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

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

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

The Assessment was guided by three committees:

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

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

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

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

This report was reviewed by Dr Ian Watson

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

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

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

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

In response, CSIRO accessed expertise from across Australia to provide data and insight to support consideration of the use of land and water resources for development in each of these regions. While the Assessment focuses mainly on the potential for agriculture and aquaculture, the detailed information provided on land and water resources, their potential uses and the impacts of those uses are relevant to a wider range of development and other interests.

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Project Director
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# Shortened forms

<table>
<thead>
<tr>
<th>SHORT FORM</th>
<th>FULL FORM</th>
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<tr>
<td>AAR</td>
<td>alkali–aggregate reaction</td>
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<tr>
<td>AEP</td>
<td>annual exceedance probability</td>
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<td>AHD</td>
<td>Australian Height Datum</td>
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<td>ALOS</td>
<td>Advanced Land Observing Satellite</td>
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<td>AMTD</td>
<td>adopted middle thread distances</td>
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<td>ANCOLD</td>
<td>Australian National Committee on Large Dams</td>
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<tr>
<td>APE</td>
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<td>Agricultural Production System SIMulator</td>
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<td>BHA</td>
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<td>Directory of Important Wetlands in Australia</td>
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<td>GDG</td>
<td>Gould-Dincer-Gamma algorithm (or method)</td>
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<td>Integrated Quantity and Quality Model</td>
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<td>probable maximum flood</td>
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<td>PMP</td>
<td>probable maximum precipitation</td>
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<td>TPC</td>
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<td>Vegetation Assets, States and Transitions</td>
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## Units

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<td>cubic metre</td>
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<tr>
<td>GL</td>
<td>gigalitre</td>
</tr>
<tr>
<td>ha</td>
<td>hectares</td>
</tr>
<tr>
<td>km</td>
<td>kilometre</td>
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<tr>
<td>m</td>
<td>metre</td>
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<tr>
<td>ML</td>
<td>megalitre</td>
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<tr>
<td>ML/year</td>
<td>megalitres per year (ML/y)</td>
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<td>millimetre</td>
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<tr>
<td>Mt</td>
<td>million tonnes</td>
</tr>
<tr>
<td>sq m</td>
<td>Square metre</td>
</tr>
<tr>
<td>y</td>
<td>year</td>
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</table>
The Northern Australia Water Resource Assessment (the Assessment) provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water and agricultural development in three priority regions shown in Preface Figure 1:

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

For each of the three regions, the Assessment:

- evaluates the soil and water resources
- identifies and evaluates water capture and storage options
- identifies and tests the commercial viability of irrigated agricultural and aquaculture opportunities
- assesses potential environmental, social and economic impacts and risks of water resource and irrigation development.
While agricultural and aquacultural developments are the primary focus of the Assessment it also considers opportunities for and intersections between other types of water-dependent development. For example, the Assessment explores the nature, scale, location and impacts of developments relating to industrial and urban development and aquaculture, in relevant locations.

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

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

Assessment reporting structure

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

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

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

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

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

**Preface Figure 2 Schematic diagram illustrating high level linkages between the ten activities (blue boxes)**

Activity boxes that contain multiple compartments indicate key sub-activities. This report is a technical report. The red oval in Preface Figure 2 indicates the primary activity (or activities) that contributed to this report.
Executive summary

Overview

Current allocations of water in the Fitzroy, Darwin and Mitchell catchments are low, relative to their median annual streamflow (<2%). The development of the surface water resources of these highly seasonal catchments to enable regional economic development, as has occurred in the south of Australia, would in many instances require rivers to be regulated and water stored.

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

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

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

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

- one to two times the equivalent annual unit cost per ML/yr supplied in 85% of years by farm-scale gully dams (~$59) with a yield (in 85% years).
- half to one times the equivalent annual unit cost per ML/yr for large farm-scale ringtanks (~4 GL, ~$115) (after accounting for evaporation and seepage losses and including maintenance and operating costs).
It should be noted that the investigation of a potential large dam site generally involves an iterative process of increasingly detailed studies over a period of years, occasionally over as few as 2 or 3 years but often over 10 or more years. For any of the options listed in this report to advance to construction, far more comprehensive studies would be needed. Studies at that detail are beyond the scope of this regional-scale resource Assessment.

**Large instream and offstream dams**

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

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

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

While a prospective dam site depends on a physiographic constriction of the river channel, it also requires favourable foundation geology. Favourable foundation conditions include a relatively shallow layer of unconsolidated materials such as alluvium, and rock that is relatively strong, non-erodible, has low permeability and is capable of being grouted. A preliminary desktop geological assessment of the DamSite results was undertaken using digital 1:250,000 geological maps. Only those new potential dam sites identified by the DamSite model that were revealed to be more favourable than known potential dam sites were investigated further. The most notable of these were in the Mitchell catchment, and included the Pinnacles site on the Mitchell River, a site on the Palmer River and two sites on the Walsh River.
To enable potential locations to be compared, the results are presented in this report using a consistent tabular format. Summaries of the results for the Darwin and Mitchell catchments are provided in Preface Table 1 and Preface Table 2, respectively. While the Assessment did investigate the suitability of soils for irrigation, that aspect is reported in the companion technical reports on digital soil mapping (Thomas et al., 2018a) and land suitability (Thomas et al., 2018b).

Potential dam sites in the Darwin catchments

One of the primary limitations to siting large dams in the Darwin catchments is that topographically suitable areas are limited to the relatively small headwater catchments. The best potential dam sites in the Darwin catchments are found where rivers have eroded through meta-sedimentary volcanic or igneous rocks in the Pine Creek Orogen, preferably where there is relatively shallow rock in the valley floor. Substantial excavation may be required to provide suitable foundations where alluvium is deep. Where the rivers are tidal, the presence of soft estuarine sediments has the potential to make dam design more challenging and construction more expensive, which may compromise the feasibility of a dam.

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

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

Preface Table 1 Potential dam sites in the Darwin catchments examined as part of the Assessment

All numbers have been rounded.

<table>
<thead>
<tr>
<th>NAME</th>
<th>DAM TYPE*</th>
<th>SPILLWAY HEIGHT ABOVE BED ** (m)</th>
<th>CAPACITY AT FSL (GL)</th>
<th>CATCHMENT AREA (km²)</th>
<th>ANNUAL WATER YIELD *** (GL)</th>
<th>CAPITAL COST# ($ MILLION)</th>
<th>UNIT COST## ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST &amp; O&amp;M### ($/y per Ml/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mount Bennett dam site on the Finniss River</td>
<td>RCC</td>
<td>20</td>
<td>343</td>
<td>1155</td>
<td>283</td>
<td>190 □</td>
<td>671</td>
<td>50</td>
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<tr>
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<td>RCC</td>
<td>23</td>
<td>298</td>
<td>616</td>
<td>153</td>
<td>182 □</td>
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<tr>
<td>Acacia Gap dam site</td>
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<td>37</td>
<td>232</td>
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<td>132 □</td>
<td>4452</td>
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<td>EB</td>
<td>18</td>
<td>91</td>
<td>34^</td>
<td>32^^</td>
<td>154 □</td>
<td>4873</td>
<td>342^^^</td>
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<td>Marrakai dam site on the Adelaide River</td>
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<td>1520</td>
<td>4341</td>
<td>861</td>
<td>855 □^A</td>
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<td>492</td>
<td>756 □</td>
<td>1537</td>
<td>114</td>
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</tbody>
</table>

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

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

Potential dam sites in the Mitchell catchment

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

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

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

### Preface Table 2 Potential dam sites in the Mitchell catchments examined as part of the Assessment

<table>
<thead>
<tr>
<th>NAME</th>
<th>DAM TYPE</th>
<th>SPILLWAY HEIGHT ABOVE BED ** (m)</th>
<th>CAPACITY AT FSL (GL)</th>
<th>CATCHMENT AREA (km²)</th>
<th>ANNUAL WATER YIELD *** (GL)</th>
<th>CAPITAL COST# ($ MILLION)</th>
<th>UNIT COST## ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST### ($/y per ML/y)</th>
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<tr>
<td>Lynd downstream dam site on the Lynd River</td>
<td>RCC</td>
<td>45</td>
<td>810</td>
<td>4554</td>
<td>507</td>
<td>731 □</td>
<td>1442</td>
<td>107</td>
</tr>
<tr>
<td>Lynd upstream dam site on the Lynd River</td>
<td>RCC</td>
<td>36</td>
<td>644</td>
<td>3983</td>
<td>412</td>
<td>750 □</td>
<td>1820</td>
<td>142</td>
</tr>
<tr>
<td>Palmer River dam site</td>
<td>RCC</td>
<td>56</td>
<td>1444</td>
<td>3801</td>
<td>553</td>
<td>690 □</td>
<td>1248</td>
<td>92</td>
</tr>
<tr>
<td>Elizabeth Creek dam site</td>
<td>RCC</td>
<td>36</td>
<td>149</td>
<td>580</td>
<td>55</td>
<td>189 □</td>
<td>3436</td>
<td>256</td>
</tr>
<tr>
<td>Pinnacles dam site on the Mitchell River</td>
<td>RCC</td>
<td>58</td>
<td>2316</td>
<td>7728</td>
<td>1248</td>
<td>755 □</td>
<td>605</td>
<td>45</td>
</tr>
<tr>
<td>Rookwood dam site on the Walsh River</td>
<td>RCC</td>
<td>61</td>
<td>1288</td>
<td>4855</td>
<td>575</td>
<td>655 □</td>
<td>1139</td>
<td>84</td>
</tr>
<tr>
<td>Chillagoe dam site on the Walsh River</td>
<td>RCC</td>
<td>50</td>
<td>600</td>
<td>3423</td>
<td>388</td>
<td>601 □</td>
<td>1549</td>
<td>115</td>
</tr>
<tr>
<td>Nullinga dam site on the Walsh River</td>
<td>RCC</td>
<td>31</td>
<td>145</td>
<td>327</td>
<td>65</td>
<td>349 □</td>
<td>5269</td>
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FSL = full supply level

* Roller compacted concrete dam (RCC).

** The height of the dam abutments and saddle dams will be higher than the spillway height.

*** Water yield is based on 85% annual time-based reliability using a perennial demand pattern for the baseline river model under Scenario A. This is yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These yield values do not take into account downstream existing entitlement holders or environmental considerations.

# □ Indicates manually derived preliminary cost estimate, which is likely to be –10% to +30% of ‘true cost’. □ Indicates modelled preliminary cost estimate, which is likely to be –25% to +50% of ‘true’ cost. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher.

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

### Assuming a 7% real discount rate and a dam service life of 100 years. Includes operation and maintenance costs, assuming operation and maintenance costs are 0.4% of the total capital cost.
Preface Table 2 shows that the potential Pinnacles dam site on the Mitchell River has the largest catchment area and highest yield of all sites examined in the Mitchell catchment. A storage at this site could support a large irrigation development at and downstream of Wrotham Park. At the level of development assessed, a very long saddle dam is required on the right bank. Nevertheless, the site has the lowest cost to yield ratio in the Mitchell catchment as a result of its high yield. Further assessment including geotechnical investigation of the saddle dam area would be required to determine the optimal level of development. Although a fish transfer facility would be constructed, the dam’s potential impact on migration, movement and colonisation of key species, including the freshwater sawfish and barramundi, would need to be further considered.

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

**Total divertible yield**

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

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

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

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

A desktop assessment of the suitability of farm-scale offstream storages in the Fitzroy, Darwin and Mitchell catchments was undertaken based on soil parameter grids developed by the Assessment team. These data were sourced from the companion technical report on digital soil mapping (Thomas et al., 2018a). Because the Assessment only sampled soil to a depth of 1.5 m, this suitability assessment does not give consideration to the nature of subsurface material below 1.5 m depth. The largest areas suitable for farm-scale offstream storages in the Fitzroy catchment are along the recent alluvial soils adjacent to the Fitzroy River. This area is, however, susceptible to flooding. Elsewhere in the Fitzroy catchment the soils are too sandy or landscape too steep and rocky for farm-scale offstream storages. The most promising areas for farm-scale offstream storages are in the upper Adelaide and Mary rivers. Although the coastal plains, which extend up
to 50 km inland, appear suitable for farm-scale offstream storages around Darwin, these areas have limited opportunity for cropping as they are generally too wet. The Mitchell catchment has the largest area of land suitable for farm-scale offstream storages, predominately located below the junction of the Mitchell and Palmer rivers. This area is susceptible to flooding so care would need to be taken when siting offstream storages.

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

**Natural water bodies**

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

**Sedimentation considerations**

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

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

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

If any of the potential dams examined in the Assessment were to be constructed, sediment yields would need to be recomputed by undertaking a detailed field measurement and modelling program of downstream impacts on river channels and an assessment of estuarine and coastal geomorphology.
Ecological considerations

A desktop assessment of potential environmental issues associated with large potential dam sites in the Darwin and Mitchell catchments was undertaken. Assessment of potential impacts was based on fish distribution and passage, for which reasonable information exists, inundation of vegetation communities (regional ecosystems), which have been mapped in reasonable detail by the Queensland Government across the Mitchell catchment, and consideration of general environmental issues that commonly arise in dam developments in similar habitats elsewhere, particularly the Burdekin Falls Dam (Lake Dalrymple) and the Ord River Dam (Lake Argyle).

Large dams constructed on the mid-reaches of the Finniss, Adelaide and Mary rivers in the Darwin catchments and mid-reaches of the Palmer, Mitchell, Walsh and Lynn rivers may limit the migration, movement or colonisation of habitat by fish species. Potential dam sites in the headwaters of the Darwin and Mitchell catchments (e.g. Upper Adelaide River dam site in the Darwin catchments and Nullinga and Elizabeth Creek dam sites in the Mitchell catchment) will have less impact because the restriction on species movement is small relative to the downstream areas and the number of fish species typically decreases with distance from the coast.

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

Cultural heritage considerations

Insufficient information relating to the cultural heritage values of the short-listed sites was accessed to allow full understanding or quantification of the likely impacts of water storages. The Fitzroy, Darwin and Mitchell catchments are very likely to contain a large number of Indigenous cultural sites, including archaeological pre-contact sites some of which are likely to be of national scientific significance. Previous studies in northern and southern Australia clearly show that Indigenous people lived along major watercourses and drainage lines. The cultural heritage value of these landforms and their immediate surrounds is therefore assumed to be moderate to very high.
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Part I  Introduction
1 Introduction

Current allocations of water in the Fitzroy, Darwin and Mitchell catchments are low relative to their median annual streamflow (i.e. <2%). The development of the surface water resources of these highly seasonal catchments to enable regional economic development would in many instances require rivers to be regulated and water stored. In the south of Australia, the construction of large reservoirs (Preface Figure 1) has provided an effective means of delivering reliable water supplies in a dry and variable temperate climate, and the elaborate series of dams and tunnels constructed as part of the Snowy Mountain Hydro-electric Scheme has enabled watering of much of the irrigated land in the Murray–Darling Basin. Elsewhere in the world a number of commentators have observed that no country or region in a tropical or sub-tropical climate has ever managed to make significant economic progress without harnessing adequately its water resources (Bisawas, 2012).

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

Thus, decisions around river regulation and water storage are complex and the consequences of decisions are inter-generational, where even small inappropriate releases of water may preclude the development of possibly larger and more appropriate developments in the future. The benefits to government and communities of having a wide range of reliable information available prior to making decisions, including all the different ways water can be stored, can have long-lasting benefits and facilitate an open and transparent debate. The broad types of dams and water storage options likely in northern Australia are described in Section 1.2.

The primary purpose of this report is to provide a comprehensive overview of the different surface water storage options in the Darwin and Mitchell catchments, to enable decision makers to take a long-term view of water resource development (i.e. >20 years), which can help inform appropriate shorter-term allocation decisions.

On the advice of the Northern Australia Water Resource Assessment Governance Committee, no new assessment was made of the potential for large instream dams in the Fitzroy catchment. A brief summary of existing material is provided in the companion catchment report (Petheram et al., 2018).

The first step in assessing potential water storage options in a catchment is to examine what water storages already exist, as these are likely to be the most cost-effective method of supplying water if unused water is available. An overview of existing surface water storages in the Fitzroy, Darwin and Mitchell catchments is provided in Section 1.3.
It is important to note that the analysis undertaken in this surface water storage assessment is pre-feasibility in nature and is intended to enable stakeholders to select with confidence one or several sites to undertake a more detailed and expensive feasibility analysis. Although the majority of large dam sites were visited and visually inspected by the Assessment’s infrastructure planner, engineering geologist and hydrologist, no new field investigations were undertaken as part of the Assessment. The broad steps in investigating a large dam are described in Section 1.4.


**Report objectives**

The objectives of this report were to:

- review all previous studies (published and unpublished) on large dams in the Darwin and Mitchell catchments
- identify and assess every location in each of the catchments for its potential for the construction of a large instream and offstream dam, including an estimate of yield and modelled cost
- undertake a manual cost estimate (for six sites) at the full supply level (FSL) height with the highest yield per million dollars of modelled cost
- undertake a pre-feasibility assessment of the best opportunities for farm-scale instream (i.e. gully and hillside dams) and offstream (i.e. ringtank) storages
- identify the more promising surface water storage option in each catchment
- represent the results in a consistent tabulated format that facilitates site comparisons.

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

**Report outline**

This report is divided into four parts and six appendices.

Part 1, introduction and Assessment area, contains three chapters. Chapter 1 provides introductory material to aspects of large instream and offstream dams and farm-scale dams, key terminology and concepts, and Chapter 2 details the methods undertaken to assess dams in the three Assessment areas. Chapter 3 presents a brief overview of the three study areas that comprise the Assessment area, with particularly emphasis on features relevant to surface water storage.

Part 2, large instream and offstream dams, contains two chapters. Chapter 4 presents summary information for the seven potential dams assessed in the Darwin catchments. Detailed information on two short-listed dam sites in the Darwin catchments is then presented. Chapter 5 in this section provides a description of the Mitchell catchment and presents summary information for the eight potential dams assessed in the catchment. Detailed information on four short-listed dam sites in the Mitchell catchment is then presented.
Part 3, farm-scale dams, re-regulating structures and natural waterholes, contains three chapters. Chapter 6 examines farm-scale storages in the three Assessment areas. Chapter 7 contains general information on regulating structures, such as weirs and sand dams, and Chapter 8 discusses the use of water from natural waterholes.

Part 4, summary comments, contains two chapters. Chapter 9 provides a discussion, looking at the results collectively. Chapter 10 presents summary remarks.

Appendix A provides a detailed summary of the five non-short-listed potential dam sites and two existing large dams in the Darwin catchments. Information is also presented for the existing Darwin River Dam and Manton Dam.

Appendix B provides a detailed summary of the four non-short-listed potential dam sites and one existing large dam in the Mitchell catchment. Information is also presented for the existing Lake Mitchell Dam.

Appendix C provides detailed costings for the two short-listed potential dam sites in the Darwin catchments.

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

Appendix E is the petrology report for rock samples taken at the six short-listed sites.

Appendix F provides additional detail for the desktop reservoir sediment infill assessment.

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. Section 1.1, a brief overview of dam safety, provides the context for a discussion on who might build different types of dams, which influences their cost. This leads into Section 1.2 of this introductory chapter, which provides an overview of the different types of large dams and farm-scale water storage infrastructure.

Section 1.3 outlines large dams that exist in the three study areas, followed by the broad steps in the investigation of a large dam site, which provides the context for the additional work needed in order to ‘prove up’ a potential dam site subsequent to this report.

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

Key linkages with other activities of the Northern Australia Water Resource Assessment

This report draws heavily on information and models generated by other activities in the Assessment, in particularly the rivers system model calibration report (Hughes et al., 2017), flood design hydrology report (Jordan et al., 2017), ecology report (Pollino et al., 2018a,b), digital soil mapping report (Thomas et al., 2018a), land suitability report (Thomas et al., 2018b), agriculture viability report (Ash et al., 2018a,b,c), flood mapping and modelling report (Karim et al., 2018), hydro-electric power report (Entura, 2017) and the Earth observation methods report (Sims et al., 2016).
**Dam terminology**

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

**1.1 Dam safety and models of dam labour construction**

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

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

- **Category 1.** Dams that have a ‘Very low’ to ‘Low’ hazard category. Depending upon the jurisdiction and the dimensions of the structure and reservoir, these dams may require a permit to undertake dam works, but in general, these require the least amount of detail to satisfy statutory planning, construction, maintenance and reporting requirements.

- **Category 2.** Dams that fall into a hazard category of ‘Significant’ and ‘High C’, or all dams that are over 10 m but less than 25 m in height and not in Category 3. These require considerably more detail to satisfy planning, construction, maintenance and reporting requirements compared to dams in Category 1.

- **Category 3.** Dams that are at the higher end of the hazard category scale. These dams include ‘High B’, ‘High A’ and ‘Extreme’ hazard dams and dams that are over 25 m in height. These generally require the services of an engineering consultancy service specialising in the construction of large dams, require considerable planning and approval, and usually require an environmental impact statement and Environment Protection and Biodiversity Conservation (EPBC) approval.

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

**Dam labour construction models and implications to cost**

The majority of on-farm dams fall into Category 1, but larger farm-scale dams may be Category 2. It is technically feasible for farm dams that fall into Category 1 to be constructed by the landholder, where they own their own plant or can purchase new or second-hand plant and compaction equipment, and the structure satisfies jurisdictional requirements.
There are no jurisdictional regulations covering construction of farm dams in WA and the NT. In Queensland, owners of dams over 10 m in height with reservoirs of more than 1500 ML capacity or over 10 m in height and more than 750 ML capacity with a catchment area more than three times the reservoir’s surface area at the FSL need to have a failure impact assessment undertaken. If the failure impact assessment determines there are two or more people at risk, the dam is determined to be a ‘referable dam’ under the Queensland Government’s Water Supply (Safety and Reliability) Act 2008. Under the Act this requires a registered professional engineer to be involved in the design and construction of the dam.

In the majority of the Mitchell catchment it is likely that less than two people would be impacted as a result of a failure of a farm dam. Hence it is possible that some farm-scale dams in the Mitchell catchment could be constructed by landholders without professional engineering oversight.

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

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

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

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

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

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

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

1.2.1 LARGE INSTREAM DAMS

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

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

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

An attraction of large dams is that if the reservoir is large enough relative to the demands on the dam (i.e. water supplied for consumptive use, evaporation and seepage), when the reservoir is full water can last 2 or more years. This has the advantage of mitigating against years with low inflows to the reservoir. For this reason large dams are sometimes referred to as carry-over storages.

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

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

Within the framework outlined in Section 1.1, large dams fall within Category 3, and it is recommended that their construction be undertaken by an engineering consultant specialising in large dams.

**Embankment dams**

Embankment dams are usually the most economical, provided that suitable construction materials can be found locally, and are best suited to smaller catchment areas where the spillway capacity requirement is small. There are two major types of embankment dams, earthfill embankment dams and rockfill embankment dams. Earthfill embankment dams are the most popular dams worldwide (61%) because they can be built on a wide range of foundation conditions, whereas gravity dams require sound foundation rock because the leakage path through the foundation under the water barrier is short (Kinstler, 2000a). In Australia, however, only 33% of large dams are classified as earthfill, while 40% are rockfill. Like earthfill dams, rockfill dams can be built on a wide range of foundation conditions but they require less material as they can be built with much steeper sides. They can also be constructed during rain and remain stable even under high seepage conditions. Rockfill embankment dams also have an advantage over earthfill embankment dams in that methods have been devised for reinforcing the downstream rockfill slope to protect it from erosion. Indeed several rockfill dams in Australia have survived overtopping during flood events with minimal damage.

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

Figure 1-1 Schematic cross-section diagram of a rockfill embankment dam with a clay core
Source: Petheram et al. (2013).

Figure 1-2 Schematic cross-section of a concrete-faced rockfill dam
Source: Petheram et al. (2013).

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

Concrete gravity dams
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 (also known as Copperfield Gorge Dam) in the Gilbert catchment, however, was the first dam in Australia where roller compacted concrete (RCC) was used with low-cement concrete placed in continuous thin layers from bank to bank and compacted with vibrating rollers. This approach allows large
The use of RCC over CC was estimated to reduce the cost of a concrete gravity dam at Copperfield Gorge by about 40% (Doherty, 1999), and the introduction of this technique resulted in the proportion of concrete gravity type dams built in Australia to increase.

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

Other types of large dams

Two other major types of dams are concrete buttress and arch dams. Each can be favourable when concrete is expensive and labour is cheap (i.e. they require more formwork and are of greater complexity), such as occurred during the Great Depression and after World War II. However, in recent decades the high cost of labour has made these types of dams less economical than concrete gravity or embankment dams. Furthermore, arch dams are generally less suitable in Australia due to a lack of suitable topography; they have greatest benefits over concrete gravity dams where the valley width is narrow and the rock is structurally sound.

A note on offstream storages

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

Offstream water storages can take the form of farm-scale ringtanks (e.g. 100 to 10,000 ML storage capacity) or large dam structures (>10,000 ML). An example of an ~4000 ML ringtank is shown in Figure 1-3. 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).

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

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

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

![Figure 1-3 Rectangular ringtank in the Flinders catchment](Photo: CSIRO)

### 1.2.2 FARM-SCALE DAMS AND WATER STORAGES

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

**Table 1-1 Types of farm-scale water storages**
Adapted from Lewis (2002).

<table>
<thead>
<tr>
<th>TYPE OF ON-FARM DAM</th>
<th>DESCRIPTION</th>
<th>STORAGE TO EXCAVATION RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gully dam</td>
<td>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.</td>
<td>10:1 (favourable conditions)</td>
</tr>
<tr>
<td>Hillside dam</td>
<td>An earth dam located on a hillside or slope and not in a defined depression or drainage line.</td>
<td>5:1 (on flatter terrain) 1:1 (on steeper slopes)</td>
</tr>
<tr>
<td>Ringtank</td>
<td>A storage confined entirely within a continuous</td>
<td>1.5:1 (small tank)</td>
</tr>
</tbody>
</table>
TYPE OF ON-FARM DAM | DESCRIPTION | STORAGE TO EXCAVATION RATIO
--- | --- | ---
embankment built from material obtained within the storage basin. | 4.5:1 (large tank) 10:1 (very large tank) |
Turkey nest tanks | A storage confined entirely within a continuous embankment but built from material borrowed from outside the storage area. All water is therefore held above ground level. | Usually smaller than 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 |

1.2.3 RE-REGULATING STRUCTURES

Re-regulating structures such as weirs differ from dams in that they are lower barriers located entirely within stream banks and are totally overtopped during flood events. Weirs are typically used as regulating structures downstream of large dams to 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. Re-regulating structures can range from concrete gravity weirs to sheet piling weirs to simple sand dams – mounds of river sand within the bed of a river to create a pumping pool. These types of structures are discussed in more detail in Section 7.

1.3 An overview of existing dams in the Fitzroy, Darwin and Mitchell catchments

When investigating the potential for new dams it is prudent to also examine existing dams in the Assessment area and the extent of regulation and quantities of general and strategic reserves in river systems. Table 1-2 lists existing large dams (>10 GL capacity and >10m wall height) in the Darwin and Mitchell catchments. No large dam structures exist in the Fitzroy catchment, although there is a low barrage on the Fitzroy River near Camballin.

Table 1-2 Constructed large dams in the Darwin and Mitchell catchments
Locations in parentheses indicate study area/catchment.

<table>
<thead>
<tr>
<th>NAME OF DAM</th>
<th>NEAREST TOWN</th>
<th>ORIGINAL OWNER</th>
<th>YEAR CONSTRUCTED</th>
<th>HEIGHT ABOVE BED LEVEL (m)</th>
<th>STORAGE CAPACITY AT FSL (GL)</th>
<th>PRIMARY INTENDED PURPOSE</th>
<th>TYPE OF DAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darwin River Dam (Darwin)</td>
<td>Darwin</td>
<td>PWCª</td>
<td>1972</td>
<td>27</td>
<td>265</td>
<td>Water supply</td>
<td>Concrete gravity</td>
</tr>
<tr>
<td>Manton Dam (Darwin)</td>
<td>Darwin</td>
<td>PWCª</td>
<td>1942</td>
<td>24</td>
<td>13</td>
<td>Recreation</td>
<td>Concrete gravity</td>
</tr>
<tr>
<td>Lake Mitchell Dam (Mitchell)</td>
<td>Mareeba</td>
<td>Southedge Daintree Pastoral Pty Ltd</td>
<td>1987</td>
<td>17</td>
<td>190</td>
<td>Residential/peri-urban*ª</td>
<td>Embankment</td>
</tr>
</tbody>
</table>
### Stages of investigation in design, costing and construction of dams

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

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

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

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

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

The likelihood of dam sites being suitable for future detailed evaluation can often be determined from a preliminary assessment of available information including maps, geology, streamflow data, and particularly from site inspections. An initial desktop assessment of the impacts of a storage
development on existing land uses, existing infrastructure and 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.

It is common in a pre-feasibility analysis for the better potential sites to be short-listed for a more detailed desktop analysis, including more time-demanding analyses such as preliminary flood design assessment (e.g. to assess the additional height above the FSL (or freeboard), that can significantly impact on dam cost). An example of such a preliminary assessment was recently undertaken in northern Australia in the Flinders and Gilbert catchments by Petheram et al. (2013a). Through this process it is possible to confidently select the most appropriate dam sites on which to undertake more detailed and costly ground-based investigations.

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

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

Ultimately the studies need to acquire the necessary level of detail and certainty to obtain the required approvals. The final step should 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.
1.5 Key terminology and concepts

1.5.1 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. In this report all yield and reliability values are expressed in terms of annual time reliability which is calculated as per Equation 1.

\[ R_t = \frac{N_S}{N} \]  

(1)

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

1.5.2 WATER YEAR AND WET AND DRY SEASONS

Northern Australia has a highly seasonal climate, with most rain falling from December to March. Unless specified otherwise, this Assessment defines the wet season as the 6-month period from 1 November to 30 April, and the dry season as the 6-month period from 1 May to 31 October. This wet season was chosen as it is the wettest 6-month period for all three study areas (see companion technical report on climate, Charles et al., 2016).

All results in the Assessment are reported over the water year, defined as the period 1 September to 31 August, unless specified otherwise. This allows each individual wet season to be counted in a single 12-month period, rather than being split over two calendar years (i.e. counted as two separate seasons). This is more realistic for reporting climate statistics from a hydrological and agricultural assessment viewpoint.

1.5.3 SCENARIO DEFINITIONS

Two scenarios are presented in this report.

- Scenario A – historical climate and current development
- Scenario B – historical climate and future water resource development

Scenario A

Scenario A is historical climate and current development. The historical climate series is defined as the observed climate (rainfall, temperature and potential evaporation for water years from 1 September 1890 to 31 August 2015). All results presented in this report are calculated over this period unless specified otherwise. The current level of surface water, groundwater and economic development were assumed (as at 31 August 2015). Scenario A was used as the baseline against which assessments of relative change were made. Historical tidal data were used to specify downstream boundary conditions for the flood modelling.
Historical climate data were sourced from the scientific information for land owners (SILO) data drill database, [http://www.longpaddock.qld.gov.au/silo/](http://www.longpaddock.qld.gov.au/silo/) (Jeffrey et al., 2001). SILO provides surfaces of daily climate data interpolated and in-filled from point measurements made by the observation network developed and maintained by the Bureau of Meteorology.

**Scenario B**

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

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

**1.5.4 REPORTING DEM-H ELEVATION AND HEIGHT DATA**

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

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

This chapter provides an overview of large dams, farm-scale storages and natural water bodies. It describes the methods used to evaluate the existing and potential large instream and offstream dam sites in the Darwin and Mitchell catchments.

2.1 Large instream and offstream dams

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

Based on the review of existing literature and the DamSite model results, Section 4.1.2 lists the sites selected for pre-feasibility analysis and Section 2.1.3 provides a summary of the methods used for 22 parameters against which each potential dam site was assessed.

The method by which potential dam sites in each catchment were short-listed is outlined in Section 2.1.4.

2.1.1 REVIEW OF PAST LITERATURE

The PWC, which is responsible for water services across the NT, has commissioned numerous studies on potential dam sites in the Darwin catchments over the past several decades. In 1979, a pre-feasibility analysis of future sources of water for Darwin (SMEC, 1979) identified 12 potential dam and weir sites in the vicinity of the city. On the basis of these investigations, three of these sites were short-listed for more detailed investigations in the early 1990s (Paiva, 1991a, 1991b): Marrakai (Stewart and Baker, 1987; GHD, 1990; Paiva, 1991a); Mount Bennett (Ullman and Nolan, 1990; Paiva, 1992); and Warrai (Paiva, 1990, 1991b). In recent years, the PWC has undertaken detailed investigations of a large offstream storage location along the mid-reaches of the Adelaide River. The PWC analysis has focused exclusively on the supply of water to Darwin, and do not consider agricultural uses of water.

By contrast, in the Mitchell catchment only two potential dams are known to have been previously identified. One of these sites, Nullinga on the Walsh River, is currently the subject of a feasibility study as part of the National Water Infrastructure Development Fund, the other is a site at the Pinnacles on the Mitchell River, for which there is a four-page reference in an unpublished Queensland Government document.

The locations of these previously identified dam sites are shown in Chapter 3.

Review of the available reports

A comprehensive review was undertaken of all available reports likely to include relevant information on past water storage studies. Reports were accessed from state and territory agency libraries including the SunWater Corporation library and PWC. 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 sites it became particularly evident that previous investigations varied considerably in scope and in rigour. For example, only the more recent studies considered 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 the majority of the water storage options, it is clear that the available technical data 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 AHD network. Any such inaccuracies have implications not just for topographic data but also for the estimation of storage volumes and surface areas.

A further issue that required consideration is that dam engineering standards have developed considerably since many of the past investigations were undertaken (e.g. Ball et al., 2016). In the mid-1980s, for example, the Bureau of Meteorology adopted new approaches to extreme precipitation so that estimates of the probable maximum flood (PMF) are now considerably higher than the estimates prepared at the time of many of the earlier studies. In Queensland the government’s policies regarding the adequacy of dam spillways specifies that 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. For example, 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 calculating probable maximum precipitation (PMP) the required spillway capacity was revised to 112,200 m$^3$/s (SunWater, 2009).

In undertaking the review, data for each site were compiled using a common framework, thus facilitating comparisons between dam proposals. The review summaries were augmented with information gathered from site inspections in November 2016 and January 2017. This was further augmented with more recent geological and topographic mapping (i.e. using DEM-H; Gallant et al., 2011), and the Advanced Land Observing Satellite (ALOS) digital elevation model (DEM), which in the majority of cases are superior to the historical topographic mapping), desktop ecological and cultural assessments, flood design assessments and new hydrological modelling using recent climate and streamflow input data over a consistent assessment period and using a consistent set of methods. The specific methods used to assess each potential dam site are described in Section 2.1.3.

2.1.2 DAMSITE MODELLING

To ensure that dam sites across the Darwin and Mitchell catchments were objectively and consistently assessed, the DamSite model (Read et al., 2012; Petheram et al., 2017) was applied across the entire area. This model is a series of algorithms that automatically determines favourable locations in the landscape as sites for intermediate-to-large water storages, and has been previously applied successfully to the Flinders and Gilbert catchments (Petheram et al., 2013).
Broadly, the approach involved calculating the potential dam and reservoir dimensions of every location in the Darwin and Mitchell catchments at 1 m height increments, constructing saddle dams as required, and using the DEM-H, the best freely available DEM across northern Australia.

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

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

**Revised DamSite model dam cost algorithm**

The original DamSite dam cost algorithm was based on a top-down approach where a relationship was developed between actual dam cost (based on a collation of more than 80 actual dam costs from across Australia) and dam dimensions. The revised approach used in this analysis is based on bottom-up principals where the dimensions of the dam were calculated based on an elevation profile along the dam axis and standard cross-sectional dimensions for RCC and EB dams. Based on this approach, the construction cost was calculated by multiplying the volume of required material by a unit cost rate, typically per cubic metre of material. The cost per cubic metre of some materials varied with the size of the dam wall (e.g. the cost of RCC cement), which was to account for economies of scale and larger plants on larger projects. Other items of significant cost such as outlet works, fish transfer facilities and grouting were also modelled as a function of the dam wall size. All of these costs contribute to a total direct construction cost (TDC). A multiplier was applied to the TDC to account for overheads and contingencies giving a total capital cost. All material costs, functions and multipliers were based on a combination of expert opinion and where available data from previous dam construction projects and detailed costings from feasibility studies of unbuilt dams.

By way of example a typical RCC dam was modelled as having a 6-m deep foundation, 9-m width of the top of the wall and a downstream wall slope of 0.8. All surfaces subject to water action were modelled as being capped with 0.6 m of CC. The spillway width was set at the width of the river channel, which in the Mitchell catchment was automatically calculated using a bankfull river width grid generated using Landsat TM imagery (see companion technical report on Earth observation (Sims et al., 2016)). The dam wall abutments and saddle dams were designed for a 1:10,000 and 1:50,000 annual exceedance probability (AEP) design flood respectively. In the case of the earth embankment saddle dams an additional 1-m allowance was provided for dry freeboard. These AEP were selected on the basis that in the majority of locations no downstream populations of people will be at risk.
For RCC dams, design flood hydrographs were calculated by using data from previous reservoir routing studies and developing relationships between the modelled peak discharge and peak volume to catchment area (Malone 2011, Lee et al., 2013, Jordan et al., 2017). Adopting the method outlined by Nathan et al. (1994) these data were used to generate a series of ‘design’ hydrographs assuming the hydrograph was triangular in shape with the peak occurring at one-third the total event time. The resulting ‘design’ hydrographs were then routed through the reservoir using the ‘storage indication method’ to calculate the flood rise for different design flood events. Earth embankment saddle dams were modelled with a 6-m deep foundation, 7-m width of the top of the wall and a downstream wall slope of 0.5. The material used in the wall was modelled as three zones to account for differing costs of each type of material used in a typical wall construction.

DamSite model parameters as applied to the Darwin and Mitchell catchments

The DamSite model as applied to the Darwin and Mitchell catchments for assessing large dams was parameterised as follows:

- minimum catchment area assessed was 20 km²
- minimum wall height of 15 m
- gridded runoff data were sourced from the Australian Water Resources Assessment landscape (AWRA-L) model runs for the two catchments (see companion technical report on river model calibration (Hughes et al., 2017)).

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

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

The results of the DamSite analysis in the Darwin and Mitchell catchments are presented in Section 4.1 and Section 5.1, respectively.

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

2.1.3 SUMMARY OF CRITERIA USED TO ASSESS LARGE DAMS

To facilitate comparison of different sites, each potential dam site was assessed and reported against the standard set of 20 criteria listed in Table 2-1. The structure of this table is identical to the water storage summary tables presented in the results (i.e. sections 4.2 and 5.2). This table provides a summary of the methods by which the criteria were investigated.

For the six short-listed sites a more detailed analysis was undertaken for a selection of criteria. This involved more detailed flood design hydrology (see companion technical report on flood
hydrology (Jordan et al., 2017)), a manual detailed dam cost estimate for the selected FSL (see appendices C and D) and a preliminary hydro-electric power generation analysis (see companion technical report on hydro-electric power (Entura, 2017)).

Table 2-1 Criteria used to assess potential dam sites

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Previous investigations</strong></td>
<td>Literature documenting previous dam site investigations was obtained from a variety of sources including state and territory agency libraries, SunWater Corporation library and PWC. Note all adopted middle thread distances (AMTD) of dam from the river source were calculated using the topographic 250 km stream network and for this reason may vary from previous distances.</td>
</tr>
<tr>
<td><strong>Description of potential dam configuration</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Regional geology</strong></td>
<td>The regional geology for each dam site was assessed using the NT and Queensland 1:100,000 and 1:250,000 geology series, previous dam studies and literature sourced from state agency libraries.</td>
</tr>
<tr>
<td><strong>Site geology</strong></td>
<td>The site geology for each dam site was assessed using the NT and Queensland 1:100,000 and 1:250,000 geology series, and some sites were visited by the Assessment geologist. A rock sample from each of the short-listed sites was sent to a petrologist to assess the suitability of the local rock for aggregate for an RCC dam (see Appendix E for petrology report.)</td>
</tr>
<tr>
<td><strong>Reservoir rim stability and leakage potential</strong></td>
<td>These parameters were assessed by overlaying inundated area at the selected FSL on 1:250,000 or 1:100,000 geology data and some sites were inspected from helicopter by the Assessment geologist.</td>
</tr>
<tr>
<td><strong>Potential structural arrangement</strong></td>
<td>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.</td>
</tr>
<tr>
<td><strong>Availability of construction materials</strong></td>
<td>Based on review of available literature, site visits and proximity to quarry locations</td>
</tr>
<tr>
<td><strong>Catchment area</strong></td>
<td>Catchment areas were derived from DEM-H. In the majority of cases the DEM-H data were considered to be superior to historical topographic data for the purposes of deriving catchment areas and calculating reservoir volumes.</td>
</tr>
<tr>
<td><strong>Flow data</strong></td>
<td>Observed and simulated mean and median annual streamflow and PMF are reported. Observed streamflow metrics were calculated using observed data from the nearest or most representative streamflow gauging station. Simulated streamflow metrics were calculated using output from the AWRA-R (river system) models produced by the Assessment (see river modelling companion technical report (Hughes et al., 2017)). These are illustrated in the figures that accompany each data table.</td>
</tr>
<tr>
<td><strong>Storage capacity</strong></td>
<td>Dam capacity was derived from the DEM-H, unless stated otherwise. For potential dams the dead storage volume was assumed to occur at 5 m above the river bed (typically 1 to 2% of the reservoir capacity at FSL).</td>
</tr>
<tr>
<td><strong>Reservoir yield assessment at dam wall</strong></td>
<td>A behaviour analysis model (McMahon and Adeloye 2005) was used to assess the relationship between yield, reliability and storage volume under Scenario B (historical daily climate data, potential dam development) for a range of dam wall heights (i.e. yield was assessed at 1-m height increments from 5 m above river bed to a maximum height beyond which a dam would not be feasible) and a perennial crop demand patterns (Figure 2-1) using the baseline river model (Hughes et al., 2017). Inflows to the behaviour analysis model were generated by the locally calibrated AWRA-R (river system) model and the AWRA-L (landscape) model (see companion technical report on</td>
</tr>
</tbody>
</table>
Table 2-2 lists the AWRA-R nodes from which simulated streamflow data were extracted for input into the behaviour analysis model. The perennial crop demand pattern was based on the Agricultural Production Systems sImulator (APSIM) (Keating et al., 2003) simulations using the sugarcane module (see companion technical report on agriculture (Ash et al., 2018)). The performance of each reservoir was reported in terms of the annual time reliability and the volumetric reliability (McMahon and Adeloye, 2005). These performance criteria are sensitive to particular aspects of unsatisfactory operation during periods of low reservoir inflows. The inability of a reservoir or system of reservoirs to provide the target demand during a given period is commonly described as a supply failure.

Open water evaporation

Morton’s wet environment areal potential evaporation (APE) (Morton, 1983) was used to calculate potential evaporation 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. Reported as the ratio of the total net evaporation (difference between evaporation and rainfall) on the reservoir surface calculated at a daily time step to the total volume of water supplied over the historical climate (with the target annual time reliability being 85%).

Potential use of supply

Based on soil and land suitability information compiled by the Assessment team (see Thomas et al., 2018a, 2018b).

Estimated rates of reservoir sedimentation

Sedimentation rates were calculated using estimated sediment yields and the FSL dam capacity for each site. Sediment yields were calculated using an empirical relationship derived from ten sediment yield studies across northern Australia (Tomkins, 2013), including the Mitchell catchment. The rates of reservoir sedimentation are presented for 30, 100 and the number of years taken to 100% infill. Minimum (best case), expected and maximum (worst case) estimates are provided.

Storage impacts

Based on review of past studies, satellite imagery, GIS overlays and site visit.

Environmental considerations

Mapped data on the ecological assets and the fish species distribution for the Fitzroy, Darwin and Mitchell catchments were sourced from the companion technical report on aquatic ecology (Pollino et al., 2018a) and complemented with datasets of endangered vertebrate and plant species at a national (Species and Ecological Communities of National Significance) and state or territory level (NT, WA and Queensland). Key datasets for both assessments were:
- Atlas of Living Australia (Atlas of Living Australia, 2016) (all regions)
- Northern Australia Fish Atlas (TropWATER, 2017) (all regions)
- Directory of Important Wetlands in Australia (DIWA) Spatial Database (Public) (Australian Government Department of the Environment, 2010) (all regions)
- Species of National Environmental Significance (public grids) Database 10 km Grids (Australian Government Department of the Environment, 2016) (all regions)
- Ecological Communities of National Environmental Significance (public grids) Database 10 km Grids (Australian Government Department of the Environment, 2016)
- Important Areas for Birds (Birdlife International, year) (all regions)
- Queensland Herbarium (2016) Regional Ecosystem Description Database (REDD). Version 10.0 (December 2016) (Queensland Department of Science, Information Technology and Innovation: Brisbane) (Mitchell only)
- Department of Agriculture and Water Resources (2012) National Scale Vegetation Assets, States and Transitions (VAST Version 2) – 2008 (Darwin and Fitzroy regions)
- Threatened Species and Communities (Western Australia Government, 2017) (Fitzroy region)
- Wildlife Online (Queensland Government, 2017) (Mitchell only)
- Threatened animals and plants (Northern Territory Government, 2017) (Darwin only).

Barrier to movement of aquatic species

The likely impacts of a dam wall in terms of creating a barrier to the movement of aquatic species was assessed by examining the distribution of species within the catchments and the
PARAMETER | DESCRIPTION
---|---
relative position of the dam within the catchment.

**Ecological implications of inundation**

The ecological implications of inundation were assessed in terms of potential habitat loss for the local biodiversity. This was done intersecting the species datasets against the catchment boundary and the inundation region. Of special interest were species listed as ‘of concern’, ‘vulnerable’, ‘endangered’, ‘critically endangered’ or ‘migratory’ in national (EPBC), state or territory (NT, WA and Queensland) and/or international level (in particular, migratory birds). The latest available (2016. V10) 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.

**Water quality and stratification considerations**

No specific assessment of water quality and stratification was made as part of the Assessment. It has been assumed that selective withdrawal baulks will be provided in the intake works so that best quality water can be drawn from the storage when releases are made.

**Indigenous land tenure, native title and cultural heritage considerations**

Desktop review of pre-existing Indigenous cultural heritage site records obtained from state and territory government sources. Land tenure and native title information were derived from regional land councils and the National Native Title Tribunal.

**Estimated cost**

For the six potential dam sites that were short-listed, new cost estimates were calculated. This was done by developing conceptual arrangements for each of the storages. Dam and saddle dam profile axes were calculated using the ALOS DEM. Unit cost rates applied for each item of work were derived from earlier estimates for the Green Hills, Connors River Dam and Wyaralong Dam. The uncertainty in cost associated with the quantity of material for short-listed sites was estimated to be between –10% and +30%. However, if non-trivial geological issues were identified as part of a feasibility analysis or during dam construction then the final cost of construction could be considerably higher than 30%.

For those dams that were not short-listed, new indicative estimates of dam cost were obtained using the cost algorithm in the DamSite model (see Section 2.1.2). The uncertainty in cost associated with quantity of material estimated by the DamSite model is estimated to be between –20% and +50%. However, if non-trivial geological issues were identified as part of a feasibility analysis or during dam construction then the final cost of construction could be considerably higher than 50%.

**Estimated cost / ML of supply**

Estimated capital cost divided by the yield at 85% reliability as computed by the Assessment under the nominated structural arrangement.

**Summary comment**

As provided by Assessment personnel.

### Table 2-2 AWRA-R nodes from which simulated streamflow data were extracted for use in the behaviour analysis model

<table>
<thead>
<tr>
<th>DARWIN POTENTIAL DAM SITES</th>
<th>STREAMFLOW/ RUNOFF DATA SOURCE</th>
<th>NODE IDENTIFIER</th>
<th>MITCHELL POTENTIAL DAM SITES</th>
<th>STREAMFLOW/ RUNOFF DATA SOURCE</th>
<th>NODE IDENTIFIER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mount Bennett dam site</td>
<td>AWRA-R</td>
<td>81500002</td>
<td>Elizabeth Creek dam site</td>
<td>AWRLA-L</td>
<td>9133121</td>
</tr>
<tr>
<td>Upper Adelaide River dam site</td>
<td>AWRA-R</td>
<td>81700021</td>
<td>Pinnacles dam site on the Mitchell River</td>
<td>AWRA-R</td>
<td>9190030</td>
</tr>
<tr>
<td>Darwin River Dam</td>
<td>AWRA-R</td>
<td>81500110</td>
<td>Rookwood dam site on the Walsh River</td>
<td>AWRA-R</td>
<td>9193100</td>
</tr>
<tr>
<td>Manton Dam</td>
<td>AWRA-R</td>
<td>81700110</td>
<td>Chillagoe dam site on the Walsh River</td>
<td>AWRA-R</td>
<td>9193102</td>
</tr>
<tr>
<td>Acacia Gap dam site</td>
<td>AWRA-L</td>
<td>81700330</td>
<td>Lynd downstream dam</td>
<td>AWRA-A</td>
<td>9190060</td>
</tr>
</tbody>
</table>
2.1.4 SHORT-LISTED DAM SITES

Six sites were selected for ‘short-listing’, based on the review of historical dam proposals and the initial pre-feasibility analysis. The purpose of short-listing was to undertake additional analysis that would not otherwise be possible for all 15 potential dam sites examined as part of the pre-feasibility analysis.

The additional analysis undertaken for the short-listed sites were:

- site-specific flood design and reservoir routing analysis (see companion technical report on reservoir routing (Jordan et al., 2017))
- manual cost estimate at the selected FSL (see appendices C and D of this report)
- preliminary hydro-electric power analysis. This is reported in a companion technical report on hydro-electric power in the Darwin and Mitchell catchments (Entura, 2017).

The short-listed sites were selected on the basis of the topography of the dam axis, geological conditions, proximity to suitable soils, general geographic location and water yield. While these sites represent some of the more promising large instream and offstream dams in the Darwin and Mitchell catchments, other sites may be more favourable depending upon the location and nature of the demand.

It should be noted that two promising large dam sites, AROWS (Darwin catchments) and Nullinga (Mitchell catchment) dam sites were not selected for short-listing on the basis that feasibility level investigations of these two sites were being undertaken by other organisations at the time. Nevertheless, both sites are included in the pre-feasibility analysis for completeness and to enable
a like-with-like comparison with other sites reported here. No information from the feasibility level investigations of the AROWS or Nullinga dam sites was included in this analysis. It should also be noted that if a demand for water occurred in a different part of the catchment to the short-listed sites then other sites in closer proximity to the demand may be more suitable.

Two sites were short-listed in the Darwin catchments and four sites were short-listed in the Mitchell catchment. For the Darwin catchments these were Mount Bennett and Upper Adelaide River. For the Mitchell catchment they were Elizabeth Creek, Mitchell River at Pinnacles, and two sites on the Walsh River. The level of previous investigation of the short-listed sites ranged from pre-feasibility level (Upper Adelaide and Mount Bennett) to no prior recorded investigation (the lower Walsh River sites and Elizabeth Creek).

For any of these options to advance to construction, far more comprehensive studies would be required, as outlined in Section 1.4. Studies of that level of detail were beyond the scope of this pre-feasibility level Assessment.

2.2 Farm-scale storages

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

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

The high-level catchment-scale investigations undertaken were an analysis of:

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

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

2.2.1 Farm-scale offstream storage suitability analysis

The suitability of landscapes and soil for the construction of earth embankment farm dams (both ringtanks and gully/hillside dams) was assessed using 90 m by 90 m gridded data of selected soil attributes generated for the three study areas as part of the Assessment (see companion technical report on digital soil mapping attributes (Thomas et al., 2018a)). These gridded datasets were generated using a relatively new approach called digital soil mapping, which makes use of advances in computing and statistics.

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

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

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

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

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

<table>
<thead>
<tr>
<th>SUITABILITY SCORE</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Likely to be suitable</td>
</tr>
<tr>
<td>2</td>
<td>Possibly suitable</td>
</tr>
<tr>
<td>3</td>
<td>Unlikely to be suitable</td>
</tr>
<tr>
<td>4</td>
<td>Not suitable</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>CLAY CONTENT</th>
<th>PERMEABILITY</th>
<th>SOIL DEPTH</th>
<th>SLOPE</th>
<th>SUITABILITY SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 to 35%</td>
<td>Slow</td>
<td>1 to 1.5 m</td>
<td>&lt;1%</td>
<td>2</td>
</tr>
<tr>
<td>25 to 35%</td>
<td>Slow</td>
<td>1 to 1.5 m</td>
<td>1 to 2%</td>
<td>2</td>
</tr>
<tr>
<td>25 to 35%</td>
<td>Slow</td>
<td>1 to 1.5 m</td>
<td>2 to 5%</td>
<td>3</td>
</tr>
<tr>
<td>25 to 35%</td>
<td>Slow</td>
<td>1 to 1.5 m</td>
<td>&gt;5%</td>
<td>4</td>
</tr>
<tr>
<td>25 to 35%</td>
<td>Moderate</td>
<td>1 to 1.5 m</td>
<td>&lt;1%</td>
<td>3</td>
</tr>
<tr>
<td>25 to 35%</td>
<td>Moderate</td>
<td>1 to 1.5 m</td>
<td>1 to 2%</td>
<td>3</td>
</tr>
<tr>
<td>25 to 35%</td>
<td>Moderate</td>
<td>1 to 1.5 m</td>
<td>2 to 5%</td>
<td>3</td>
</tr>
<tr>
<td>25 to 35%</td>
<td>Moderate</td>
<td>1 to 1.5 m</td>
<td>&gt;5%</td>
<td>4</td>
</tr>
</tbody>
</table>
Irrespective of the values of the other parameters, a grid cell was assigned a suitability score of 4 if at that location the:

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

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

**Locations most suitable for gravity drainage**

Where water can be conveyed from a river to an offstream storage under gravity there can be substantial savings in operating pumping infrastructure, though there may be additional costs in the form of regular maintenance and removal of debris and sediment from the channel. To identify suitable locations for gravity drainage, persistent water datasets produced by the Assessment were visually inspected to identify ‘flood runners’ leading away from the main river channel. The companion technical report on Earth observation methods (Sims et al., 2016) outlines the method by which the images captured by the Landsat TM sensors were used to identify persistent water. These data are too fine to display within a report and are best viewed using the Assessment’s Google Earth Engine interface.

### 2.2.2 TOPOGRAPHIC AND HYDROLOGICAL ANALYSIS OF SUITABLE LOCATIONS FOR GULLY AND HILLSIDE DAMS

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

The DamSite model was run using 85% gridded annual exceedance runoff datasets generated by the Assessment for the three study areas (see companion technical report on river model calibration (Hughes et al., 2017)), and net evaporative losses were calculated by multiplying the reservoir surface area at 0.7 capacity by (i) the median net evaporation between March and August (inclusive) for the Fitzroy and Mitchell catchments, and (ii) the median net evaporation between April and August (inclusive) for the Darwin catchments.

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

Every SRTM grid cell location with a catchment area greater than 1 km² and less than 120 km² was assessed for its potential as a farm-scale dam by constructing earth embankment structures at 1-m height intervals between 5 and 20 m in height, including freeboard. Dam wall heights of less than 5 m were not examined in this analysis because the uncertainty in the DEM-H elevations were deemed to be too large relative to the height and capacity of the dam and reservoir, respectively.
Dam walls were constructed assuming a 3:1 (horizontal to vertical) ratio on the upstream face and a 2.5:1 ratio on the downstream face with a crest width of the square root of the height +1. The results are reported in terms of GL per 1000 m³ of earth moved. The dry freeboard was a function of the reservoir surface area plus 0.5 m wet freeboard. These values are broadly in line with the recommendations in the farm water supplies design manual (QWRC, 1984).

2.3 Natural water bodies

Naturally occurring water bodies, where they exist in close proximity to suitable soil or other demand (e.g. homestead), can offer the most cost-effective supply of water. However, in a seasonally arid landscape like northern Australia natural water bodies containing sufficient volume of water throughout the dry season to irrigate 50 ha or more are scarce. Furthermore, water bodies that persist throughout the dry season are considered to be key ecological refugia (Waltham et al., 2013) and can have cultural and social significance. Ecological, cultural and social values aside, extracting water from natural water bodies will not enable broad-scale irrigation to occur across northern Australia or within the three study areas. However, there may be local-scale opportunities that may enable a landholder to undertake small-scale irrigation (i.e. 1 to 10 ha) and build irrigation and cropping skills and experience before investing large amounts of capital in an irrigation enterprise.

2.3.1 METHODS FOR ASSESSING THE EXTENT OF PERSISTENT NATURAL WATER BODIES

For the purposes of this analysis persistent natural water bodies are defined as occurring where water was inferred using Landsat TM at the end of the dry season in more than 90% of years over the available record. The method by which pixels were classified as either water or non-water is detailed in the companion technical report on Earth observation methods (Sims et al., 2016).

Limitations

Importantly the persistent natural water body analysis presented here should not be seen as the definitive mapping of all instream pools for the Fitzroy, Darwin or Mitchell catchments. This is because the resolution of the Landsat TM pixels is 30 m, therefore channels in narrow river reaches, such as heavily braided sections, or reaches with thick riparian vegetation as occurs in the Darwin catchments, are likely to be under-represented in the analysis. This limitation, as well as deliberate exclusion of offstream pools through the application of a 500-m buffer, may mean that some permanent pools, including some that may be well known to the local people, may not be identified. Identification of pools in narrow river reaches would require the use of a higher resolution remote-sensing product and would benefit greatly from local knowledge. However, for instream pools larger than 3600 m², there is confidence in the approach taken within the analysed areas by the Assessment.
3  Assessment area

More than 60% of Australia’s runoff is generated north of the Tropic of Capricorn (Petheram et al., (2010)). However, a large proportion of northern Australia’s runoff is generated near the coast (CSIRO 2009a,b,c) and unlike the large internally draining Murray-Darling Basin, catchments in northern Australia tend to be smaller, the rivers shorter, more numerous and externally draining (Figure 3-1). These differences present both opportunities and challenges. Figure 3-1 presents the median annual streamflow of rivers in the Fitzroy, Darwin and Mitchell catchments within a national context.

![Figure 3-1 Modelled streamflow under natural conditions](image)

Streamflow under natural conditions is indicative of median annual streamflow prior to European settlement (i.e. without any large-scale water resource development/extractions) assuming the historical climate (i.e. 1890 to 2015). This figure was generated by accumulating gridded runoff data generated by Vaze et al. (2013). Catchments in northern Australia were scaled to match the median annual flow calculated by Petheram et al. (2012). Accumulated runoff in the Lake Eyre Basin was based on observed data.

The rest of this section provides a brief overview of the three study areas that comprise the Assessment area, with particular emphasis on features relevant to surface water storage.
3.1 Fitzroy catchment

3.1.1 OVERVIEW: CATCHMENT, LAND AND PEOPLE

The Fitzroy catchment has an area of 93,830 km² and extends from Halls Creek and the King Leopold Ranges (~420 m AHD) in the east to Derby and King Sound in the west (Figure 3-2).

The Fitzroy River has a median annual discharge of 4903 GL, the largest of any river in WA and the ninth largest median annual discharge of any river discharging in Australia north of the Tropic of Capricorn (Petheram et al., 2014).

The Fitzroy catchment is comprised of two main population centres; Derby, population 3261 (Australian Bureau of Statistics, 2014a), and Fitzroy Crossing, population 1144 (Australian Bureau of Statistics, 2013b). There are also 57 smaller Indigenous communities contributing to a combined catchment population of about 7000 people.

The main land use is pastoralism (95%), with large cattle grazing leases where cattle graze on native pastures, shrubs, and some introduced forages and legumes. Indigenous Protected Areas cover the remaining area. The majority of the catchment is overlaid with Indigenous native title determinations or claims that are in progress (Figure 3-3). There are also substantial, although still incomplete, records of cultural heritage sites throughout the catchment (Figure 3-4).
Figure 3-2 Flood inundation and major rivers and towns of the Fitzroy catchment
Shaded relief map illustrates topography. Flood inundation extent derived using MODIS satellite imagery. This figure illustrates the maximum percentage of each MODIS pixels inundated between 2000 and 2015.
Figure 3-3 Indigenous native title claims and determinations in the Fitzroy catchment as at July 2017
Source: National Native Title Tribunal. For more information on Indigenous values, rights and development goals in the Fitzroy catchment see the companion technical report, Barber and Woodward (2018).
3.1.2 CLIMATE

The Fitzroy catchment lies near the southernmost extent of the typical deep westerly wind regime associated with the Australian summer monsoon, and its climate is characterised by a highly distinctive wet and dry season (Figure 3-5 and Figure 3-6). The largest proportion of rainfall in coastal areas of the Fitzroy catchment comes from active monsoon periods, while further inland and up the catchment a greater contribution of rainfall results from monsoon bursts and daily thunderstorm activity.

The mean annual rainfall, over the 125-year historical period (1890 to 2015) over the Fitzroy catchment was 552 mm, with close to 93% of rain falling during the wet season (1 November to 30 April) (Charles et al., 2016). Rainfall is highest in the north of the catchment (Figure 3-7) as these locations are more frequently affected by monsoonal westerly winds and the Kimberley heat trough. The trough, a primary trigger for diurnal storm activity in the catchment, results in moist
maritime winds to its north and much drier continental air to its south (Charles et al., 2017). The King Leopold Ranges in the eastern half of the catchment can act as a lifting mechanism for convection, though the effect on rainfall is not pronounced. However, the higher elevation (300 to 400 m) in the eastern half of the catchment can result in spatial differences in minimum temperature of 2 to 4 °C during the dry season. Minimum temperatures are consistently higher in coastal areas.

Areal potential evaporation in the Fitzroy catchment exceeds 2000 mm in most years (Charles et al., 2017). It exhibits a strong seasonal pattern, ranging from 200 mm per month during the build-up and the wet season (October to December), to about 100 mm per month during the middle of the dry season (June). The high potential evaporation rates and relatively low rainfall result in a large annual rainfall deficit across most of the catchment. Consequently, a large proportion of the catchment is semi-arid (95%).

**Figure 3-5 Historical rainfall in the Fitzroy catchment at Fitzroy Crossing**
(a) Monthly rainfall at Fitzroy Crossing; (b) time series of annual rainfall at Fitzroy Crossing. A range is the 10th to 90th percentile monthly rainfall. Dark blue line represents 10-year moving mean.

**Figure 3-6 Potential evaporation in the Fitzroy catchment at Fitzroy Crossing**
(a) Monthly potential evaporation at Fitzroy Crossing; (b) time series of annual potential evaporation at Fitzroy Crossing. A range is the 10th to 90th percentile monthly potential evaporation. Dark blue line represents 10-year moving mean. Period of analysis 1 September 1965 to 31 August 2015. Potential evaporation calculated using Morton’s areal potential evaporation (Morton, 1983).
Figure 3-7 Maps of rainfall, potential evaporation and rainfall deficit in the Fitzroy catchment
Historical median (a) annual, (b) wet season, (c) dry-season rainfall; (d) annual, (e) wet season (f) dry-season potential evaporation; and (g) annual, (h) wet season and (i) dry-season rainfall deficit in the Fitzroy catchment. Sourced from Charles et al. (2016).
3.1.3 HYDROLOGY

Mean annual flow observed near the mouth of the Fitzroy River at Willare (Gauge 802008) is 6600 GL (see companion technical report on river model calibration, Hughes et al. 2017). The Fitzroy River is fed by the Leopold and Margaret rivers that rise in the eastern parts of the catchment and join the Fitzroy near Fitzroy Crossing. The Margaret River has a contributing area of 16,561 km². This area includes the Leopold River catchment, which has a contributing area of 5820 km². Christmas Creek rises in the south-east of the catchment and joins the Fitzroy River between Fitzroy Crossing and Noonkanbah. Its contributing area is 11,446 km².

Streamflow varies between perennial and intermittent in reaches downstream of Fitzroy Crossing, while flow in most other parts of the catchment is ephemeral. The floodplain that extends downstream of Fitzroy Crossing to Willare is regularly flooded and maximum flow rates in this part of the catchment are very high. Maximum flow rates between 11,000 and 26,000 m³/s have been recorded at gauges downstream of Fitzroy Crossing.
The Fitzroy Barrage (at the site for gauge 802003) is a flow control structure that was constructed for the diversion of water to the Camballin Irrigation Area in the 1960s. Although irrigation diversions have occurred in the Fitzroy in the past, no records have been found of volumes and timing of these diversions. This scheme has not operated since the mid-1980s, and there are no other flow control structures in the catchment.

3.1.4 ECOLOGY

The Fitzroy catchment has three wetlands of national significance: Geikie Gorge, Camballin Floodplain and Gladstone Lake (Environment Australia, 2001; SKM, 2009) (Figure 3-9). Camballin Floodplain supports internationally significant waterbird populations (Department of Water, 2009). Geikie Gorge is located within a national park.

![Figure 3-9 Recorded extent of key aquatic species and habitats in Fitzroy catchment](image)

A large part of the vegetation in the Fitzroy catchment is considered to have had anthropogenic disturbance (Figure 3-10, Department of Agriculture and Water Resources, 2012). A resource condition survey in the west Kimberley in 1972, covering much of the Fitzroy catchment,
concluded that nearly 30% of the area was in bad range condition, 51% in fair condition and only 20% in good range condition (Payne et al., 1979).

A high-value habitat in the Fitzroy River is in-channel permanent pools. Some of these are hydrologically connected to groundwater during the dry season and are considered the only persistent water source for terrestrial and aquatic fauna, including waterbirds (Vogwill, 2015). Seasonal flooding of the river sustains off-river wetlands and leads to a boom in productivity, while the groundwater baseflow maintains permanent pools as important refuge habitat (Vogwill, 2015).

![Figure 3-10 Recorded extent of selected terrestrial species in Fitzroy catchment](image)

Source: National Scale Vegetation Assets, States and Transitions (VAST Version 2) (Department of Agriculture and Water Resources (2012).

The Fitzroy River has a high biodiversity (Vogwill, 2015). Aquatic fauna of interest include barramundi, freshwater sawfish, dwarf sawfish and the saltwater crocodile; all species are of regional or national interest. The Fitzroy River supports 35 of 43 fish species known from the Kimberley, with 18 of these being endemic (Department of Water, 2009). Many are migratory fish and stable flow spawners and could be negatively impacted by artificial barriers (Figure 3-9). The
Fitzroy features critically endangered fish: freshwater sawfish, dwarf sawfish and northern river shark. Freshwater whipray is listed as vulnerable (IUCN, 2011). King Sound and the adjacent Fitzroy River are the only known nursery areas for freshwater sawfish in the Kimberley (Thorburn and Morgan, 2005a, 2005b).

The Fitzroy River end-of-system, King Sound, is high-value estuarine–coastal habitat. It is a large semi-enclosed water body that is fringed by broad tidal mudflats. These mudflats and mangroves provide nursery habitat for a wide variety of fish (Pollino et al., 2018a) and crustaceans, which are important prey for inshore dolphins. Australian snubfin dolphins and the Indo–Pacific humpback dolphin use the tidal rivers, while bottlenose dolphins are found in deeper waters (Thiele, 2005).
3.2 Darwin catchments

3.2.1 OVERVIEW: CATCHMENT, LAND AND PEOPLE

The Darwin catchments are comprised of four northerly draining catchments defined by their Australian Water Resources Council (AWRC) river basin boundaries: the Finniss (9490 km²), Adelaide (7460 km²), Mary (8075 km²) and Wildman (4820 km²) (Figure 3-11). The major population centre is Darwin, located within the Finniss catchment and the capital of the NT.

Figure 3-11 Flood inundation and major rivers and towns of the Darwin catchments
Shaded relief map illustrates topography. Flood inundation extent derived using MODIS satellite imagery. This figure illustrates the maximum percentage of each MODIS pixels inundated between 2000 and 2015.

The greater Darwin region (including the local government areas of Darwin, Palmerston and Litchfield, and the city of Darwin) has a population of 140,368 (Australian Bureau of Statistics, 2014b), with the total NT population of 245,079 (Australian Bureau of Statistics, 2014b). The main land use is for nature conservation (53%), with some extensive grazing (31%) and farming (7%) (dryland cropping and horticulture, forestry and modified pastures).
Indigenous land tenure and land interests in the area include freehold land held under the *Aboriginal Land Rights (NT) Act 1976* and native title claims that have been accepted for registration under the Commonwealth’s *Native Title Act 1993* (Figure 3-12). There are also substantial, though incomplete, records of Indigenous cultural heritage sites in the Darwin catchments (Figure 3-13).

**Figure 3-12 Indigenous freehold land and native title claims in the Darwin catchments as at July 2017**

Source: National Native Title Tribunal and the Northern Land Council. For more information on Indigenous values, rights and development goals in the Darwin catchments see the companion technical report, Barber (2018).
3.2.2 GEOLOGY

The geology of the four Darwin catchments suitable for large instream dams (i.e. Finniss, Adelaide, Mary and Wildman rivers) may be divided into two major topographical and geological divisions: the Pine Creek Orogen and the coastal plains (Figure 3-14).

The Pine Creek Orogen is a geological province underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The area is undulating with isolated ranges of quartzite and other metamorphic and igneous rocks. The rocks in the Pine Creek Orogen have been intruded with granite, have been folded, faulted and uplifted and subject to long periods of erosion since they were formed. Soils over the older rocks are thin in much of the area but there are channel deposits in the rivers, and alluvial terraces and colluvium on many of the slopes. On the lower reaches of the rivers in the Pine Creek Orogen, deeper alluvium is likely to
occur and in tidal sections of the rivers there are also likely to be soft estuarine sediments in the valley floor.

The coastal plains extend up to 50 km inland. The plains are underlain by up to at least 20 m of alluvium and estuarine sediments, which in turn are underlain by soils and rocks of Cretaceous age.

**Broad-scale geological consideration in siting large dams in the Darwin catchments**

The best potential large dam sites in the Darwin catchments region are found where rivers have eroded through meta-sedimentary volcanic or igneous rocks in the Pine Creek Orogen, particularly where there is relatively shallow rock in the valley floor. Substantial excavation may be required to provide suitable foundations where alluvium is deep. Where the rivers are tidal, the presence of soft estuarine sediments has the potential to make dam design more challenging and construction more expensive, which may compromise the feasibility of a dam. Offstream storages may avoid some of these potential problems with deep alluvium.

Quartzite and granite in the Pine Creek Orogen are potential sources of aggregate for RCC and possibly for CC. Floodplains and colluvial slopes are potential sources of cohesive soils, sand and gravel for embankment dams if required.

Potential dams in the coastal plains would have to have long low dams spanning the valleys, which are typically 1 to 3 km wide. Rivers on the coastal plains are likely to be tidal and underlain by soft estuarine sediments, which will make finding a suitable foundation and construction difficult and compromise the feasibility of potential dams. Designing and constructing spillways to safely pass large floods would also be very difficult on the coastal plains.
Figure 3-14 Main geological units of the Darwin catchments

1. This unit includes the Edith River, Tolmer, Katherine River and Fitzmaurice Groups
2. This unit includes the Mantoe, Mount Partridge and Nameona Groups
3.2.3 CLIMATE

The Darwin catchments are characterised by a distinctive wet and dry season due to their location in the Australian summer monsoon. The mean annual rainfall over the 125-year historical period (1890 to 2015) over the Darwin catchments was 1423 mm, with close to 90% of rain falling during the wet season (1 November to 30 April) (Figure 3-15).

The Darwin catchments experience two categories of large-scale weather pattern, defined by low-level easterly or low-level westerly winds (e.g. Wilson et al., 2001; May and Ballinger, 2007). During the build-up months (typically September to December), low-level easterly winds dominate. These easterlies can carry pockets of dry or humid air, depending on available moist air mass advection from the Gulf of Carpentaria and Coral Sea, and can result in short-lived thunderstorm activity under certain conditions (see companion technical report on climate (Charles et al., 2016)). During the ‘build-up’ months (September to October) the bulk of rain falls within about 100 km of the west coast of the Darwin catchments including the Finniss and Adelaide river catchments, while the Mary and Wildman catchments generally receive less rainfall over these months (Figure 3-16). From November onwards, rainfall distribution is more uniform across the four catchments.

During the wet season, westerly regimes dominate, where a ‘shallow westerly’ regime is typical of an inactive monsoon period, and a ‘deep westerly’ regime corresponds to an active monsoon period. The former favours early morning thunderstorms along the coast and has high levels of lightning activity. In the afternoon, thunderstorm activity is more common inland. During the active monsoon there is less lightning but showers and thunderstorms can be gusty and cause heavy rainfall due to the large water content of the maritime air mass. In coastal areas, the active monsoon makes the largest contribution to rainfall, while further inland there is more of a balance between contributions from the monsoon and daily thunderstorm activity. The Darwin catchments are flat, and consequently there is no topographic influence on climate parameters such as rainfall and temperature.

![Figure 3-15](image_url) Historical rainfall in the Darwin catchments at Darwin
(a) Monthly rainfall at Adelaide River; (b) time series of annual rainfall at Darwin. A range is the 10th to 90th percentile monthly rainfall. Dark blue line represents 10-year moving mean.
Areal potential evaporation in the Darwin catchments exceeds 1800 mm most years (Charles et al., 2016). It exhibits a strong seasonal pattern, ranging from 200 mm in October to about 125 mm in June (Figure 3-17).
Figure 3-17 Potential evaporation in the Darwin catchments at Darwin
(a) Monthly potential evaporation at Adelaide River; (b) time series of annual potential evaporation at Darwin. A range is the 10th to 90th percentile monthly potential evaporation. Blue line represents 10-year moving mean. Period of analysis 1 September 1965 to 31 August 2015. Potential evaporation calculated using Morton’s areal potential evaporation (Morton, 1983).

3.2.4 HYDROLOGY

The Darwin catchments (Finniss, Adelaide, Mary and Wildman) feature extensive flat, tidally affected floodplains extending from the river outlets back upstream for considerable distances. It is difficult to estimate flow rates in tidally affected streams, at least with standard stream gauge methods and, for this reason, the gauge network in these rivers is concentrated in the upper part of their respective catchments.

The lowermost gauge on the Finniss River is located at Gitchams Crossing (Gauge 8150180), approximately 73 km upstream from the outlet to the ocean. Flow is perennial with a mean annual flow of 522 GL. The catchment area of the Finniss River is calculated to be 2590 km².

The lowermost gauge on the Adelaide River is located at Dirty Lagoon (Gauge 8170020), approximately 125 km upstream of the river mouth. Despite its distance from the ocean, this gauge is still tidally affected, and therefore can only be used to estimate high flows (when stage exceeds the maximum tidal level). Maximum recorded flow rate at Dirty Lagoon is 3629 m³/s. Mean annual flow in the two streams that feed the Adelaide River at Dirty Lagoon are 771 GL and 980 GL. Flow is perennial in these tributaries. The AWRC estimates the Adelaide River area to be 7462 km².

The lowermost gauge on the Mary River is located at Mount Bundy (Gauge 8180035), approximately 97 km upstream from the outlet to the ocean. Flow is perennial at Mount Bundy with a mean annual flow of 2351 GL. The Mary River catchment area calculated from the catchment outlet is estimated to be 7574 km², while the AWRC estimate for the Mary River area is 8073 km².

The Wildman River has no current or discontinued stream gauging. Gauges are located nearby on the West Alligator River (8190001) and Swim Creek (8190072). Based on the AWRC boundaries the Wildman River catchment was calculated to be 4818 km².

Figure 3-18 shows the mean annual streamflow accumulation in the Darwin catchments and the potential dam sites examined as part of this pre-feasibility analysis.
The Darwin catchments have extensive seasonal wetlands and floodplain systems (Figure 3-19). There are five wetlands of national significance: the Finniss Floodplain and Fog Bay Systems (Finniss River), the Port of Darwin (Finniss River), the Adelaide River Floodplain System (Adelaide River), the Mary Floodplain System (Mary River) and Kakadu National Park (Wildman section) (Environment Australia, 2001). Only Kakadu National Park is Ramsar listed, and the greater park area extends into the neighbouring Alligator River catchment. Large areas of the Darwin catchments are considered to have been modified (Department of Agriculture and Water Resources, 2012). Although modified in some degree, the Arnhem Plateau Sandstone Shrubland Complex is considered an ecological community of national significance; it is also an important area for bird biodiversity (Figure 3-20).
The inland aquatic ecosystems within this region form a complex mosaic of habitats, supporting rich biodiversity. This is attributed to the integrity, extent and heterogeneity of the wetland habitats throughout the region (Environment Australia, 2001; DLRM, 2016). The Adelaide River Floodplain and Mary Floodplain systems are recognised as important breeding areas for waterbirds and crocodiles and are among the most important breeding sites for magpie geese in Australia (SKM, 2009).

The region also has a high dependence on groundwater. Spring-fed monsoon vine forests of high conservation value in the Wildman catchment are vulnerable to increased use of groundwater resources (Figure 3-19). Many persistent waterholes throughout the river systems are also in part replenished by groundwater, with the waterholes creating refugia in the dry season. Riparian zones, which support high biodiversity and productivity, are sensitive to changes in both surface water and groundwater regimes (Pusey and Kennard, 2009).

Significant fauna in the region include saltwater and freshwater crocodiles, the dwarf sawfish, the freshwater sawfish, and the northern river shark. The ecology of many of these species is highly dependent on the quality and quantity of water resources, and maintenance of habitat.
heterogeneity. In this catchment, the barramundi, sawfish and other species, have life histories that span freshwater through estuarine to marine environments, and are valuable to the commercial, recreational and Indigenous fishery sectors (Bayliss et al., 2014).

Figure 3-20 Recorded extent of selected terrestrial species in Darwin catchments
Source: National Scale Vegetation Assets, States and Transitions (VAST Version 2) (Department of Agriculture and Water Resources (2012).
3.3 Mitchell catchment

3.3.1 OVERVIEW: CATCHMENT, LAND AND PEOPLE

The Mitchell River study area is defined by the Mitchell AWRC basin. It encompasses an area of 71,530 km² and contains part of the Mareeba–Dimbulah Water Supply Scheme, which extends into the upper headwaters of the Walsh River (Figure 3-21). The population in the catchment is small (less than 6000), and there are no major urban population centres. The largest settlements are the towns of Dimbulah, population 1414 (Australian Bureau of Statistics, 2013b), Kowanyama, population 1031 (Australian Bureau of Statistics, 2013c) and Chillagoe, population 192 (Australian Bureau of Statistics, 2013d).
The main land use is pastoralism (95%), with large grazing leases with cattle grazing native pastures and shrubs, and little clearing of trees to support sown and improved pastures or crops. Conservation reserves are the second-largest land use, but make up only 3% of the catchment. The land types and climate generally support cattle breeding operations with limited capacity to fatten stock.

Indigenous land tenure and land interests in the area include freehold land held under the Queensland Government’s *Aboriginal Land Act (1991)* and native title claims and determinations under the Commonwealth’s Native Title Act (Figure 3-22). There are also substantial, though incomplete, records of Indigenous cultural heritage in the Mitchell catchment (Figure 3-23).

**Figure 3-22** Indigenous freehold land and native title claims and determinations in the Mitchell catchment as at July 2017
Source: National Native Title Tribunal and the North Queensland Land Council. For more information on Indigenous values, rights and development goals in the Mitchell catchment see the companion technical report, Lyons and Barber (2018).
3.3.2 GEOLOGY

The geology of the Mitchell catchment may be divided into three major divisions. From east to west (upstream to downstream) these are the Hodgkinson Province, the Etheridge Province and the Carpentaria Basin (Figure 3-24).

The highest part of the catchment is underlain by the meta-sedimentary and igneous rocks of the Hodgkinson Province (of Ordovician to Devonian age), which lie between the Great Divide and the north/south to north-west/south-east-trending Palmerville Fault. The province (which is part of the Mossman Orogen) includes large areas of volcanic rocks associated with large volcanic complexes of ignimbrites (welded pyroclastic flows) and lavas of Carboniferous to Permian age. The rocks in the Hodgkinson Province have been intruded with granite, folded, faulted and
uplifted and subject to long periods of erosion since they were formed. The Chillagoe Province is a narrow strip of folded and faulted rocks (including limestone), which crop out near to the Palmerville Fault along the western and south-western boundary of the Hodgkinson Province. In places the Hodgkinson Province rocks are overlain by younger rocks, such as sandstones of Triassic age, and there are also basalts of Cenozoic age (e.g. the headwaters of the Lynd River). Soils over much of the Hodgkinson Province are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on many of the slopes.

The oldest rocks in the Mitchell catchment are the metamorphic and igneous rocks of the Etheridge Province of Proterozoic age, which crop out north-west and south-west of the Palmerville Fault. The Etheridge Province is underlain mainly by weathered granite, gneiss and schist and has relatively subdued relief. In places the older rocks in the province are overlain by volcanic rocks of Carboniferous to Permian age and by sedimentary rocks of Jurassic or Cretaceous age.

The Carpentaria Basin (which is part of the Great Artesian Basin) occupies the remainder of the catchment (west of the Hodgkinson and Etheridge provinces). This area is underlain by sedimentary rocks of Jurassic and Cretaceous age of the Gilbert River Formation (mainly sandstone) or the Rolling Downs Group (mainly mudstone and siltstone). There are also large areas of younger soils and rocks of Cenozoic age, including alluvial, colluvial and residual soils.

**Broad-scale geological consideration in siting dams in the Mitchell catchment**

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

While there are potential dam sites in the Chillagoe Formation, care would be needed to avoid potential problems with karstic limestone in the foundations or storage area. Care would also have to be taken with potential dam sites in the upper reaches of the Lynd River where high leakages could be associated with relatively young basalts and the unconformities at the base of the basalts.

Much of the Etheridge Province produces topography unfavourable for dam construction but there are some places where the topography is more favourable (e.g. on the Lynd River where the river has eroded through or down to the volcanic rocks).

The gentle rolling downs topography of the Carpentaria Basin presents few opportunities for instream dams. Embankments generally have to be very long to provide adequate storage and construction and operation of a spillway to cope with the large flood events that can occur could pose significant risks. Offstream storages may be a better option in some areas.
Figure 3-24 Major geological units of the Mitchell catchment

The Palmerve Fault is the western boundary of the Hodgkinson Province (and the Messoman Dolerite).

The Etheridge Province is the brown area north-west and south-west of the Palmerve Fault.

The Carpentaria Basin is the area of Late Permian to Cretaceous and Cenozoic-age sediments west of the Palmerve Fault and the Etheridge Province.
Gorges within mudstones of the Rolling Downs Group (of Cretaceous age) may not be suitable for dam construction 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 streambed. The low shear strength seams may compromise the stability of the abutments and the foundations of the potential dam.

3.3.3 CLIMATE

The Mitchell catchment is characterised by a distinctive wet and dry season due to its location in the Australian summer monsoon. The mean annual rainfall, over the 125-year historical period (1890 to 2015) over Mitchell catchment was 996 mm, with close to 90% of rain falling during the wet season (1 November to 30 April) (Figure 3-25). Of this, a considerable proportion is due to tropical cyclones or tropical lows, which cross the catchment every few years.

Areal potential evaporation in the lower and upper Mitchell catchment exceeds 1850 and 1750 mm, respectively, in most years (see companion technical report on climate (Charles et al., 2016)). It exhibits a strong seasonal pattern, ranging from 200 mm per month during the build-up and the wet season (October to December), to about 100 mm per month during the middle of the dry season (June) (Figure 3-26).

The bulk of wet-season rainfall comes from active monsoon bursts, which bring significant shower and thunderstorm activity into the catchment from the west. Other major rainfall contributions come from thunderstorm activity during the transition months of October, November and April, and during monsoon break periods.

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**Figure 3-25 Historical rainfall in the Mitchell catchment at Chillagoe**

(a) Monthly rainfall at Chillagoe; (b) time series of annual rainfall at Chillagoe. A range is the 10th to 90th percentile monthly rainfall. Dark blue line represents 10-year moving mean.
In a south-easterly wind regime, which is common between the months of April and November in northern Queensland, rainfall on the western side of the ranges is reduced due to a localised orographic rain-shadow effect produced by the ranges. It is worth noting that some parts of the far upper Mitchell catchment receive rainfall throughout the dry-season months (approximately 20 to 50 mm per month) before the air mass completely dries out as it moves down the western side of the ranges (Figure 3-27).
Figure 3-27 Maps of rainfall, potential evaporation and rainfall deficit in the Mitchell catchment
Historical median (a) annual, (b) wet season, (c) dry-season rainfall; (d) annual, (e) wet season (f) dry-season potential evaporation; and (g) annual, (h) wet season and (i) dry-season rainfall deficit in the Mitchell catchment. Sourced from Charles et al. (2016).
3.3.4 HYDROLOGY

The Mitchell catchment is comprised of four main rivers: the Lynd, Mitchell, Palmer and Walsh (Figure 3-28). Streamflow in the upper sections of the Mitchell, Lynd, Palmer and Walsh rivers is generally perennial. In the middle of the catchment, flow is close to perennial in the Palmer River and Mitchell River while the Walsh and Lynd rivers remain ephemeral (dry on 20% to 50% of days). Flow converges at Gamboola (919011) and Dunbar (919009) where flow is effectively perennial.

The lower portion of the Mitchell River features a very large alluvial fan where river flow becomes divergent and there are numerous outlets to the ocean. The nature of the connection of the main river with any of these distributary streams is relatively unknown, and no stream gauge data are available downstream of the Dunbar gauge (919009), which is 136 km upstream from the mouth of the Mitchell River. Flow in the Mitchell River is perennial at Dunbar with a mean annual flow of 7880 GL, and recorded maximum flow of 6387 m³/s. The Alice River joins the Mitchell River near the main outlet of the Mitchell to the ocean, although no gauge data are available for this stream.

Flow in the lower Palmer River at Drumduff (919204) is perennial with a mean annual flow of 1797 GL. Flow in the lower Walsh River at Trimbles Crossing (919309) is ephemeral, having a mean of 82 no-flow days per year. Mean annual flow is 1552 GL. No observations are available for the lower Lynd River.

During large flood events water spills out of the Mitchell River and enters the Staaten River catchment and other smaller streams further south. Based on the AWRC river basins, the catchment area of the Mitchell catchment was calculated to be 71,529 km². Two major tributaries of the Mitchell River are the Palmer River and the Lynd River. They have contributing areas of 33,225 km² and 11,920 km², respectively.

The Mitchell catchment features a substantial irrigation development, the Mareeba–Dimbulah Water Supply Scheme (MDWSS), in its headwaters. Most water used in this irrigation development is supplied from Lake Tinaroo in the neighbouring Barron catchment to the east. Estimates of outflow from the MDIA (Mareeba–Dimbulah Irrigation Area, previous name of MDWSS) into the upper Mitchell system were estimated as a part of the Barron Integrated Quantity and Quality Model (IQQM) model at around 800 ML/year (Alex Loy, 2017, pers. comm.). Irrigation outflow moves into the Mitchell system via a circuitous path and eventually into Lake Mitchell. Lake Mitchell is an unregulated storage in the upper portion of reach 919014.
3.3.5 ECOLOGY

The Mitchell catchment has a highly variable flow regime and this is important for maintaining the ecological character of the system (CSIRO, 2009b, Pollion et al., 2018b). The Assessment area contains three wetlands of national significance: the Mitchell River Fan Aggregation, the Southeast Karumba Plain Aggregation and the Spring Tower Complex (Department of the Environment, 2010) (Figure 3-29). The Mitchell River Fan Aggregation comprises deeply incised stream lines with numerous permanent waterholes and floodplains and is habitat to a wide range of waterbirds (Department of Environment, 2010). The Southeast Karumba Plain Aggregation contains varied habitats, including tidal flats, stream channels, and ephemeral and permanent wetlands. This supports important waterbird breeding habitat, including the second-largest summer population of wader birds in Australia, and is recognised as having high wilderness value (Department of the Environment, 2010). The Spring Tower Complex contains spring-fed freshwater cave systems and
is recognised as a good example of a karst wetland; these have restricted distribution in Australia. The Spring Tower Complex contains relict fauna and flora, including vine thickets and blind amphipods (Department of the Environment, 2010).

Figure 3-29 Recorded extent of key aquatic species and habitats in Mitchell catchment

Terrestrial and freshwater biodiversity of the Mitchell catchment is rich and many species and ecological communities are listed for conservation at a federal and state level (Figure 3-29 and Figure 3-30). Species of conservation importance that could be impacted by potential dams include migratory birds, migratory fish and stable spawners, and vulnerable water monitors.

Estuarine and coastal marine waters of the Mitchell catchment support a suite of important species. Species of conservation importance include dugongs, sea snakes, speartooth sharks, sea turtles and sawfish. Banana prawns are of considerable value to the Northern Prawn Fishery and are highly dependent on river flow. Species such as barramundi, threadfins and mudcrab are also dependent on river flow, particularly to commercial and Indigenous fisheries, and they support fishing tourism in the south-eastern Gulf of Carpentaria (Bayliss et al., 2014).
Figure 3-30 Recorded extent of selected terrestrial species in Mitchell catchment
Part II  Large instream and offstream dams
4 Darwin catchments

4.1 Broad-scale analysis of potential dam sites in the Darwin catchments

Fifteen potential dam, weir and causeway locations in the Darwin catchments were identified from published and unpublished literature. The extent of prior investigations ranged from a single reference of potential locations (e.g. Blackmore Causeway) to detailed hydrological and geotechnical investigations (e.g. AROWS). Five of the more promising and larger yielding sites were selected for the pre-feasibility analysis. The studies were reviewed and all locations were reassessed using a consistent set of methods, using updated data where available.

4.1.1 DAMSITE MODEL RESULTS IN THE DARWIN CATCHMENTS

To ensure that no potential dam options had been overlooked, the DamSite model (Section 2.1.2) was used to undertake a preliminary assessment of over 20 million potential dam sites in the Darwin catchments. 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 using different criteria, and the locations compared to the previously identified potential dam locations and likely arable land.

Large dams for irrigation and water supply in the Darwin catchments

Large offstream storages in the Darwin catchments

Figure 4-1 displays the most promising sites across the study area in terms of storage volume (GL) per million dollars of construction cost. Only those locations with a ratio of storage to cost greater than 0.25 GL per million dollars (or sites less than $4000/ML) are shown. This provides a simple way of displaying those locations in the study area with the most favourable topography for a large reservoir relative to the size (i.e. cost) of the dam wall necessary to create the reservoir. This figure is particularly useful for identifying more promising sites for offstream storage (i.e. where some or all of the water is pumped into the reservoir from an adjacent drainage line). The threshold value of 0.25 GL per million dollars is nominal and is used to minimise the amount of data displayed. It should be noted that this analysis does not consider evaporation or hydrology.

This figure shows that the topography of the Darwin catchments is generally unfavourable for the construction of large dams. Those parts of the Darwin catchments with the most favourable topography for storing water are on the Adelaide River immediately upstream of Adelaide River town. Other topographically favourable locations are immediately west of the Adelaide River south of the Arnhem Land Highway. This area coincides with the AROWS.
Figure 4-1 Minimum cost per ML storage capacity
This figure can be used to identify locations where topography is suitable for large offstream storages. At each location the minimum cost per ML storage capacity is displayed. The smaller the minimum cost per ML storage capacity the more suitable the site for a large offstream storage. Analysis does not take into consideration geological considerations, hydrology or proximity to water. Only sites with a minimum cost to storage volume ratio of less than $4000/ML are shown. $1000/ML is equivalent to 1 GL per million dollars. Costs are based on unit rates and quantity of material and site establishment for a RCC dam. Data are underlain by a shaded relief map. Inset displays height of full supply level (FSL) at the minimum cost per ML storage capacity.

Large instream dams in the Darwin catchments
In addition to suitable topography (and geology), instream dams require sufficient inflows to meet a potential demand. Potential dams that command smaller catchments with lower runoff have smaller yields. Results concerning this criterion can be summarised and conveniently presented in terms of maximum yield (GL) per million dollars to construct the dam. This is similar to the storage volume per million dollars term described above, except that it incorporates hydro-climate. The DamSite model was initially run using a preliminary storage-yield-reliability calculation method, the GDG method (see Section 2.1.2), which is very rapid to apply. The top 5000 sites for the
Darwin catchments ranked in terms of the GDG yield (GL) per million dollars are displayed in Figure 4-2.

As discussed in Section 2.1.2, the yield of the top 5000 sites ranked in terms of GDG yield (GL) per million dollars (Figure 4-2) was remodelled using a more accurate, but computationally intensive behaviour analysis model (Section 2.1.2). Figure 4-3 presents the results of the behaviour analysis model yield (GL) per million dollars. No values less than 0.1 GL yield per million dollars are displayed.

Based on this analysis the highest yielding sites per unit cost are Mount Bennett on the Finniss River, Upper Adelaide River on the Adelaide River and Marrakai dam site on the Adelaide River. However, as discussed in Appendix A the DamSite model cost does not reflect the poor foundations and logistical challenges of constructing a large dam at the last site.
Figure 4-3 Minimum cost per ML yield at the dam wall calculated using behaviour analysis model
This figure indicates those sites more suitable for major dams in terms of cost per ML yield at the dam wall in 85% of years. At each location the minimum cost per ML storage capacity is displayed. The smaller the cost per ML yield ($/ML) the more favourable the site for a large instream dam. Only sites with a minimum cost to yield ratio less than $4000/ML are shown. Costs are based on unit rates and quantity of material required for a RCC dam with a flood design of 1 in 10,000. Cost includes site establishment, fish ladders and land resumption for that area of land impounded by a flood event of annual exceedance probability 1%. Data are underlain by a shaded relief map. Left inset displays height of full supply level (FSL) at the minimum cost per ML yield and right inset displays width of FSL at the minimum cost per ML yield.

Hydro-electric power generation potential in the Darwin catchments
The potential for major instream dams to generate hydro-electric power is presented in Figure 4-4, following an assessment of more than 20 million potential dam sites in the Darwin catchments. This figure provides indicative estimates of hydro-electric power generation potential but does not consider the existence of supporting infrastructure. The companion technical report on hydro-electric power generation (Entura 2017) provides a pre-feasibility assessment of Mount Bennett and Upper Adelaide River dam.
4.1.2 SITES SELECTED FOR PRE-FEASIBILITY ANALYSIS IN THE DARWIN CATCHMENTS

Based on the review of the available literature and the DamSite modelling, seven potential dam sites in the Darwin catchments were selected for pre-feasibility level investigation. These sites are summarised in Table 4-1. In addition to the seven potential dam sites, two existing dams were also examined, Darwin River Dam and Manton Dam.

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 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 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, 126 crop × irrigation type × season combinations were assessed; see Thomas et al. (2018b) for a full description of the land suitability methods and all land suitability maps. Figure 4-5 displays the existing and potential dam sites assessed in the Darwin catchments together with the land suitability map for sugarcane under spray irrigation.

Table 4-1 Potential dams assessed in Darwin catchments

<table>
<thead>
<tr>
<th>NAME</th>
<th>SPILLWAY</th>
<th>DAM TYPE**</th>
<th>CAPACITY AT FSL</th>
<th>SURFACE AREA AT FSL</th>
<th>AVE. DEPTH^</th>
<th>CATCHMENT AREA</th>
<th>VOL TO AREA RATIO^^</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mount Bennett dam site on the Finniss River</td>
<td>20</td>
<td>RCC</td>
<td>343</td>
<td>6,202</td>
<td>5.5</td>
<td>1,155</td>
<td>0.30</td>
</tr>
<tr>
<td>Upper Adelaide River dam site</td>
<td>23</td>
<td>RCC</td>
<td>298</td>
<td>3,830</td>
<td>7.8</td>
<td>616</td>
<td>0.48</td>
</tr>
<tr>
<td>Acacia Gap dam site</td>
<td>11</td>
<td>RCC</td>
<td>37</td>
<td>1,294</td>
<td>2.8</td>
<td>232</td>
<td>0.16</td>
</tr>
<tr>
<td>AROWS offstream storage</td>
<td>18</td>
<td>EB</td>
<td>91</td>
<td>1,208</td>
<td>7.5</td>
<td>34#</td>
<td>2.7##</td>
</tr>
<tr>
<td>Marrakai dam site on the Adelaide River</td>
<td>15</td>
<td>EB</td>
<td>1520</td>
<td>27,462</td>
<td>5.5</td>
<td>4,341</td>
<td>0.35</td>
</tr>
<tr>
<td>McKinlay River dam site</td>
<td>14</td>
<td>EB</td>
<td>512</td>
<td>8,022</td>
<td>6.4</td>
<td>922</td>
<td>0.56</td>
</tr>
<tr>
<td>Mary River dam site</td>
<td>30</td>
<td>RCC</td>
<td>1,311</td>
<td>16,488</td>
<td>8.0</td>
<td>3,063</td>
<td>0.43</td>
</tr>
</tbody>
</table>

FSL = full supply level
* Based on DEM-H bed height. In some areas the drainage enforcement may exaggerate the river bed. If matching to a different DEM should match on the absolute height of the spillway.
** Embankment dam (EB), roller compacted concrete dam (RCC).
^ Ratio of the capacity of the reservoir to the surface area of the reservoir at FSL.
^^ Ratio of the capacity of the reservoir at FSL to the catchment area of the dam.
# Catchment area of Adelaide River at point of extraction is approximately 4500 km².
## Based on catchment area of offstream storage. The ratio of volume to area at point of extraction ratio is 0.02.

Two potential dam sites in the Darwin catchments were selected for further analysis because each was deemed to be the most cost effective in two distinct geographical areas. The assessment of the two most cost-effective 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 were the Mount Bennett dam site on the Finniss River and the Upper Adelaide River dam site on the Adelaide River. Preliminary studies of these two potential dam sites was made in the early 1990s (Pavia, 1990, 1991, 1992; Ullman and Nolan, 1990), and more recently the PWC commissioned a desktop assessment of the Upper Adelaide River (Entura, 2015).

The two short-listed sites are reported in Section 4.2. The five non-short-listed sites and the existing Darwin River Dam and Manton Dam are reported in Appendix A.
Figure 4-5 Versatile agricultural land and potential dam sites selected for pre-feasibility analysis in the Darwin catchments

Versatile agricultural land data (Thomas et al., 2018b) indicate those parts of the catchment that are more or less versatile for irrigated agriculture.
Two short-listed potential dam sites in the Darwin catchments

Two potential dam sites are listed from west to east.

4.2.1 MOUNT BENNETT DAM SITE ON THE FINNISS RIVER; AMTD 80.0 KM

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous investigations</td>
<td>Previous investigations of the Mount Bennett dam site have included the following: S Lynch (1986) Darwin water supply future source – appraisal study. Snowy Mountains Engineering Corporation, December 1986.</td>
</tr>
<tr>
<td>Description of potential dam</td>
<td>The Mount Bennett dam site is an instream storage with potential to provide additional urban water supply to the Darwin area and supply for irrigation development in the region.</td>
</tr>
<tr>
<td>configuration</td>
<td>The Mount Bennett dam site was one of three preferred major dam options adopted by the Northern Territory Government in 1988 but is now less favoured by PWC than the Upper Adelaide River storage option since the catchment area cannot be closed or easily managed and consequently water treatment costs could be significantly higher than options where the catchment area can be controlled.</td>
</tr>
<tr>
<td></td>
<td>The following figures accompany this description of the site</td>
</tr>
<tr>
<td></td>
<td>The potential Mount Bennett dam is illustrated in Figure 4-6. Figure 4-7 provides a map showing its location in the Darwin catchments, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Figure 4-8. Figure 4-9 and Figure 4-10 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Figure 4-11 to Figure 4-13. Conceptual dam arrangements are provided in Figure 4-14.</td>
</tr>
<tr>
<td>Regional geology</td>
<td>The potential dam site and reservoir area are located in a geological province known as the Pine Creek Orogen, which is an area underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The rocks in the area have been intruded by granite, folded, faulted and uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the older rocks in the project area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on some of the slopes. The main geological unit in the project area is the Burrell Creek Formation, which consists mainly of greywacke (or lithic arenite), shale, slate, phyllite and siltstone. Fold axes are north/south (or north-northeast/south-southwest) and bedding dips steeply (typically 70° to 90°) east to east-southeast or west to west-northwest. There are also north/south to north-east/south-west-trending faults in the project area and north. Steeply dipping quartz veins and silicified breccia and cleavage or foliation (where developed) tend to be parallel to the fold axes. There are also north-northeast/south-southwest, north-east/south-west and east-west-trending lineaments in the project area that are probably associated with fold axes and the major faults, smaller faults and joints. The Finniss River and its tributaries tend to flow parallel to the faults and lineaments indicating that the down-cutting river has preferentially eroded channels along major defects in the rock mass.</td>
</tr>
</tbody>
</table>
| Site geology                   | The potential main dam is on a west to west-south-southwest-trending section of the river where it cuts through a relatively narrow gorge in the Finniss Range. Previous investigations indicate that both abutments are underlain by greywacke and describe the rock as ranging from coarse grained to fine grained and micaceous. The investigations also indicate that the rocks are metamorphic and refer to metasandstones, quartzites and phyllites. Petrology reports on samples from the dam sites and potential quarry sites in the area describe the rocks as quartzites (including graphitic to micaceous quartzite) and schist (Appendix E). The previous
investigations also indicated that siliceous fault breccia crops out at the main dam site and the Breakneck Pass saddle dam.

The valley floor is about 100 m wide at the dam axis and includes silty clay alluvium, sandy channel deposits, levee banks of fine sand and the river channel. Investigations have shown that the alluvium overlies weathered rock. Sandy colluvium with rock fragments occurs on the lower slopes of the abutments.

There are three sets of near vertical joints (upstream/downstream, cross-valley and obliquely cross-valley (north-west/south-east)). There are also shallow dipping joints (less than 40°) roughly parallel to the valley sides (i.e. generally dipping towards the river on both abutments). Open joints and infilled seams indicate that downslope movements on these flatter defects have occurred in the past. Water pressure tests in investigation boreholes indicate that the rock mass has relatively high permeability to depths of at least 30 m in places. Evidence of faults (a sheared zone, a crushed seam and several sheared surfaces) was found in an inclined investigation borehole on the right abutment of the main dam.

For initial costing purposes, mean foundation depths of 7 m have been assumed for the valley floor (although locally deeper excavation may be required if there is an upstream/downstream fault in the bed of the river). Mean foundation depths of 4 m have been assumed for both abutments. Most of the loosened near-surface rock may be excavatable by bulldozers and excavators but drilling and blasting is likely to be required in places to reach a suitable foundation.

At the suggested highest likely full storage level (of 30 m AHD) there will need to be a saddle dam at Breakneck Pass on the right bank of the reservoir and several low saddle dams on the left bank of the reservoir. The geology at Breakneck Pass is similar to the geology of the main dam. For initial costing purposes, mean foundation depths of 5 m have been assumed for the valley floor (although locally deeper excavation may be required if there is an upstream/downstream fault in the bed of the river). Mean foundation depths of 3 m have been assumed for the left abutment core trench and 4 m for the right abutment core trench (because the abutment is steeper and may be more prone to shallow instability). Mean foundation stripping depths of 2 m have been assumed for the shoulders of the potential embankment dam on both abutments. Much of the loosened near-surface rock may be excavatable by bulldozers and excavators but drilling and blasting is likely to be required in places to reach a suitable foundation.

Foundation conditions for the saddle dams on the left bank of the reservoir vary from weathered greywacke to colluvium and or higher alluvial terraces. There has been limited investigation in these areas so there is uncertainty about the likely depth of core or cut-off trenches. For initial costing purposes, mean foundation excavation depths of 3 m have been assumed for the core trenches of all of the saddle dams (although greater depths are likely to be required in some places) and 1 m for the shoulders of all of the saddle dams. The weathered materials may be excavatable by bulldozers or excavators to the full depths required at most of the saddle dams.

The permeability and the stability of the foundations and abutments of the main dam and saddle dam, and the potential for scour downstream of the spillway, are largely related to the continuity and nature of the defects (e.g. faults and joints) in the rock mass, which will need to be investigated during feasibility studies, but based on present knowledge there is potential shallow instability on the abutments of the main dam and Breakneck Pass saddle dam and foundation grouting is planned for both the main dam and the saddle dams. During the foundation and abutment feasibility and design investigations particular attention will need to be paid to the location, orientation, shear strength and continuity of faults.

**Reservoir rim stability and leakage potential**

Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue.

Given the lack of soluble rocks in the storage area and the lack of narrow, low, steep-sided saddles, reservoir leakage is unlikely to be a significant issue provided the dam foundations are grouted.

**Potential structural arrangement**

SMEC proposed that a concrete-faced rockfill embankment be constructed across the main river section with a CC gravity dam incorporating a central overflow spillway constructed in the section on the northern side of the storage area known as Breakneck Pass.

Given the larger spillway capacities now required, an RCC dam is proposed across the river section with a 150-m wide central overflow spillway. The abutments would be set at the 1:10,000 AEP peak storage level. A hydraulic jump type stilling basin would be provided to
PARAMETER | DESCRIPTION
---|---
A zoned earth and rockfill embankment is proposed at the Breakneck Pass saddle.

A number of low embankment saddle dams are required on the southern side of the storage.
The crest level of the Breakneck Pass embankment and of the saddle dams has been set to contain the peak storage level of a 1:50,000 AEP flood.
The main dam abutment and the saddle dam crest levels will need to be reviewed if this option is to be further considered.
If supply to the Darwin area was required, a conduit would be constructed under the Breakneck Pass saddle dam with an intake tower in the storage with bulkhead gate control. A pump station would be located at the downstream toe of the saddle dam.
Releases downstream of the dam would be via outlets installed in a diversion conduit located in the right abutment of the dam. A fish transfer facility would also be located on the right abutment.
Access to the Breakneck Pass and main dam areas would be via a 17-km long road branching from the Mount Finniss road south of the Kangaroo Flats training area. The site is some 107 km by road from Darwin.

Availability of construction materials

Previous investigations have been carried out for both soil (gravels, sands and clays) and rock construction materials including initial review of 12 potential quarry sites. Soil materials are available from colluvial slopes and alluvial floodplains both upstream and downstream of the Finniss Range. Large volumes of cohesive soils, fine to medium-grained sand and some gravels are available from these floodplains and colluvial slopes.
Based on previous investigations the most prospective source of aggregate for RCC (and perhaps CC) may be the north/south ridge of quartzite on the right bank of the river about 2 km east (upstream) of the main dam, although the potential for alkali reactivity will need more detailed study.
The petrology report on a sample from the main dam site (collected during this Assessment) described the rock as a quartz, muscovite schist and expressed concerns about excessive fines on crushing and its durability as an aggregate.

Catchment area

Based on SRTM data, the catchment area upstream of the dam site is estimated to be 1155 km².

Flow data

Rainfall and river height data has been recorded since October 1960 at gauging station G81500180, Finnis River at Gitchams Crossing, which is located 6 km upstream of the dam site. Catchment area at the gauge site is 1048 km².
Summary data extracted from the Northern Territory Government Water Data Portal is as follows:
- Maximum recorded annual flow volume: 532 GL
- Mean recorded annual flow volume: 186 GL
- Median recorded annual flow volume: 170 GL
- Minimum recorded annual flow volume: 3.9 GL

Storage capacity

Storages with FSL of 28, 30 and 32 mAHDD and capacities of 410, 565 and 760 GL, respectively, were considered in the 1988 GHD study.
The yield study by Paiva (1992) reported on expected yields for storages with FSL ranging from 24 to 34 m with probability of failure ranging from 0 to 5%. These results indicated that an optimum level of development was likely to be lower than 30 m since at the higher levels, yields only increased marginally and the expected maximum interval between overflows rose dramatically (to 62 years at the 32 m level) as did expected time of storage filling (to 4 years at the 32 m level).
For this Assessment, FSL of 26, 28 and 30 m were considered initially with storage capacities derived from SRTM data as follows:

<table>
<thead>
<tr>
<th>FSL</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 mEGM96</td>
<td>233 GL</td>
</tr>
<tr>
<td>28 mEGM96</td>
<td>343 GL</td>
</tr>
<tr>
<td>30 mEGM96</td>
<td>483 GL</td>
</tr>
</tbody>
</table>

Reservoir yield assessment at dam wall

<table>
<thead>
<tr>
<th>FSL</th>
<th>Estimated yield at 85% annual time reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>26 mEGM96</td>
<td>231.4 GL</td>
</tr>
<tr>
<td>28 mEGM96</td>
<td>283.3L</td>
</tr>
<tr>
<td>30 mEGM96</td>
<td>339.1 GL</td>
</tr>
</tbody>
</table>
Open water evaporation

At FSL, the surface area of the storage derived from SRTM data are as follows:

<table>
<thead>
<tr>
<th>EGM96 level</th>
<th>Surface area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSL 26</td>
<td>4789</td>
</tr>
<tr>
<td>FSL 28</td>
<td>6202</td>
</tr>
<tr>
<td>FSL 30</td>
<td>7839</td>
</tr>
</tbody>
</table>

Mean annual evaporation and mean annual net evaporation at FSL 28 mEGM96 at 85% annual reliability is 68.7 GL and 11.0 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.040.

Potential use of supply

Agriculture

The alluvial plains downstream of the potential dam typically have a distinct narrow levee, extensive level alluvial plains subject to occasional to regular flooding for extended periods, and frequent drainage depressions and swamps.

Soils on the level alluvial plains in the upper catchments are predominantly imperfectly to poorly drained, slowly permeable, structured gradational soils (Dermosols, Hydrosols) with hard-setting clay loam to silty clay loam surfaces over sodic, mottled, grey or brown clay subsoils. Hard-setting poorly drained clay soils also occur throughout the alluvial plains. Soils are generally too wet for cropping with some minor areas suitable for dry-season grain and forage cropping. Soils are likely to be suitable for ringtanks.

The areas either side of the Finniss River are dominated by gently undulating rises on granite. The poorly drained soils in the drainage depressions and on mid to lower slopes are unsuitable for irrigated cropping. The imperfectly drained soils with sandy surfaces over massive sandy clay loam to sandy clay subsoils (Kandosols, Kurosols) on upper slopes have limited cropping potential due to very low soil water storage, shallow soil depth, seasonal wetness and frequent rock outcrops. Soils are unsuitable for ringtanks due to shallow soil depth and excessive slope.

See companion technical report on land suitability by Thomas et al. (2018b).

Urban

The proximity of the Mount Bennett potential dam site to Darwin and the Darwin River Dam make it attractive for urban water supply. However, a major limitation to using water from the potential reservoir is that the catchment area cannot be closed to the public, thereby increasing the level of treatment required to achieve a potable water supply. Furthermore, the quality of water flowing into the reservoir could be adversely affected by the existence of the (closed) Rum Jungle uranium mine in the upper reaches of the catchment.

Storage impacts

A storage at FSL 28 mEGM96 would inundate about 18.8 km of the Finniss River bed.

Allowing for a 1:100 AEP flood rise above FSL, the area of land that would need to be acquired would be approximately as follows:

<table>
<thead>
<tr>
<th>EGM96 level</th>
<th>Area to be acquired (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSL 26</td>
<td>7200</td>
</tr>
<tr>
<td>FSL 28</td>
<td>8800</td>
</tr>
<tr>
<td>FSL 30</td>
<td>10,600</td>
</tr>
</tbody>
</table>

Environmental considerations

Barrier to movement of aquatic species

A dam constructed at this site could affect the migration, movement or colonisation of the following fish species, the barred grunter (*Amniataba percoideus*), flyspecked (*Craterocephalus stercusmuscarum stercusmuscarum*), blackmast (*Craterocephalus stramineus*), mouth almighty (*Glossamia aprion*), sooty grunter (*Hephaestus fuliginosus*), barramundi (*Lates calcarifer*), spangled perch (*Leiopotherapon unicolor*), western rainbowfish (*Melanotaenia australis*), blackbanded rainbowfish (*Melanotaenia nigrans*), bony herring (*Nematalosa erebi*), black catfish (*Neosilurus ater*), Hyrtl’s catfish (*Neosilurus hyrtlii*), freshwater longtom (*Strongylura krefftii*).

Also if a barrier was set there, important wetlands, habitat of the magpie goose and several other waterbirds such as egrets (*Ardea intermedia*, *Egretta garzetta*), spoonbills (*Platalea flavipes*, *Platalea regia*) and herons (*Nycticorax caledonicus*, *Ardea pacifica*, *Egretta*).
**PARAMETER**

- **novaehollandiae** downstream in the Finniss River could be negatively impacted.

**Ecological implications of inundation**

At this site only one vulnerable species was listed, the partridge pigeon (*Geophaps smithii*). Although records for this species are not found within the potential inundated area, it could be impacted by potential reductions to its habitat. This species has declined substantially in the NT and it is thought to be affected by anthropogenic changes to water sources and loss of its habitat.

The potential inundated area at FSL at this site could have a direct impact on waterbirds such as the intermediate egret (*Ardea intermedia*), eastern great egret (*Ardea modesta*), white faced heron (*Egretta novaehollandiae*), black bittern (*Ixobrychus flavicollis*), Nankeen night heron (*Nycticorax caledonicus*) and the Australian white ibis (*Threskiornis molucca*). Complex changes in habitat resulting from inundation could create new habitat to benefit some of these species, while other species would be impacted by loss of habitat.

**Upstream considerations**

The Rum Jungle uranium mine is in the Mount Bennett dam site catchment area. Since the mine closed in 1971, there have been a number of initiatives to rehabilitate the site and reduce contamination caused primarily by acid rock drainage. These activities have significantly reduced contamination in the East Finniss and Finniss River itself but are continuing. (The mine site area is some 28 km upstream of the upstream limit of a storage at the Mount Bennett site). Monitoring and remedial works are continuing.

The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).

**Indigenous land tenure, native title and cultural heritage considerations**

Substantial land in the area is held as collective and inalienable freehold title under NT-specific land rights legislation. Substantial land is also subject to future native title claims. A number of registered and/or recorded sacred or cultural heritage sites are known to exist in the inundation area. There is a high likelihood of currently unrecorded sites. The inundation area also includes a portion of Litchfield National Park.

**Estimated cost**

A manual cost estimate undertaken as part of the Assessment for an RCC dam at the Mount Bennett dam site at FSL 28 mEGM96 found the dam would cost approximately $190 million. Details of this cost estimate are provided in Appendix C.

To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO’s generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below:

- FSL 26 mEGM96: $207 million
- FSL 28 mEGM96: $236 million
- FSL 30 mEGM96: $292 million

**Estimated cost / ML of supply**

Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows:

- FSL 26 mEGM96: $895/ML
- FSL 28 mEGM96: $833/ML
- FSL 30 mEGM96: $861/ML

On the basis of these estimated costs of supply, a dam with FSL 28 mEGM96 was selected for a more detailed assessment of irrigation and hydro-electric power generation potential at the site and for a more detailed costing.

Based on the manual cost estimate, the cost/ML of supply at FSL of 28 mEGM96 is $671/ML.

**Summary comment**

This site has the lowest cost to yield ratio of all potential dam sites in the Darwin catchments. However, the yield from the dam is likely to be larger than that required to meet Darwin’s projected water requirements over the next 30 years and for irrigation of the suitable land downstream.

The quality of water flowing into the reservoir could be a potential problem because of the existence of the (closed) Rum Jungle uranium mine in the upper reaches of the catchment. Additionally, part of the Wagait Aboriginal Reserve would be inundated by a storage at this site. There are a number of registered and/or recorded sacred or cultural heritage sites known to exist in the area that would be potentially inundated. Substantial land in the area is subject to current or future native title claim.
Figure 4-6 Mount Bennett dam site looking upstream

Figure 4-7 Location map of potential Mount Bennett dam site, reservoir extent and catchment area
Figure 4-8 Potential Mount Bennett dam reservoir and property boundaries

Figure 4-9 Geology underlying the potential Mount Bennett dam site and reservoir
Figure 4-10 Known water-dependent ecological assets in the vicinity of the potential Mount Bennett dam site and depth of reservoir
Figure 4-11 Mount Bennett potential dam site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and PMF events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance.
Figure 4-12 Mount Bennett potential dam site cost, yield at the dam wall and evaporation
(a) dam length and dam cost versus full supply level (FSL); (b) dam yield at 85% and 95% annual time reliability and
yield per million dollars at 85% and 95% annual time reliability; (c) annual time reliability plotted against yield for
different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% annual time
reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f)
yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.
Figure 4-13 Mount Bennett potential dam site storage levels and yield
(a) maximum and minimum annual storage trace at the selected full supply level (FSL) (28 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL.
Figure 4-14 Conceptual arrangement of the potential Mount Bennett dam
### 4.2.2 UPPER ADELAIDE RIVER DAM SITE ON THE ADELAIDE RIVER; AMTD 199.2 KM

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
</table>
| Previous investigations | Previous investigation of dam sites in this area have included the following:  

### Description of potential dam configuration

The Upper Adelaide River dam site is an instream storage with potential to provide additional urban water supply to the Darwin area and supply for irrigation development in the Adelaide River area downstream of the dam.  
The Upper Adelaide potential dam site was one of three preferred major dam options adopted by the Northern Territory Government in 1988.  
Five possible axes in the gorge section upstream of the Adelaide River township have been identified.  
The 1988 GHD study proposed that to minimise the potential for geological problems, the dam be located midway between sites 3 and 4 and that the dam comprise a concrete-faced rockfill embankment across the river with an unlined spillway through a right-bank saddle. This site is described as site 35 for the purpose of this Assessment.  
While a concrete-faced rockfill dam with a spillway excavated through a right-bank saddle was originally proposed, Entura developed an RCC arrangement with a central overflow spillway for the purpose of the comparative cost estimates in their 2015 study.  
Supply from a dam in the Upper Adelaide River area is considered to be a potential medium-to long-term option to augment water supply to Darwin. Water would be conveyed to the Darwin water supply system via a 68-km long pipeline directly from the dam.  

#### The following figures accompany this description of the site

The potential Upper Adelaide River dam is illustrated in Figure 4-15. Figure 4-16 provides a map showing its location in the Darwin catchments, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Figure 4-17. Figure 4-18 and Figure 4-19 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Figure 4-20 to Figure 4-22.

### Regional geology

The potential dam site and reservoir area are located in a geological province known as the Pine Creek Orogen, which is an area underlain by sedimentary, metamorphic and igneous rocks of Precambrian age (Archean to Neoproterozoic). The rocks in the area have been intruded by granite, folded, faulted and uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the older rocks in the project area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on some of the slopes.  
The main geological unit in the project area is the Burrell Creek Formation, which consists mainly of greywacke (or lithic arenite), quartzite, shale, slate, phyllite and siltstone. Fold axes are north/south (or north-northwest/south-southeast) and bedding typically dips steeply (e.g. 70° to 90°) east to east-northeast or west to west-southwest. There are also north/south to north-east/south-west-trending faults in the project area including the Adelaide River Fault about 1 km east of the potential main dam. A 5-m wide fault striking north-east/south-west...
(parallel to the Adelaide River Fault) dipping 40° north-west was found during investigations of a potential dam site about 2 km upstream of the potential main dam. There are also north/south, north-east/south-west, north-northeast/south-southwest and east/west-trending lineaments in the project area that are probably associated with fold axes and smaller faults and joints. The Adelaide River and its tributaries tend to flow parallel to the faults and lineaments indicating that the down-cutting river has preferentially eroded channels along major defects in the rock mass.

**Site geology**

The potential main dam is on a north-west-trending section of the river where it cuts through a ridge of greywacke forming a narrow gorge. Previous investigations indicate that both abutments are underlain by folded greywacke or quartzite and refer to a group of tight drag folds with two synclines grouped with a minor central anticline. The bedding strikes across the river and typically dips 50° to 70° downstream. Apparently there are rock bars in the river and gaps in outcrop were assumed to represent weaker bands of phyllite or siltstone (or perhaps schist), which are likely to be interbedded with the greywacke. As the river cuts across the strike of the rocks and is not on a photolineament it was assumed that there is less likely to be a significant fault in the bed of the river than some of the other potential dam sites considered in the earlier investigations.

The valley floor is about 100 m wide and there are sand deposits in the river channel. The right abutment is steeper than the left and there is a cliff near the top and downstream of the potential dam. Colluvium is probably deeper on the left abutment than the right.

Aerial photographs indicate that there are steeply dipping defects oriented obliquely upstream/downstream (north/south) and cross-valley (east-northeast/west-southwest). Most of the defects observed are probably joints or partings parallel to bedding or foliation but there may also be some faults in the same orientations. Near-horizontal defects are also visible on both abutments. These may be tectonic joints associated with regional stresses during deformation or they may be regional stress relief joints associated with regional erosion. Some may also be local stress relief joints associated with valley sides. On the locally steep sides of the valley (particularly on the left abutment), stress relief is likely to have resulted in the inward (towards the river) movement (partly along shallow dipping defects) of the valley sides. This movement causes pre-existing defects (particularly steep joints parallel to the valley) to open and the formation and opening of new stress relief joints roughly parallel to, or flatter than the valley sides. There are likely to be many open joints in the outcrops on the abutments. Transported material filling the joints may result in the formation of infilled seams. As a result of the stress relief and weathering effects in the near-surface rock mass on the valley sides, joints and other defects are likely to be longer and more closely spaced and the near-surface rock mass is likely to be more permeable than in the less disturbed rock mass at greater depths.

For initial costing purposes, mean foundation depths of 6 m have been assumed for the valley floor. Mean foundation depths of 5 m have been assumed for the left abutment (because of the greater depth of colluvium) and 4 m on the right abutment. Most of the colluvium and loosened near-surface rock may be excavatable by bulldozers and excavators but drilling and blasting is likely to be required in places to reach a suitable foundation.

At the suggested highest likely full storage level (of 80 mAHD) there will need to be a saddle dam about 4 km south of the dam on the right bank of the reservoir. According to the geological map, the saddle dam is underlain by sandstone (of the Depot Creek Sandstone) close to the Adelaide River Fault. For initial costing purposes, mean foundation depths of 3 m have been assumed for the core trench of the saddle dam and 1 m for the shoulders. Most of the material is likely to be excavatable by bulldozers and excavators.

The permeability and the stability of the foundations and abutments of the main dam and saddle dam, and the potential for scour downstream of the spillway, are largely related to the continuity and nature of the defects (e.g. faults and joints) in the rock mass, which will need to be investigated during feasibility studies, but based on present knowledge there is no cause for concern. It has been assumed that foundation grouting will be required for both the main dam and the saddle dam.

**Reservoir rim stability and leakage potential**

Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue.

Given the lack of soluble rocks in the storage area and the lack of narrow, low, steep-sided saddles, reservoir leakage is unlikely to be a significant issue provided the dam foundations are grouted.
### Potential structural arrangement

For the Assessment an RCC dam is outlined with a 180-m wide central overflow spillway. A hydraulic jump type stilling basin would be provided to protect the river bed against erosion during spillway overflows.

Such a dam will have significant advantages compared with the concrete-faced embankment previously proposed since:

- flood overtopping during construction will involve far less risk, which is a significant issue given the location of the Adelaide River township downstream
- a central spillway in the river section will involve far less erosion risk during larger flood events than the saddle spillway previously proposed.

A diversion conduit on the left-bank side is proposed in which permanent outlets would be installed providing for releases to the river and for a pipeline connection to a downstream pump station and delivery main conveying supply to the Darwin area. A fish transfer facility would also be located on the left abutment.

An earth and rockfill embankment is suggested for the saddle dam required on the southern side of the reservoir.

Both the main dam abutments and the saddle dam crest have been set at the PMF peak storage level given the significant population at risk downstream of the dam (see companion technical report on flood design hydrology, Jordan et al., 2017).

Access to the site will involve a 3.5-km long road branching from the Stuart Highway north of the Adelaide River township, which is 114 km south of Darwin.

### Availability of construction materials

The petrology report on a distinctly weathered sample collected from near the potential dam site during this Assessment described the rock as a very coarse-grained sandstone and expressed concern about its durability as an aggregate (Appendix E). Further investigations are required but less weathered greywacke (or quartzite) in the area may provide suitable aggregate for RCC and possibly for CC. A local quarry in these rocks would also be likely to be able to provide rockfill and riprap for the saddle dam and sand and aggregate suitable for the filters required in the saddle dam.

There is some sand in the river channel near the dam site but there may be more in the river channel upstream and downstream of the dam site and in alluvial terraces in the area. Cohesive earthfill for the core of the saddle dam may be harder to find as natural soils in the area are relatively thin. Extremely weathered siltstone, phyllite or other fine-grained material, residual soils and colluvium may provide suitable sources of core material.

It may be possible to reuse some of the material obtained from the foundation excavations for construction.

### Catchment area

Based on SRTM data, the catchment area upstream of the dam site is estimated to be 616 km².

### Flow data

Rainfall and river height data has been recorded at gauging station G8170002 Adelaide River – Railway Bridge site since May 1952 although continuous data has only been collected since June 1959. Catchment area at the station is 632 km².

Summary data extracted from the Northern Territory Government Water Data Portal is as follows:

- Maximum recorded annual flow volume: 1916 GL
- Mean recorded annual flow volume: 288 GL
- Median recorded annual flow volume: 243 GL
- Minimum recorded annual flow volume: 3.7 GL

(Note data are missing in a considerable number of days across a number of years.)

### Storage capacity

Storages with FSL 82, 84 and 86 mAHD and capacities of 623, 753 and 950 GL, respectively, were considered in the 1988 GHD study.

The yield study by Paiva (1991) reported on expected yields for storages with FSL ranging from 74 to 86 m with probability of failure ranging from 0 to 5%. These results indicated that an optimum level of development was likely to be lower than 80 m since at the higher levels, yields only increased marginally and the estimated maximum interval between overflows rose dramatically (to 203 years at the 86 m level) as did expected time of storage filling (to 25 years at the 86 m level).

For this Assessment, FSL of 70, 75 and 80 m were considered initially with storage capacities...
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>derived from SRTM data as follows:</td>
<td></td>
</tr>
<tr>
<td>FSL 70 mEGM96</td>
<td>Capacity</td>
</tr>
<tr>
<td>FSL 75 mEGM96</td>
<td>Capacity</td>
</tr>
<tr>
<td>FSL 80 mEGM96</td>
<td>Capacity</td>
</tr>
</tbody>
</table>

**Reservoir yield assessment at dam wall**

For this Assessment yields were assessed by CSIRO as follows:

| FSL 70 mEGM96 | Estimated yield at 85% annual time reliability | 55.8 GL |
| FSL 75 mEGM96 | Estimated yield at 85% annual time reliability | 114.1 GL |
| FSL 80 mEGM96 | Estimated yield at 85% annual time reliability | 153.0 GL |

**Open water evaporation**

At FSL, the surface area of the storage based on SRTM data are estimated to be as follows:

| FSL 70 mEGM96 | 1240 ha |
| FSL 75 mEGM96 | 2373 ha |
| FSL 80 mEGM96 | 3830 ha |

Mean annual evaporation and mean annual net evaporation at FSL 80 mEGM96 at 85% annual reliability is 46.5 GL and 12.7 GL respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.086.

**Potential use of supply**

**Agriculture**

The alluvial plains upstream of the Adelaide River above the confluence of the Adelaide and Margaret rivers typically have a deeply incised main channel; a distinct narrow levee; and extensive level alluvial plains subject to occasional to regular flooding and frequent drainage depressions and swamps.

The duration of flooding increases downstream with areas north of the highway on the Adelaide River subject to annual flooding for extended periods.

Soils on the level alluvial plains in the upper catchments are predominantly imperfectly to poorly drained, slowly permeable, structured gradational soils (Dermosols, Hydrosols) with hard-setting clay loam to silty clay loam surfaces over sodic, mottled, grey or brown clay subsoils. In the vicinity of Adelaide River town, the ratio of imperfectly drained to poorly drained soils is estimated to be 60:40. The proportion of poorly drained soils increases downstream where the ratio of imperfect to poorly drained soils at Tortilla Flats above the confluence of the Adelaide and Margaret rivers is estimated at 30:70. Below the confluence, all soils are poorly drained and subject to annual flooding. Soils are suitable for sugarcane, rice and dry-season grain and forage cropping. Soils are likely to be suitable for ringtanks.

Well-drained to moderately well-drained massive red loamy soils (Kandosols) predominate on the narrow levees from the upper catchment to Tortilla Flats above the confluence of the Adelaide and Margaret rivers. Downstream, very narrow levees occur with imperfectly drained, moderately permeable, mottled brown, massive, loamy soils (Kandosols) and friable loamy soils (Dermosols). The red soils on the levees are suitable for all agriculture except for furrow and flood irrigation methods. The generally long thin units associated with the levees may restrict irrigation layout and machinery use in some areas. Soils are unlikely to be suitable for ringtanks.

Extensive areas of poorly drained, slowly permeable, poorly drained soils (Hydrosols) with hard-setting sandy surfaces over mottle sodic grey clay subsoils occur in some areas. Soils are likely to be suitable for ringtanks.


**Urban**

The yield from the dam could augment Darwin’s future water demand via a supply pipeline as well, as irrigating all of the land suitable for irrigated agriculture downstream of Adelaide River township and upstream of Dirty Lagoon, south of the Arnhem Highway. A recent strategy statement by the Northern Territory Land and Water Corporation concluded that of the three storage sites endorsed by the Northern Territory Government in 1988 (Upper Adelaide River dam site, Marrakai dam site and Mount Bennett dam site), an Upper Adelaide River dam was preferred by the PWC since the site is the only one for which the catchment can be closed to the public, thereby reducing the level of treatment required to achieve a potable water supply.

<table>
<thead>
<tr>
<th>Estimated rates of reservoir sedimentation</th>
<th>Best case</th>
<th>Expected</th>
<th>Worst case</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 years (%)</td>
<td>0.0</td>
<td>0.4</td>
<td>0.6</td>
</tr>
</tbody>
</table>
### Storage impacts

A storage at FSL 80 mEGM96 would inundate some 19 km of the Adelaide River bed. Allowing for a 1:100 AEP flood rise above FSL, the area of land that would need to be acquired would be approximately as follows:

- **FSL 70 mEGM96**: 1950 ha
- **FSL 75 mEGM96**: 3180 ha
- **FSL 80 mEGM96**: 4700 ha

Part of the storage would inundate sections of the Litchfield Park area, which is managed by the Northern Territory Conservation Land Corporation. The balance of the storage would inundate part of the Silkwood Downs, a pastoral lease with few existing improvements.

### Environmental considerations

#### Barrier to movement of aquatic species

Within the potential inundation area of this site there are no records of migratory or stable flow spawning fish. Creation of a barrier may limit movement, migration or colonisation of habitat by fish species.

Upstream of the potential barrier are some locality records of magpie geese and 16 species of water-nesting birds.

#### Ecological implications of inundation

At the Upper Adelaide River dam site, three endangered species are listed under the Northern Territory Parks and Wildlife Conservation Act, the critically endangered northern quoll (*Dasyurus hallucatus*), the vulnerable red goshawk (*Erythrotriorchis radiates*) and partridge pigeon (*Geophaps smithii*). Each could be impacted by loss of habitat as a result of inundation by the reservoir. Cane toads are listed as a key threatening process for the northern quoll. Creation of new sources of water may increase breeding opportunity for cane toads.

The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).

### Indigenous land tenure, native title and cultural heritage considerations

Substantial land in the area is subject to current or future native title claims. A number of registered and/or recorded sacred and cultural heritage sites are known to exist in the inundation area. There is a high likelihood of currently unrecorded sites. The inundation area also includes a portion of Litchfield National Park.

### Estimated cost

A manual cost estimate undertaken as part of the Assessment for an RCC at the Upper Adelaide River site at FSL 80 mEGM96 found the dam to cost $182 million. Details of this cost estimate are provided in Appendix C.

Subsequently, CSIRO generated preliminary estimates of cost based on its generalised costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways and cost items for embankment type saddle dams. Costs for a selection of FSL are reported below:

- **FSL 70 mEGM96**: $131 million
- **FSL 75 mEGM96**: $160 million
- **FSL 80 mEGM96**: $199 million

PWC commissioned Entura (2015) to undertake a cost estimate for the Upper Adelaide River dam site. This information is commercial in-confidence.

### Estimated cost / ML of supply

Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows:

- **FSL 70 mEGM96**: $2348/ML
- **FSL 75 mEGM96**: $1402/ML
- **FSL 80 mEGM96**: $1301/ML

On the basis of these estimated costs of supply over this range of storage levels, a dam with FSL 80 mEGM96 was selected for an assessment of irrigation and hydro-electric power.
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>generation potential at the site and for a more detailed costing.</td>
<td></td>
</tr>
<tr>
<td>Based on the manual cost estimate, the cost/ML of supply at FSL of 80 mEGM96 is $1190/ML.</td>
<td></td>
</tr>
</tbody>
</table>

**Summary comment**

The Upper Adelaide River dam site, also known as the Warrai site, is the most topographically favourable site for a dam in the Darwin catchments. It has the third-lowest cost to yield ratio of all the potential dam sites in the Darwin catchments. The yield from the dam could augment Darwin’s future water demand via a supply pipeline as well as irrigating all of the land suitable for irrigated agriculture downstream of Adelaide River township and upstream of Dirty Lagoon, south of the Arnhem Highway. A recent strategy statement by the Northern Territory Land and Water Corporation concluded that of the three storage sites endorsed by the Northern Territory Government in 1988 (Upper Adelaide River dam site, Marrakai dam site and Mount Bennett dam site), an Upper Adelaide River dam was preferred by the PWC since the site is the only one for which the catchment can be closed to the public, thereby reducing the level of treatment required to achieve a potable water supply.

There are a number of registered and/or recorded sacred or cultural heritage sites known to exist in the area that would potentially be inundated. Substantial land in the area is subject to current or future native title claim.

*Figure 4-15 Upper Adelaide River dam site looking upstream*
Figure 4-16 Location map of potential Upper Adelaide River dam site, reservoir extent and catchment area

Figure 4-17 Potential Upper Adelaide River dam reservoir and property boundaries
Figure 4-18 Geology underlying the potential Upper Adelaide River dam site and reservoir

Figure 4-19 Known water-dependent ecological assets in the vicinity of the potential Upper Adelaide River dam site and depth of reservoir
Figure 4-20 Upper Adelaide River potential dam site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and PMF events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance.
Figure 4-21 Upper Adelaide River potential dam site cost, yield at the dam wall and evaporation
(a) dam length and dam cost versus full supply level (FSL); (b) dam yield at 85% and 95% annual time reliability and yield per million dollars at 85% and 95% annual time reliability; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% annual time reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f) yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.
Figure 4-22 Upper Adelaide River potential dam site storage levels and yield
(a) maximum and minimum annual storage trace at the selected full supply level (FSL) (80 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL.
5 Mitchell catchment

5.1 Broad-scale analysis of potential dam sites in the Mitchell catchment

Two potential dams in the Mitchell catchment were identified from published and unpublished literature, the Pinnacles dam site on the Mitchell River and Nullinga dam site on the Walsh River. The former had been referred to in a four-page unpublished document with no prior investigation, while the latter had some more detailed hydrological assessments and preliminary level geotechnical and costing studies.

5.1.1 DAMSITE MODEL RESULTS IN THE MITCHELL CATCHMENT

To ensure that no potential dam options had been overlooked, the DamSite model (see Section 2.1.2) was used to undertake a preliminary assessment of over 50 million potential dam sites in the Mitchell catchment. 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 using different criteria, and the locations compared to the previously identified potential dam locations and likely arable land.

Large dams for irrigation and water supply in the Mitchell catchment

Large offstream storages in the Mitchell catchment

Figure 5-1 displays the most promising sites across the Mitchell catchment in terms of storage volume (GL) per million dollars of construction cost. Only those locations with a ratio of storage to cost greater than 0.25 GL per million dollars (i.e. sites less than $4000/ML) are shown. This provides a simple way of displaying those locations in the Mitchell catchment with the most favourable topography for a large reservoir relative to the size (i.e. cost) of the dam wall necessary to create the reservoir. This figure is particularly useful for identifying more promising sites for offstream storage (i.e. where some or all of the water is pumped into the reservoir from an adjacent drainage line). The threshold value of 0.25 GL per million dollars is nominal and is used to minimise the amount of data displayed. It should be noted that this analysis does not consider evaporation or hydrology.

This figure shows that the parts of the Mitchell catchment with the most favourable topography for storing water are on the upper Walsh River immediately downstream of the Mareeba–Dimbulah Water Supply Scheme. Other topographically favourable locations are on the upper Palmer and upper Mitchell rivers.
Figure 5-1 Minimum cost per ML yield at the dam wall
This figure can be used to identify locations where topography is suitable for large offstream storages. At each location the minimum cost per ML storage capacity is displayed. The smaller the minimum cost per ML storage capacity the more suitable the site for a large offstream storage. Analysis does not take into consideration geological considerations, hydrology or proximity to water. Only sites with a minimum cost to storage volume ratio of less than $4000/ML are shown. $1000/ML is equivalent to 1 GL per million dollars. Costs are based on unit rates and quantity of material and site establishment for a RCC dam. Data are underlain by a shaded relief map. Inset displays height of full supply level (FSL) at the minimum cost per ML storage capacity.

Large instream dams in the Mitchell catchment
In addition to suitable topography (and geology), instream dams require sufficient inflows to meet a potential demand. Potential dams that command smaller catchments with lower runoff have smaller yields. Results concerning this criterion can be summarised and conveniently presented in terms of maximum yield (GL) per million dollars to construct the dam. This is very similar to the storage volume per million dollars term described above. The DamSite model was initially run using a preliminary storage-yield-reliability calculation method, the GDG method (see Section
2.1.2), which is very rapid to apply. Only the top 5000 sites for the Mitchell catchment ranked in terms of the GDG yield (GL) per million dollars are displayed in Figure 5-2.

The yield of the top 5000 sites ranked in terms of GDG yield (GL) per million dollars (Figure 5-2) was remodelled using a more accurate, but computationally intensive behaviour analysis model (Section 2.1.2). Figure 5-3 presents the results of the behaviour analysis model yield (GL) per million dollars. No values less than 0.1 yield (GL) per million dollars are shown.

The DamSite modelling indicates that the most cost-effective potential dam sites are on the Palmer River, the Mitchell River at the Pinnacles and on the Walsh River immediately downstream of the Mareeba–Dimbulah Water Supply Scheme. The latter site would inundate large areas of the Mareeba–Dimbulah Water Supply Scheme along the Walsh River.
This figure indicates those sites more suitable for major dams in terms of cost per ML yield at the dam wall in 85% of years. At each location the minimum cost per ML storage capacity is displayed. The smaller the cost per ML yield ($/ML) the more favourable the site for a large instream dam. Only sites with a minimum cost to yield ratio less than $4000/ML are shown. Costs are based on unit rates and quantity of material required for a RCC dam with a flood design of 1 in 10,000. Cost includes site establishment, fish ladders and land resumption for that area of land impounded by a flood event of annual exceedance probability 1%. Data are underlain by a shaded relief map. Left inset displays height of full supply level (FSL) at the minimum cost per ML yield and right inset displays width of FSL at the minimum cost per ML yield.

**Figure 5-3 Minimum cost per ML yield at the dam wall calculated using behaviour analysis model**

The potential for major instream dams to generate hydro-electric power is presented in Figure 5-4, following a reconnaissance assessment of more than 50 million potential dam sites in the Mitchell catchment. This figure provides indicative estimates of hydro-electric power generation potential, but does not consider the existence of supporting infrastructure. The companion technical report on hydro-electric power generation (Entura 2017) provides a pre-feasibility assessment of the four short-listed dam sites in the Mitchell catchment.

**Hydro-electric power generation potential in the Mitchell catchment**

The potential for major instream dams to generate hydro-electric power is presented in Figure 5-4, following a reconnaissance assessment of more than 50 million potential dam sites in the Mitchell catchment. This figure provides indicative estimates of hydro-electric power generation potential, but does not consider the existence of supporting infrastructure. The companion technical report on hydro-electric power generation (Entura 2017) provides a pre-feasibility assessment of the four short-listed dam sites in the Mitchell catchment.
5.1.2 SITES SELECTED FOR PRE-FEASIBILITY ANALYSIS IN THE MITCHELL CATCHMENT

Based on the review of the available literature and the DamSite modelling, eight potential dam sites in the Mitchell catchment were selected for pre-feasibility level investigation. These sites are summarised in Table 5-1. As part of the pre-feasibility assessment, each site was assessed against a consistent set of criteria using a consistent set of methods so as to make it easy to compare one site to another. In addition to the eight potential dam sites an existing dam, Lake Mitchell, was also assessed.

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 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 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, 126 crop × irrigation type × season combinations were assessed, see Thomas et al. (2018b) for a full description of the land suitability methods and all land suitability maps. Figure 5-5 displays the existing and potential dam sites assessed in the Mitchell catchment together with the land suitability map for sugarcane under spray irrigation. This figure indicates that the potential dams closest to large contiguous areas of land moderately suitable for irrigation are the Pinnacles on the Mitchell River and the Rookwood site on the Walsh River.

Table 5-1 Potential dams assessed in Mitchell catchment

All parameters are with respect to the nominated structural arrangement. All sites were visited by a member of the Assessment team.

<table>
<thead>
<tr>
<th>NAME</th>
<th>SPILLWAY HEIGHT ABOVE BED* (m)</th>
<th>DAM TYPE**</th>
<th>CAPACITY FSL (GL)</th>
<th>SURFACE AREA AT FSL (ha)</th>
<th>AVE. DEPTH^ (m)</th>
<th>CATCHMENT AREA (km²)</th>
<th>VOL TO AREA RATIO^^</th>
<th>CATCHMENT AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynd downstream dam site on the Lynd River</td>
<td>45</td>
<td>RCC</td>
<td>810</td>
<td>7,781</td>
<td>10.4</td>
<td>4,554</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Lynd upstream dam site on the Lynd River</td>
<td>36</td>
<td>RCC</td>
<td>644</td>
<td>5,722</td>
<td>11.3</td>
<td>3,983</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Palmer River dam site</td>
<td>56</td>
<td>RCC</td>
<td>1,444</td>
<td>9,975</td>
<td>14.5</td>
<td>3,801</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td>Elizabeth Creek dam site</td>
<td>36</td>
<td>RCC</td>
<td>149</td>
<td>1,479</td>
<td>10.0</td>
<td>580</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Pinnacles dam site on the Mitchell River</td>
<td>58</td>
<td>RCC</td>
<td>2,316</td>
<td>14,437</td>
<td>16.0</td>
<td>7,728</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>Rookwood dam site on the Walsh River</td>
<td>61</td>
<td>RCC</td>
<td>1,288</td>
<td>10,530</td>
<td>12.2</td>
<td>4,855</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>Chillagoe dam site on the Walsh River</td>
<td>50</td>
<td>RCC</td>
<td>600</td>
<td>2,978</td>
<td>20.1</td>
<td>3,423</td>
<td>0.18</td>
<td></td>
</tr>
<tr>
<td>Nullinga dam site on the Walsh River</td>
<td>31</td>
<td>RCC</td>
<td>145</td>
<td>1,431</td>
<td>10.1</td>
<td>327</td>
<td>0.44</td>
<td></td>
</tr>
</tbody>
</table>

FSL = full supply level
* Based on DEM-H bed height. In some areas the drainage enforcement may exaggerate the river bed. If matching to a different DEM should match on the absolute height of the spillway.
** Roller compacted concrete dam (RCC).
^ 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.

Four potential dam sites in the Mitchell catchment were selected for further analysis because each was deemed to be the most likely site to proceed in four distinct geographical areas. The assessment of the four 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 were the Elizabeth Creek dam site on the Elizabeth Creek, the Pinnacles dam site on the Mitchell River and the Rookwood and Chillagoe dam sites on the Walsh River. No previous analysis had been undertaken on these sites.
The four short-listed sites are reported in Section 5.2. The four non-short-listed sites and the existing Lake Mitchell Dam are reported in Appendix B.

**Figure 5-5 Versatile agricultural land and potential dam sites selected for pre-feasibility analysis in the Mitchell catchment**

Versatile agricultural land data (Thomas et al., 2018b) indicate those parts of the catchment that are more or less versatile for irrigated agriculture.
5.2 Four short-listed potential dam sites in the Mitchell catchment

Four potential dam sites in the Mitchell catchment are listed from west to east.

5.2.1 ELIZABETH CREEK DAM SITE ON THE ELIZABETH CREEK; ATMD 37.2 KM

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous investigations</td>
<td>No record of any previous investigation of this site has been located. The site was identified from a CSIRO DamSite model run.</td>
</tr>
<tr>
<td>Description of potential dam configuration</td>
<td>A dam at this site could potentially provide a water supply for irrigation of suitable soil areas downstream. There are no known urban or mining demands that could be met by a dam at this site.</td>
</tr>
<tr>
<td>The following figures accompany this description of the site</td>
<td>The potential Elizabeth Creek dam is illustrated in Figure 5-6. Figure 5-7 provides a map showing its location in the Mitchell catchment, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Figure 5-8. Figure 5-9 and Figure 5-10 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Figure 5-11 to Figure 5-13. Conceptual dam arrangements are provided in Figure 5-14.</td>
</tr>
<tr>
<td>Regional geology</td>
<td>The potential dam site is located near the upstream end of a gorge cut through about 20 m of near horizontal sandstone of Jurassic age (the Gilbert River Formation) into the underlying older rocks of the Hodgkinson Formation of Silurian to Devonian ages. The dam is confined to the lower half of the 120-m deep gorge and according to the geological maps is likely to be founded entirely on Hodgkinson Formation rocks that have been intruded by granite, faulted, uplifted and subject to long periods of weathering and erosion since they were formed. The reservoir area is underlain by the Hodgkinson Formation and volcanics (mainly rhyolite and ignimbrite) of Permian age. Soils over the project area are relatively thin but there may be channel deposits within the river, alluvial terraces in some places and colluvium on many of the slopes. Bedding in the Hodgkinson Formation in the reservoir area tends to dip steeply (75° to 90°) west (downstream). There are major faults trending north-west/south-east and west-northwest/east-southeast in the project area. There are also north-east/south-west and west-northwest/east-southeast-trending lineaments in the project area that are probably associated with joints or smaller faults.</td>
</tr>
<tr>
<td>Site geology</td>
<td>The potential dam site is on a west-trending section of the river. According to geological maps, the Hodgkinson Formation in the area consists of ‘cream to pale grey, medium to thick bedded to massive fine to coarse-grained arenite; subordinate mudstone; minor pebbly arenite, conglomerate, metabasalt, chert; rare limestone’. The valley profile at the potential dam site and photographs from a helicopter elsewhere in the gorge indicate that it is likely that there is some sand in the valley floor at or near the dam site and there is likely to be colluvium on the lower slopes. There does not appear to be large outcrops of arenite in the valley floor or sides but there may be smaller outcrops not visible from the air. Based on the geological history and observations of the Hodgkinson Formation elsewhere, there are likely to be at least three sets of defects (mainly joints) in the rock mass and loosening of the rock mass on the valley sides, likely to have occurred as a result of stress relief. For initial costing purposes, mean foundation depths of 2 m have been assumed for the valley floor. Mean foundation depths of 4 m have been assumed for both abutments. Most of the colluvium and some of the loosened near-surface rock may be excavatable by bulldozers and excavators but drilling and blasting may be required in places to reach a suitable foundation. At the suggested highest likely full storage level (of 245 mEGM96 AHD) saddle dams are not likely to be required. The permeability and the stability of the foundations and abutments of the dam, and the potential for scour downstream of the spillway, are largely related to the continuity and</td>
</tr>
<tr>
<td>PARAMETER</td>
<td>DESCRIPTION</td>
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</tr>
<tr>
<td>nature of the defects (e.g. faults and joints) in the rock mass, which will need to be investigated during feasibility studies, but based on present knowledge there is no reason for concern. It has been assumed that foundation grouting will be required for the dam.</td>
<td></td>
</tr>
<tr>
<td>Reservoir rim stability and leakage potential</td>
<td>Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. Given the lack of soluble rocks in the storage area and the lack of narrow, low, steep-sided saddles, reservoir leakage is unlikely to be a significant issue provided the dam foundations are grouted.</td>
</tr>
<tr>
<td>Potential structural arrangement</td>
<td>An RCC gravity dam with a 150-m wide central uncontrolled spillway and crest level up to 36 m above bed level is proposed. A hydraulic jump type stilling basin is proposed to protect the river bed against erosion during spillway overflows. For the purpose of this Assessment the abutment crest level has been set at the peak storage level of the 1:10,000 AEP flood. This would need to be reviewed if this option were to be considered further. Outlet works providing for selective withdrawal from the storage would be located in the left abutment. A fish transfer facility would also be located on the left abutment. Access for construction and operations would be via a 12-km long new road branching from the Burke Development Road some 72 km north-west of Chillagoe.</td>
</tr>
<tr>
<td>Availability of construction materials</td>
<td>The arenite in the area may provide suitable aggregate for RCC and possibly CC, although this will have to be confirmed during feasibility studies. If the arenite is unsuitable, volcanic rocks in the reservoir area could be considered for aggregate, rockfill and sand. There is some sand in the valley floor but many of the deposits may be relatively shallow. It may be possible to reuse some of the material obtained from the foundation excavations for construction.</td>
</tr>
<tr>
<td>Catchment area</td>
<td>Based on SRTM data, the catchment area upstream of the dam axis is estimated to be 580 km².</td>
</tr>
<tr>
<td>Flow data</td>
<td>Flow data are available for Elizabeth Creek from GS 919312A Elizabeth Creek at Greenmantle at AMTD 32 km, catchment area 629 km². Data are available from October 1969 until October 1988. Over this period data were as follows: Maximum recorded annual flow volume 701 GL, Mean annual flow volume 185 GL, Median annual flow volume 163 GL, Minimum annual flow volume 14 GL. (The stage discharge relationship at this gauge is not as robust as the relationship at other gauging stations in the catchment.)</td>
</tr>
<tr>
<td>Storage capacity</td>
<td>Based on SRTM data, storage levels and capacities have been considered as follows: FSL 235 mEGM96 Capacity 149 GL, FSL 240 mEGM96 Capacity 240 GL, FSL 245 mEGM96 Capacity 366 GL</td>
</tr>
<tr>
<td>Reservoir yield assessment at dam wall</td>
<td>FSL 235 mEGM96 Estimated yield at 85% annual time reliability 54.8 GL, FSL 240 mEGM96 Estimated yield at 85% annual time reliability 60.9 GL, FSL 245 mEGM96 Estimated yield at 85% annual time reliability 64.6 GL</td>
</tr>
<tr>
<td>Open water evaporation</td>
<td>At FSL, the surface area of the storage based on DEM-H data are estimated as follows: FSL 235 mEGM96 1479 ha, FSL 240 mEGM96 2158 ha, FSL 245 mEGM96 2876 ha. Mean annual evaporation and mean annual net evaporation at FSL 235 mEGM96 at 85% annual reliability is 15.2 GL and 8.4 GL, respectively. The ratio of total net evaporation to mean annual water supplied is 0.158.</td>
</tr>
<tr>
<td>Potential use of supply</td>
<td>Agriculture A small area of very deep red sands (Tenosols) developed on the quartz sandstone Jurassic</td>
</tr>
</tbody>
</table>
sandstone plateau to the south-east of Wrotham Park is suitable for irrigated horticulture. Soils are unsuitable for ringtanks.

From the sandplains derived from the ‘old’ (Tertiary-Quaternary) alluvium and elevated recent alluvium adjacent to the Walsh River channels in the Wrotham Park area, red, yellow and grey massive loamy soils with sandy surfaces (Kandosols) are suitable for a wide variety of spray-irrigated crops and horticultural crops. Rounded gravels often occur on lower slopes where dissected by creeks. Narrow levees and channel benches adjacent to the major channels throughout the Assessment area have sandy and loamy surfaced well-drained very deep red and yellow massive soils (Kandosols). All Kandosols are unlikely to be suitable for ringtanks. The channel benches are subject to regular flooding. In the vicinity of the confluence of Elizabeth Creek and the Walsh River, hard-setting clay loam surfaced brown gradational soils with strongly sodic, dispersive structured clay subsoil are suitable for sugarcane and dry-season grain and forage cropping.


<table>
<thead>
<tr>
<th>Estimated rates of reservoir sedimentation</th>
<th>Best case</th>
<th>Expected</th>
<th>Worst case</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 years (%)</td>
<td>0.1</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>100 years (%)</td>
<td>0.3</td>
<td>2.4</td>
<td>3.5</td>
</tr>
<tr>
<td>Years to fill</td>
<td>39,770</td>
<td>4,170</td>
<td>2,860</td>
</tr>
</tbody>
</table>

Storage impacts

Allowing for a 1:100 AEP flood rise margin above FSL:
- an area of 1865 ha would need to be acquired for a storage FSL 235 mEGM96
- an area of 2500 ha would need to be acquired for a storage FSL 240 mEGM96
- an area of 3200 ha would need to be acquired for a storage FSL 245 mEGM96

In each case, land acquisition would have a significant impact on the Kitoba land lease SP 275854, total area 41,300 ha, and a smaller impact on the lease 289/OL36, total area 15,500 ha.

Additionally, some 10 km of the OK road may need to be relocated. If this were the case, some 12 km of new road would be required.

Environmental considerations

Barrier to movement of aquatic species
No species of interest were found near this site.

Ecological implications of inundation
Approximately 16% of the reservoir extent is listed as ‘Of concern’ (235 ha) regional ecosystems, including riverine wetlands. These ecosystems provide important sites for feeding and movement of birds, fish and reptiles and can be adversely affected by changes to the hydrological regimes. No listed species are recorded near this site.

The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).

Indigenous land tenure, native title and cultural heritage considerations
Substantial land in the area is subject to current and/or future native title claims. There are no currently recorded cultural heritage sites in the inundation area, but there are recorded sites in the vicinity and in the wider catchment. There is a high likelihood of unrecorded sites in the inundation area.

Estimated cost
A manual cost estimate undertaken as part of the Assessment for an RCC dam at the Elizabeth Creek site at FSL 235 mEGM96 found the dam would cost approximately $189 million. Details of this cost estimate are provided in Appendix D.

To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO’s generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below:

<table>
<thead>
<tr>
<th>FSL</th>
<th>Cost (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>235 mEGM96</td>
<td>$225</td>
</tr>
<tr>
<td>240 mEGM96</td>
<td>$259</td>
</tr>
<tr>
<td>245 mEGM96</td>
<td>$295</td>
</tr>
<tr>
<td>PARAMETER</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| **Estimated cost / ML of supply** | Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows:  
  FSL 235 mEGM96          $4109/ML  
  FSL 240 mEGM96          $4248/ML  
  FSL 245 mEGM96          $4571/ML  
  On the basis of these estimated costs of supply over this range of storage levels, a dam with FSL 235 mEGM96 was selected for an assessment of irrigation and hydro-electric power generation potential at the site and for a more detailed costing.  
  Based on the manual cost estimate, the cost/ML of supply at FSL of 235 mEGM96 is $3436/ML. |
| **Summary comment**         | The Elizabeth Creek dam site has the smallest catchment area and the lowest yield of the potential dam sites examined in the Mitchell catchment. However, the site is situated in a narrow sandstone gorge and is relatively close to land suitable for irrigated agriculture.                                      |
Figure 5-7 Location map of potential Elizabeth Creek dam site, reservoir extent and catchment area

Figure 5-8 Potential Elizabeth Creek reservoir and property boundaries
Figure 5-9 Geology underlying the potential Elizabeth Creek dam site and reservoir

Figure 5-10 Regional ecosystem mapping and reservoir extent of the potential Elizabeth Creek dam site
Figure 5-11 Elizabeth Creek potential dam site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and PMF events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance.
Figure 5-12 Elizabeth Creek potential dam site cost, yield at the dam wall and evaporation
(a) dam length and dam cost versus full supply level (FSL); (b) dam yield at 85% and 95% annual time reliability and yield per million dollars at 85% and 95% annual time reliability; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% annual time reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f) yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.
Figure 5-13 Elizabeth Creek potential dam site storage levels and yield
(a) maximum and minimum annual storage trace at the selected full supply level (FSL) (235 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL.
Figure 5-14 Conceptual arrangement of the potential Elizabeth Creek dam
5.2.2 PINNACLES DAM SITE ON THE MITCHELL RIVER; AMTD 423.9 KM

<table>
<thead>
<tr>
<th>PARAMETER</th>
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<tbody>
<tr>
<td>Previous investigations</td>
<td>A very preliminary investigation of this site was undertaken by the then Department on Natural Resources as part of a Gulf Region study in 1998: Department of Natural Resources, Regional Infrastructure Development (1998) Gulf region study – engineering assessment of identified storage options. December 1998. At the time, a concrete-faced rockfill dam was proposed with an estimated storage capacity of 879 GL.</td>
</tr>
<tr>
<td>Description of potential dam configuration</td>
<td>The site is on the Mitchell River some 80 km north-northwest of the township of Chillagoe. The left abutment is formed by a narrow high ridge known as the Pinnacle Range. A dam at this site could potentially provide a water supply for irrigation development downstream. There are no known urban or mining demands that could be met by a dam at this site. The following figures accompany this description of the site The potential Pinnacles dam on the Mitchell River is illustrated in Figure 5-15. Figure 5-16 provides a map showing its location in the Mitchell catchment, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Figure 5-17. Figure 5-18 and Figure 5-19 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Figure 5-20 to Figure 5-22. Conceptual dam arrangements are provided in Figure 5-23.</td>
</tr>
<tr>
<td>Regional geology</td>
<td>The potential dam site and reservoir area are located in an area of folded and faulted sedimentary, metamorphic and igneous rocks of the Hodgkinson Formation of Silurian to Devonian ages, which form part of the Mossman Orogen. The Hodgkinson Formation rocks have been intruded by granite, faulted, uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the project area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on some slopes. Foliation in the metamorphic rocks in the project area tends to dip steeply west. Fold axes in the Hodgkinson Formation tend to trend north-south (ranging from north-northwest to north-northeast) and both bedding and foliation tend to be steeply dipping. Foliation in the metamorphic rocks near the dam site dips steeply downstream (75° to 85° west-southwest). There are major faults trending north-west/south-east and west-northwest/east-southeast in the project area including the Big Watson shear zone, which is immediately downstream of the potential dam site. There are also north-northeast/south-southwest and east/west-(ranging from east-northeast/west-southwest to east-southeast/west-northwest) trending lineaments in the project area that are probably associated with joints or smaller faults. The Mitchell River and its tributaries tend to flow parallel to the faults and lineaments indicating that the down-cutting river has preferentially eroded channels along major defects in the rock mass.</td>
</tr>
<tr>
<td>Site geology</td>
<td>The potential dam is on a west-southwest-trending section of the river. According to geological maps, thinly bedded to massive chert occurs on the left abutment and interbedded arenite, mudstone (locally phyllitic) and minor chert outcrops on the right abutment. There are large outcrops of mottled dark red brown and dark grey green, slightly weathered, very high to extremely high-strength chert at the base of the right abutment and smaller outcrops of grey green slightly weathered medium to high-strength phyllite, which dips steeply downstream. The phyllite is interbedded with pale brown, slightly weathered arenite. The potential dam is located in a relatively wide gorge (about 230 m bed width) with outcrop on the valley floor and on both abutments and in the river bed. The left abutment is a very steep rocky slope at the end of a prominent steep-sided north-west/south-east-trending ridge of chert known as the Pinnacles. Chert is exposed in a steep cliff on the north-eastern side of the ridge. There is a fan of colluvium below the cliffs and there are also colluvial fans covered by trees on the south-west side of the ridge. There is an isolated rocky pinnacle of chert separated from the main part of the left abutment in the river channel. The right abutment ridge is lower with gentler and more rounded slopes than the left abutment ridge with less outcrop on the upper slopes. There are isolated pockets of well graded fine to coarse-grained sand in places in the river bed.</td>
</tr>
</tbody>
</table>
and on the abutments near the dam axis. The river flows in several distinct channels upstream of, and through, the gorge. There is a large island (at least 900 m long and up to 200 m wide) of channel deposits, including sand upstream of the dam axis and another large area of sand on the right bank of the river upstream of the island.

There are prominent steeply dipping defects oriented upstream/downstream (south-west/north-east) and cross-valley (north-west/south-east). Most of the defects observed were joints but there may also be some faults in the same orientations and many of the cross-valley defects may be foliation partings which dip steeply downstream. Near-horizontal defects are also visible on both abutments. These may be tectonic joints associated with regional stresses during deformation or they may be regional stress relief joints associated with regional erosion. Some may also be local stress relief joints associated with valley sides. On the locally steep sides of the valley, stress relief is likely to have resulted in the inward (towards the river) movement (partly along shallow dipping defects) of the valley sides. This movement causes pre-existing defects (particularly steep joints parallel to the valley) to open and the formation and opening of new stress relief joints roughly parallel to, or flatter than, the valley sides.

There are likely to be many open joints in the outcrops on the abutments. Transported material filling the joints may result in the formation of infilled seams. As a result of the stress relief and weathering effects in the near-surface rock mass on the valley sides, joints and other defects are likely to be longer and more closely spaced, and the near-surface rock mass is likely to be more permeable than in the less disturbed rock mass at greater depths.

For initial costing purposes, mean foundation depths of 2 m have been assumed for the valley floor (although locally deeper excavation may be required if there is an upstream/downstream fault in the bed of the river). Mean foundation depths of 3 m have been assumed for the left abutment and 4 m for the right abutment (because of the greater depth of colluvium). Some of the loosened near-surface rock may be excavatable by bulldozers and excavators but drilling and blasting is likely to be required in places to reach a suitable foundation. Drilling costs in the chert are likely to be relatively high because it is a very hard and very strong rock.

At the suggested highest likely full storage level (of 240 mAHD) a major saddle dam is required on the right bank of the reservoir. According to geological maps, the saddle dam on the right bank is likely to be founded on arenite, mudstone, phyllite and chert of the Hodgkinson Formation. The rocks underlying the saddle dam are likely to be more weathered and weaker than the less weathered rocks observed at the main dam site. For initial costing purposes, mean foundation excavation depths of 3 m have been assumed for the core trench for the saddle dam and 1 m for the shoulder zones. The weathered materials may be excavatable by bulldozers or excavators to the full depths required at most of the saddle dams.

The permeability and the stability of the foundations and abutments of the main dam and saddle dam, and the potential for scour downstream of the spillway, are largely related to the continuity and nature of the defects (e.g. faults and joints) in the rock mass, which will need to be investigated during feasibility studies, but based on present knowledge there is no reason for concern. It has been assumed that foundation grouting will be required for both the main dam and for the saddle dam.

### Reservoir rim stability and leakage potential

Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. Given the lack of soluble rocks in the storage area and the lack of narrow, low, steep-sided saddles, reservoir leakage is unlikely to be a significant issue provided the main and saddle dam foundations are grouted.

### Potential structural arrangement

Given the need to provide a large spillway capacity and to minimise the risk of flood damage during construction, an RCC structure with a 240-m wide central uncontrolled spillway with crest level up to 60 m above bed level is proposed. A hydraulic jump type stilling basin would be provided to protect the river bed against erosion during spillway overflows.

Outlet works and a fish transfer facility are proposed to be located on the left abutment of the dam.

The level of the dam abutments has been set at the 1:10,000 AEP peak storage level and the right bank saddle dam crest set at the 1:50,000 AEP peak storage level. An RCC retaining wall will be required at the top of the right abutment to retain the zoned earth and rockfill saddle dam, which would be up to 1.85 km in length and have a height of up to 42 m. Over the higher section of the saddle dam embankment, the crest level has been set 0.5 m higher than over the lower section of the saddle dam. These levels would need to be reviewed if this option...
was to be further considered.

Access to the site would via the existing Bellevue Road from the Burke Developmental Road at a point some 90 km north-west of Chillagoe. A substantial upgrade of the Bellevue Road would be required to improve wet-season access. From near the Bellevue homestead, a new road some 15 km long would be required to reach the site on the left-bank side.

### Availability of construction materials

The petrology report on a sample of chert from the dam site collected during this Assessment described the rock as potentially deleterious for use as a concrete aggregate because it may cause alkali–silica reaction (see Appendix E). Further testing will be required to assess this possibility including long-term mortar bar testing using representative mix samples. Past experience has shown that fly ash in the mix can suppress the alkali reaction so that it may be possible to develop a suitable RCC mix using the chert.

The chert in the area is likely to provide suitable aggregate for RCC and possibly for CC. A quarry in the chert is also likely to provide rockfill and riprap for the saddle dam and sand and aggregate suitable for the filters required in the saddle dam. Drilling, blasting and crushing the chert is likely to be relatively expensive because of the strength and hardness of the material. Chert consists almost entirely of microcrystalline or cryptocrystalline silica and crushed chert is a very abrasive material.

There is relatively little sand in the river channel near the dam site but there may be more in the river channel upstream and downstream of the dam site and in alluvial terraces in the area. Cohesive earthfill for the core of the saddle dam may be harder to find as natural soils in the area are relatively thin. Extremely weathered mudstone, phyllite or other fine-grained material, residual soils and colluvium may provide suitable sources of core material.

It may be possible to reuse some of the material obtained from the foundation excavations for construction. It may also be possible to obtain some of the chert from the colluvial fans on the north-east and south-west slopes of the Pinnacles ridge.

### Catchment area

Based on SRTM data, the catchment area at the dam site is estimated to be 7728 km².

### Flow data

Flow data are available for the Mitchell River from GS 919003A at OK Bridge, AMTD 408.9km, catchment area 7724 km². Data are available from October 1967 to date. Over this period data were as follows:

- Maximum recorded annual flow volume: 7756 GL
- Mean annual flow volume: 1770 GL
- Median annual flow volume: 1535 GL
- Minimum annual flow volume: 65 GL

### Storage capacity

Based on SRTM data, storage levels and capacities have been considered as follows:

- FSL 215 mEGM96: Capacity 355 GL
- FSL 220 mEGM96: Capacity 563 GL
- FSL 225 mEGM96: Capacity 842 GL
- FSL 240 mEGM96: Capacity 2460 GL

### Reservoir yield assessment at dam wall

- FSL 215 mEGM96: Estimated yield at 85% annual time reliability: 489.2 GL
- FSL 220 mEGM96: Estimated yield at 85% annual time reliability: 588.8 GL
- FSL 225 mEGM96: Estimated yield at 85% annual time reliability: 732.4 GL
- FSL 240 mEGM96: Estimated yield at 85% annual time reliability: 1248.0 GL

### Open water evaporation

At FSL, the surface area of the storage based on SRTM data are estimated to be as follows:

- FSL 215 mEGM96: 3533 ha
- FSL 220 mEGM96: 4808 ha
- FSL 225 mEGM96: 6377 ha
- FSL 240 mEGM96: 7727 ha

Mean annual evaporation and mean annual net evaporation at FSL 240 mEGM96 at 85% annual reliability is 82.2 GL and 43.4 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.061.

### Potential use of supply

**Agriculture**

Downstream of the potential dam site the ‘younger’ alluvial plains of the Mitchell River and all tributaries with sodic subsoils are suitable for a range of irrigated grain and fodder crops and sugarcane. The main limitations are seasonal wetness during the wet season, erosion on
sloping land adjacent to channels, and restrictions on irrigation water to wet up the soil profile due to impermeable subsoils and sealing surfaces. The loamy soils of the levees, prior streams and 'old' alluvial plains are suitable for a range of irrigated crops, particularly horticultural crops.

Downstream and above the confluence with the Walsh River, gently undulating to undulating plains and rises with moderately deep to very deep self-mulching black cracking clays of the 'Rolling Downs Group' of the Great Artesian Basin (GAB) occur in the Wrotham Park area. Soils are suitable for irrigated and dryland grain, pulse and fodder crops, sugarcane, cotton and a range of horticultural crops but may have secondary salinity limitations due to deep drainage water from irrigation potentially raising watertables. Soils are possibly suitable for ringtanks on gently sloping lower slopes with deep soils.

Further downstream of the confluence of the Lynd and the Mitchell rivers, the river breaks out into a regularly flooded 'broad' delta with numerous flood channels, which become more numerous and meandering closer to the coast. Soils are dominated by hard-setting clay loam surfaced brown gradational soils with strongly sodic, dispersive structured clay subsoil and hard-setting coarse structured grey cracking clay soils. Soils are suitable for sugarcane and dry-season grain and forage cropping, and likely to be suitable for ringtanks. Narrow levees, prior streams and elevated 'old' Tertiary-Quaternary alluvial plains have predominantly red and brown massive loamy soils suitable for a range of irrigated crops, particularly horticultural crops, and are unlikely to be suitable for ringtanks.

See companion technical report on land suitability by Thomas et al. (2018b).

<table>
<thead>
<tr>
<th>Estimated rates of reservoir sedimentation</th>
<th>Best case</th>
<th>Expected</th>
<th>Worst case</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 years (%)</td>
<td>0.1</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>100 years (%)</td>
<td>0.2</td>
<td>1.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Years to fill</td>
<td>46,400</td>
<td>5,660</td>
<td>3,340</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage impacts</th>
<th>A storage with FSL 240 mEGM96 would inundate some 38 km of the Mitchell River bed and some 13 km of the St Georges River bed. Including a 1:100 AEP allowance for flood rise above FSL, the area of land that would need to be acquired would be approximately as follows:</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSL 215 mEGM96</td>
<td>6130 ha</td>
</tr>
<tr>
<td>FSL 220 mEGM96</td>
<td>7960 ha</td>
</tr>
<tr>
<td>FSL 225 mEGM96</td>
<td>10,270 ha</td>
</tr>
<tr>
<td>FSL 240 mEGM96</td>
<td>27,220 ha</td>
</tr>
</tbody>
</table>

<p>| Water quality and stratification considerations | It has been assumed that selective withdrawal baulks will be provided in the intake works so that best quality water can be drawn from the storage when releases are made. |
| Environmental considerations | Barrier to movement of aquatic species |
| A dam constructed at this site could affect the migration or movement of the following fishes, most of them stable flow spawners such as barred grunter (Amniataba percoides), flyspecked hardyhead (Craterocephalus stercusmuscarum stercusmuscarum), mouth almighty (Glossamia aprion), sooty grunter (Hephaestus fuliginosus), spangled perch (Leiopotherapon uniclor), bony herring (Nematalosa erebi), black catfish (Neosilurus ater) and Hyrtl's catfish (Neosilurus hyrtlil). Other freshwater fish that are found near this site, including the gulf grunter (Scortum ogilbyi) and the northern purplespotted gudgeon (Magurnda magurnda), could be indirectly... |</p>
<table>
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<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
</table>

affected by a dam as it would limit the amount of available prey such as other fish, crustaceans and molluscs.

**Ecological implications of inundation**

Of the eight sites examined in the Mitchell catchment this site has the highest number of species of national significance (41 species), most of them migratory birds (27 species), including the critically endangered great knot (*Calidris tenuirostris*) and curlew sandpiper (*Calidris ferruginea*). Migratory bird species can be particularly threatened by degradation of their habitat, with can occur with changes to flow regimes. The high diversity of migratory birds found at this site is highlighted by the presence of two important areas for birds. There are six frog species found near this site, two of which are critically endangered. Approximately 25% of the potential inundated area at FSL is covered by a regional ecosystem ‘Of concern’ (3641 ha).

The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).

**Indigenous land tenure, native title and cultural heritage considerations**

Substantial land in the area is subject to current and/or future native title claims. There are no currently recorded cultural heritage sites in the inundation area, but there are recorded sites in the vicinity and in the wider catchment. There is a high likelihood of unrecorded sites in the inundation area.

**Estimated cost**

A manual cost estimate undertaken as part of the Assessment for an RCC dam at the Pinnacles dam site at FSL 240 mEGM96 found the dam would cost approximately $755 million. Details of this cost estimate are provided in Appendix D.

To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO’s generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below:

- FSL 215 mEGM96: $438 million
- FSL 220 mEGM96: $521 million
- FSL 225 mEGM96: $607 million
- FSL 240 mEGM96: $963 million

**Estimated cost / ML of supply**

Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows:

- FSL 215 mEGM96: $895/ML
- FSL 220 mEGM96: $884/ML
- FSL 225 mEGM96: $828/ML
- FSL 240 mEGM96: $772/ML

On the basis of these estimated costs of supply over this range of storage levels, a dam with FSL 240 mEGM96 was selected for an assessment of irrigation and hydro-electric power generation potential at the site and for a more detailed costing.

Based on the manual cost estimate, the cost/ML of supply at FSL of 240 mEGM96 is $605/ML.

**Summary comment**

This site has the largest catchment area and highest yield of all sites examined in the Mitchell catchment. A storage at this site could support a large irrigation development downstream of Wrotham Park. At the level of development assessed, a very long saddle dam is required on the right bank. Nevertheless, the site has the lowest cost to yield ratio in the Mitchell catchment as a result of its high yield. Further assessment including geotechnical investigation of the saddle dam area would be required to determine the optimal level of development. Although a fish transfer facility has been proposed, the dam’s potential impact on migratory fish species including the freshwater sawfish and barramundi would need to be further considered.
Figure 5-15 Pinnacles dam site on the Mitchell River looking upstream

Figure 5-16 Location map of potential Pinnacles dam site, reservoir extent and catchment area
Figure 5-17 Potential Pinnacles dam reservoir and property boundaries

Figure 5-18 Geology underlying the potential Pinnacles dam site and reservoir
Figure 5-19 Regional ecosystem mapping and reservoir extent of the potential Pinnacles dam site
Figure 5-20 Pinnacles potential dam site on the Mitchell River site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and PMF events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance.
Figure 5-21 Pinnacles potential dam site on the Mitchell River cost, yield at the dam wall and evaporation
(a) dam length and dam cost versus full supply level (FSL); (b) dam yield at 85% and 95% annual time reliability and yield per million dollars at 85% and 95% annual time reliability; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% annual time reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f) yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.
Figure 5-22 Pinnacles potential dam site on the Mitchell River site storage levels and yield
(a) maximum and minimum annual storage trace at the selected full supply level (FSL) (240 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL.
Figure 5-23 Conceptual arrangement of the potential Pinnacles dam on the Mitchell River
## 5.2.3 ROOKWOOD DAM SITE ON THE WALSH RIVER; AMTD 121.3 KM

<table>
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<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous investigations</td>
<td>No record of any previous investigation of this site has been located.</td>
</tr>
<tr>
<td></td>
<td>The site was identified from a CSIRO DamSite model run.</td>
</tr>
<tr>
<td>Description of potential dam</td>
<td>The potential site is near the upstream end of a straight gorge-like section of the Walsh River some 28 km north-west of the town of Chillagoe. In the gorge section, fresh rock is exposed in the river bed and over much of both banks. A dam at this site could potentially provide a water supply for irrigation development downstream. There are no known urban or mining demands that could be met by a dam at this site. Other options that could impact on this proposal are the Nullinga dam proposal on the Walsh River at 259.6 km and the potential Chillagoe dam on the Walsh River at 169.8 km.</td>
</tr>
<tr>
<td>configuration</td>
<td>The following figures accompany this description of the site: Figure 5-24 illustrates the potential Rookwood dam on the Walsh River. Figure 5-25 provides a map showing its location in the Mitchell catchment, the extent of the reservoir at the selected FSL, the reservoir catchment area and the nearest streamflow gauging station. Satellite imagery and property boundaries in the vicinity of the reservoir are shown in Figure 5-26. Figure 5-27 and Figure 5-28 show the geology and selected ecological assets in the vicinity of the site. Site topography and dam cost and hydrology are shown in Figure 5-29 to Figure 5-31. Conceptual dam arrangements are provided in Figure 5-32.</td>
</tr>
<tr>
<td>Regional geology</td>
<td>The potential dam site is located in an area of volcanic rocks (mainly ignimbrites and rhyolite, dacite, andesite and basalt lava) of Permian age within the Hodgkinson Province of older folded and faulted sedimentary, metamorphic and igneous rocks, which form part of the Mossman Orogen. The volcanic rocks are part of a large volcanic complex formed on and within (down faulted into) the older rocks. The rocks in the Hodgkinson Provinces have been intruded by granite, faulted, uplifted and subject to long periods of weathering since they were formed. The reservoir area is underlain by a mixture of volcanic rocks, Hodgkinson Formation arenites and granitic rocks. Soils over the project area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on many of the slopes. There are major faults trending north-west/south-east and west-northwest/east-southeast in the project area including the Walsh Fault and the Palmerville Fault, which are both downstream of the potential dam site. The Palmerville Fault is a major regional fault, which forms the western boundary of the Hodgkinson Province and the Mossman Orogen. There are also north-east/south-west and east/west-(ranging from east-northeast/west-southwest to east-southeast/west-northwest) trending lineaments that are probably associated with joints or smaller faults. The Walsh River and its tributaries tend to flow parallel to the faults and lineaments indicating that the down-cutting river has preferentially eroded channels along major defects in the rock mass.</td>
</tr>
<tr>
<td>Site geology</td>
<td>The potential dam is on a west-trending section of the river. According to geological maps, rhyolitic ignimbrite underlies both abutments but rhyolite or dacite lavas and microgranite may also occur in the area, as the companion petrology report on a sample from the main dam site described the rock as a dacite or a rhyodacite (Appendix E). Where observed in outcrop on the right bank of the river, the ignimbrite was coarse grained, mottled pale grey and dark green and was slightly to distinctly weathered and of very high strength. The potential dam is located in a relatively narrow gorge (about 50 m bed width) with outcrop on both abutments and in the river bed. There are isolated pockets of well graded fine to coarse-grained sand in places in the river bed and on the abutments but the deposits are probably too shallow and too small to provide significant amounts of construction material. There are prominent steeply dipping defects oriented upstream/downstream (south-west/north-east) and cross-valley (north-west/south-east). Most of the defects observed were joints but there may also be some faults in the same orientations. Most of the cross-valley joints dip steeply (60° to 90°) upstream. Near-horizontal defects are also visible on both abutments. These may be partings associated with the original layering of the volcanic rocks, tectonic joints associated with regional stresses or they may be regional stress relief joints associated with regional erosion. Some may also be local stress relief joints associated with...</td>
</tr>
</tbody>
</table>
On the locally steep sides of the valley, stress relief is likely to have resulted in the inward (towards the river) movement (partly along shallow dipping defects) of the valley sides. This movement causes pre-existing defects (particularly steep joints parallel to the valley) to open and the formation and opening of new stress relief joints roughly parallel to, or flatter than the valley sides. Many open joints (open up to at least 50 mm in places) were observed in the outcrops on the lower steep slopes of each abutment. Transported material filling the joints may result in the formation of infilled seams. As a result of the stress relief and weathering effects in the near-surface rock mass on the valley sides, joints and other defects are likely to be longer and more closely spaced and the near-surface rock mass is likely to be more permeable than in the less disturbed rock mass at greater depths.

For initial costing purposes, mean foundation depths of 2 m have been assumed for the valley floor (although locally deeper excavation may be required if there is an upstream/downstream fault in the bed of the river). Mean foundation depths of 4 m have been assumed for both abutments. Some of the loosened near-surface rock may be excavatable by bulldozers and excavators but drilling and blasting is likely to be required in places to reach a suitable foundation.

At the highest potential full storage level (of 295 mAHD) saddle dams are required on both the right and on the left bank of the reservoir to contain reservoir rises during flood inflows. According to geological maps, the potential saddle dams on the right bank of the reservoir are likely to be founded on volcanic rocks (mainly lavas) of Permian age or on granite of Carboniferous age. On the left bank of the reservoir the saddle dams are likely to be founded on either volcanic or granites of Permian age or metamorphic rocks (probably arenites of the Hodgkinson Formation) of Silurian or Devonian age. The rocks underlying all of the saddle dams are likely to be more weathered than the very high strength slightly weathered rocks observed at the main dam site. For initial costing purposes, mean foundation excavation depths of 3 m have been assumed for the core trenches of all the saddle dams and 1 m for the shoulders of all of the saddle dams. The weathered materials may be excavatable by bulldozers or excavators to the full depths required at most of the saddle dams.

The permeability and the stability of the foundations and abutments of the main dam and saddle dams, and the potential for scour downstream of the spillway, are largely related to the continuity and nature of the defects (e.g. faults and joints) in the rock mass, which will need to be investigated during feasibility studies, but based on present knowledge there is no reason for concern. It has been assumed that foundation grouting will be required for both the dam to control leakage and saddle dams.

Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. The saddle dam foundations and nearby ridges will need to be thoroughly investigated for their leakage potential. Given the lack of soluble rocks in the storage area, reservoir leakage is unlikely to be a significant issue provided the main dam foundations, and where necessary the saddle dam foundations, are grouted.

An RCC gravity dam with crest level up to 66 m above bed level is proposed with a 300-m wide uncontrolled central overflow spillway. A hydraulic jump type stilling basin would be provided to protect the river bed against erosion during spillway overflows.

For the purpose of this Assessment, the level of the dam abutments has been set at the 1:10,000 AEP peak storage level. Crest level of the saddle dams has been set at the 1:50,000 AEP peak storage level. This would need to be reviewed if this option was to be considered further.

Outlet works and a fish transfer facility would be located in the left abutment. Access to the site would be by some 3 km of road on the left bank of the river from the Burke Development Road, which crosses the Walsh River about 1 km downstream of the gorge section. The turnout from the Burke Development Road would be some 32 km north-west of Chillagoe.

The companion petrology report on a sample of rhyolite from the dam site collected during this Assessment (Appendix E) described the rock as potentially deleterious for use as a concrete aggregate because it may cause alkali–aggregate reaction (AAR). Further testing will be required to assess this possibility including long-term mortar bar testing using representative mix samples. Past experience has shown that fly ash in the mix can suppress the AAR so that it may be possible to develop a suitable RCC mix using the volcanic rocks in valley sides.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir rim stability and leakage potential</td>
<td>Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. The saddle dam foundations and nearby ridges will need to be thoroughly investigated for their leakage potential. Given the lack of soluble rocks in the storage area, reservoir leakage is unlikely to be a significant issue provided the main dam foundations, and where necessary the saddle dam foundations, are grouted.</td>
</tr>
<tr>
<td>Potential structural arrangement</td>
<td>An RCC gravity dam with crest level up to 66 m above bed level is proposed with a 300-m wide uncontrolled central overflow spillway. A hydraulic jump type stilling basin would be provided to protect the river bed against erosion during spillway overflows. For the purpose of this Assessment, the level of the dam abutments has been set at the 1:10,000 AEP peak storage level. Crest level of the saddle dams has been set at the 1:50,000 AEP peak storage level. This would need to be reviewed if this option was to be considered further. Outlet works and a fish transfer facility would be located in the left abutment. Access to the site would be by some 3 km of road on the left bank of the river from the Burke Development Road, which crosses the Walsh River about 1 km downstream of the gorge section. The turnout from the Burke Development Road would be some 32 km north-west of Chillagoe.</td>
</tr>
<tr>
<td>Availability of construction materials</td>
<td>The companion petrology report on a sample of rhyolite from the dam site collected during this Assessment (Appendix E) described the rock as potentially deleterious for use as a concrete aggregate because it may cause alkali–aggregate reaction (AAR). Further testing will be required to assess this possibility including long-term mortar bar testing using representative mix samples. Past experience has shown that fly ash in the mix can suppress the AAR so that it may be possible to develop a suitable RCC mix using the volcanic rocks in valley sides.</td>
</tr>
</tbody>
</table>
A quarry in the volcanic rocks is also likely to provide suitable aggregate for RCC and possibly for CC. A quarry in the volcanics is also likely to be able to provide rockfill and riprap for the saddle dams and sand and aggregate suitable for the filters required in the saddle dams. There is relatively little sand in the river channel near the dam site but there may be more in the river channel upstream and downstream of the dam and in alluvial terraces in the area. Cohesive earthfill for the cores of the saddle dams may be harder to find as natural soils in the area are relatively thin. Extremely weathered granite, which typically consists of silty sand with some clay when remoulded, has been successfully used for embankment dam cores elsewhere (e.g. in the Snowy Mountains) and may be available near some of the saddle dams. Elsewhere other extremely weathered material, residual soils and colluvium may provide suitable sources of core material. It may be possible to reuse some of the material obtained from the foundation excavations for construction.

| Catchment area | Catchment area at the dam site, based on SRTM data, is 4990 km².
| Flow data | Flow data are available for the Walsh River from GS 919310 at Rookwood AMTD 108 km, catchment area 4927 km². Data are available from October 1967 to date. Over this period data were as follows:
| | Maximum annual flow volume | 5671 GL |
| | Mean annual flow volume | 1076 GL |
| | Median annual flow volume | 737 GL |
| | Minimum annual flow volume | 66 GL |
| Storage capacity | Storage levels and capacities have been considered as follows:
| | FSL 275 mEGM96 | Capacity | 166 GL |
| | FSL 285 mEGM96 | Capacity | 510 GL |
| | FSL 295 mEGM96 | Capacity | 1288 GL |
| Reservoir yield assessment at dam wall | Estimated yield at 85% annual time reliability |
| | FSL 275 mEGM96 | 182.1 GL |
| | FSL 285 mEGM96 | 361.5 GL |
| | FSL 295 mEGM96 | 574.6 GL |
| Open water evaporation | At FSL, the surface area of the storage is as follows:
| | FSL 275 mEGM96 | 1934 ha |
| | FSL 285 mEGM96 | 5248 ha |
| | FSL 295 mEGM96 | 10530 ha |
| | Mean annual evaporation and mean annual net evaporation at FSL 295 mEGM96 at 85% annual reliability is 115.0 GL and 65.1 GL respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.116.
| Potential use of supply | Agriculture |
| | Loam over brown sodic and intractable clays (sodic Dermosols, Sodosols) occur extensively throughout the alluvial plains upstream of the confluence of the Mitchell and Walsh rivers. These occasionally to rarely flooded alluvial plains are generally deeply incised by the main channel resulting in relatively narrow usable areas. Soils are dominated by hard-setting clay loam to silty clay loam surfaced brown gradational soils with strongly sodic, dispersive, structured clay subsoil less than 0.15 m below the surface supporting open eucalyptus woodland. These slowly permeable moderately well-drained to imperfectly drained soils predominantly have moderate soil water storage (75 to 100 mm), and are subject to erosion on slopes, particularly gully erosion adjacent to stream channels. Soils are likely to be suitable for ringtanks.
| | See companion technical report on land suitability by Thomas et al. (2018b).
| Estimated rates of reservoir sedimentation | Best case | Expected | Worst case |
| 30 years (%) | 0.1 | 0.6 | 1.0 |
| 100 years (%) | 0.2 | 2.0 | 3.4 |
| Years to fill | 41,070 | 4,975 | 2,960 |
**PARAMETER** | **DESCRIPTION**
---|---
**Storage impacts** | A storage at FSL 295 would inundate about 33 km of the Walsh River bed. Including a 1:100 AEP allowance for flood rise above FSL, the area of land that would need to be acquired would approximately as follows:

<table>
<thead>
<tr>
<th>FSL</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>275</td>
<td>3510</td>
</tr>
<tr>
<td>285</td>
<td>7620</td>
</tr>
<tr>
<td>295</td>
<td>13,040</td>
</tr>
</tbody>
</table>

The storage immediately upstream of the site would have a significant impact on the Pratt land lease 4/BW18, which has a total area of 128,000 ha.

Further upstream, the storage would impact the Aroonbeta land lease, SP 150971 which has a total area of 208,000 ha.

On the right bank, the storage would inundate a section of the Nychum Road. A relocation would involve some 12 km of new road construction.

**Environmental considerations** **Barrier to movement of aquatic species**

Migratory fishes have been recorded near and upstream of this site including the barred grunter (*Amniataba percoidei*), sooty grunter (*Hephaestus fuliginosus*), spangled perch (*Leiopotherapon unicolor*), bony herring (*Nematalosa erebi*), and Hyrtl’s catfish (*Neosilurus hyrtlii*). Other freshwater fish found near this site, such as northern purplespotted gudgeon (*Mogurnda mogurnda*) and sleepy cod (*Oxyeleotris lineolata*), could be indirectly affected by a barrier that limits the amount of prey such as other fish, crustaceans, and molluscs.

**Ecological implications of inundation**

A potential reservoir at this site may impact the habitat of a number of species. There are records of 12 migratory bird species and 2 bird species are listed as endangered. There are also records of four mammals (one critically endangered, one endangered and one vulnerable); three frog species, two of them endangered and one vulnerable and four plant species listed as vulnerable. The potential reservoir would inundate a regional ecosystem ‘Of concern’.

The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).

**Indigenous land tenure, native title and cultural heritage considerations**

Substantial land in the area is subject to current and/or future native title claims. There are no currently recorded cultural heritage sites in the inundation area, but there are recorded sites in the vicinity and in the wider catchment. There is a high likelihood of unrecorded sites in the inundation area.

**Estimated cost**

A manual cost estimate undertaken as part of the Assessment for an RCC dam at the Rookwood dam site on the Walsh River at FSL 295 mEGM96 found the dam would cost approximately $655 million. Details of this cost estimate are provided in Appendix D.

To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO’s generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below:

<table>
<thead>
<tr>
<th>FSL</th>
<th>Cost (m$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>275 mEGM96</td>
<td>394</td>
</tr>
<tr>
<td>285 mEGM96</td>
<td>686</td>
</tr>
<tr>
<td>295 mEGM96</td>
<td>1074</td>
</tr>
</tbody>
</table>

**Estimated cost / ML of supply**

Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows:

<table>
<thead>
<tr>
<th>FSL</th>
<th>Cost (m$) / ML</th>
</tr>
</thead>
<tbody>
<tr>
<td>275 mEGM96</td>
<td>2165</td>
</tr>
<tr>
<td>285 mEGM96</td>
<td>1891</td>
</tr>
<tr>
<td>295 mEGM96</td>
<td>1868</td>
</tr>
</tbody>
</table>

On the basis of these estimated costs of supply over this range of storage levels, a dam with FSL 295 mEGM96 was selected for an assessment of irrigation and hydro-electric power generation potential at the site and for a more detailed costing.

Based on the manual cost estimate, the cost/ML of supply at FSL of 295 mEGM96 is $1139/ML.

**Summary comment**

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

**Figure 5-24 Potential Rookwood dam site on the Walsh River looking upstream**
Figure 5-25 Location map of potential Rookwood dam site on the Walsh River, reservoir extent and catchment area

Figure 5-26 Potential Rookwood dam site on the Walsh River, reservoir and property boundaries
Figure 5-27 Geology underlying the potential Rookwood dam site on the Walsh River and reservoir

Figure 5-28 Regional ecosystem mapping and reservoir extent of the potential Rookwood dam site on the Walsh River
Figure 5-29 Rookwood potential dam site on the Walsh River site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and PMF events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance.
Figure 5-30 Rookwood potential dam site on the Walsh River site cost, yield at the dam wall and evaporation
(a) dam length and dam cost versus full supply level (FSL); (b) dam yield at 85% and 95% annual time reliability and
yield per million dollars at 85% and 95% annual time reliability; (c) annual time reliability plotted against yield for
different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% annual time
reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f)
yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.
Figure 5-31 Rookwood potential dam site on the Walsh River site storage levels and yield
(a) maximum and minimum annual storage trace at the selected full supply level (FSL) (295 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL.
Figure 5-32 Conceptual arrangement of the potential Rookwood dam on the Walsh River
5.2.4 CHILLAGOE DAM SITE ON THE WALSH RIVER; AMTD 169.8 KM

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous investigations</td>
<td>No record of any previous study of this site has been located. The site was identified from a CSIRO Dam Site model run.</td>
</tr>
<tr>
<td>Description of potential</td>
<td>The proposal is for a storage at a site on the Walsh River which could provide for releases to be made to the river or to a distribution system for the irrigation of suitable lands downstream of the dam site towards the township of Chillagoe. The site is 21 km to the north-east of the town. Other proposals that could impact on this proposal are the Nullinga dam proposal on the Walsh River at 259.6 km and Site 4 on the Walsh River at about 115 km.</td>
</tr>
<tr>
<td>dam configuration</td>
<td>The following figures accompany this description of the site</td>
</tr>
<tr>
<td>Regional geology</td>
<td>The potential dam site and reservoir area are located in an area of volcanic rocks (mainly rhyolite to dacite lavas and ignimbrites) of Permian age within the Hodgkinson Province of older folded and faulted, sedimentary metamorphic and igneous rocks, which form part of the Mossman Orogen. The volcanic rocks are part of a large volcanic complex formed on and within (down faulted into) the older rocks. The rocks in the Hodgkinson Province have been intruded by granite, faulted, uplifted and subject to long periods of weathering and erosion since they were formed. Soils over the project area are relatively thin but there are channel deposits within the river, alluvial terraces in some places and colluvium on many of the slopes. In places, several kilometres upstream and downstream of the dam site, there are older and higher alluvial terraces next to the river (of Tertiary or Quaternary age). There are major faults trending north-west/south-east and west-northwest/east-southeast in the project area and also north-east/south-west and east/west-(ranging from east-northeast/west-southwest to east-southeast/west-northwest) trending lineaments that are probably associated with joints or smaller faults. The Walsh River and its tributaries tend to flow parallel to the faults and lineaments indicating that the down-cutting river has preferentially eroded channels along major defects in the rock mass.</td>
</tr>
</tbody>
</table>
| Site geology                | The potential dam is on a south-west-trending section of the river. According to geological maps, rhyolitic ignimbrite underlies both abutments: the Combella Rhyolite on the right abutment and the Fisherman Rhyolite overlain by the Combella Rhyolite on the left abutment. The petrology report on a sample collected from the base of the left abutment during this Assessment described the rock as rhyolite (Appendix E). The higher level Combella Rhyolite on the left abutment and the outcrop pattern in the area implies that there may be a fault in the bed of the river. Where observed in outcrop on the valley floor, the rock was pale grey to pale brown, distinctly weathered and of high strength. The rock is likely to be less weathered and probably stronger at depth. There are some relatively small and probably relatively shallow well graded fine to coarse-grained sand in places near the axis of the potential dam, and larger deposits in places further upstream and downstream of the dam axis. On the dam axis the left abutment is steeper than the right abutment. On the left abutment there are relatively large outcrops and local cliffs. On the right abutment there is relatively little outcrop and there appears to be colluvium on the lower slopes. There are prominent steeply dipping defects oriented upstream/downstream (south-west/north-east) and cross-valley (north-west/south-east). Most of the defects observed were joints but there may also be some faults in the same orientations. Near-horizontal defects are also visible on the left abutment. These may be partings associated with the original layering of the volcanic rocks, tectonic joints associated with regional stresses or they may be regional stress relief joints associated with regional erosion. Some may also be local stress relief joints associated with valley sides. On the locally steep sides of the valley, stress relief is likely to have resulted in the inward (towards the river) movement (partly along shallow dipping defects) of the valley sides. This movement has caused pre-existing defects (particularly steep joints parallel to the valley) to open and the formation and
### Reservoir rim stability and leakage potential

Given the relatively subdued topography and the lack of pre-existing landslides in the reservoir area, reservoir rim stability is not expected to be a significant issue. The low saddle on the left bank of the reservoir will need to be thoroughly investigated for its leakage potential. Given the lack of soluble rocks in the storage area, reservoir leakage is unlikely to be a significant issue provided the main dam foundations are grouted.

### Potential structural arrangement

An RCC gravity dam with a 450-m wide central uncontrolled spillway with a crest level up to 50 m above bed level is proposed for the cross-river section. A hydraulic jump type stilling basin would be provided to protect the river bed against erosion during spillway overflows.

For this Assessment, the level of the dam abutments has been set at the 1:10,000 AEP peak storage level.

Outlet works and a fish transfer facility are proposed to be located on the left abutment of the main dam section.

Access to the site would be via a 23-km long new road branching from the Mareeba–Chillagoe Road some 9 km south-east of Chillagoe. A substantial flood causeway would be required across Crooked Creek.

### Availability of construction materials

The volcanic rocks in the area are likely to provide suitable aggregate for RCC and possibly CC. The sand bars in the river channel are probably relatively shallow but sand may also be available from the alluvial terraces.

### Catchment area

Based on SRTM data, the catchment area upstream of the site is estimated to be 3423 km².

### Flow data

Gauging stations are located on the Walsh River as follows:
- GS 919311A at 199 km, that is, some 37 km upstream of the site
- GS 919310A at 108 km, that is, some 54 km downstream of the site.

Data from these sites are as follows:

<table>
<thead>
<tr>
<th>Station</th>
<th>Catchment area (km²)</th>
<th>Maximum annual flow volume (GL)</th>
<th>Mean annual flow volume (GL)</th>
<th>Median annual flow volume (GL)</th>
<th>Minimum annual flow volume (GL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS 919311A</td>
<td>2792</td>
<td>3902</td>
<td>674</td>
<td>481</td>
<td>2.9</td>
</tr>
<tr>
<td>GS 919310A</td>
<td>4927</td>
<td>5671</td>
<td>1076</td>
<td>737</td>
<td>66</td>
</tr>
</tbody>
</table>

GS 919310A Walsh River at Rookwood, catchment area 4927 km², from October 1967 to date.

<table>
<thead>
<tr>
<th>Station</th>
<th>Catchment area (km²)</th>
<th>Maximum annual flow volume (GL)</th>
<th>Mean annual flow volume (GL)</th>
<th>Median annual flow volume (GL)</th>
<th>Minimum annual flow volume (GL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GS 919310A</td>
<td>4927</td>
<td>5671</td>
<td>1076</td>
<td>737</td>
<td>66</td>
</tr>
<tr>
<td>GS 919311A</td>
<td>2792</td>
<td>3902</td>
<td>674</td>
<td>481</td>
<td>2.9</td>
</tr>
</tbody>
</table>

### Storage capacity

Based on SRTM data, storage levels and capacities have been considered as follows:

<table>
<thead>
<tr>
<th>Limiting elevation (mEGM96)</th>
<th>Capacity (GL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSL 370</td>
<td>339</td>
</tr>
<tr>
<td>FSL 380</td>
<td>600</td>
</tr>
<tr>
<td>FSL 400</td>
<td>1338</td>
</tr>
</tbody>
</table>
### Reservoir yield assessment at the dam wall

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>FSL 370 mEGM96</th>
<th>FSL 380 mEGM96</th>
<th>FSL 400 mEGM96</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir yield assessment at the dam wall</td>
<td>Estimated yield at 85% annual time reliability</td>
<td>271.0 GL</td>
<td>387.8 GL</td>
<td>548.8 GL</td>
</tr>
<tr>
<td>FSL 370 mEGM96</td>
<td>Estimated yield at 85% annual time reliability</td>
<td>271.0 GL</td>
<td>387.8 GL</td>
<td>548.8 GL</td>
</tr>
<tr>
<td>FSL 380 mEGM96</td>
<td>Estimated yield at 85% annual time reliability</td>
<td>271.0 GL</td>
<td>387.8 GL</td>
<td>548.8 GL</td>
</tr>
</tbody>
</table>

### Open water evaporation

At FSL, the surface area of the storage based on SRTM data are estimated to be as follows:

| FSL 370 mEGM96 | 2238 ha |
| FSL 380 mEGM96 | 2978 ha |
| FSL 400 mEGM96 | 4393 ha |

Mean annual evaporation and mean annual net evaporation at FSL 380 mEGM96 at 85% annual reliability is 38.1 GL and 21.3 GL, respectively. The ratio of mean annual net evaporation to mean annual water supplied is 0.057.

### Potential use of supply

#### Agriculture

The land immediately north of Chillagoe is dissected by the Walsh River and numerous creeks draining into the Walsh. Fragmentation of the area, and soil distribution will limit the usable areas for various uses (mainly horticulture). It is estimated that the total area suitable for agricultural development is approximately 5700 ha. Soils are unsuitable or unlikely to be suitable for ringtanks.

Downstream of Rookwood Crossing on the Walsh River and upstream of the confluence with the Mitchell River, loam over brown sodic and intractable clays (sodic Dermosols, Sodosols) occur extensively throughout the alluvial plains. These occasionally to rarely flooded alluvial plains are generally deeply incised by the main channel resulting in relatively narrow usable areas. Soils are likely to be suitable for ringtanks.

See companion technical report on land suitability by Thomas et al. (2018b).

#### Estimated rates of reservoir sedimentation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Best case</th>
<th>Expected</th>
<th>Worst case</th>
</tr>
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<tr>
<td>30 years (%)</td>
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<td>1.5</td>
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<tr>
<td>100 years (%)</td>
<td>0.4</td>
<td>3.1</td>
<td>5.1</td>
</tr>
</tbody>
</table>

### Storage impacts

Allowing for a 1:100 AEP flood rise above FSL, the area of land that would need to be acquired is as follows:

| FSL 370 mEGM96 | 2570 ha |
| FSL 380 mEGM96 | 2978 ha |
| FSL 400 mEGM96 | 4680 ha |

The land required for a storage at this site is entirely within the Aroonbeta lease area SP 150971, total area 208,000 ha.

There are no surveyed roads impacted by a storage at this site.

### Environmental considerations

#### Barrier to movement of aquatic species

A dam constructed at this site could affect the migration, movement or colonisation of a number of fish species, including Hyrtl’s catfish (*Neosilurus hyrtlii*), sooty grunter (*Hephaestus fuliginosus*), black catfish (*Neosilurus ater*), spangled perch (*Leiopotherapon uniclor*), barred grunter (*Amniataba percoidei*), mouth almighty (*Glossamia aprion*), bony herring (*Nematalosa erebi*) and a rainbowfish (*Melanotaenia splendida inornata*).

#### Ecological implications of inundation

At FSL of 380 mEGM96 a dam at the potential Chillagoe dam site would inundate the largest area of regional ecosystem ‘Of concern’ (62%; 1805 ha) of the eight potential dam sites examined in the Mitchell catchment. No threatened species have been recorded in the potential inundated area. However, there are at least 21 listed species listed: 14 birds (12 as migratory, 1 endangered and 1 vulnerable), 3 frogs (2 endangered and 1 vulnerable), 2 mammals (1 endangered and 1 vulnerable) and 2 plants (1 critically endangered and 1 vulnerable). *Acacia purpureopetala*, which is found near this site, is listed as critically endangered as there are only about 500 plants left in the wild.

The potential for ecological change as a result of changes to the downstream flow regime is examined in the companion technical report on ecology (Pollino et al., 2018).
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>DESCRIPTION</th>
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</thead>
<tbody>
<tr>
<td>Indigenous land tenure, native title and cultural heritage considerations</td>
<td>Substantial land in the area is subject to current and/or future native title claims. There are no currently recorded cultural heritage sites in the inundation area, but there are recorded sites in the vicinity and in the wider catchment. There is a high likelihood of unrecorded sites in the inundation area.</td>
</tr>
<tr>
<td>Estimated cost</td>
<td>A manual cost estimate undertaken as part of the Assessment for an RCC dam at the Chillagoe dam site on the Walsh River at FSL 380 mEGM96 found the dam would cost approximately $601 million. Details of this cost estimate are provided in Appendix D. To enable a like-for-like comparison with the non-short-listed sites, dam costs were calculated using CSIRO’s generalised dam costing algorithm, which takes into account major cost elements for RCC type dams with central overflow spillways. These are reported for a selection of FSL below:</td>
</tr>
<tr>
<td>FSL 370 mEGM96 $521 million</td>
<td></td>
</tr>
<tr>
<td>FSL 380 mEGM96 $677 million</td>
<td></td>
</tr>
<tr>
<td>FSL 400 mEGM96 $1041 million</td>
<td></td>
</tr>
<tr>
<td>Estimated cost / ML of supply</td>
<td>Based on the yields estimated by CSIRO BHA modelling and the costs derived from the CSIRO generalised costing algorithm, the estimated cost/ML of supply at the following storage levels are as follows:</td>
</tr>
<tr>
<td>FSL 370 mEGM96 $1923/ML</td>
<td></td>
</tr>
<tr>
<td>FSL 380 mEGM96 $1745/ML</td>
<td></td>
</tr>
<tr>
<td>FSL 400 mEGM96 $1897/ML</td>
<td></td>
</tr>
<tr>
<td>Summary comment</td>
<td>This site is approximately 30 km from Chillagoe and is one of the less remote sites in the Mitchell catchment although it is somewhat wider than the alternative Rookwood site downstream. The site commands a relatively large catchment and has a favourable cost to yield ratio. The nearest large contiguous land area suitable for irrigated agriculture is downstream of the Rookwood dam site.</td>
</tr>
</tbody>
</table>
Figure 5-33 Potential Chillagoe dam site on the Walsh River looking upstream

Figure 5-34 Location map of potential Chillagoe dam site on the Walsh River, reservoir extent and catchment area
Figure 5-35 Potential Chillagoe dam site on the Walsh River, reservoir and property boundaries

Figure 5-36 Geology underlying the potential Chillagoe dam site on the Walsh River and reservoir
Scale and reference geology map data.
Figure 5-37 Regional ecosystem mapping and reservoir extent of the potential Chillagoe dam site on the Walsh River
Figure 5-38 Chillagoe potential dam site on the Walsh River site topographic dimensions and inflow hydrology
(a) Elevation profile along dam axis; (b) reservoir volume, surface area and height relationship; (c) dam wall height versus dam width and flood rise for 1:10,000 and 1:50,000 AEP and PMF events plotted against full supply level (FSL); (d) annual streamflow; (e) annual flow exceedance.
Figure 5-39 Chillagoe potential dam site on the Walsh River site cost, yield at the dam wall and evaporation
(a) dam length and dam cost versus full supply level (FSL); (b) dam yield at 85% and 95% annual time reliability and yield per million dollars at 85% and 95% annual time reliability; (c) annual time reliability plotted against yield for different FSL; (d) volumetric reliability plotted against yield for different FSL; (e) yield at 85% and 95% annual time reliability and degree of regulation (ratio of total controlled releases to total reservoir inflows) plotted against FSL; (f) yield and net evaporation (evaporation minus rainfall) divided by yield plotted against annual time reliability.
Figure 5-40 Chillagoe potential dam site on the Walsh River site storage levels and yield
(a) maximum and minimum annual storage trace at the selected full supply level (FSL) (380 mEGM96) and annual spilled volume (i.e. uncontrolled releases); (b) annual exceedance of ratio of annual quantity of water released to annual demand (i.e. yield) under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL; (c) annual exceedance plot of released volume under conditions where the reservoir was operated to supply the full demand (yield) in 55, 65, 75, 85 and 95% of years at the selected FSL.
Figure 5-41 Conceptual arrangement of the potential Chillagoe dam on the Walsh River
Part III  Farm-scale dams, re-regulating structures and natural waterholes
6 Farm-scale dams

The primary aim of this section is to provide a broad-scale assessment of the suitability of farm-scale water storage locations in the Fitzroy, Darwin and Mitchell catchments. It also provides a summary of farm-scale dam construction and operation and maintenance costs detailed in the companion technical report on farm-scale dam costs, Benjamin (2018). It should be noted, however, in assessing regional-scale economics of water-harvesting schemes, local variations in scale and site-specific nuances result in considerably different construction and 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, availability of materials, remoteness). Hence, operationally, each site would require its own specifically tailored engineering design. Many landholders will have observed the way water moves across their land and will have given considerable thought to their most suitable water-harvesting configurations. 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 online tools provide detailed information on nearly all facets of offstream water storage. For instructional information the reader is directed in the first instance to QWRC (1984), Lewis (2002) and IAA (2007).

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

6.1 Offstream farm-scale storages (ringtanks)

In this section the following analysis are reported for each of the three study areas:

- an assessment of the suitability of the landscape for farm-scale offstream storage
- indicative evaporative and seepage losses from farm-scale offstream storages
- indicative capital, operating and maintenance costs of farm-scale offstream storages.

6.1.1 LAND SUITABILITY ASSESSMENT OF OFFSTREAM STORAGES

This section presents the results of a desktop land suitability assessment for farm-scale offstream storages in the Fitzroy, Darwin and Mitchell catchments. As described in Section 2.2.1, this assessment is based on the soils data in the top 1.5 m of the soil profile generated as part of the Assessment (see companion technical report on digital soil mapping (Thomas et al., 2018a)). Because of a lack of data on soils below a depth of 1.5 m, this analysis does not consider the suitability of subsurface material below this depth. An example of an offstream storage is shown in Figure 1-3.
Farm-scale offstream water storages require consideration at a scale finer than is possible to assess in a regional-scale resource assessment. Hence the results presented here are only indicative of where suitable locations may occur. The design and construction of offstream water storages should be undertaken following a site investigation by a suitability qualified professional.

Figure 6-1 displays the broad-scale suitability of farm-scale offstream water storages (e.g. ringtanks) in the Fitzroy catchment. The majority of the Fitzroy catchment is classed as being unsuitable or possibly unsuitable for offstream storages. This is largely because a large proportion of the soils in the middle to lower half of the catchment are sandy, while much of the landscape in the upper catchment is steep with skeletal soils. The most promising areas for siting offstream storages are the recent alluvium along the Fitzroy River (Djada land system) and the Gogo and Fossil land systems (see companion technical report on digital soil mapping (Thomas et al., 2018a)). These areas are flat, have deep soils and have soil with high clay content. The recent Fitzroy alluvium is frequently subject to flooding (Figure 3-2), however, in many places floodwaters are likely to be slow moving and simply maintaining good grass coverage on the outside embankment slope of a well-constructed ringtank and/or reducing the slope of the lower part of the outer batter may provide adequate protection. At locations closer to drainage lines flow velocities may be higher and riprap protection to above the peak flood elevation may be required.

Figure 6-2 displays the broad-scale suitability of farm-scale offstream water storages (e.g. ringtanks) in the Darwin catchments. Approximately 10% of the Darwin catchments are classed as being suitable, though the majority of this land (>80%) is located on the coastal plains of the Reynolds, Finniss, Adelaide, Mary and Wildman rivers. These areas are particularly susceptible to flooding (Figure 3-11) and the soils are typically too wet to grow crops using heavy machinery. Elsewhere and less flood prone, the largest contiguous area of land suitable for offstream storages lies adjacent to the McKinlay River south (upstream) of the Arnhem Highway. Narrower areas of land suitable for farm-scale offstream storages lie adjacent to the Adelaide and Margaret rivers in the Adelaide catchment, south (upstream) of the Arnhem Highway. The remaining land in the Darwin catchments has soils that are too shallow and/or sandy to be suitable for ringtank construction.

Figure 6-3 displays the broad-scale suitability of farm-scale offstream water storages (e.g. ringtanks) in the Mitchell catchment. Large contiguous areas of land downstream of the Mitchell and Palmer rivers (>1 million ha) are classed as being suitable for farm-scale offstream water storages. However, this part of the Mitchell catchment is particularly susceptible to flooding (Figure 3-21) so cropping would be limited to the dry season. As per the Fitzroy catchment well designed and constructed ringtanks and be built in areas of slow moving floodwaters. In areas with higher flow velocities riprap protection to above the peak flood elevation may be required. Narrow sections of land adjacent to the lower Lynd and lower Palmer rivers are also classed as being suitable as is a relatively large area of heavier soils in the vicinity of Wrotham Park. With the exception of small areas of land along the upper Mitchell and Walsh rivers, the upper parts of the Mitchell catchment are unsuitable for farm-scale offstream storages because the soils are generally too shallow and/or the land too steep.
Figure 6-1 Suitability of farm-scale offstream water storage (i.e. ringtanks) in the Fitzroy catchment
Soil and subsurface data were only available to a depth of 1.5 m, hence this Assessment does not consider the suitability of subsurface material below this depth. This figure does not take into consideration flood risk or the availability of water. Data overlaid on shaded relief map.
Figure 6-2 Suitability of farm-scale offstream water storage (i.e. ringtanks) in the Darwin catchments
Soil and subsurface data were only available to a depth of 1.5 m, hence this Assessment does not consider the suitability of subsurface material below this depth. This figure does not take into consideration flood risk or the availability of water. Data overlaid on shaded relief map.
Figure 6-3 Suitability of farm-scale offstream water storage (i.e. ringtanks) in the Mitchell catchment
Soil and subsurface data were only available to a depth of 1.5 m, hence this Assessment does not consider the suitability of subsurface material below this depth. This figure does not take into consideration flood risk or the availability of water. Data overlaid on shaded relief map.

6.1.2 RIVER FLOW EXCEEDANCE IN 85% OF YEARS

To enable a first-pass assessment of the potential for water harvesting in different parts of the Fitzroy, Darwin and Mitchell catchments, information on streamflow exceeded in 85% of years is presented. This reliability threshold was selected because it is the value used to assess the yield of large instream dams and provides an indication of the minimum amount of water in the river in 85% of years. However, it should be noted that physical pumping constraints, environmental flow considerations and existing downstream usage mean the actual amount of water available for extraction may be considerably less than shown for the Fitzroy (Figure 6-4), Darwin (Figure 6-5) and Mitchell (Figure 6-6) catchments.
Figure 6-4 displays the 85% exceedance of annual streamflow in the Fitzroy catchment under the historical climate (Scenario A). The figure indicates that the tributaries joining the Fitzroy River downstream of Fitzroy Crossing have relatively low 85% exceedance of annual streamflow. This is significant in terms of both offstream storage and gully dams, as it indicates the lower tributaries of the Fitzroy River will only be able to support limited farm-scale water storage developments. Although the 85% exceedance of annual streamflow in the Fitzroy River downstream of Fitzroy Crossing is large, those areas adjacent to the river are particularly susceptible to flooding (Figure 3-2), limiting wet-season cropping.

Figure 6-5 displays the 85% exceedance of annual streamflow in the Darwin catchments under the historical climate (Scenario A). The figure indicates there are a relatively large number of rivers in the Darwin catchments carrying moderate to high volumes of water (i.e. >100 GL) in more than 85% of years. Based on the data presented in Figure 6-2 and Figure 6-5, land suitable for siting offstream storages will be the limiting factor in most parts of the Darwin catchments.
Figure 6-5 85% exceedance of annual streamflow in the Darwin catchments under Scenario A. Flow accumulation scale does not exceed 400 GL.

Figure 6-6 displays the 85% exceedance of annual streamflow in the Mitchell catchment under the historical climate (Scenario A). The figure indicates that several thousand kilometres of rivers in the Mitchell catchment have an annual streamflow that exceeds 100 GL in 85% of years. See the companion technical report on case studies for more detail on the opportunities for water harvesting in the Mitchell catchment, Petheram et al., (2018).
6.1.3 EVAPORATIVE AND SEEPAGE LOSSES

Losses from a farm-scale dam occur through evaporation and seepage. When calculating evaporative losses from a storage it is important to calculate net evaporation (i.e. evaporation minus rainfall) rather than just evaporation. Strategies to minimise evaporation include liquid and solid barriers, but these are typically expensive per unit of inundated area (e.g. $10 to $30 per m$^2$), see Section 6.1.4). In non-laboratory settings liquid barriers such as oils are susceptible to being dispersed by wind and have not been shown to reduce evaporation from a water body (Barnes, 2008). Solid barriers can be effective in reducing evaporation but are expensive. Evaporation losses from a ringtank can also be reduced slightly by sub-dividing the storage into multiple cells and extracting water from each cell in turn so as to minimise the total surface water area.
However, constructing a ringtank with multiple cells requires more earthworks and incurs higher construction costs than outlined in this section.

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

Ringtanks with greater average water depth lose a lower percentage of their total storage capacity to evaporation and seepage losses, however, they have a smaller storage capacity to excavation ratio. In Table 6-1 effective volume refers to the actual volume of water that could be used for consumptive purposes after losses due to evaporation and seepage. For example, if water is stored in a ringtank in the Fitzroy catchment (at Fitzroy Crossing) with average water depth of 3.5 m until December and the average seepage loss is 2 mm/day, about half the stored volume would be lost to evaporation and seepage. The example provided in Table 6-1, Table 6-2 and Table 6-3 are for 4000 ML ringtanks in the Fitzroy, Darwin and Mitchell catchments respectively, however, the effective volume expressed as a percentage of the ringtank capacity is applicable to any storage (e.g. ringtanks or gully dams) of any capacity for average water depths of 3.5, 6 and 8.5 m.

Table 6-1 Effective volume after net evaporation and seepage for ringtanks of three average water depths and under three seepage rates at Fitzroy Crossing in the Fitzroy catchment

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

<table>
<thead>
<tr>
<th>AVERAGE WATER DEPTH†</th>
<th>S:E RATIO</th>
<th>SEEPAGE LOSS</th>
<th>EFFECTIVE VOLUME</th>
<th>EFFECTIVE VOLUME AS PERCENTAGE OF CAPACITY</th>
<th>EFFECTIVE VOLUME</th>
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†Average water depth above ground surface.
Table 6-2 Effective volume after net evaporation and seepage for ringtanks of three average water depths and under three seepage rates at Wildman station in the Darwin catchments

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

<table>
<thead>
<tr>
<th>AVERAGE WATER DEPTH</th>
<th>S:E RATIO</th>
<th>SEEPAGE LOSS</th>
<th>EFFECTIVE VOLUME</th>
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†Average water depth above ground surface.
Table 6-3 Effective volume after net evaporation and seepage for ringtanks of three average water depths and under three seepage rates at Chillagoe

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

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<thead>
<tr>
<th>AVERAGE WATER DEPTH†</th>
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<td>83</td>
<td>2981</td>
<td>75</td>
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<td>7.5:1</td>
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<td>90</td>
<td>3404</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td>5:1</td>
<td>2</td>
<td>3707</td>
<td>93</td>
<td>3527</td>
<td>88</td>
<td>3280</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>5:1</td>
<td>5</td>
<td>3542</td>
<td>89</td>
<td>3280</td>
<td>82</td>
<td>2909</td>
<td>73</td>
</tr>
</tbody>
</table>

6.1.4 INDICATIVE CAPITAL, OPERATION AND MAINTENANCE COSTS OF OFFSTREAM STORAGES

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

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

In the Fitzroy and Mitchell catchments, the majority of moderate to large streamflow events occur before the end of March. Assuming the storage is full at this time, one strategy is to sow suitable crops during the early dry season (i.e. April, assuming it is possible to access cropping areas) to minimise evaporative and seepage losses and enable crops to utilise existing soil water. Hence the configurations in the following tables provide general information on construction costs and effective volumes in the Fitzroy, Darwin and Mitchell catchments for three seepage rates (1 mm/day, 2 mm/day and 5 mm/day) and for three storage durations (4 months, 6 months and 9 months). Sorghum planted for hay is an example of a crop where water may be required for irrigation for a 4-month period, sorghum planted for grazing is an example of a crop where water may be required for irrigation for a 6-month period and Rhodes grass is an example of a perennial crop or a crop for which water is needed throughout the dry season (i.e. water may be required...
over a 9-month period). See companion technical report on agriculture viability for information on
cropping in the Fitzroy, Darwin and Mitchell catchments (Ash et al., 2018a,b,c).

Table 6-4 provides a high-level breakdown of the capital and operation and maintenance (O&M)
costs of a large farm-scale ringtank, including the cost of the water storage, pumping
infrastructure and up to 100 m of pipes, and operation and maintenance of the scheme. The costs
and analyses presented in Table 6-4 and Table 6-5 are based on costs of $5/m³ for earthfill and
topsoil and $6.50/ m³ for compacted clay (Benjamin 2018); it was assumed this includes the cost
of compaction and that all earth can be obtained within close vicinity of the site. In this example it
is assumed that the ringtank is within 100 m of the river and pumping infrastructure. It should
be noted that the cost of pumping infrastructure and conveying water from the river to the storage is
particularly site-specific. For more detailed breakdown of ringtank costs see the companion
technical report on large farm-scale dams (Benjamin, 2018).

In flood-prone areas where flood waters move at moderate to high velocities, riprap protection
may be required, and this may increase the construction costs presented in Table 6-4 and
Table 6-5 by 10 to 20% depending upon volume of rock required and proximity to a quarry with
suitable rock. By way of example covering the reservoir surface (110 ha) of the 4000 ML
hypothetical ringtank detailed in Table 6-4 with an impermeable barrier to prevent evaporation at
a cost of $25/m² would increase the capital cost of the storage from $2.1 million to $29.6 million,
more than a factor of ten.

**Table 6-4 Indicative costs for a 4000-ML ringtank**

Assumes a 4.25-m wall height, 0.75-m freeboard, 3:1 ratio on upstream slope, 3:1 ratio on downstream slope and
crest width of 3.1 m, approximately 60% of material can be excavated from within storage, and cost of earthfill and
compacted clay is $5/m³ and $6.50/m³, respectively. Earthwork costs include vegetation clearing,
mobilisation/demobilisation of machinery and contractor accommodation. For more detail on costs see companion
technical report on large farm-scale dams (Benjamin, 2018).

<table>
<thead>
<tr>
<th>SITE DESCRIPTION/ CONFIGURATION</th>
<th>EARTHWORKS ($)</th>
<th>GOVERNMENT PERMITS AND FEES ($)</th>
<th>INVESTIGATION AND DESIGN FEES ($)</th>
<th>PUMP STATION ($)</th>
<th>TOTAL CAPITAL COST ($)</th>
<th>O&amp;M OF RINGTANK ($)</th>
<th>O&amp;M OF PUMP STATION ($)</th>
<th>TOTAL O&amp;M ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000-ML ringtank</td>
<td>1,602,500</td>
<td>35,500</td>
<td>76,000</td>
<td>500,000</td>
<td>2,214,000</td>
<td>17,000</td>
<td>84,000</td>
<td>101,000</td>
</tr>
</tbody>
</table>

The capital costs can be expressed over the service life of the infrastructure (assuming a 7%
discount rate, see Chapter 6) and combined with O&M costs to give an equivalent annual cost for
construction and operation. This enables infrastructure with differing capital and O&M costs and
service lives to be compared. The total equivalent annual costs for the construction and operation
of a 1000-ML ringtank with 4.25-m high embankments and 55 ML/day pumping infrastructure is
about $117,100 (Table 6-5). For a 4000-ML ringtank with 4.25-m high embankments and
160 ML/day pumping infrastructure, the total equivalent annual cost is about $284,500. For a
4000-ML ringtank with 6.75-m high embankments and 160 ML/day pumping infrastructure, the
total equivalent annual cost is about $402,000.
Table 6-5 Annualised cost for the construction and operation of three ringtank configurations

Assumes freeboard of 0.75 m, pumping infrastructure can fill ringtank in 25 days and assumes a 7% discount rate. Costs based on those provided for 4000 ML provided in companion technical report on large farm-scale dams (Benjamin, 2018).

<table>
<thead>
<tr>
<th>CAPACITY AND EMBANKMENT HEIGHT</th>
<th>ITEM</th>
<th>CAPITAL COST ($</th>
<th>LIFESPAN (y)</th>
<th>EQUIVALENT ANNUAL CAPITAL COST ($)</th>
<th>ANNUAL O&amp;M COST ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 ML and 4.25 m</td>
<td>Ringtank</td>
<td>858,000</td>
<td>40</td>
<td>64,000</td>
<td>8,600</td>
</tr>
<tr>
<td></td>
<td>Pumping infrastructure†</td>
<td>200,000</td>
<td>15</td>
<td>22,000</td>
<td>4,000</td>
</tr>
<tr>
<td></td>
<td>Pumping cost (diesel)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>4000 ML and 4.25 m</td>
<td>Ringtank</td>
<td>1,714,000</td>
<td>40</td>
<td>128,500</td>
<td>17,000</td>
</tr>
<tr>
<td></td>
<td>Pumping infrastructure†</td>
<td>500,000</td>
<td>15</td>
<td>55,000</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>Pumping cost (diesel)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>18,500†</td>
</tr>
<tr>
<td>4000 ML and 6.75 m</td>
<td>Ringtank</td>
<td>3,095,000</td>
<td>40</td>
<td>232,000</td>
<td>31,000</td>
</tr>
<tr>
<td></td>
<td>Pumping infrastructure†</td>
<td>500,000</td>
<td>15</td>
<td>55,000</td>
<td>10,000</td>
</tr>
<tr>
<td></td>
<td>Pumping cost (diesel)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>74,000†</td>
</tr>
</tbody>
</table>

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

Although ringtanks with an average water depth of 3.5 m (embankment height of 4.25 m) lose a higher percentage of their capacity to evaporative and seepage losses than ringtanks of equivalent capacity with average water depth of 6 m (embankment height of 6.75 m) (Table 6-1 to Table 6-3), their annualised unit costs are lower (Table 6-6 to Table 6-8) due to the considerably lower cost of constructing embankments with lower walls (Table 6-5).

In Table 6-6 to Table 6-8 the equivalent annual cost of the water supplied from the ringtank takes into consideration net evaporation and seepage from the storage, which increase with the length of time water is stored (i.e. crops with longer growing seasons will require water to be stored longer). In these tables, the results are presented for the equivalent annual cost of water yield from a ringtank of different seepage rates and lengths of time for storing water.

Table 6-6 Equivalent annual cost per ML for two different capacity ringtanks under three seepage rates at Fitzroy Crossing in the Fitzroy catchment

Assumes a 0.75-m freeboard, 3:1 ratio on upstream slope, 3:1 ratio on downstream slope. Crest widths are 3.1 m and 3.6 m for embankments with heights of 4.25 m and 6.75 m respectively and assumes earthenfill and compacted clay costs $5/m$³ and $6.50/m$³ respectively. Earthwork costs include vegetation clearing, mobilisation/demobilisation of machinery and contractor accommodation. 1000-ML ringtank reservoir has surface area of 27 ha and storage volume to excavation ratio of about 7:1. 4000-ML ringtank and 4.25 m embankment height reservoir has surface area of 110 ha and storage volume to excavation ratio of about 14:1. 4000-ML ringtank with 6.75 m embankment height reservoir has surface area of 64 ha and storage volume to excavation ratio of about 7.5:1.

<table>
<thead>
<tr>
<th>CAPACITY AND EMBANKMENT HEIGHT</th>
<th>ANNUALISED COST* ($</th>
<th>SEEPAGE LOSS (mm/day)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y per ML/y)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y per ML/y)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y per ML/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 ML and 4.25 m</td>
<td>117,100</td>
<td>1</td>
<td>1253</td>
<td>139</td>
<td>1417</td>
<td>157</td>
<td>1823</td>
<td>202</td>
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</tbody>
</table>

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### Table 6-7 Equivalent annual cost per ML for two different capacity ring tanks under three seepage rates at Wildman station in the Darwin catchments

Assumes a 0.75-m freeboard, 3:1 ratio on upstream slope, 3:1 ratio on downstream slope. Crest widths are 3.1 m and 3.6 m for embankments with heights of 4.25 m and 6.75 m respectively and assumes earthfill and compacted clay costs $5/m³ and $6.50/m³, respectively. Earthwork costs include vegetation clearing, mobilisation/demobilisation of machinery and contractor accommodation. 1000-ML ringtank reservoir has surface area of 27 ha and storage volume to excavation ratio of about 7:1. 4000-ML ringtank and 4.25-m embankment height reservoir has surface area of 110 ha and storage volume to excavation ratio of about 14:1. 4000-ML ringtank with 6.75-m embankment height reservoir has surface area of 64 ha and storage volume to excavation ratio of about 7.5:1.

<table>
<thead>
<tr>
<th>CAPACITY AND EMBANKMENT HEIGHT</th>
<th>ANNUALISED COST* ($/y)</th>
<th>SEEPAGE LOSS (mm/d)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y per ML/y)</th>
<th>UNIT COST ($/y)</th>
<th>SEEPAGE LOSS (mm/d)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y per ML/y)</th>
<th>UNIT COST ($/y)</th>
<th>SEEPAGE LOSS (mm/d)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y per ML/y)</th>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>117,100</td>
<td>4 months (April to July)</td>
<td>1</td>
<td>1271</td>
<td>141</td>
<td>1467</td>
<td>162</td>
<td>163</td>
<td>181</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>117,100</td>
<td>6 months (April to September)</td>
<td>2</td>
<td>1327</td>
<td>147</td>
<td>1581</td>
<td>175</td>
<td>185</td>
<td>206</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>117,100</td>
<td>9 months (April to December)</td>
<td>5</td>
<td>1527</td>
<td>169</td>
<td>2066</td>
<td>229</td>
<td>133</td>
<td>351</td>
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<td></td>
<td></td>
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<tr>
<td>4000 ML and 4.25 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>284,500</td>
<td>4 months (April to July)</td>
<td>1</td>
<td>659</td>
<td>85</td>
<td>755</td>
<td>97</td>
<td>835</td>
<td>107</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>284,500</td>
<td>6 months (April to September)</td>
<td>2</td>
<td>687</td>
<td>88</td>
<td>810</td>
<td>104</td>
<td>941</td>
<td>121</td>
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<tr>
<td>284,500</td>
<td>9 months (April to December)</td>
<td>5</td>
<td>784</td>
<td>101</td>
<td>1038</td>
<td>133</td>
<td>1527</td>
<td>196</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4000 ML and 6.75 m</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>402,000</td>
<td>4 months (April to July)</td>
<td>1</td>
<td>993</td>
<td>111</td>
<td>1067</td>
<td>119</td>
<td>1122</td>
<td>125</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>402,000</td>
<td>6 months (April to September)</td>
<td>2</td>
<td>1015</td>
<td>114</td>
<td>1106</td>
<td>124</td>
<td>1188</td>
<td>133</td>
<td></td>
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</tr>
<tr>
<td>402,000</td>
<td>9 months (April to December)</td>
<td>5</td>
<td>1088</td>
<td>122</td>
<td>1241</td>
<td>139</td>
<td>1442</td>
<td>161</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Table 6-8 Equivalent annual cost per ML for two different capacity ringtanks under three seepage rates at Chillagoe in the Mitchell catchment

Assumes a 0.75-m freeboard, 3:1 ratio on upstream slope, 3:1 ratio on downstream slope. Crest widths are 3.1 m and 3.6 m for embankments with heights of 4.25 m and 6.75 m, respectively, and assumes earthfill and compacted clay costs of $5/m³ and $6.50/m³, respectively. Earthwork costs include vegetation clearing, mobilisation/demobilisation of machinery and contractor accommodation. 1000-ML ringtank reservoir has surface area of 27 ha and storage volume to excavation ratio of about 7:1. 4000-ML ringtank and 4.25-m embankment height reservoir has a surface area of 110 ha and a storage volume to excavation ratio of about 14:1. 4000-ML ringtank with 6.75-m embankment height reservoir has a surface area of 64 ha and a storage volume to excavation ratio of about 7.5:1.

<table>
<thead>
<tr>
<th>CAPACITY AND EMBANKMENT HEIGHT</th>
<th>ANNUALISED COST* ($)</th>
<th>SEEPAGE LOSS (mm/day)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 months (April to July)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 ML and 4.25 m</td>
<td>117,100</td>
<td>1</td>
<td>1237</td>
<td>137</td>
<td>1389</td>
<td>154</td>
<td>1661</td>
<td>184</td>
</tr>
<tr>
<td>4000 ML and 4.25 m</td>
<td>284,500</td>
<td>1</td>
<td>647</td>
<td>83</td>
<td>726</td>
<td>93</td>
<td>2553</td>
<td>111</td>
</tr>
<tr>
<td>4000 ML and 6.75 m</td>
<td>402,000</td>
<td>1</td>
<td>982</td>
<td>110</td>
<td>1043</td>
<td>117</td>
<td>1139</td>
<td>127</td>
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<td>6 months (April to September)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 ML and 4.25 m</td>
<td>117,100</td>
<td>2</td>
<td>1288</td>
<td>143</td>
<td>187</td>
<td>165</td>
<td>1884</td>
<td>208</td>
</tr>
<tr>
<td>4000 ML and 4.25 m</td>
<td>284,500</td>
<td>2</td>
<td>673</td>
<td>87</td>
<td>777</td>
<td>100</td>
<td>2252</td>
<td>126</td>
</tr>
<tr>
<td>4000 ML and 6.75 m</td>
<td>402,000</td>
<td>2</td>
<td>1003</td>
<td>112</td>
<td>1080</td>
<td>121</td>
<td>1206</td>
<td>135</td>
</tr>
<tr>
<td>9 months (April to December)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 ML and 4.25 m</td>
<td>117,100</td>
<td>5</td>
<td>1467</td>
<td>162</td>
<td>1885</td>
<td>209</td>
<td>3155</td>
<td>349</td>
</tr>
<tr>
<td>4000 ML and 4.25 m</td>
<td>284,500</td>
<td>5</td>
<td>767</td>
<td>99</td>
<td>984</td>
<td>126</td>
<td>1350</td>
<td>211</td>
</tr>
<tr>
<td>4000 ML and 6.75 m</td>
<td>402,000</td>
<td>5</td>
<td>1073</td>
<td>120</td>
<td>1207</td>
<td>135</td>
<td>1465</td>
<td>164</td>
</tr>
</tbody>
</table>

Taking into consideration the cost of constructing ringtanks and net evaporation and seepage losses, the optimal embankment height will vary depending upon the capacity of the storage. Based on the cost assumptions used in this section and assuming 2 mm/day of seepage and a requirement that water is stored until August (i.e. 6 months), Table 6-9 provides an indication of how the optimum embankment height and annualised cost at the optimum embankment height vary with increasing ringtank capacity in the three study areas.
Table 6-9 Annualised unit cost at optimum embankment height for ringtanks of varying capacity in the Fitzroy, Darwin and Mitchell catchments
Value assumes 2 mm/day of seepage and a requirement that water is stored until August (i.e. 6 months).

<table>
<thead>
<tr>
<th>CAPACITY (ML)</th>
<th>FITZROY CATCHMENT (FITZROY CROSSING)</th>
<th>DARWIN CATCHMENTS (WILDMAN STATIONS)</th>
<th>MITCHELL CATCHMENT (CHILLAGOE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Optimum embankment height (m)</td>
<td>Annualised unit cost at optimum embankment height ($/ML)</td>
<td>Optimum embankment height (m)</td>
</tr>
<tr>
<td>1,000</td>
<td>3.8</td>
<td>166</td>
<td>3.9</td>
</tr>
<tr>
<td>2,000</td>
<td>3.85</td>
<td>123</td>
<td>3.95</td>
</tr>
<tr>
<td>4,000</td>
<td>4.0</td>
<td>102</td>
<td>4.1</td>
</tr>
<tr>
<td>6,000</td>
<td>4.15</td>
<td>93</td>
<td>4.25</td>
</tr>
<tr>
<td>8,000</td>
<td>4.3</td>
<td>87</td>
<td>4.35</td>
</tr>
<tr>
<td>10,000</td>
<td>4.4</td>
<td>83</td>
<td>4.45</td>
</tr>
<tr>
<td>15,000</td>
<td>4.6</td>
<td>77</td>
<td>4.65</td>
</tr>
</tbody>
</table>

6.2 Farm-scale gully and hillside dams

Large farm-scale gully dams are generally constructed of earth or earth and rockfill embankments with compacted clay cores and usually to a maximum height of about 20 m. Dams with a crest height of over 10 or 12 m typically require some form of downstream batter drainage incorporated in embankments. Large farm-scale gully dams typically have a maximum catchment area of about 30 km² due to the challenges in passing peak floods from large catchments (large farm-scale gully dams are generally designed to pass an event with an annual exceedance probability of 1%), unless a site has an exceptionally good spillway option.

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

In this section the following assessments are reported:

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

Net evaporation and seepage losses also occur from large farm-scale gully dams. The analysis presented in Section 6.1.3 is also applicable to gully dams.
6.2.1 DAMSITE MODEL RESULTS

The DamSite model (Petheram et al., 2017) was used to assess every location in the Fitzroy, Darwin and Mitchell catchments for their potential as a farm-scale earth embankment gully or hillside dam. As discussed in Section 2.2.2, the model was used to assess dams of between 5 m and 20 m in height.

Figure 6-7, Figure 6-8 and Figure 6-9 provide an indication of those locations where it may be more economical to construct large farm-scale gully dams in the Fitzroy, Darwin and Mitchell catchments respectively, and the likely density of options. This analysis takes into consideration those sites likely to have more favourable topography and soil for the construction of the embankment and to minimise seepage from the reservoir base. In reality, dams can be constructed on eroded or skeletal soils provided there is access to a clay borrow pit nearby for the cut-off trench and core zone. However, these sites are likely to be less economically viable.
Figure 6-7 Most economically suitable locations for large farm-scale gully dams in the Fitzroy catchment
Gully dam data overlaid on agricultural versatility data (see Section 4.3). Agricultural versatility data indicate those parts of the catchment that are more or less versatile for irrigated agriculture. For the gully dam analysis soil and subsurface data were only available to a depth of 1.5 m, hence this Assessment does not consider the suitability of subsurface material below this depth. Sites with catchment areas greater than 30 km² or yield to excavation ratio less than 10 are not displayed. The results presented in this figure are modelled and consequently only indicative of the general locations where siting a gully dam may be most economically suitable. This analysis may be subject to errors in the underlying digital elevation model, such as affects due to the vegetation removal process. An important factor not considered in this analysis was the availability of a natural spillway. Site-specific investigations by a suitably qualified professional should always be undertaken prior to their construction.
Figure 6-7 shows that the most suitable locations for large farm-scale gully dams are largely confined to the Hann River and its tributaries in the north-east of the Fitzroy catchment, which in many places have limited opportunities for irrigated cropping.

This figure indicates that there are a limited number of favourable large farm-scale gully dam sites in the Darwin catchments. The favourable modelled locations are on the coastal floodplains, which have negligible agricultural value, and are likely to be remnant channels rather than genuine gully dam sites. The subdued topography in the vicinity of land more suitable for irrigated agriculture...
means hillslope dams (which have a lower storage to excavation ratio than gully dams) are more likely than gully dams.

Figure 6-9 Most economically suitable locations for large farm-scale gully dams in the Mitchell catchment
Gully dam data overlaid on agricultural versatility data (see Section 4.3). Agricultural versatility data indicate those parts of the catchment that are more or less versatile for irrigated agriculture. For the gully dam analysis soil and subsurface data were only available to a depth of 1.5 m, hence this Assessment does not consider the suitability of subsurface material below this depth. Sites with catchment areas greater than 30 km² or yield to excavation ratio less than 10 are not displayed. The results presented in this figure are modelled and consequently only indicative of the general locations where siting a gully dam may be most economically suitable. This analysis may be subject to errors in the underlying digital elevation model, such as affects due to the vegetation removal process. An important factor not considered in this analysis was the availability of a natural spillway. Site-specific investigations by a suitably qualified professional should always be undertaken prior to their construction.

In the Fitzroy, Darwin and Mitchell catchments there were 4165, 4708 and 8519 locations, respectively, that were modelled as having a maximum yield of 0.01 GL per 1000 m³ of excavation or greater (i.e. a water yield to excavation ratio of greater than 10:1). In each of the three study areas for those sites with maximum yield greater than 0.01 GL per 1000 m³ of excavation, the median of the mean depth of reservoir at FSL was 2.2 m and the mean wall height (including wet and dry freeboard) was 6 m. However, it should be noted that many of these locations are unsuitable for siting embankment dams because the soils are too sandy and permeable and/or the
soil too shallow to provide sufficient material for construction. The maximum yield (GL) per 1000 m³ of excavation was observed to be independent of catchment area. Data on farm-scale gully and hillside dams showing those locations with the highest yield to cost ratios are available through the Northern Australia Water Resource Assessment explorer.

6.2.2 INDICATIVE CAPITAL, OPERATION AND MAINTENANCE COSTS OF FARM-SCALE GULLY AND HILLSIDE DAMS

The cost of a large farm-scale gully dam will vary depending upon a range of factors including the suitability of the topography of the site, the size of the catchment area, quantity of runoff, proximity of site to good quality clay, availability of durable rock in the upper bank for a spillway and the size of the embankment. The height of the embankment, in particular, has a strong influence on cost. An earth dam to a height of 8 m is about 3.3 times more expensive to construct than a 4-m high dam, and a dam to a height of 16 m will require 3.6 times more material than the 8-m high version, but the cost may be more than five times greater, due to design and construction complexity (Benjamin 2018). Figure 6-10 shows an example of a hillside dam in the Darwin catchments.

Figure 6-10 Example of a hillside dam in the Darwin catchment
Photo: CSIRO.
Performance and cost of three hypothetical farm-scale gully dams in northern Australia

A summary of the key parameters for three hypothetical 4-GL capacity farm-scale gully dam configurations is provided in Table 6-10 and a high-level breakdown of the major components of the capital costs for each of the three configurations is provided in Table 6-11. Detailed costs for the three sites are provided in the companion technical report on large farm-scale dams (Benjamin, 2018).

Table 6-10 Cost of three hypothetical large farm-scale gully dams of capacity 4 GL

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

<table>
<thead>
<tr>
<th>SITE DESCRIPTION/CONFIGURATION</th>
<th>CATCHMENT AREA</th>
<th>EMBANKMENT HEIGHT</th>
<th>EMBANKMENT LENGTH</th>
<th>S:E RATIO</th>
<th>AVERAGE DEPTH</th>
<th>RESERVOIR SURFACE AREA</th>
<th>TOTAL CAPITAL COST</th>
<th>O&amp;M COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Favourable site with large catchment, suitable topography and simple spillway (e.g. natural saddle)</td>
<td>30</td>
<td>9.5</td>
<td>1100</td>
<td>29:1</td>
<td>5.0</td>
<td>80</td>
<td>1,280,000</td>
<td>55,000</td>
</tr>
<tr>
<td>Unfavourable site with small catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)</td>
<td>15</td>
<td>14</td>
<td>750</td>
<td>21:1</td>
<td>6.3</td>
<td>63</td>
<td>1,474,000</td>
<td>35,000</td>
</tr>
<tr>
<td>Unfavourable site with moderate catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)</td>
<td>20</td>
<td>14</td>
<td>750</td>
<td>21:1</td>
<td>6.3</td>
<td>63</td>
<td>1,554,000</td>
<td>40,000</td>
</tr>
</tbody>
</table>

Table 6-11 High-level breakdown of capital costs for three hypothetical large farm-scale gully dams of capacity 4 GL

Earthworks include vegetation clearing, mobilisations/demobilisation of equipment and contractor accommodation. Investigation and design fees include design and investigation of fish passage device and failure impact assessment (i.e. investigation of possible existence of population at risk downstream of site). For a complete list of costs and assumptions see companion technical report on farm-scale dams (Benjamin, 2018).

<table>
<thead>
<tr>
<th>SITE DESCRIPTION/CONFIGURATION</th>
<th>EARTHWORKS ($)</th>
<th>GOVERNMENT PERMITS AND FEES ($)</th>
<th>INVESTIGATION AND DESIGN FEES ($)</th>
<th>TOTAL CAPITAL COST ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Favourable site with large catchment, suitable topography and simple spillway (e.g. natural saddle)</td>
<td>1,157,500</td>
<td>36,000</td>
<td>86,500</td>
<td>1,280,000</td>
</tr>
<tr>
<td>Unfavourable site with small catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)</td>
<td>1,340,000</td>
<td>40,000</td>
<td>94,000</td>
<td>1,474,000</td>
</tr>
<tr>
<td>Unfavourable site with moderate catchment, challenging topography and limited spillway options (e.g. steep gully banks, no natural saddle)</td>
<td>1,420,000</td>
<td>40,000</td>
<td>94,000</td>
<td>1,554,000</td>
</tr>
</tbody>
</table>

In Queensland if a large farm-scale gully dam is constructed on a watercourse, as defined by the state’s legislation, then it is likely that conditions applicable to the water licence would include bed-level outlet works capable of passing a prescribed flow. This may range from relatively small volumes required to meet downstream riparian rights (stock and domestic water supplies), to
relatively large volumes to meet existing entitlements of downstream irrigators. Small throughflows of less than about 0.5 ML/day could best be achieved by means of an overbank syphon at relatively minimal cost. Releases of more than about 25 ML/day would, however, require considerable investment. Cost varies greatly, with a likely range of $50,000 to $100,000 (Benjamin, 2018). Table 6-12 presents calculations of the effective volume for three configurations of 4-GL capacity gully dams (varying average water depth/embankment height) for combinations of three seepage losses and water storage over three time periods in the Darwin catchments. The values are indicative of those in the Fitzroy and Mitchell catchments.

**Table 6-12 Effective volumes and cost per ML for a 4-GL storage with different average depths and seepage loss rates at Wildman in the Darwin catchments**

Values are indicative of Fitzroy and Mitchell catchments.

<table>
<thead>
<tr>
<th>AVERAGE DEPTH AND RESERVOIR SURFACE AREA</th>
<th>CONSTRUCTION COST</th>
<th>SEEPAGE LOSS</th>
<th>EFFECTIVE VOLUME 4 months (April to July)</th>
<th>EFFECTIVE VOLUME 6 months (April to September)</th>
<th>EFFECTIVE VOLUME 9 months (April to December)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 m and 133 ha</td>
<td>1,000,000</td>
<td>250</td>
<td>1</td>
<td>3217</td>
<td>2700</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>250</td>
<td>375</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>129</td>
<td>1991</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>59</td>
<td>50</td>
</tr>
<tr>
<td>6 m and 66 ha</td>
<td>1,500,000</td>
<td>375</td>
<td>1</td>
<td>3527</td>
<td>3228</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3350</td>
<td>3179</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>79</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>3080</td>
<td>3179</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>2456</td>
<td>2445</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>50</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1991</td>
<td>1991</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>59</td>
<td>59</td>
</tr>
<tr>
<td>9 m and 44 ha</td>
<td>2,000,000</td>
<td>500</td>
<td>1</td>
<td>3739</td>
<td>3567</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>93</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3567</td>
<td>3453</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2995</td>
<td>2995</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

Based on the information presented in Table 6-10 an equivalent annual unit cost including annual operation and maintenance cost for a 4-GL gully dam with an average depth of about 6 m is about $174,000 (Table 6-13 and Table 6-14).

**Table 6-13 Cost of construction and operation of three hypothetical 4-GL gully dams**

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

<table>
<thead>
<tr>
<th>AVERAGE DEPTH AND RESERVOIR SURFACE AREA</th>
<th>ITEM</th>
<th>CAPITAL COST ($)</th>
<th>EQUivalent ANNUAL CAPITAL COST ($)</th>
<th>ANNUAL O&amp;M COST ($)</th>
<th>EQUivalent ANNUAL UNIT COST ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 m and 1133 ha</td>
<td>Low embankment wide gully dam</td>
<td>1,000,000</td>
<td>86,000</td>
<td>30,000</td>
<td>116,000</td>
</tr>
<tr>
<td>6 m and 66 ha</td>
<td>Moderate embankment gully dam</td>
<td>1,500,000</td>
<td>129,000</td>
<td>45,000</td>
<td>174,000</td>
</tr>
<tr>
<td>9 m and 44 ha</td>
<td>High embankment narrow gully dam</td>
<td>2,000,000</td>
<td>172,000</td>
<td>60,000</td>
<td>232,000</td>
</tr>
</tbody>
</table>
Table 6-14 Equivalent annualised cost and effective volume for three hypothetical 4-GL gully dams at Wildman in the Darwin catchments

Dam details are in Table 6-13. Annual cost assumes a 7% discount rate. Values are indicative of Fitzroy and Mitchell catchments.

<table>
<thead>
<tr>
<th>AVERAGE DEPTH AND RESERVOIR SURFACE AREA</th>
<th>EQUIVALENT ANNUAL COST ($/y)</th>
<th>SEEPAGE LOSS (mm/d)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)</th>
<th>UNIT COST ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST ($/y PER ML/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 m and 133 ha</td>
<td>116,000</td>
<td>1</td>
<td>311</td>
<td>36</td>
<td>370</td>
<td>43</td>
<td>424</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>116,000</td>
<td>2</td>
<td>327</td>
<td>38</td>
<td>407</td>
<td>47</td>
<td>502</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>116,000</td>
<td>5</td>
<td>390</td>
<td>45</td>
<td>580</td>
<td>67</td>
<td>1123</td>
<td>130</td>
</tr>
<tr>
<td>6 m and 66 ha</td>
<td>174,000</td>
<td>1</td>
<td>416</td>
<td>48</td>
<td>448</td>
<td>52</td>
<td>472</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>174,000</td>
<td>2</td>
<td>425</td>
<td>49</td>
<td>465</td>
<td>54</td>
<td>501</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>174,000</td>
<td>5</td>
<td>457</td>
<td>53</td>
<td>524</td>
<td>61</td>
<td>613</td>
<td>71</td>
</tr>
<tr>
<td>9 m and 44 ha</td>
<td>232,000</td>
<td>1</td>
<td>535</td>
<td>62</td>
<td>561</td>
<td>65</td>
<td>579</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td>232,000</td>
<td>2</td>
<td>543</td>
<td>63</td>
<td>574</td>
<td>67</td>
<td>601</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>232,000</td>
<td>5</td>
<td>568</td>
<td>66</td>
<td>617</td>
<td>72</td>
<td>675</td>
<td>78</td>
</tr>
</tbody>
</table>

Where the topography is suitable for large farm-scale gully dams and a natural spillway is present, large farm-scale gully dams are typically cheaper to construct than ringtanks.
Re-regulating structures, such as weirs, are typically located downstream of large dams. They allow for more efficient releases from the storages and for some additional yield from the weir storage itself, thereby reducing the transmission losses normally involved in supplemented river systems.

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

Broadly speaking, there are two types of weir structure: concrete gravity weirs and sheet piling weirs. These are discussed below. 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.

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

Figure 7-2 shows an example of a concrete gravity weir in the Mitchell catchment.

Concrete gravity type weirs

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

Sheet piling weirs

Where rock foundations are not available, stepped steel sheet piling weirs have been successfully used in many locations across Queensland. These weirs consist of parallel rows of steel sheet piling, generally about 6 m apart with a step of about 1.5 to 1.8 m high between each row. Reinforced concrete slabs placed between each row of piling absorb much of the energy as flood flows cascade over each step. The upstream row of piling is the longest, driven to a sufficient depth to cut off the flow of water through the most permeable material (Figure 7-1). Indicative costs are provided in Table 7-1.
Sand dams

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

Typically, sand dams take three to four large excavators about 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 more quickly 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 are known to have quantified losses from sand dams.
Figure 7-2 Leafgold weir on the Walsh River (Mitchell catchment)
An example of a re-regulating structure in the Mareeba–Dimbulah Water Supply Scheme.
Photo: CSIRO.
Chapter 8 Natural waterbodies

Wetland systems and waterholes (Figure 8-1) that persist throughout the dry season are natural water bodies characteristic of large parts of the northerly draining catchments of northern Australia. Many station homesteads in northern Australia use natural waterholes for stock and domestic purposes. However, the quantities of water required for stock and domestic supply are orders of magnitude less than that required for irrigated cropping and it is in part for this reason that naturally occurring persistent water bodies in northern Australia are generally not used to source water for irrigation. For example, a moderately sized 5 ha rectangular water body of mean depth of 3 m may contain about 150 ML of water. Assuming minimal leakage (i.e. 1 mm/day) approximately 77%, 63% and 39% of these volumes would be available if a crop were to be irrigated until July, September and December, respectively. Assuming a crop or fodder with a 6-month growing season requires 5 ML/ha of water for irrigation through the plant (i.e. before losses), and assuming an overall efficiency of 80% (i.e. the waterhole is adjacent to land suitable for irrigation, 95% conveyance efficiency and 85% field application efficiency), a 150 ML waterhole could potentially be used to irrigate about 15 ha of land if all the water was able to be used for this purpose. A very large natural water body of 20 ha and mean depth of 3 m could potentially be used to irrigate about 60 ha of land if all the water was able to be used for this purpose.

Although the areas of land that could be watered using natural water bodies are likely to be small, the costs associated with storing water are minimal. Consequently, where these waterholes occur in sufficient size and adjacent to land suitable for irrigated agriculture, they can be a very cost-effective source of water. It would appear that where natural water bodies of sufficient size and suitable land for irrigation coincide, natural water bodies may be effective in staging a development, where lessons are learned and mistakes made on a small-scale area before large capital investment has occurred (see companion technical report on socio-economics, Stokes et al., 2017).

The main limitations to the use of wetlands and persistent waterholes for the consumptive use of water is that they have considerable ecological significance (e.g. Kingsford, 2000; Waltham et al., 2013), and in many cases there is a limited quantity of water contained within the water bodies. In particular, water bodies that persist throughout the dry season are considered key ecological refugia (Waltham et al., 2013).

It should also be noted that where a water body is situated in a sandy river, the waterhole is highly likely to be connected to water within the bedsands of the river. Hence during and following pumping water within the bedsands of a river, the bedsands may in part replenish the waterhole and vice versa. While water within the bedsands of the river may in part replenish a depleted waterhole, in these circumstances it also means that pumping from a waterhole will have a wider environmental impact than the local waterhole.

Figure 8-2, Figure 8-3 and Figure 8-4 indicate the location of waterholes that persist at the end of the dry season in more than 90% of years (see companion technical report on Earth observation methods (Sims et al., 2016)) in the Fitzroy, Darwin and Mitchell catchments, respectively. For the purpose of this report they are referred to as ‘persistent’ waterholes.
To broadly indicate where moderate to large persistent waterholes may coincide with land that may be suitable for irrigated agriculture the persistent waterhole dataset is underlain by the versatile agriculture land datasets (see Thomas et al., 2018b) for the Fitzroy, Darwin and Mitchell catchments. Note in the Darwin catchments the dense riparian vegetation means many persistent water bodies are not detected in the imagery.
Persistent waterholes are defined as being those waterholes present at the end of the dry season in more than 90% of years (base on Landsat TM satellite imagery). Versatile agricultural land data (Thomas et al., 2018b) indicate those parts of the catchment that are more or less versatile for irrigated agriculture.
Persistent waterholes are defined as being those waterholes present at the end of the dry season in more than 90% of years (base on Landsat TM satellite imagery). Versatile agricultural land data (Thomas et al., 2018b) indicate those parts of the catchment that are more or less versatile for irrigated agriculture.
Persistent waterholes are defined as being those waterholes present at the end of the dry season in more than 90% of years (based on Landsat TM satellite imagery). Versatile agricultural land data (Thomas et al., 2018b) indicate those parts of the catchment that are more or less versatile for irrigated agriculture.
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Part IV Summary comments
9 Discussion and collective analysis

9.1 Comparison of dam yields in the Darwin and Mitchell catchments
under current and future climates

Fifteen potential dam sites were examined as part of this pre-feasibility analysis, seven in the Darwin catchments and eight in the Mitchell catchment. Table 9-1 and Table 9-2 provide a summary of key performance measures of the potential dam sites examined in the Darwin and Mitchell catchments, respectively.

In the Darwin catchments the larger yielding dams (Marrakai dam site and Mary River dam site) have large catchment areas and are typically located on floodplain material and as a result have poor and uncertain foundations. The potential dam sites with a lower technical risk and which are more technically plausible have considerably lower yields. The better of these sites, the Mount Bennett dam site on the Finniss River and the Upper Adelaide River dam site on the Adelaide River, have favourable unit costs (~$700/ML to $1200/ML) compared to better sites recently examined in the Flinders (~$6000/ML) and Gilbert (~1500/ML) catchments (Petheram et al., 2013).

Table 9-1 Potential dams in the Darwin catchments selected for pre-feasibility analysis

<table>
<thead>
<tr>
<th>NAME</th>
<th>DAM TYPE*</th>
<th>SPILLWAY HEIGHT ABOVE BED **</th>
<th>CAPACITY AT FSL (GL)</th>
<th>CATCHMENT AREA (km²)</th>
<th>ANNUAL WATER YIELD *** (GL)</th>
<th>CAPITAL COST# ($ MILLION)</th>
<th>UNIT COST## ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST &amp; O&amp;M### ($ PER y ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mount Bennett dam site on the Finniss River</td>
<td>RCC</td>
<td>20</td>
<td>343</td>
<td>1155</td>
<td>283</td>
<td>190 □</td>
<td>671</td>
<td>50</td>
</tr>
<tr>
<td>Upper Adelaide River dam site</td>
<td>RCC</td>
<td>23</td>
<td>298</td>
<td>616</td>
<td>153</td>
<td>182 □</td>
<td>1190</td>
<td>88</td>
</tr>
<tr>
<td>Acacia Gap dam site</td>
<td>EB</td>
<td>11</td>
<td>37</td>
<td>232</td>
<td>29</td>
<td>132 □</td>
<td>4452</td>
<td>337</td>
</tr>
<tr>
<td>AROWS</td>
<td>EB</td>
<td>18</td>
<td>91</td>
<td>34^</td>
<td>32^^</td>
<td>154 □</td>
<td>4873</td>
<td>342^^</td>
</tr>
<tr>
<td>Marrakai dam site on the Adelaide River</td>
<td>EB</td>
<td>15</td>
<td>1520</td>
<td>4341</td>
<td>861</td>
<td>855 □^</td>
<td>992</td>
<td>73</td>
</tr>
<tr>
<td>McKinlay River dam site</td>
<td>EB</td>
<td>14</td>
<td>512</td>
<td>922</td>
<td>158</td>
<td>492 □</td>
<td>3114</td>
<td>231</td>
</tr>
<tr>
<td>Mary River dam site</td>
<td>RCC</td>
<td>30</td>
<td>1311</td>
<td>3063</td>
<td>492</td>
<td>756 □</td>
<td>1537</td>
<td>114</td>
</tr>
</tbody>
</table>
FSL = full supply level
* Embankment dam (EB), roller compacted concrete dam (RCC).
** The height of the dam abutments and saddle dams will be higher than the spillway height.
*** Water yield is based on 85% annual time-based reliability using a perennial demand pattern for the baseline river model under Scenario A. This is yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These yield values do not take into account downstream existing entitlement holders or environmental considerations.
# Indicates manually derived preliminary cost estimate, which is likely to be –10% to +30% of ‘true cost’. □ Indicates modelled preliminary cost estimate, which is likely to be –20% to +50% of ‘true’ cost. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher.
## This is the unit cost of annual water supply and is calculated as the capital cost of the dam divided by the water yield at 85% annual time reliability.
### Assuming a 7% real discount rate and a dam service life of 100 years. Includes operation and maintenance costs, assuming operation and maintenance costs are 0.4% of the total capital cost.
^ Catchment area of offstream storage only. Catchment area of Adelaide River at point of extraction is approximately 4500 km².
^^ Yield at 95% annual time reliability. Based on a 26 m³/s pump capacity at Adelaide River, 20:80 rule, 144 m³/s minimum pumping threshold and extraction only permitted during the falling limb of the hydrograph.
^^^^ Includes cost of pumping water from Adelaide River into the reservoir.
& The original modelled cost ($657 million) was inflated by a nominal 30% to better reflect the likely additional costs of constructing a dam at a site with the poor foundation conditions, the additional costs involved for protecting the construction site from flooding (e.g. levees protecting the construction site) and the complex logistical challenges of constructing a large dam at this site.

The Mitchell catchment has a large number of high yielding potential dam sites. Unlike the potential dam sites in the Darwin catchments of equivalent catchment area, there is no reason for concern about their foundations. The better of these sites in terms of unit cost were the Pinnacles dam site on the Mitchell River (~$600/ML), the Rookwood dam site on the Walsh River (~$1140/ML) and the Palmer River dam site on the Palmer River (~$1250/ML). Unit costs for these (~$700/ML to $1200/ML) are lower than the better sites recently examined in the Flinders (~$6000/ML) and Gilbert (~$1500/ML) catchments (Petheram et al., 2013) and comparable to the better sites in the Darwin catchments.

Table 9-2 Potential dam sites in the Mitchell catchment selected for pre-feasibility analysis

<table>
<thead>
<tr>
<th>NAME</th>
<th>DAM TYPE*</th>
<th>SPILLWAY HEIGHT ABOVE BED ** (m)</th>
<th>SPILLWAY HEIGHT AT FSL (GL)</th>
<th>CATCHMENT AREA (km²)</th>
<th>ANNUAL WATER YIELD *** (GL)</th>
<th>CAPITAL COST# ($ MILLION)</th>
<th>UNIT COST## ($/ML)</th>
<th>EQUIVALENT ANNUAL UNIT COST### ($ PER y ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynd downstream dam site on the Lynd River</td>
<td>RCC</td>
<td>45</td>
<td>810</td>
<td>4,554</td>
<td>507</td>
<td>731 □</td>
<td>1442</td>
<td>107</td>
</tr>
<tr>
<td>Lynd upstream dam site on the Lynd River</td>
<td>RCC</td>
<td>36</td>
<td>644</td>
<td>3983</td>
<td>412</td>
<td>750 □</td>
<td>1820</td>
<td>142</td>
</tr>
<tr>
<td>Palmer River dam site</td>
<td>RCC</td>
<td>56</td>
<td>1444</td>
<td>3801</td>
<td>553</td>
<td>690 □</td>
<td>1248</td>
<td>92</td>
</tr>
<tr>
<td>Elizabeth Creek dam site</td>
<td>RCC</td>
<td>36</td>
<td>149</td>
<td>580</td>
<td>55</td>
<td>189 □</td>
<td>3436</td>
<td>256</td>
</tr>
<tr>
<td>Pinnacles dam site on the Mitchell River</td>
<td>RCC</td>
<td>58</td>
<td>2316</td>
<td>7728</td>
<td>1248</td>
<td>755 □</td>
<td>605</td>
<td>45</td>
</tr>
<tr>
<td>Rookwood dam site on the Walsh River</td>
<td>RCC</td>
<td>61</td>
<td>1288</td>
<td>4855</td>
<td>575</td>
<td>655 □</td>
<td>1139</td>
<td>84</td>
</tr>
<tr>
<td>Chilagoe dam site on the Walsh River</td>
<td>RCC</td>
<td>50</td>
<td>600</td>
<td>3423</td>
<td>388</td>
<td>601 □</td>
<td>1549</td>
<td>115</td>
</tr>
<tr>
<td>Nullinga dam site on the Walsh River</td>
<td>RCC</td>
<td>31</td>
<td>145</td>
<td>327</td>
<td>65</td>
<td>349 □</td>
<td>5269</td>
<td>398</td>
</tr>
</tbody>
</table>
9.2 Total divertible yield

This section examines the total divertible yield in the Darwin and Mitchell catchments. No consideration is given to whether that water could be put to a productive use.

To calculate the amount of water that may be available ‘through the crop’, and hence how much land could potentially be irrigated, for both catchments an overall efficiency of 55% was applied to the combined yield at the dam wall. This assumes a river transmission conveyance of 80%, trunk-channel efficiency of 90%, on-farm storage and distribution efficiency of 90% and a field application efficiency (i.e. assuming spray irrigation) of 85%.

9.2.1 THE TOTAL DIVERTIBLE YIELD IN THE DARWIN CATCHMENTS

Figure 9-1a shows the combined or cumulative water yield at the dam wall of one or more dams. It shows that the total divertible yield, before losses, from five of the more promising potential dam sites in the Darwin catchments is about 1100 GL in 85% of years. With the addition of more potential dam sites, the construction cost per ML of yield increased from about $600/ML for the first potential dam site (i.e. Mount Bennett) to nearly $1600/ML for all five 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. Note cost estimates do not include the cost of irrigation distribution infrastructure.

Figure 9-1b shows the combined or cumulative water yield after losses (i.e. the amount of water that is available through the plant). This figure indicates that about 600 GL of water would be available ‘through the plant’ (i.e. after losses) in 85% of years. Assuming a perennial or rotation crop water requirement of 10 ML/ha per year this would be sufficient water to irrigate approximately 60,000 ha in 85% of years. However, the results from the suitability analysis indicate that there is less than 60,000 ha of land suitable for irrigation in the Darwin catchments (Thomas et al., 2018b).

Figure 9-1a indicates that this level of water resource development would result in about a 25% reduction in the combined mean annual flow at the end-of-systems of the Finniss, Adelaide and Mary rivers. This highlights the importance of considering metrics other than means. Changes in streamflow resulting from different levels of development is further explored in the companion river system modelling report and ecology report (Pollino et al., 2018b).
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 regulatory, environmental, social, cultural or economic factors or downstream entitlement holders. It should be noted that the purpose of this analysis is to broadly illustrate the viability of incrementally constructing additional dams in the Darwin catchments. 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.

**Figure 9-1 Cost of water in $/ML versus cumulative divertible yield at 85% annual time reliability and change in flow at the end-of-system in the Darwin catchments**

(a) Yield at the dam wall versus cost of water at the dam wall under Scenario B and (b) yield after river, channel (10%), on-farm (10%) and field application (15%) losses (i.e. equivalent to the amount of water available to go through the plant) versus cost of water after losses under Scenario B. Plot (b) is indicative of the amount of water that may be available to go through the plant. Triangles 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. Squares indicate change in median (a) and mean (b) annual streamflow at the end-of-system from the baseline (i.e. Scenario A).

**9.2.2 THE TOTAL DIVERTIBLE YIELD IN THE MITCHELL CATCHMENT**

Figure 9-2a shows the combined or cumulative water yield at the dam wall of one or more dams. It shows that the total divertible yield, before losses, from four and six of the more promising potential dam sites in the Mitchell catchment is about 2800 GL and 3000 GL, respectively, in 85% of years. It was found that after the fourth dam there were marginal returns with the addition of each subsequent dam. 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 seventh dam (Nullinga dam site on the Walsh River) where the combined
yield of the seven dams was 2976 GL, which was less than the combined yield from the six best
dams, 2977 GL. Note cost estimates do not include the cost of irrigation distribution
infrastructure.

Figure 9-2b shows the combined or cumulative water yield after losses (i.e. the amount of water
that is available through the plant) is about 1450 GL of water would be available ‘through the
plant’ (i.e. after losses) in 85% of years. Assuming a perennial or rotation crop water requirement
of 10 ML/ha per year this would be sufficient water to irrigate approximately 150,000 ha in 85% of
years. The results from the suitability analysis indicate that there is more than 150,000 ha of land
suitable for irrigated agriculture in adjacent to and within the vicinity of the Mitchell River
(Thomas et al., 2018b).

Figure 9-2a shows that this level of water resource development would result in about a 25%
reduction in mean annual discharge from the Mitchell catchment (Figure 9-2b). Changes in
streamflow resulting from different levels of development is further explored in the companion
river system modelling report and ecology report (Pollino et al., 2018b).

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 regulatory, environmental, social, cultural or economic factors or downstream
entitlement holders.

It should be noted that the purpose of this analysis is to broadly illustrate the viability of
incrementally constructing additional dams in the Mitchell 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.
Figure 9-2 Cost of water in $/ML versus cumulative divertible yield at 85% annual time reliability and change in flow at the end-of-system in the Mitchell catchment
(a) Yield at the dam wall versus cost of water at the dam wall under Scenario B and (b) yield after river, channel (10%), on-farm (10%) and field application (15%) losses (i.e. equivalent to the amount of water available to go through the plant) versus cost of water after losses under Scenario B. Plot (b) is indicative of the amount of water that may be available to go through the plant. Triangles 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. Squares indicate change in median (a) and mean (b) annual streamflow at the end-of-system from the baseline (i.e. Scenario A).
10 Summary comments

The relatively undeveloped state of the water resources across northern Australia represents a globally unique opportunity for governments and communities to take a long-term view to water resource development and to strategically investigate different potential development pathways. This report documents the results of a catchment-scale pre-feasibility assessment of surface water storage options in the Fitzroy, Darwin and Mitchell catchments. Large instream and offstream dams were examined in the Darwin and Mitchell catchments. Larger sites were a major focus of this study as the design and construction of smaller farm-scale dams is highly site specific. Regional-scale information on the prospectivity of farm-scale dams is provided for the three study areas.

The Darwin catchments have few areas with topography suitable for siting large dams. However, the large volumes of runoff per unit area and low inter-annual variability of annual runoff relative to other parts of northern Australia mean those few topographically suitable sites can yield modest quantities of water at a relatively low cost to yield ratio. Two of the most cost-effective sites in the Darwin catchments were the Mount Bennett dam site on the Finniss River (~$670/ML) and Upper Adelaide River dam (~$1200/ML) on the Adelaide River. These were short-listed for further analysis, though for either of these options to advance to construction, far more comprehensive studies would be required. Although several potentially high yielding dam sites were identified on the floodplains of the mid-reaches of the Mary River and Adelaide River (i.e. Marrakai dam site), siting dams on these reaches 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 geotechnical risk. Furthermore, numerous environmental issues would need to be addressed to construct and operate a large dam on these floodplains.

The majority of the potential dam sites examined in the Darwin catchments would restrict the movement of aquatic species, including barramundi. However, the catchment area of the upper Adelaide River dam site is small and consequently the impact on movement of aquatic species is likely to be small relative to those sites with large catchment areas and that are situated closer to the ocean. Substantial areas of land in the Darwin catchments are subject to native title claims and some of the potential inundation areas are known to contain recorded sacred or cultural heritage sites, including the potential Mount Bennett and Upper Adelaide River dam sites.

Table 10-1 provides a summary for each of the sites in the Darwin catchments examined as part of the pre-feasibility analysis.

Table 10-1 Summary comments for potential dams in the Darwin catchments

<table>
<thead>
<tr>
<th>NAME</th>
<th>SUMMARY COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mount Bennett dam site on the Finniss River</td>
<td>The Mount Bennett dam site has the lowest cost to yield ratio of all potential dam sites in the Darwin catchments. The yield from the dam is likely to be larger than that required to meet Darwin’s projected water requirements over the next 30 years and for irrigation of the suitable land downstream. The quality of water flowing into the reservoir could be a potential problem because of the existence</td>
</tr>
<tr>
<td>NAME</td>
<td>SUMMARY COMMENT</td>
</tr>
<tr>
<td>------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Part IV Summary comments</td>
<td>187</td>
</tr>
<tr>
<td>of the (closed) Rum Jungle uranium mine in the upper reaches of the catchment. Additionally, part of the Wagait Aboriginal Reserve would be inundated by a storage at this site. There are a number of registered and/or recorded sacred or cultural heritage sites known to exist in the area that would be potentially inundated. Substantial land in the area is subject to current or future native title claim.</td>
<td></td>
</tr>
<tr>
<td>Upper Adelaide River dam site</td>
<td>The Upper Adelaide River dam site, also known as the Warrai site, is the most topographically favourable site for a dam in the Darwin catchments. It has the third-lowest cost to yield ratio of all the potential dam sites in the Darwin catchments. The yield from the dam could augment Darwin’s future water demand via a supply pipeline, as well as irrigating all of the land suitable for irrigated agriculture downstream of Adelaide River township and upstream of Dirty Lagoon, south of the Arnhem Highway. A recent strategy statement by the Northern Territory Land and Water Corporation concluded that of the three storage sites endorsed by the Northern Territory Government in 1988 (Upper Adelaide River dam site, Marrakai dam site and Mount Bennett dam site), an Upper Adelaide River storage was preferred by the Northern Territory Land and Water Corporation since the site is the only one for which the catchment can be closed to the public, thereby reducing the level of treatment required to achieve a potable water supply. There are a number of registered and/or recorded sacred or cultural heritage sites known to exist in the area that would potentially be inundated. Substantial land in the area is subject to current or future native title claim.</td>
</tr>
<tr>
<td>Acacia Gap dam site</td>
<td>The Acacia Gap site is downstream of the Manton Dam and is attractive because of its proximity to Darwin. However, it has the highest cost to yield ratio of all of the potential sites in the Darwin catchments. Furthermore, if a dam were constructed at the site it would have major impacts on horticulture producers in the area and the Acacia Indigenous Community.</td>
</tr>
<tr>
<td>AROWS offstream storage</td>
<td>The AROWS offstream storage proposal would see the storage filled by pumped diversions from the Adelaide River. This site has one of the higher cost to yield ratios of all of the potential sites in the Darwin catchments, and the highest annualised cost per ML of yield. It does, however, have various advantages over other sites as it is an offstream storage. It will not for example, impede the movement of migratory fish species. Subject to the outcomes of further studies, Northern Territory Power and Water consider that the AROWS scheme is the preferred medium to long-term option to meet the Darwin region’s water supply needs.</td>
</tr>
<tr>
<td>Marrakai dam site on the Adelaide River</td>
<td>In 1988 the Marrakai dam site was listed as one of three preferred storage sites adopted by the then Northern Territory Government. The potential yield from a dam at this site is likely to far exceed the future demand for water from Darwin and the amount of land downstream that could potentially be irrigated. Given the very high construction risks, poor foundation conditions and the likely environmental issues involved with construction and operating a dam at this site, it was not short-listed for further consideration.</td>
</tr>
<tr>
<td>McKinlay River dam site</td>
<td>Relative to other sites in the Darwin catchments, the McKinlay River dam site is remote and would be expensive to construct relative to its potential yield due to the width of the main wall and uncertain foundation conditions. For these reasons it was not short listed for further consideration.</td>
</tr>
<tr>
<td>Mary River dam site</td>
<td>The Mary River Dam site offers the second-highest yield of the options considered in the Darwin catchments. However, given the width of the site and the high costs of access and construction as well as potential impacts on the Mount Bundy military training area and the Kakadu and Mary River national parks, this site was not short listed for further consideration.</td>
</tr>
<tr>
<td>Manton Dam</td>
<td>Manton Dam is a small existing dam currently only used for recreational purposes. PWC have identified that their short-term water supply risks (to 2020) will be most effectively managed by the return to service of Manton Dam in combination with their Living Water Smart demand-management strategy. Water quality studies indicate that significant water treatment would be necessary for the water from Manton Dam to be potable.</td>
</tr>
<tr>
<td>Darwin River Dam</td>
<td>Current annual demand for water in the Darwin region (i.e. between about 40 to 45 GL) is approaching the current water supply system yield. The Darwin River Dam supplies 85% of Darwin’s water, the other 15% being sourced from the McMinns and Howard East borefields. PWC is currently investigating short and medium-term supply augmentation options. The Darwin River Dam storage level was raised in 2010, as a short-term option at the time. Future annual water demand to 2065 is...</td>
</tr>
</tbody>
</table>
The Mitchell catchment has a number of suitable locations for siting large instream dams. This is because the upper reaches of the catchment are topographically favourable for large dams, have relatively high runoff and sites have large catchment areas. Although no geotechnical investigations were undertaken as part of the Assessment, there is no reason for concern regarding the foundations of the more cost-effective potential dam sites in the Mitchell catchment, based on present knowledge. Four sites were short-listed for further analysis in the Mitchell catchment. These were the Elizabeth Creek dam site, Pinnacles dam site on the Mitchell River, Rookwood dam site on the Walsh River and Chillagoe dam site on the Walsh River. Their cost to yield ratios at the dam wall were calculated to be $3436/ML, $605/ML, $1139/ML and $1549/ML, respectively. The potential dam sites on the Walsh River, and particularly the Mitchell River which has a large catchment area, will restrict the migration, movement and colonisation of fish species. Although the reservoirs of the potential dams did not intercept any officially recorded sites of cultural significance, in Queensland many culturally significant sites do not appear in official state government databases. It is likely that culturally significant sites would be inundated, as Indigenous people were known to locate campsites and subsistence activities along major watercourses and drainage lines.

For any of the potential dam options in the Mitchell catchment to advance to construction, far more comprehensive studies would be needed.

Table 10-2 provides a summary for each of the sites in the Mitchell catchment examined as part of the pre-feasibility analysis.

**Table 10-2 Summary comments for potential dams in the Mitchell catchment**

<table>
<thead>
<tr>
<th>NAME</th>
<th>SUMMARY COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynd downstream dam site on the Lynd River</td>
<td>The Lynd downstream dam site is remote and is situated in a relatively wide valley and has poor quality rock on the abutments. Compared to potential sites on the Walsh, Mitchell and Palmer rivers the site has a high cost to yield ratio. The nearest large continuous areas of land suitable for irrigated agriculture occur below the junction of the Mitchell and Lynd rivers. For these reasons the site was not short-listed.</td>
</tr>
<tr>
<td>Lynd upstream dam site on the Lynd River</td>
<td>The Lynd upstream dam site is situated in a relatively wide valley and has a high cost to yield ratio relative to the potential sites on the Walsh, Mitchell and Palmer rivers. It has a similar cost to yield ratio as the Lynd downstream site and is also similar in terms of having poor quality rock on the abutments and being remote. The site is slightly further from large contiguous areas of land suitable for irrigated agriculture than the downstream site. For these reasons the site was not short-listed.</td>
</tr>
<tr>
<td>Palmer River dam site</td>
<td>The Palmer River dam site has one of the lowest cost to yield ratios of the potential dam sites in the Mitchell catchment. However, the site is relatively remote and the nearest large contiguous areas of land suitable for irrigated agriculture are located a considerable distance downstream on more flood-prone areas below of the junction of the Mitchell and Palmer rivers. For these reasons the site was not short-listed.</td>
</tr>
<tr>
<td>Elizabeth Creek dam site</td>
<td>The Elizabeth Creek dam site has the smallest catchment area and the lowest yield of the potential dam sites examined in the Mitchell catchment. However, the site is situated in a narrow sandstone gorge and is relatively close to land suitable for irrigated agriculture.</td>
</tr>
<tr>
<td>Pinnacles dam site</td>
<td>The Pinnacles dam site has the largest catchment area and highest yield of all sites examined in the Mitchell catchment. A storage at this site could support a large irrigation development downstream of</td>
</tr>
<tr>
<td>NAME</td>
<td>SUMMARY COMMENT</td>
</tr>
<tr>
<td>------</td>
<td>----------------</td>
</tr>
<tr>
<td>on the Mitchell River</td>
<td>Wrotham Park. At the level of development assessed, a very long saddle dam is required on the right bank. Nevertheless, the site has the lowest cost to yield ratio in the Mitchell catchment as a result of its high yield. Further assessment including geotechnical investigation of the saddle dam area would be required to determine the optimal level of development. Although a fish transfer facility has been proposed, the dam’s potential impact on migratory fish species including the freshwater sawfish and barramundi would need to be further considered.</td>
</tr>
<tr>
<td>Rookwood dam site on the Walsh River</td>
<td>The Rookwood dam site is situated at the upstream end of a straight gorge section and is the most downstream site on the Walsh River suitable for a large dam. The site is easily accessed from the Bourke Development Road and is about 30 km from Chillagoe. It is about 60 km upstream of large contiguous areas of land suitable for irrigated agriculture near Wrotham Park. Commanding a larger catchment area than the upstream Chillagoe dam site, the Rookwood dam site has the second-lowest cost to yield ratio. Extensive saddle dams are required, at the level of development assessed.</td>
</tr>
<tr>
<td>Chillagoe dam site on the Walsh River</td>
<td>The Chillagoe dam site is approximately 30 km from Chillagoe and is one of the less remote sites in the Mitchell catchment although it is somewhat wider than the alternative Rookwood site downstream. The site commands a relatively large catchment and has a favourable cost to yield ratio. The nearest large contiguous land area suitable for irrigated agriculture is downstream of the Rookwood dam site.</td>
</tr>
<tr>
<td>Nullinga dam site on the Walsh River</td>
<td>The Nullinga dam site on the upper Walsh River was first examined as an alternative to the Tinaroo Falls Dam as the major storage development in the Mareeba–Dimbulah irrigation area. The latter site was ultimately adopted because of the higher rainfall experienced in its catchment area and its better location and elevation to service the proposed irrigation area. Since the Nullinga site was first considered, considerable irrigation development has occurred within the inundation area. A dam at the Nullinga site on the Walsh River could provide for an expansion of irrigated production of lands riparian to the Walsh River downstream as far as the Leafgold Weir area and with a delivery pipeline to the West Barron Main Channel could supply areas currently supplied from Tinaroo Falls Dam. This would free up supply from the dam which then could be used to supplement supply to Cairns and to the Barron Gorge hydro-electric power station. Although the site has a high cost to yield ratio, its proximity to the existing MDWSS and its potential to ensure the long-term security of Cairns water supply have led to interest in its possible development. A preliminary business case is currently being prepared by Building Queensland with funding provided by the Australian Government.</td>
</tr>
<tr>
<td>Lake Mitchell on the Mitchell River</td>
<td>The Lake Mitchell Dam is an existing privately owned development on the headwaters of the Mitchell River. Originally intended to support commercial and residential development with associated recreation, the dam has never been used. There are small areas of soil downstream that could be used for irrigation development. If the Lake Mitchell Dam owners agreed to supply water at a price comparable to that charged by SunWater it is technically feasible that water could be pumped from Lake Mitchell to parts of the MDWSS near Mareeba. The existing Water Plan provides for a general reserve volume of 20 GL/year in the Mitchell River section upstream of the Rifle Creek junction, which includes the dam.</td>
</tr>
</tbody>
</table>

In all three study areas land suitable for siting farm-scale offstream storages was geographically constrained, and in many of the better locations in each study area broad-scale flooding may be a concern. In the Fitzroy catchment those areas suitable for offstream storage were largely limited to the recent alluvium adjacent to the Fitzroy River. In the Darwin catchments the largest contiguous areas suitable for siting offstream storages were on the coastal floodplains. Smaller suitable areas of land for offstream storages were found upstream of the Arnhem Highway adjacent to the Adelaide and Mary rivers. In the Mitchell catchment large areas of suitable land were found below the junction of the Mitchell and Palmer rivers. Care would be needed to find a location that is not susceptible to flooding.


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Water for a Healthy Country and Sustainable Agriculture flagships, Australia. © CSIRO 2013. See


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