Lump sum	2.5%of TDC		6,404,400
Acquisition and Approvals	Environmental assessment and approvals	Lump sum			4,000,000
	Cultural heritage	Lump sum			2,000,000
	Native title	Lump sum			1,000,000
	Storage area acquisition	ha	9,000	900	8,100,000
	Storage area access relocations	Lump sum			3,000,000
	Surveys and legals	Lump sum			2,500,000
Permanent Onsite Buildings and Services		Lump sum			2,200,000
Principal's Insurances (1.1% of TOC)		Lump sum			3,480,387
Owners Management and Supervision (0.15% of TOC)					474,598
Total Owners Costs					40,313,786
Total Project Costs (TPC)					356,712,645
Risk Adjustment					117,715,173
TOTAL CAPITAL COST					$474 million

Green Hills dam

Table D.5 Green Hills dam, Gilbert River – Direct Construction Costs

DIRECT CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
General	Environmental management	Lump sum			400,000
	Cultural heritage management	Lump sum			300,000
	Community consultation	Lump sum			100,000
Mobilisation and Demobilisation	Establishment of workforce accommodation	Lump sum			4,000,000
	Establishment of survey control	Lump sum			200,000
	Establish construction (and permanent) power supply	Lump sum			5,000,000
	Establish communications	Lump sum			250,000
	Mobilisation of major plant	Lump sum			2,250,000
	Demobilisation of major plant	Lump sum			660,000
	Demobilisation of workforce accommodation	Lump sum			1,600,000
	Clear site and 50% of storage area	ha	2,600	2,000	5,200,000
	Mobilise/demobilise site laboratory	Lump sum			150,000
Access	Access road to site from Gulf Development Road	km	20	600,000	12,000,000
	Establish site access roads	Lump sum			6,000,000
	Rehabilitation of roads on construction completion	Lump sum			500,000
	Road relocations in storage area	km	25	300,000	7,500,000

Table D.6 Green Hills dam, Gilbert River – Construction Costs

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
Material Sources	Remove quarry overburden	Lump sum			200,000
	Develop quarry	Lump sum			400,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Access road to quarry	km	3	500,000	1,500,000
	Access road to sand gravel sources	km	2	500,000	1,000,000
Diversion and Care of River	Excavate diversion channel (OTR)	m³	30,000	5	150,000
	Excavate diversion channel (rock)	m³	20,000	30	600,000
	Excavation for coffer dams	m³	17,250	15	260,000
	Place material for coffer dams	m³	31,400	30	942,000
	Dewatering	Lump sum			400,000
	Divert river	Lump sum			300,000
	Removal of coffer dams	m³	25,000	15	376,000
Foundations	Excavate sand from river bed	m³	151,250	8	1,210,000
	Excavate rock from abutments	m³	38,000	30	1,140,000
	Detailed excavation	m³	20,000	160	3,200,000
	Detailed clean up	m²	12,750	90	1,150,000
	Dental concrete	m³	500	400	200,000
Foundation Grouting	Concrete to grouting plinth	m³	1,315	450	592,000
	Reinforcement to grout plinth	tonne	50	5,000	250,000
	Drill and grout holes	m	7,300	100	730,000
	Supply and install standpipes	no	365	150	55,000
	Hook ups and pressure tests	no	630	320	202,000
	Pressure grouting	bags	15,000	35	525,000
RCC Dam	Mobilise RCC placement plant	Lump sum			3,000,000
	De mobilise RCC placement plant	Lump sum			880,000
	Trial mixes	Lump sum			400,000
	Conventional concrete to faces	m³	10,100	450	4,545,000
	RCC concrete to dam wall	m³	214,000	230	49,220,000
	Gallery floor units and precast slabs	m	540	2,500	1,350,000
	Conventional concrete to spillway crest	m³	2,185	600	1,310,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Reinforcement to spillway crest	tonne	50	6,500	325,000
	Conventional concrete to spillway crest	m³	3,330	500	1,665,000
	Reinforcement to spillway apron	tonne	180	6,000	1,080,000
	Drill anchor bar holes for apron	m	6,300	60	378,000
	Anchor bars to spillway apron	tonne	60	6,000	360,000
	Conventional concrete to training walls	m³	1,800	750	1,350,000
	Reinforcement to training walls	tonne	30	6,000	180,000
	Supply and install anchor bars to training walls	tonne	6	6,000	36,000
	Drill drainage holes	m	5,200	100	520,000
	Water stops	m	500	40	20,000
	Backfill on abutments	m³	14,000	30	420,000
	Instrumentation HW/TW recorders etc	Lump sum			200,000
	Miscellaneous metalwork	Lump sum			100,000
Outlet Works	Intake tower concrete	m³	700	750	525,000
	Intake tower reinforcement	tonne	45	6,000	270,000
	Intake tower guides and seals	tonne	20	14,000	280,000
	Trash racks	tonne	20	14,000	280,000
	Selective withdrawal baulks	tonne	26	12,000	312,000
	Bulkhead gate	tonne	10	10,000	100,000
	Hoist crane, install and commission	Lump sum			350,000
	Ladders and platforms	tonne	8	14,000	112,000
	Supply and install 2 by DN 1400 16mm plate CL pipes	tonne	50	10,000	500,000
	Supply and install Dn 800 10mm plate fishway pipe	tonne	12	3,000	36,000
	Outlet conduits concrete encasement	m³	620	300	186,000
	Outlet conduits concrete reinforcement	tonne	28	4,000	112,000
	Outlet works drill holes	m	900	50	45,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
	for anchor bars				
	Supply and install anchor bars	tonne	7	6,000	42,000
	Concrete to outlet works floor and walls	m³	350	1,000	350,000
	Reinforcement to outlet works	tonne	25	6,000	150,000
	Outlet works pipework	Lump sum			300,000
	Butterfly valves and actuators	no	2	220,000	440,000
	Fixed cone regulating valves	no	2	600,000	1,200,000
	Electrical installations	Lump sum			350,000
Fish Transfer Facility	Concrete to intake channels, hopper chamber and valve pit	m³	700	750	525,000
	Reinforcement to intake channels, hopper chamber and valve pit	tonne	45	6,000	270,000
	Fish attraction pipework, valves and diffusers	Lump sum			1,000,000
	Fish traps	Lump sum			1,000,000
	Fish lift hopper	no	2	500,00	1,000,000
	Hopper tracks	Lump sum			700,000
	Overhead crane at crest	Lump sum			1,000,000
	Monitoring and control equipment	Lump sum			350,000
	Electrical and mechanical installations	Lump sum			200,000
	Fish lift commissioning	Lump sum			250,000

Table D.7 Green Hills dam, Gilbert River – Saddle dam Costs

SADDLE DAM		UNIT	QUANTITY	RATE	AMOUNT
Saddle Dam 1	Foundation excavation	m³	5,100	30	153,000
	Miscellaneous fill	m³	12,300	25	307,500
Saddle Dam 2	Foundation excavation	m³	91,600	22	2,015,200
	Drill and grout holes	m	6,750	100	675,000
	Supply and install standpipes	no	1,000	150	150,000
	Hook ups and pressure tests	no	1,250	320	400,000
	Pressure grouting	bags	13,800	30	414,000

SADDLE DAM		UNIT	QUANTITY	RATE	AMOUNT
	Foundation clean up and treatment	sq m	20,300	90	1,827,000
	Place Zone 1 material	m³	81,400	22	1,791,000
	Place Zone 2 material	m³	208,900	28	5,849,000
	Place Zone 3 material US and DS	m³	90,800	35	3,178,000
Saddle Dam 3	Foundation excavation	m³	24,600	20	492,000
	Drill and grout holes	m	1,695	100	169,000
	Supply and install standpipes	no	200	150	30,000
	Hook ups and pressure tests	no	200	320	64,000
	Pressure grouting	bags	3,500	30	105,000
	Foundation clean up and treatment	m²	6,300	90	567,000
	Place Zone 1 material	m³	81,300	22	1,788,600
	Place Zone 2 material	m³	74,900	25	1,872,500
	Place Zone 3 material US and DS	m³	30,400	35	1,064,000
Saddle Dam 4	Foundation excavation	m³	46,700	20	934,000
	Drill and grout holes	m	3,450	100	345,000
	Supply and install standpipes	no	550	150	83,000
	Hook ups and pressure tests	no	700	320	224,000
	Pressure grouting	bags	7,100	30	203,000
	Foundation clean up and treatment	m²	10,400	90	936,000
	Place Zone 1 material	m³	35,400	22	778,800
	Place Zone 2 material	m³	69,000	20	1,380,000
	Place Zone 3 material US and DS	m³	42,400	30	1,272,000
Downstream Access Crossing		Lump sum			2,000,000
Total Direct Construction Costs (TDC)					172,133,600

Table D.8 Green Hills dam, Gilbert River – On Site Overheads

ON SITE OVERHEADS		UNIT	QUANTITY	RATE	AMOUNT
On Site Overheads	Project and field staff	Lump sum	3% of TDC		5,164,008

ON SITE OVERHEADS		UNIT	QUANTITY	RATE	AMOUNT
	Staff recruitment and training	Lump sum	0.6% of TDC		1,032,802
	Camp operations	Lump sum	3.5% of TDC		6,024,676
	Site office expenses	Lump sum	0.6% of TDC		1,032,802
	Site water and power expenses	Lump sum	0.1% of TDC		172,134
	Site communication, IT expenses	Lump sum	0.45% of TDC		774,601
	Site cleaning, rubbish removal	Lump sum	0.04% of TDC		68,853
	Project control testing	Lump sum			800,000
	Misc. travel expenses	Lump sum	0.2% of TDC		344,267
	Insurances, public liability	Lump sum	3.4% OF TDC		5,852,542
Total On Site Overheads (OSO)					21,266,685
TDC and OSO costs					193,400,285
Profit and Off Site Overheads (10% of TDC and OSO)					19,340,029
Total Out Turn Costs (TOC)					212,740,314

Table D.9 Green Hills dam, Gilbert River – Owners Costs

OWNERS COSTS		UNIT	QUANTITY	RATE	AMOUNT
Investigation and Design	Preliminary design	Lump sum	0.5% of TDC		860,668
	Geotechnical and materials	Lump sum	2.0% of TDC		3,442,672
	Hydraulic model study	Lump sum			400,000
	Detailed design and documentation	Lump sum	2.5%of TDC		4,303,340
Acquisition and Approvals	Environmental assessment and approvals	Lump sum			4,000,000
	Cultural heritage	Lump sum			3,000,000
	Native title	Lump sum			1,000,000
	Storage area acquisitions	Lump sum			12,000,000
	Storage area access relocations	Lump sum			3,000,000
	Surveys and legals	Lump sum			2,000,000
Permanent Onsite Buildings and Services		Lump sum			2,500,000
Principal's Insurances (1.1%		Lump sum			2,340,143

OWNERS COSTS	UNIT	QUANTITY	RATE	AMOUNT
of TOC)				
Owners Management and Supervision (0.15% of TOC)	Lump sum			319,110
Total Owners Costs				39,165,934
TOTAL PROJECT COSTS (TPC)				251,906,247
Risk Adjustment				83,129,062
TOTAL CAPITAL COST				$335 million

Kidston Dam raising

Table D.10 Kidston Dam Raising – Direct Construction Costs

DIRECT CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
General	Environmental management	Lump sum			20,000
	Cultural heritage management	Lump sum			15,000
	Community consultation	Lump sum			10,000
Mobilisation and Demobilisation	Establishment of workforce accommodation	Lump sum			250,000
	Establishment of survey control	Lump sum			20,000
	Establish construction power supply	Lump sum			20,000
	Establish communications	Lump sum			10,000
	Mobilisation of major plant	Lump sum			100,000
	Demobilisation of major plant	Lump sum			50,000
	Demobilisation of workforce accommodation	Lump sum			100,000
Access	Upgrade existing dam access road from Kidston	km	26	10,000	260,000
	Reconstruct culvert at Christmas Creek	Lump sum			250,000
	Re-establish site access roads	Lump sum			20,000

Table D.11 Kidston Dam Raising – Construction Costs

CONSTRUCTION COSTS	UNIT	QUANTITY	RATE	AMOUNT

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
Dam Raising	Downstream coffer dam	Lump sum			50,000
	Dewatering	Lump sum			20,000
	Flow diversion from river outlet	Lump sum			20,000
	Foundation excavation for dam wall extension	m^3	1,000	30	30,000
	Foundation excavation for fuse plug embankment extension	m^3	300	30	9,000
	Extend foundation grouting	Lump sum			200,000
	Concrete surface preparation	m^2	14,000	30	420,000
	Drill and grout anchor bars at interface	m	5,300	80	424,000
	Drainage provisions at interface	Lump sum			200,000
	Mass concrete - abutment raising	m^3	11,500	350	4,025,000
	Mass concrete - spillway raising	m^3	7,000	350	2,450,000
	Reinforced concrete - spillway bucket	m^3	1,500	600	900,000
	Modify outlet works incl. power actuators	Lump sum			350,000
	Modify other appurtenances	Lump sum			150,000
	Excavate existing fuse plug embankment material	m^3	12,700	15	190,000
	Place fuse plug embankment Zone 1	m^3	4,940	20	99,000
	Place fuse plug embankment Zone 2	m^3	11,960	16	190,000
	Place fuse plug embankment Zone 3	m^3	1,100	80	88,000
	Non-estimated items	Lump sum			900,000
	Project control testing	Lump sum			100,000
Distribution to South Bank Irrigation Area	Narrawa Weir	Lump sum			2,000,000
	Pump station and pipeline	Lump sum			1,200,000
Distribution to North Bank Irrigation Area	Einasleigh Weir	Lump sum			2,000,000
	Pump station and pipeline	Lump sum			1,200,000

CONSTRUCTION COSTS		UNIT	QUANTITY	RATE	AMOUNT
Diversion from Einasleigh River to South Bank Irrigation Area	Weir	Lump sum			2,000,000
	Pump station and pipeline	Lump sum			1,200,000
Total Direct Construction Costs					21,540,000

Table D.12 Kidston Dam Raising – On Site Overheads

ON SITE OVERHEADS		UNIT	QUANTITY	RATE	AMOUNT
On Site Overheads	Project and field staff	Lump sum	3% of TDC		646,200
	Staff recruitment and training	Lump sum	0.6% of TDC		129,240
	Site office expenses	Lump sum	0.6% of TDC		129,240
	Site water and power expenses	Lump sum	0.04% of TDC		8,616
	Site communication, IT expenses	Lump sum	0.45% of TDC		96,930
	Site cleaning, rubbish removal	Lump sum	0.04% of TDC		8,616
	Misc. travel expenses	Lump sum	0.05% of TDC		10,770
	Insurances, public liability	Lump sum	3.4% OF TDC		732,360
Total On Site Overheads (OSO)					1,761,972
TDC and OSO Costs					23,301,972
Profit and Off Site Overheads (10% of TDC and OSO)					2,330,197
Total Out Turn Costs (TOC)					25,632,169

Table D.13 Kidston Dam Raising – Owner Costs

OWNER COSTS		UNIT	QUANTITY	RATE	AMOUNT
Investigation and Design	Preliminary design	Lump sum	0.5% of TDC		107,700
	Geotechnical and materials	Lump sum	0.5% of TDC		107,700
	Hydraulic model study	Lump sum			100,000
	Detailed design and documentation	Lump sum	4%of TDC		861,600
Acquisition and Approvals	Environmental assessment and approvals	Lump sum			50,000

OWNER COSTS		UNIT	QUANTITY	RATE	AMOUNT
	Cultural heritage	Lump sum			50,000
	Native title	Lump sum			50,000
	Surveys and legals	Lump sum			100,000
Principal's Insurances (1.1% of TOC)		Lump sum	1.1% of TDC		236,940
Owners Management and Supervision (0.15% of TOC)		Lump sum	0.4% of TDC		86,160
Total Owners Costs					1,750,100
Total Project Costs (TPC)					27,382,269
Risk Adjustment					6,845,567
TOTAL CAPITAL COST					$34 million

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