5 Opportunities for irrigation in the Flinders catchment

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Chapter 5 examines the opportunities for irrigated agriculture in the Flinders catchment. Evaluating the possibility of establishing a greenfield irrigation development requires an understanding of the development-related infrastructure required and its associated costs. This includes being able to answer questions such as:

- Where are the better locations in the catchment for storing water?
- How will water be conveyed from the water storage and applied to the crop, and what are the likely water losses?
- What land development is required for irrigation to take place?

It also requires an understanding of the crops likely to be suitable, their potential location within the catchment, the likely returns and production risks.

The key components and concepts of Chapter 5 are shown in Figure 5.1.
5.1 Summary

This chapter establishes the scale and nature of the cropping opportunity in the Flinders catchment, for both dryland and irrigated cropping, taking into consideration the availability of water and potential water storage opportunities.

There is currently limited cropping in the catchment – there is small and occasional dryland production for human food or fibre and approximately 500 ha of irrigated production. The catchment has the theoretical potential to produce around 18 million tonnes of grain per year with a gross value of over $4.5 billion.

5.1.1 SOIL SUITABILITY

More than 8 million ha of the Flinders catchment are at least moderately suitable (class 3 or above) for cropping. These soils have considerable limitations that lower production potential and require careful management. In this respect, they are similar to much of Australia’s agricultural soils.

5.1.2 WATER STORAGE OPPORTUNITIES

The Flinders catchment has a highly variable climate and evaporation rates that typically exceed rainfall by a factor of 3.8. The highly variable semi-arid climate of the Flinders catchment means that in the absence of suitable groundwater, water storages are essential to enable irrigation during the dry season. The geology and topography of the catchment is best suited to farm-scale offstream storages. The few potential large dam sites would be expensive to develop compared to many farm-scale options.

5.1.3 DRYLAND CROPPING

A wide range of crops is potentially suited to dryland production in the Flinders catchment. Break-even yields could be expected more than eight years in ten for short-season dryland crops such as mungbean, approximately two years in ten for dryland crops such as sorghum (grain), and approximately one year in ten for crops such as dryland cotton.

High rainfall variability and high potential evaporation means that continuous year-on-year dryland cropping is not feasible. Opportunistic cropping during favourable conditions is likely to be a more profitable and sustainable approach to dryland cropping.

If the approximately 8 million ha of suitable arable soil in the Flinders catchment were, for example, devoted to dryland sorghum (grain), median potential regional production of around 18.4 million tonnes and a gross value of production of $4232 million are theoretically possible. Actual yields would be lower and would vary significantly from year to year. This estimate does not take into account any legislative or regulatory constraints on development; it is purely a biophysical estimate. Change in land use of this scale would have a considerable impact on cultural, social and environmental values and would transform the catchment.

5.1.4 IRRIGATED CROPPING

There is more soil suited to irrigation in the Flinders catchment than there is water to irrigate it. Using the most promising instream storage or all currently allocated water, it would be possible to irrigate a maximum of approximately 0.2% of the catchment’s suitable soils.

If this irrigation water (110 GL allocated but <58 GL after evaporation, seepage, conveyance and field application losses) were, for example, devoted to irrigated sorghum (grain) production, there would be potential to produce 110,000 tonnes of grain over 15,000 ha with a gross value of around $26 million. Actual yields would probably be lower and would vary significantly from year to year.
The volume of water available for irrigation will vary year on year and, as a consequence, irrigated and dryland cropping are likely to closely co-exist.

5.2 Water storage opportunities

In a highly seasonal climate, such as that of the Flinders catchment, and in the absence of suitable groundwater, water storages are essential to enable irrigation during the dry season and other periods when soil water is insufficient for crop growth.

The Assessment identified and assessed over 100,000 potential dam sites within the Flinders catchment using an automated process. No new potential dam sites notably better than those documented in the published or unpublished literature were identified. This process, supported by field investigation, indicated that the topography, geology and hydrology of the Flinders catchment significantly limit the number of sites suitable for large dams. The best potential large dam locations are in the headwater catchment of the Flinders and Cloncurry rivers. Three potential dam sites were short-listed for further analysis. These were Cave Hill, O’Connell Creek and Porcupine Creek. The construction of large dams at these locations would be expensive (i.e. greater than $5000 per ML of water supplied in 85% of years, excluding water distribution costs and losses) and no locations in the Flinders catchment were considered to be particularly suitable for development. The better large dams in the Flinders catchment have an equivalent annual unit cost per ML of water supply in 85% of years of more than $430, excluding operation and maintenance costs, water distribution costs and losses. This is nearly twice the equivalent annual unit cost per ML of effective offstream storage (i.e. after accounting for evaporation and seepage losses from the offstream storage), storing water for 12 months of the year. Consequently offstream storages are the most promising water storage option in the Flinders catchment.

Overview

Section 5.2 examines two types of water storages: (i) large dams, which supply water to multiple properties; and (ii) on-farm dams, which supply water to a single property. The former are typically used to supply water to the broad-scale irrigation schemes such as those common in southern Australia, while the latter are typically used to supply water for stock and domestic purposes or for mosaics of small-scale irrigation.

Both large dams and on-farm dams can be further classified as instream or offstream water storages. In the 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 from another drainage line. Re-regulating structures are also discussed. Ring tanks and turkey nest tanks are examples of offstream storages with a continuous embankment.

The performance of a dam is often assessed in terms of water yield or demand. This is the amount of water that can be supplied for consumptive use at a given reliability. For a given dam, an increase in water yield results in a decrease in reliability.

This section is structured as follows.

Section 5.2.1 examines large dams in the Flinders catchment. It starts with an introduction to large dams, examines the potential for large dams across the Flinders catchment discusses ecological, sedimentation and cultural considerations and provides summary information for 15 potential dam sites in the Flinders catchment. An assessment of the cost and cumulative water yield from multiple dams in the Flinders catchment is then presented. Finally the three short-listed dams are discussed in more detail.

Section 5.2.2 presents information on weirs and re-regulating structures.

Finally Section 5.2.3 examines on-farm dams in the Flinders catchment. This section contains information on the reliability at which different quantities of water can be extracted from selected rivers of the Flinders catchment, presents information on the likely suitability of the soils of the Flinders catchment for offstream
storages, and discusses evaporative and seepage losses and possible capital, operation and maintenance costs of offstream storages in the Flinders catchment.

Unless otherwise stated, the material in Section 5.2 originates from the companion technical report about water storage options (Petheram et al., 2013).

### 5.2.1 LARGE DAMS

#### Types of large dams

Dams are usually constructed from earth, rock or concrete materials as a barrier wall across a river, designed to store water in the reservoir so created. They need to be able to safely discharge the largest flood flows likely to enter the reservoir and the structure needs to be designed so that the dam meets its purpose, generally for at least 100 years. Large dams are sometimes referred to as carry-over storages. That is, they are large enough relative to the demands on the dam (i.e. water supplied for consumptive use, evaporation and seepage) so that, when full, water can last two or more years. This has the advantage of mitigating against years with low inflows to the dam.

While there are many different types of dam, the two types of dams most relevant to the Flinders catchment are embankment dams and concrete gravity dams, of which roller compacted concrete dams are a subset.

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

#### Embankment dams

Embankment dams (EB) are usually the most economical (provided that suitable construction materials can be found locally) and are best suited to smaller catchment areas where the spillway capacity requirement is small, such as Belmore Creek Dam in the nearby Norman catchment and Corella Dam in the Flinders catchment. In the case of Belmore Creek Dam, a central earth core within the embankment is the watertight barrier that prevents water percolating through the rock fill, whereas at Corella Dam, the seepage barrier is a thin reinforced concrete slab placed on the upstream face of the rock fill. Figure 5.2 shows a schematic diagram of a typical embankment dam.

![Figure 5.2 Schematic diagram of an embankment dam](image)

*Figure 5.2 Schematic diagram of an embankment dam*

Storage full supply level (FSL) is the water level when the storage is full (i.e. this is the level of the dam spillway).

Where sound foundation rock is not available at reasonable depth, an embankment 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 generally minimal.

**Concrete gravity dams and roller compacted concrete dams**

Where a large capacity spillway is needed to discharge flood inflows from a large catchment, 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’. Roller compacted concrete (RCC) dams are a type of concrete gravity dam and are best used for higher dams where a larger scale plant can provide significant economies of scale. These types of dam are now the favoured type of construction in Australia whenever foundation rock is available within reasonable depth and where a large capacity spillway is required. Kidston Dam (officially known as Copperfield River Gorge Dam) in the Gilbert catchment was the first dam in Australia where roller compacted concrete was used, with low cement concrete placed in continuous thin layers from bank to bank and compacted with vibrating rollers. This approach allows quite large dams to be constructed in a far shorter time frame than required for conventional concrete construction.

**Potential dam sites in the Flinders catchment**

A prospective dam site requires inflows of sufficient volume and frequency, topography that provides a physiographic constriction of the river channel, and critically, favourable foundation geology. Favourable foundation conditions include a relatively shallow layer of unconsolidated materials such as alluvium, and rock which is relatively strong, resistant to erosion, non-permeable or capable of being grouted. Geological features that make dam construction challenging include the presence of faults, weak geological units, landslides and deeply weathered zones.

In the Flinders catchment the most favourable topography for dam construction occurs in the Eastern Fold Belt Province (a province is an area in which geological history has been the same) of the Mount Isa Inlier, the Cape River Province and Galilee Basin in the east, and the Sturgeon Basalt Province to the north and east of Hughenden (Figure 3.2).

The rocks in the Eastern Fold Belt Province have a complex and repeated history of deposition, deformation and granite batholith emplacement. Potential dam sites occur where major streams cut through the more erosion resistant units. Some of these sites are complicated by the presence of quartz ‘blows’ where hydrothermal quartz has been emplaced along a fault zone. The hydrothermal quartz often contains voids infilled with soil. The soil in these voids may erode from the increased water pressure of a dam. The primarily limitation with dams sited in this Province is that the catchments are small to moderate in size (i.e. less than 6000 km²) and mean annual rainfall is low (i.e. less than 450 mm/year). As a result dam inflows would be relatively small.

The Cape River Province is in the upper Flinders River catchment. It consists of metamorphic rocks, mostly quartzite, schist and gneiss, derived from sandstone and fine-grained sedimentary rocks. The best potential sites occur where a basalt cap is present. There are potential sites within sandstones of the Galilee Basin in the upper Flinders River area. The sites are topographically favourable and could be suitable for dam construction. However, some of the steeper slopes adjoining major streams show evidence of slope instability (block toppling) and these would require careful assessment.

The gorges formed within the basalt plateaus of the Sturgeon Province appear to offer better prospects for development of dams. However, dam construction may be inappropriate where the streams have eroded below the basalt into the mudrocks of the Great Artesian Basin. This occurs because these rocks contain weak seams and the slopes below the basalt cap are unstable. There are better prospects in Porcupine Creek where the underlying rock is sandstone, but the catchment area is small (i.e. less than 1500 km²).

The gentle rolling downs topography of the Great Artesian Basin presents few opportunities for large instream dams. Embankments have to be very long to provide adequate storage capacity. Also, construction and operation of a spillway to cope with the large flood events would entail significant risk and cost. Offstream storages may be a better option in these areas.
Fifteen potential dam locations were identified from published and unpublished literature accessed from the Queensland Government and SunWater archives. The extent of prior investigations ranged from single reference to potential locations (e.g. Black Fort) to detailed hydrological and geotechnical investigations (e.g. Cave Hill and Glendower). The studies were reviewed and all locations were reassessed using a consistent set of methods, using updated data where available. To ensure that no potential dam options had been overlooked, the DamSite model was used to assess over 100,000 potential dam sites in the Flinders catchment (Figure 5.3). This model uses a series of algorithms that automatically locate and assess favourable locations in the landscape as sites for intermediate to large water storages.

Other than the geologically and geographically unfavourable sites identified in the lower reaches of the Flinders catchment (Figure 5.3), no new potential dam sites notably better than those documented in the published and unpublished literature were identified by the DamSite model. In some cases, the model confirmed the relative potential of known dam site locations (e.g. Cave Hill, Black Fort). In other cases it demonstrated that known dam site locations were topographically and hydrologically inferior to other nearby locations (e.g. Mount Beckworth, Alston Vale and Richmond Dam).

The most favourable site at each of the 15 previously identified potential dam locations is summarised in Table 5.1. Three potential dam sites in the Flinders catchment were short-listed and assessed in more detail because each was initially deemed to be one of the more promising sites in each of three distinct geographical areas. The selection of these three sites was based on consideration of topography of the dam axis, geological conditions, proximity to suitable soils and water yield. The short-listed sites were Cave Hill, O’Connell Creek and Porcupine Creek. For these sites, conceptual layouts were developed and preliminary desktop costings undertaken. It should be noted, however, that none of the three short-listed sites in the Flinders catchment is particularly suited to development.
Ecological considerations

The water impounded by a dam inundates an area of land, drowning not only instream habitat but surrounding flora and fauna communities. The majority of potential dam sites in the Flinders catchment would inundate some regional ecosystems considered to be either ‘endangered’ or ‘of concern’.

For instream ecology, the dam wall acts as a barrier to movements of plants, animals and energy, potentially disrupting connectivity of populations and ecological processes. There are thousands of studies linking water flow with nearly all the elements of instream ecology in freshwater systems (e.g. Robins et al., 2005).

Dams also create a large, deep lake, a habitat that is in stark contrast to the usually shallow and often flowing habitats it replaces. This lake-like environment favours some species over others and will function completely differently to natural rivers and streams. The lake-like environment of an impoundment is often used by sports anglers to augment natural fish populations, through artificial stocking. Whether fish stocking is a benefit of dam construction is a matter of debate and point-of-view. Stocked fisheries provide a welcome source of recreation and food for fishers, and no doubt an economic benefit to local businesses, but they have also created a variety of ecological challenges. Numerous reports of disruption of river ecosystems (e.g. Drinkwater and Frank, 1994; Gillanders and Kingsford, 2002) highlight the need for careful
study and regulatory management. Impounded waters may be subject to unauthorised stocking of native fish and releases of exotic flora and fauna.

About 50 fish species are found in the Flinders catchment (see companion technical report about waterhole ecology (Waltham et al., 2013)). The locations of potential dam sites on the Flinders River upstream of Richmond, and the Cloncurry River upstream of Cloncurry, generally have fewer than ten species present, though further, more intensive survey may lift that number slightly. With the exception of a dam on the Flinders River near Richmond and the diversion weir for O’Connell Creek offstream storage near Richmond, none of the potential dam sites in the Flinders catchment are likely to impinge upon the known or expected habitat of important populations of barramundi, freshwater whipray or freshwater sawfish (see Figure 4.3).

Despite the majority of the Flinders catchment containing regional ecosystems that are ‘not of concern’ (~76%) (see Figure 4.6) the inundation areas for the majority of potential dam sites in the Flinders catchment contain some regional ecosystems considered to be either ‘endangered’ or ‘of concern’. This is in part because riparian vegetation is limited to drainage lines and consequently is often classed as being endangered.

If any potential dam site were to be considered for further investigation, the vegetation and fauna communities present would need to be investigated with a thorough field investigation.

**Sedimentation**

Rivers carry fine and coarse sediment eroded from hill slopes, gullies, banks and sediment stored within the channel. Sediment delivery to dams can be a major problem for water storage capacity since infilling progressively reduces the volume available for active water storage.

There is a strong relationship between the capacity of the dams and sediment infilling rates. Of the 15 potential dams examined in the Flinders catchment, 87% are estimated to have between 0.3% and 7.2% sediment infilling after 30 years and between 1% and 24% sediment infilling after 100 years. These are predicted to be the most likely percentages, although infilling under the worst case could be as high as 0.9% to 22% after 30 years and 3% to 72% after 100 years for 87% of dams. The remaining two dams, Black Fort and Richmond, are estimated to have 50% to 60% sediment infilling after 100 years but both may be at or close to 100% after 100 years (worst case scenario).

There is good agreement in the scientific literature on the key processes that generate sediment in northern Australian catchments (see companion technical report about sediment infilling rates, Tomkins, 2013). Alluvial gully erosion has been identified as a major source of fine sediment in some rivers draining into the Gulf of Carpentaria (Brooks et al., 2007). Alluvial gullies have been shown to affect only a small area of the Gulf region (less than 1%), but their high connectivity with major river channels enables direct transfer of significant quantities of fine sediment to downstream reaches (Brooks et al., 2009).

On hill slopes, colluvial gully erosion has been shown to be locally important, especially in the headwaters of some of the eastern draining catchments such as the Fitzroy (Hughes et al., 2009) and Burdekin (Bartley et al., 2007). Colluvial gully erosion appears to be less widespread in the Gulf region, possibly due to different geology and/or lower land use pressure. However, the rates and distribution of alluvial and colluvial gully erosion have been found to have increased through post-European disturbance. Overgrazing and other poor land management in a catchment can result in seriously high erosion and sediment loss.

Often deposition of coarser grained sediments occurs in the backwater (upstream) areas of reservoirs, which can cause back-flooding beyond the flood limit originally determined for the reservoir. Downstream impacts can occur as well, including sediment starvation, which can trigger channel bed incision and bank erosion.

Based on a desktop assessment of ten sediment yield studies from across northern Australia (Tomkins, 2013), sediment yield to catchment area relationships for northern Australia were developed and found to predict slightly lower sediment yield values than global relationships. This was not unexpected given the antiquity of the Australian landscape (i.e. it is flat and slowly eroding under ‘natural’ conditions).
Reliable estimation of sediment infill rates requires analysis of specific dam proposals. These would need to be completed if any of the potential dams examined in the Flinders catchment were considered further.

Cultural heritage considerations

Indigenous people traditionally situated their campsites and subsistence activities along major watercourses and drainage lines. Consequently dams are more likely to impact on areas of high cultural significance than most other infrastructure developments (e.g. irrigation schemes, roads). As a result the cost of cultural heritage investigations associated with dam sites is high relative to other development activities.

It is highly likely that the Flinders catchment will contain a large number of Indigenous cultural sites, including archaeological pre-colonial sites, some of which are likely to be of national scientific significance. Archaeological sites in parts of the catchment area potentially date to the Pleistocene (see geological timeline in Appendix B). The cultural heritage value of these landforms and their immediate surrounds is therefore assumed to be moderate to very high. There is insufficient information relating to the cultural heritage values of the short-listed dam sites to allow full understanding or quantification of the likely impacts of water storages on Indigenous cultural heritage.

If any potential dam sites in the Flinders catchment were investigated further an archaeological survey would be required to assess the potential Indigenous archaeological impact of the dam and reservoir. Any such investigation should be undertaken in consultation with the Indigenous parties. Should works proceed in this area, it is recommended that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding contemporary use of water sources in the area.

Dam cost estimates

Previous studies are likely to significantly underestimate the cost of establishing dams in the Flinders catchment because:

- Construction costs, particularly in remote areas, have escalated at a higher rate than the consumer price index (CPI), particularly during the recent boom period of mining activity.
- The costs estimated by many past studies do not adequately reflect the uncertainty in these projects.
- Probable maximum flood (PMF) estimates have steadily increased over the last 40 years, requiring larger spillways and higher embankments to contain the flood rises (only three past studies in the Flinders catchment undertook PMF computations).
- There are now stricter environmental provisions such as fish passage facilities and variable level intake towers, as well as more time-consuming and expensive environmental approval and community consultation processes.

Preliminary cost estimates were prepared for the three short-listed dam sites based on current construction costs (see Petheram et al., 2013 for more detail). For the remaining potential dam sites, costs were estimated relative to the short-listed dams in the Flinders and Gilbert catchments. This was a subjective assessment that included the parameters: dam height, width, capacity, catchment area and geological uncertainty. Preliminary cost estimates of potential dams in the Flinders catchment are provided in Table 5.1.

Summary of potential dams assessed in the Flinders catchment

Table 5.1 and Table 5.2 provide summaries of potential dams assessed in the Flinders catchment. In presenting this information it should be noted, however, the geological structure at a particular dam site can be very complex, is always unique and requires thorough investigation because of the high financial risks involved. The investigation of a potential dam site generally involves an iterative process of increasingly detailed studies over a period of years, occasionally as few as two or three years but often over ten or more years. For any of the options listed in this report to advance to construction, far more comprehensive studies would be needed than were possible in this regional scale assessment.
Table 5.1 Potential and existing dams assessed in the Flinders catchment

At some locations, up to three alternative sites were assessed. For these locations, the most suitable alternative site is reported. Dam ID column corresponds to numbers shown on Figure 5.3.

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<th>DAM ID</th>
<th>DAM NAME</th>
<th>CATCHMENT AREA</th>
<th>SPILLWAY HEIGHT**</th>
<th>FULL SUPPLY LEVEL</th>
<th>CAPACITY</th>
<th>ANNUAL WATER YIELD***</th>
<th>CAPITAL COST#</th>
<th>UNIT COST##</th>
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* Conventional concrete (CC), embankment dam (EB), roller compacted concrete dam (RCC).
** The height of the dam abutments will be higher than the spillway height.
*** Water yield is based on 85% annual time-based reliability using a perennial demand pattern for the baseline river model under Scenario A. This is yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These yield values do not take into account downstream existing entitlement holders or environmental considerations.
# ■ indicates preliminary cost estimate is likely to be −10% to +30%. □ indicates preliminary cost estimate is likely to be −10% to +50%. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher. Operation and maintenance costs are typically about 0.4% of the capital cost.
## This is the unit cost of annual water supply and is calculated as the capital cost divided by the water yield at 85% annual time reliability.
### Assuming a 7% real discount rate and a dam life of 100 years. Capital cost only. Does not include operation and maintenance costs.
§ Details of original dam proposal could not be located. Dam type listed is considered most likely based on available information.
& This includes the cost of the diversion weir and diversion channel as well as the EB dam across O’Connell Creek. Operation and maintenance costs of the O’Connell Creek offstream storage would be about 1% of the capital cost per year due to operation and maintenance of the diversion weir and erodibility of the berm and batters slopes of the diversion channel.
^ This analysis did not assume a threshold flow requirement above which water can be diverted from the Flinders River nor did it take into consideration the hydraulic connection between the river and the O’Connell Creek offstream storage.
### Table 5.2 Summary comments for potential dams in the Flinders catchment

The companion technical report about water storage options (Petheram et al., 2013) provides a comprehensive review of each of the potential dams listed below.

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

The total divertible yield, before losses, from six of the most promising dam sites in the Flinders catchment is about 140 GL in 85% of years. Divertible yield is the amount of water that can be released annually from one or more storages in a controlled manner.

To undertake this analysis the number of dams simulated in the Flinders River model was incrementally increased, starting with the most viable dam and finishing with the worst combination of the seven most promising dams. Cost estimates were obtained from Table 5.1 and do not include the cost of irrigation distribution infrastructure.

In Figure 5.4a the water yield from each dam was calculated at 85% annual time reliability at the dam wall. In Figure 5.4b the water yield from each dam was calculated at 85% annual time reliability and a 30% loss was applied to the water yield to approximate the loss of water that occurs during conveyance between the dam wall and the farm gate (Section 5.3). Given the distance between many of the dams in the Flinders catchment and suitable soil, 30% is likely to be an underestimate. It is important to note that these estimates of divertible yield take into consideration evaporation losses, and seasonality and inter-annual variability in streamflow. They do not, however, take into account environmental, social, cultural or economic factors, or downstream entitlement holders.

![Figure 5.4 Cost of water in $/ML versus cumulative divertible yield at 85% annual time reliability](image)

(a) At dam wall and (b) at farm gate. A 30% loss between dam wall and farm gate is assumed. Dots indicate combined water yield at 85% annual time reliability of one or more dams, with the colour of the dot indicating the most recently included dam in the cumulative yield calculation. For example, Cave Hill has a yield at the dam wall of 40 GL; Cave Hill and Glendower have a cumulative yield of 97 GL; Cave Hill, Glendower and White Mountains have a cumulative yield of 115 GL. See Figure 5.3 for dam locations. Squares indicate existing dams, triangles indicate proposed dams.

Figure 5.4 illustrates that with the addition of more dam sites, the construction cost per ML of yield increases considerably with the third and subsequent dams. This is in part because i) each subsequent potential dam site is less favourable than its predecessor; and ii) in those instances where a dam is constructed upstream of an existing dam, their combined yield is less than the sum of their individual yields because the upstream dam reduces inflows to the downstream dam. An extreme example of this is provided with the addition of the 7th dam (i.e. for a combined cost of $13,360/ML). This dam (Flinders 456) and the dam upstream (White Mountains) reduced the inflows to Glendower dam to the extent that the storage volume of Glendower dam rarely exceeded the dead storage volume (i.e. the volume below which there can be no outflow).

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

Three short-listed potential dam sites in the Flinders catchment

The three short-listed sites are provided in alphabetical order. These sites are deliberately situated in three distinct geographic areas. Cave Hill was selected for further analysis because it is one of the highest yielding dams in the Flinders catchment that is closely situated to moderately suitable soil. Porcupine Creek was selected because it was initially thought to be one of the more geologically suitable sites in the Hughenden area. O’Connell Creek was selected because it is one of the more promising options in the Richmond area and there has been long standing interest in this storage.

Cave Hill

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

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

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

It is now proposed that the dam comprise a zoned earth and rock fill embankment located 100 m upstream of the original axis (Figure 5.5) with a slurry trench cut-off through the river bed sands rather than the clay blanket as originally proposed. A separate saddle dam approximately 900 m long and 5 m maximum height would be required on the left bank some 6.5 km west of the river to contain flood rises in the reservoir (Figure 5.6). The saddle dam would be an earth fill embankment with an erodible downstream zone. The saddle dam required on the right bank side would also be an earth and rockfill embankment approximately 720 m long with a maximum height of 16 m.

The capital cost of the dam is estimated to be $249 million (with estimates ranging between $225 million and $325 million), not including the cost of any downstream distribution works. Annual operating and maintenance costs are likely to be relatively low for the type of dam proposed. It is emphasised that the viability of this proposal depends on detailed foundation drilling, demonstrating that the hydrothermal quartz outcrop exposed on the right abutment can be avoided by the axis relocation now proposed.
Over half of the reservoir created by the potential Cave Hill dam would be less than 5 m in depth at FSL (Figure 5.7). This figure shows the dam wall, and the saddle dams that are required to contain the reservoir at FSL where the reservoir touches the catchment boundary. The crest level of the left bank saddle dam would be set slightly above the 1:1000 annual exceedance probability (AEP) flood and serve as an auxiliary spillway in the event of more extreme flood events. Additionally, the crest level of the right bank saddle
Agricultural resource assessment for the Flinders catchment dam was set to contain a 1:100,000 AEP flood and the crest level of the cross river embankment 1 m higher.

![Map of Cave Hill Dam depth of inundation and property boundaries](image)

**Figure 5.7 Cave Hill Dam depth of inundation and property boundaries**

Property boundaries are indicated by the bronze and green coloured shading.

Figure 5.8 shows the annual time reliability (the percentage of years that a given demand could be supplied by the reservoir) and the volumetric reliability (the total volume of water supplied expressed as a percentage of the total volumetric demand) for the reservoir created by a dam at the Cave Hill site. Under Scenario A (historical climate) for the baseline model the yield of the reservoir is approximately 40 GL at 85% annual time reliability. The ensemble of models has a 95% range of 33 to 41 GL at 85% annual time reliability. The ensemble of models provides an estimate of the uncertainty in the water yield as a result of uncertainty in the streamflow data.

Topographically Cave Hill storage area is not favourable. Although the storage capacity is moderate in size, the reservoir surface area is large and the dam is shallow. Consequently evaporative losses from the reservoir are large relative to the water actually supplied, i.e. ratio of evaporation to water supplied is approximately 1.2 (at 85% annual time reliability) or evaporation is approximately 55% of the regulated flow. This means that for every GL of water able to be supplied for consumptive use, 1.2 GL is lost to evaporation.
The baseline (i.e. original) model under Scenario A is shown by the black line. The wet future climate (Cwet), mid future climate (Cmid) and dry future climate (Cdry) yield estimates were generated using the baseline model and future climate data. The orange shading indicates the 95% range of the 50 model ensembles under Scenario A. Yields are at the dam wall (i.e. they do not account for distribution losses).

Figure 5.9 illustrates the difference in the simulated inundated area of the floodplain without Cave Hill dam and with Cave Hill dam, empty prior to the 2001 and 2009 flood events (companion technical report about floodplain inundation, Dutta et al., 2013). Construction of the Cave Hill dam would not result in a noticeable reduction in inundated area on the Flinders coastal floodplain for small or large flood events.

The reservoir created by a 16 m high dam at the Cave Hill site is likely to have very little persistent thermal stratification due to large summer inflow events (Petheram et al., 2013). This leads to full mixing of the water column and the introduction of relatively warm inflow water results in a much lower temperature difference across the reservoir water column, which reduces resistance to mixing. Hence the risk of blue-green algal blooms is low. The water column is predicted to be generally mixed and dissolved oxygen drawdown is unlikely to be a problem under most circumstances.

The potential Cave Hill dam site is approximately 18 km from the existing Chinaman Creek Dam. Hence the fish species present are likely to be the same as those found in Chinaman Creek. The values of the aquatic habitat upstream of the dam wall site are unknown.
Figure 5.10 Regional ecosystems inundated by the potential Cave Hill dam reservoir at full supply level

Figure 5.10 indicates that the area inundated at full supply level covers large areas of regional vegetation communities that are ‘of concern’ and riparian vegetation that is ‘endangered’.

O’Connell Creek offstream storage

The O’Connell Creek offstream storage and associated diversion weir on the Flinders River is the most promising water storage scheme in the Richmond area. The major limitation of the site is that it is very flat (Figure 5.11 and Figure 5.12), resulting in a very shallow storage (Figure 5.13). Hence, although the reservoir can hold 127 GL at FSL, it can only supply 34 GL in 85% of years under a generous set of assumptions (see below). The annual operating costs for the storage and diversion scheme are likely to be high compared to other water storage developments in the Flinders catchment. The diversion weir would impinge upon the known range of barramundi and the predicted range of freshwater sawfish, and most of the reservoir created by the water storage and diversion weir would inundate areas of regional community ecosystems that are likely to be ‘of concern’.

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

The O’Connell Creek proposal involves a diversion weir downstream of Richmond, which diverts water into a 55 m wide diversion channel running between the Flinders River and the nearby O’Connell Creek. The O’Connell Creek offstream storage would consist of a 4 km long earthfill embankment dam located approximately 17 km north-west of Richmond. No geological investigations have been carried out at the site. An airborne electromagnetic survey indicates a possible anticlinal structure and fault underlying the creek and left abutment approximately 4 km downstream of the dam axis (Munday et al., 2013). Future investigations should target this area to assess shear strength properties of the underlying rock. Based on investigations at the Flinders River dam site to the north of the site and a site inspection as part of the Assessment, the right abutment is an alluvial terrace of the Flinders River and the left abutment is residual clay overlying mudstone. Subject to detailed surveys and analysis of flood effects, work may be required to
protect the racecourse and airport area from flooding and a portion of the Great Northern Railway may need to be raised.

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

The majority of the O’Connell Creek offstream storage has a depth of less than 5 m at full supply level (Figure 5.13).

Figure 5.11 A depiction of the O’Connell Creek offstream storage, looking upstream
Photo: CSIRO.
Figure 5.12 Dam cross-section, height, volume and reservoir surface area for O’Connell Creek offstream storage
(a) Cross-section of ground surface along dam axis. (b) Relationship between dam height, reservoir volume and reservoir surface area.

Figure 5.13 O’Connell Creek offstream storage depth of inundation and property boundaries
Property boundaries are indicated by coloured shading.
Figure 5.14a shows the annual time reliability (the percentage of years that a given demand could be supplied by the reservoir) and the volumetric reliability (the total volume of water supplied expressed as a percentage of the total volumetric demand) of the reservoir created by a dam on O’Connell Creek. Under Scenario A for the baseline model the yield of the reservoir was approximately 34 GL at 85% annual time reliability. The ensemble of models had a 95% range of 32 to 36 GL at 85% annual time reliability. The ensemble of models provides an estimate the uncertainty in the water yield as a result of uncertainty in the streamflow data.

These yield estimates, however, assume that the water in the Flinders River does not have to be above a certain level before it can be diverted and that the channel capacity is 150 m$^3$/s (for more detail see Petheram et al. 2013). These yield estimates also do not take into consideration the hydraulic connection between the river and the storage – that is the discharge through the diversion channel will be largely controlled by the water level in the Flinders River relative to the water level in the O’Connell Creek storage. A preliminary assessment taking into consideration the relative difference in water levels indicated the water yield from the storage may be as low as 14 GL in 85% of years. To accurately assess the discharge through the diversion channel requires high-resolution elevation data across the general area.

The impact of O’Connell Creek offstream storage on the area of land inundated on the Flinders coastal floodplain was not assessed but is likely to be negligible.

The unfavourable physiographic constriction of the river channel at the O’Connell Creek site and low dam wall (Figure 5.11) result in relatively large evaporative losses, i.e. ratio of evaporation to water supplied is approximately 1.07 (at 85% annual time reliability) or evaporation is approximately 52% of regulated flow.

This dam option includes construction of a diversion weir on the main Flinders River and thus creates barriers to fish passage and areas of inundation on two waterways. The Flinders River at Richmond is within the known range of barramundi and the freshwater sawfish, albeit close to their upstream limits. Figure 5.15 indicates that the area inundated at full supply level covers large areas of regional vegetation communities that are ‘of concern’.
Porcupine Creek

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

The Porcupine Creek potential dam site is immediately downstream of the Porcupine Gorge National Park and adjacent to the Kennedy Development Road (Figure 5.16). This site would be suitable for a RCC dam with a central overflow crest 35 m above bed level, with RCC abutments extending to the top of the bank. A short earth embankment saddle dam would be required on the right bank to contain flood rises in the reservoir. In the area of the potential dam site, Porcupine Creek has eroded a gorge through a basalt plateau and the underlying sedimentary rocks of the Great Artesian Basin. No site geological investigations have been undertaken. A site inspection as part of the Assessment identified a layer of gravel marking the contact between the basalt and underlying sedimentary rocks. This unconformity presents a major issue for both stability and reservoir leakage. It is proposed that potential seepage and piping through a right bank gravel layer would be controlled by a concrete slab anchored to the abutment extending upstream to blanket the gravel layer, or by other suitable treatment. If further investigations were to conclude that clay material in the layer is dispersive, additional treatment such as a downstream filter blanket would be necessary. The storage would extend into the downstream section of the Porcupine Gorge National Park but would not be seen from the park lookout area upstream. Four cultural heritage sites listed in the Queensland Department of Aboriginal and Torres Strait Islander and Multicultural Affairs database would be affected.

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

Figure 5.17a shows a cross-section of the ground surface along the dam axis and Figure 5.17b and illustrates the relationship between the dam height, reservoir volume and reservoir surface area.

Figure 5.16 Porcupine Creek dam site looking upstream
Photo: CSIRO.

Figure 5.17 Dam cross-section, height, volume and reservoir surface area for Porcupine Creek potential dam site
(a) Cross-section of ground surface along dam axis; looking upstream. (b) Relationship between dam height, reservoir volume and reservoir surface area.
A short embankment is required on the east bank to contain flood rises at the catchment boundary. A large proportion of the reservoir created by the Porcupine Creek dam would be greater than 10 m in depth at FSL (Figure 5.18). In Figure 5.18 a dam wall is required to contain the reservoir at FSL where the reservoir touches the catchment boundary.

Figure 5.19a shows the annual time reliability (the percentage of years that a given demand could be supplied by the reservoir) and the volumetric reliability (the total volume of water supplied expressed as a percentage of the total volumetric demand) of the reservoir created by a dam at Porcupine Creek. Under Scenario A for the baseline model, the yield of the reservoir is approximately 11.5 GL at 85% annual time reliability. The ensemble of models had a 95% range of 11 to 12 GL at 85% annual time reliability. The ensemble of models provides an estimate the uncertainty in the water yield as a result of uncertainty in the streamflow data.

Although the dam axis of the potential Porcupine Creek site is located in a relatively narrow valley, so is the reservoir. Consequently, the reservoir has a relatively small volume (31 GL) given the height of the wall (35 m). However, the evaporative loss is small relative to other sites in the Flinders catchment, i.e. ratio of evaporation to water supplied is approximately 0.25 (at 85% annual time reliability) or evaporation is approximately 20% of the regulated flow.
Figure 5.19 Annual time reliability and volumetric reliability for Porcupine Creek dam under scenarios A and C
(a) Annual time reliability. (b) Volumetric reliability. The baseline (i.e. original) model under Scenario A is shown by the black line. The wet future climate (Cwet), mid future climate (Cmid) and dry future climate (Cdry) yield estimates were generated using the baseline model and future climate data. The orange shading indicates the 95% range of the 50 model ensembles under Scenario A. Yields are at the dam wall (i.e. they do not account for distribution losses).

Figure 5.20 Comparisons of inundated area with and without the construction of Porcupine Creek dam under Scenario A
(a) For an event in 2001 (equivalent to 1-in-10-year event at gauging station 915003A). (b) For an event in 2009 (equivalent to 1-in-35-year event at gauging station 915003A). Gauging station locations are shown in Figure 3.30. In this graph Scenario A (green line) underlies Scenario B (blue line).

Figure 5.20 illustrates the difference in coastal floodplain area simulated as being inundated without Porcupine Creek dam and with Porcupine Creek dam empty prior to the 2001 and 2009 flood events. This figure illustrates that the construction of Porcupine Creek dam would not result in any notable reduction in the area of land inundated on the Flinders coastal floodplain during large or small events.

The reservoir created by a 35 m high dam at the Porcupine Creek site is likely to be strongly stratified with a single winter deep-mixing event each year and a characteristic temperature difference of 7 to 10 °C (Petheram et al., 2013). The risk of blue-green algal blooms is high. The very long duration of stratification and weak mixing behaviour suggests this storage is highly susceptible to anoxic conditions and associated water quality issues. Summer inflows may resupply oxygen near the bottom and may reduce the severity of oxygen depletion and associated metal and nutrient release from the sediments.

The reservoir would extend into the downstream section of the Porcupine Gorge National Park, which is listed on the Register of the National Estate. However, the dam and reservoir would not be visible from the park lookout area upstream. Limited ecological data were available from this site. The potential dam...
location is above the distribution of the majority of fish species that breed within freshwater rivers in the Flinders catchment. Hogan and Vallance (2005) surveyed a waterhole in Porcupine Creek on Mt Emu Plains station, upstream of this dam site, and found six fish species, all widespread and common species that breed in freshwater.

Figure 5.21 indicates that the inundated area at the FSL would mostly cover regional vegetation communities that are ‘not of concern’, with the exception of the riparian vegetation which is ‘of concern’.

The Indigenous Cultural Heritage Body for this area is Yirendali Operations Pty Limited.

No previous archaeological reporting relating specifically to this area has been located. However, four sites (two paintings and two engravings) are listed in the DATSIMA database, which indicates that some investigation has previously been undertaken. Results of investigations in the Flinders catchment more generally indicate that the area is likely to have high archaeological potential.

Figure 5.21 Regional ecosystems inundated by the Porcupine Creek dam at full supply level

5.2.2 WEIRS AND RE-REGULATING STRUCTURES

Weirs differ from dams in that they are lower barriers located entirely within stream banks and are totally overtopped during flood events. No specific investigations of possible regulating weir sites have been undertaken in the Flinders catchment. As a rule of thumb, however, weirs are constructed to half the bank height.

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

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

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

**Concrete gravity weirs**

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

**Sheet piling weirs**

Where rock foundations are not available, stepped steel sheet piling weirs have been successfully used in many locations. These weirs consist of parallel rows of steel sheet piling, generally about six metres apart, with a step of about 1.5 to 1.8 m high between each row (Figure 5.22). Reinforced concrete slabs placed between each row of piling absorb much of the energy as flood flows cascade over each step. The upstream row of piling is the longest being driven to a sufficient depth to cut off the flow of water through the most permeable material.

The general absence of rock foundations under the Flinders River and its tributaries mean that sheet piling weirs will be the most suitable form of weir structure in most locations. They would, however, be susceptible to sediment infill and scouring of the downstream bed during large flood events.

Table 5.3 provides a preliminary cost estimate for sheet piling weirs.

**Figure 5.22 Schematic diagram of sheet piling weir**

Storage full supply level (FSL) is the water level when the storage is full.

**Table 5.3 Estimated construction cost of 3-m-high sheet piling weir**

For a full list of assumptions, see the companion technical report about water storage options (Petheram et al., 2013).

<table>
<thead>
<tr>
<th>WEIR CREST LENGTH (m)</th>
<th>ESTIMATED CAPITAL COST ($ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>$24</td>
</tr>
<tr>
<td>150</td>
<td>$31</td>
</tr>
<tr>
<td>200</td>
<td>$37</td>
</tr>
</tbody>
</table>
These construction costs are sensitive to a number of factors, including:

- remoteness of location, which can result in higher freight and travel times
- piling costs, because piles are imported into Australia and therefore subject to currency exchange rates
- subsurface material – the presence of rock at shallow depth, for example, would require a different weir arrangement and could result in higher costs.

Annual operating costs are likely to be low, depending on location. However, the frequency and magnitude of flood events could lead to significant costs from time to time in the repair of scour damage (e.g. replacement of mattresses). Annual operating costs could average between 1 and 2% of capital costs. A full list of assumptions upon which these costs are based is provided in Petheram et al. (2013).

### Sand dams

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

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

### 5.2.3 ON-FARM DAMS

On-farm dams are constructed on a single farm using earth embankments and can take a number of forms, including gully dams, hillside dams, ring tanks, turkey nest tanks and excavated tanks (described in more detail in Table 5.4). The most suitable type of on-farm dam depends on various factors, including topography, the availability of suitable soils, excavation costs and source of water (i.e. groundwater or surface water pumping, flood harvesting).

Earth embankment on-farm dams are best located only in smaller drainage lines because they are highly susceptible to failure during large floods where spillway capacity could be exceeded. However, many minor drainage lines, such as those on the Mitchell Grass Downs, receive no runoff in greater than 20% of years and are therefore unlikely to be able to reliably supply water for irrigation. For this reason this section focuses on offstream storages.
Table 5.4 Types of on-farm dam storages
Adapted from Lewis (2002).

<table>
<thead>
<tr>
<th>TYPE OF ON-FARM DAMS</th>
<th>DESCRIPTION</th>
<th>STORAGE TO EXCAVATION RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavated tanks</td>
<td>Restricted to flat sites, excavated tanks comprise excavations below the natural surface. Excavated material is wasted. Generally limited to stock and domestic use and irrigation of high-value crops. 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>Low</td>
</tr>
<tr>
<td>Gully dam</td>
<td>Gully dams consist of an earth embankment built across a drainage line. Dams are normally built from material located in the storage area upstream of dam site.</td>
<td>10:1 (favourable conditions)</td>
</tr>
<tr>
<td>Hillside dam</td>
<td>Hillside dams are earth dams 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>Ring tank</td>
<td>A ring tank is a storage confined entirely within a continuous embankment built from material obtained within the storage basin.</td>
<td>1.5:1 (small tank) 4.5:1 (large tank)</td>
</tr>
<tr>
<td>Turkey nest tanks</td>
<td>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</td>
<td></td>
</tr>
</tbody>
</table>

Offstream storages, such as ring tanks (Figure 5.23), require water to be diverted or pumped from the river into the storage. Diverting water is advantageous because the pumping requirements and hence operating costs are typically lower than a storage that requires water to be pumped directly from the river. Maintenance of diversion infrastructure can be high, however, where considerable quantities of sediment and debris need to be removed. Diverting water requires a unique set of topographic circumstances and although some opportunities to divert water in the Flinders catchment exist, in many instances water will need to be pumped directly from the river into the storage.

This section discusses the following aspects of offstream water storages:

- reliability of supply of water for water harvesting
- suitability for siting storages in the Flinders catchment
- evaporative and seepage losses
- construction, operation and maintenance costs of offstream storages.

The Assessment does not seek to provide instruction on the design and construction of farm-scale water storages. Numerous books and online tools provide detailed information on nearly all facets of farm-scale water storage. For instructional information the reader is directed in the first instance to Lewis (2002) and IAA (2007). Siting, design and construction of farm-scale offstream storage should always be undertaken in conjunction with a suitably qualified professional and tailored to the nuances that occur at every site.
Reliability of supply of water for water harvesting

The exact nature and form of water harvesting licences is subject to policy decisions which are outside the scope of the Assessment. However, to guide potential water users on the reliability of supply from various water harvesting locations in the Flinders catchment the Assessment explored a range of potential options based on three locations in the Flinders system catchment (915204A, 915008A and 915003A), four commence to pump thresholds (i.e. the streamflow value above which pumping or extraction can commence) and five pump capacities (i.e. the maximum volume of water that can be extracted by a pump in a day). Commence to pump thresholds of 100 and 2000 ML/day are presented together with a range of pump capacities i.e. 500, 1000, 2000 and 3000 ML/day. Figure 5.25 presents the results from a headwater catchment (915204A), Figure 5.24 presents results from the middle reaches of the Flinders River (915008A) and Figure 5.26 presents results from the most downstream gauging station on the Flinders River (915003A).
Figure 5.24 Annual volume of streamflow extracted versus annual time reliability for streamflow gauge 915204A
(a) Commence to pump threshold of 100 ML/day. (b) Commence to pump threshold of 2000 ML/day. Pump capacities are in ML/day.

Figure 5.25 Annual volume of streamflow extracted versus annual time reliability for streamflow gauge 915008A
(a) Commence to pump threshold of 100 ML/day. (b) Commence to pump threshold of 2000 ML/day. Pump capacities are in ML/day.

Figure 5.26 Annual volume of streamflow extracted versus annual time reliability for streamflow gauge 915003A
(a) Commence to pump threshold of 100 ML/day. (b) Commence to pump threshold of 2000 ML/day. Pump capacities are in ML/day.
The water harvesting figures show the reliability of extracting water at two thresholds for a range of pump capacities. The reliability is derived by choosing an annual water extraction on the y-axis and following that line across to the desired pump capacity, then following a vertical line to the x-axis. This gives the reliability of annual extraction. For example in Figure 5.26a, a 5000 ML/day pump can extract 300 GL of water in about 40% of years.

Collectively these water harvesting curves show some interesting behaviours:

- The pump curves converge on the x-axis. This represents the years when there is no flow to extract. For example in Figure 5.26 in 10% of years there is no water to extract.
- The years where water cannot be extracted are not strongly dependent on the commence to pump threshold. Comparing Figure 5.25a and Figure 5.25b shows that increasing the commence to pump from 100 ML/day to 2000 ML/day does not significantly change the number of years where no water can be extracted.
- In some cases the increase in pump capacity does not increase the amount of water that can be extracted. This is because all of the water has been taken and consequently there is no more to take with a larger pump.
- The relationship between the commence to pump threshold and pump capacity is reasonably planar, i.e. for a higher commence to pump threshold the same reliability can be achieved by using a larger pump. However, the larger the pump the larger the capital cost of the pump.
- At lower percentage exceedance the volume of water extracted is directly related to pump capacity. At the lower percentage exceedance the streamflow events are extremely large and consequently the volume that can be taken is only limited by the size of the pump. At these low exceedance levels the streamflow events are large and water levels rise and fall quickly, i.e. the duration of the streamflow events is short.
- The reliability increases with catchment area, i.e. more downstream gauges are more reliable.

In using the water reliability curves presented in Figure 5.24 to Figure 5.26, the reader needs to recognise that these curves do not provide any indication of the sequencing of dry spells or events. Successive years without any water extraction will have a considerable impact on the viability of a water user. The curves do not indicate when or how often water is extracted in a year. For example the volume of extraction does not distinguish between taking all of the water from a single event or from several events across a year. This may have implications on the cost of infrastructure required to store the water to obtain a sufficiently reliable supply.

**Suitability assessment of offstream storages in the Flinders catchment**

The top 1.5 m of the soil profile adjacent to the main rivers in the Flinders catchment appears to be broadly suitable for siting offstream storages (Figure 5.27).

Figure 5.27 shows a desktop assessment of the suitability of offstream storages in the Flinders catchment, based on available data from the top 1.5 m of the soil profile (Bartley et al., 2013). This assessment was based on soil depth, drainage, slope and regional geology mapping (see Petheram et al., 2013). It does not give consideration to the nature of subsurface material below 1.5 m, with the exception of general information from broad-scale geological mapping. Nor does the suitability assessment consider the impacts of flooding or proximity to rivers.

On-farm offstream water storages require consideration at a scale finer than is possible to assess in a regional scale resource assessment. Hence these 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 5.27 Land suitability for offstream water storages in the Flinders catchment
Information below 1.5 m is not available, thus the nature of subsurface material below that depth is not considered, with the exception of general information from broad-scale geological mapping. Flood risk is not considered.

Evaporative and seepage losses
Losses from an on-farm dam occur through evaporation and seepage. Mean daily evaporation losses from open water in the Flinders catchment have been modelled to be between 4.5 and 6 mm (Petheram et al., 2013). When computing evaporative losses from a storage it is important to compute net evaporation (i.e. evaporation minus rainfall) rather than just evaporation. Strategies to minimise evaporation include liquid and solid barriers, but these are typically expensive per unit of inundated area (e.g. $10/m^2$ to $26/m^2$).

A reservoir constructed on suitable soils will have seepage losses equal to or less than 1 to 2 mm/day and losses will be greater than 5 mm/day if sited on less suitable (i.e. permeable) soils (IAA, 2007). The effect of evaporation and seepage loss on offstream storages is explored in Table 5.5.

Capital, operation and maintenance costs of offstream storages
The cost of an offstream storage scheme needs to include the cost of the water storage, pumping infrastructure, supply channels, 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. Effective volume refers to the actual volume of water that could be used for consumptive purposes after losses due to evaporation and seepage. For example, if water is stored for 12 months and there is only 1 mm/day seepage loss, nearly half the stored volume would be lost to evaporation and seepage.

In the Flinders catchment, the majority of streamflow has occurred by the end of March. Assuming the storage is full at this time, one strategy is to sow suitable crops during the late wet season (i.e. March) to minimise evaporative and seepage losses and enable crops to utilise existing soil water. Hence the configurations provided in Table 5.5 refer to a crop sowed in March. Sorghum planted for hay is an example of a crop grown for about four months, sorghum planted for grazing is an example of a crop grown for about six months and Rhodes grass an example of a perennial crop. See Section 5.5.5 for sowing and growing dates for different crops in the Flinders catchment.

Data in Table 5.5 are based on costs of $4/m³ for earthworks. Recent estimates of cost for earthworks from companies in the Flinders catchment ranged from $3 to $5/m³ (B Cornfoot and W Lillyman, 2013, pers. comm.) depending on the site. Ring tank construction costs in the Flinders were also reported at $4/m³ by Mason and Larard (2011). Petheram et al. (2013) computed the cost of an 8000-ML storage, based on the design of SunWater (2009), to be $10 million.

Table 5.5 Construction costs for a 1000-ML storage based on costs of $4/m³ for earthworks near Richmond

<table>
<thead>
<tr>
<th>BANK HEIGHT (m)</th>
<th>AREA (ha)</th>
<th>CONSTRUCTION COST (S)</th>
<th>SEEPAGE LOSS (mm/day)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>COST ($/ML)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>COST ($/ML)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>COST ($/ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>25</td>
<td>$1,000,000</td>
<td>1</td>
<td>855</td>
<td>1170</td>
<td>785</td>
<td>1273</td>
<td>528</td>
<td>1894</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>$1,000,000</td>
<td>2</td>
<td>824</td>
<td>1213</td>
<td>739</td>
<td>1352</td>
<td>437</td>
<td>2290</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>$1,000,000</td>
<td>5</td>
<td>732</td>
<td>1365</td>
<td>601</td>
<td>1663</td>
<td>163</td>
<td>6135</td>
</tr>
</tbody>
</table>

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

This analysis makes the following assumptions (see Brennan McKellar et al. (2013) for more details).

- Pumping infrastructure costs $850/ML per day and to fill the storage in most years the pumps have to extract the required water in only five days (see Holz et al. (2013)).
- The cost of pumping is $16/ML (or $11/ML after a full rebate of $0.38/L) (assumes about a 10-m head is required; see Section 5.3.5).
- The water storage has a life span of 40 years and operation and maintenance costs are 1% of the capital costs.
- The pumping infrastructure has a life span of 15 years and an operation and maintenance cost of 2% of capital costs.
- A discount rate of 7%.
- Residual value calculated using straight line depreciation approach.
- 15-year investment time frame.
Table 5.6 Annualised cost of the construction and operation of a 1000-ML ring tank and 100 ML/day pumping infrastructure assuming a real discount rate of 7%

<table>
<thead>
<tr>
<th>ITEM</th>
<th>CAPITAL COST ($)</th>
<th>LIFESPAN (y)</th>
<th>EQUIVALENT ANNUAL CAPITAL COST ($)</th>
<th>ANNUAL OPERATION AND MAINTENANCE COST ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offstream storage (ring tank)</td>
<td>$1,000,000</td>
<td>40</td>
<td>$75,000</td>
<td>$10,000</td>
</tr>
<tr>
<td>Pumping infrastructure</td>
<td>$170,000</td>
<td>15</td>
<td>$18,650</td>
<td>$3,400</td>
</tr>
<tr>
<td>Pumping cost (diesel)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>$16,000</td>
</tr>
</tbody>
</table>

Table 5.7 Equivalent annual cost per ML for storages with different seepage rates near Richmond

Annual cost is the sum of the equivalent annual capital cost and operation and maintenance cost in Table 5.6. Effective volume refers to the actual volume of water that could be used for consumptive purposes after losses due to evaporation and seepage (Table 5.5). Annual unit cost is the annual cost per ML of effective volume of stored water.

<table>
<thead>
<tr>
<th>BANK HEIGHT (m)</th>
<th>AREA (ha)</th>
<th>ANNUAL COST* ($)</th>
<th>SEEPAGE LOSS (mm/day)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>4 months (March to June)</th>
<th>6 months (March to August)</th>
<th>12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>25</td>
<td>$123,000</td>
<td>1</td>
<td>855</td>
<td>$144</td>
<td>785</td>
<td>157</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>$123,000</td>
<td>2</td>
<td>824</td>
<td>$149</td>
<td>739</td>
<td>166</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>$123,000</td>
<td>5</td>
<td>732</td>
<td>$168</td>
<td>601</td>
<td>205</td>
</tr>
</tbody>
</table>

The total equivalent annual costs for the construction and operation of a 1000-ML ring tank and 100 ML/day pumping infrastructure is $123,000 or $123 per ML of storage. In Table 5.7 the equivalent annual cost of the water yield from the offstream storage needs to take into consideration evaporation and seepage from the storage, which increase with the length of the crop growing season (i.e. time required to store water). In this table results are presented for the equivalent annual cost of water yield from an offstream storage for different seepage rates and lengths of time for storing water. See Section 5.5 for information on crop growing seasons in the Flinders catchment.

For the large instream dams presented in Table 5.1, the lowest equivalent annual capital cost is $430 per ML at 85% annual time reliability and supplying water for 12 months a year. Including operation and maintenance costs, this annual value is about $460 per ML at the dam wall.

Approximately 68% of the Flinders catchment is covered by clay soils (Section 3.3) and consequently there are likely to be many locations in close proximity to rivers where seepage losses are likely to be low (i.e. less than 2 mm/day; Figure 5.27). The equivalent annual cost of an offstream storage with a seepage loss of 2 mm/day or less and storing water for 12 months of the year is less than half that of a large instream dam in the Flinders catchment, even before the large dam water yields are adjusted for conveyance losses.

5.3 Water distribution systems – conveyance of water from storage to the crop

In all irrigation systems, water needs to be diverted from rivers or dams through artificial and/or natural water distribution systems, before ultimately being used on-field for irrigation. Some water diverted for irrigation is lost during conveyance to the field, before it can be used by a crop. These losses need to be taken into account when planning irrigation systems and developing likely irrigated areas. The amount of water lost during conveyance depends on the:
• river conveyance efficiency, from the water storage to the irrigation scheme
• channel distribution efficiency (within an irrigation scheme), from the river offtake to the farm gate
• on-farm distribution efficiency, in getting water from the farm gate to the field
• field application efficiency, which is the efficiency to which water can be delivered from the edge of the field and applied to the crop.

Little previous research on irrigation systems has previously been undertaken in the Flinders catchment. In the 1960s and 1970s, Clewett (1986) undertook field and modelling studies on an irrigation system known as ‘shallow storage irrigation’, which is similar to ‘recession irrigation’ practised in less developed countries throughout the world. These systems rely on shallow storages that capture runoff, and then crops are planted on the receding edges of the storage bed itself, as evaporation causes the water to recede. Results of the study indicated that system was not reliable in the Flinders catchment, with sufficient runoff for irrigated cropping estimated to occur in only 42% of years.

The time frame of the Assessment did not permit on-ground research into irrigation systems. Consequently, a brief discussion of the above items is provided based on relevant literature from elsewhere in Australia and overseas. Table 5.8 summarises the broad range of efficiencies associated with each of the above components. These components are examined in more detail in sections 5.3.1 to 5.3.4.

The total conveyance and application efficiency of the delivery of water from the water storage to the crop is dependent upon the product of the four components listed in Table 5.8. For example if an irrigation development has a river conveyance efficiency of 80%, a channel distribution efficiency of 90%, an on-farm distribution efficiency of 90% and a field application efficiency of 85%, the overall efficiency is 55% (i.e. 80% * 90% * 90% * 85%). This means only 55% of all water released from the dam will be used by the crop.

Section 5.3.1 to Section 5.3.4 provide further detail on each of the efficiencies terms listed in Table 5.8.

Table 5.8 Summary of conveyance and application efficiencies

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>TYPICAL EFFICIENCY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>River conveyance efficiency</td>
<td>50 to 90%*</td>
</tr>
<tr>
<td>Channel distribution efficiency</td>
<td>50 to 95%</td>
</tr>
<tr>
<td>On-farm distribution efficiency</td>
<td>80 to 95%</td>
</tr>
<tr>
<td>Field application efficiency</td>
<td>60 to 90%</td>
</tr>
</tbody>
</table>

* River conveyance efficiency varies with a range of factors (including distance) and may be lower than the range quoted here. Under such circumstances, it is unlikely that irrigation would proceed. It is also possible for efficiency to be 100% in gaining rivers, but there are no gaining rivers in the Flinders catchment during the dry season (see Section 3.5.4).

** Achieving higher efficiencies requires a re-regulating structure (see Section 5.2.2).

5.3.1 RIVER CONVEYANCE EFFICIENCY

The conveyance efficiency of rivers is difficult to measure and even more difficult to predict. Although there are many methods for estimating groundwater discharge to surface water, there are few suitable methods for estimating the loss of surface water to groundwater. In the absence of existing studies for northern Australia, conveyance efficiency as nominated in Water Resource Plans and Resource Operation Plans for four irrigation water supply schemes in Queensland was examined collectively. The results are summarised in Table 5.9.

Water resource plans and resource operations plans prepared under the provisions of the Queensland Water Act 2000 define the allocation volumes and priority of supplies provided from each water supply scheme in a catchment. Additionally, the plans detail water sharing rules which determine the allocation to be provided in those years when the available supply is insufficient to provide the full volume of allocation. The determination in each case takes into account the volume of storage at the particular time and losses such as evaporation from storages and distribution and operational losses.
It should be noted that the conveyance efficiencies listed in Table 5.9 are from the water storage to the farm gate and that these are nominated efficiencies, based on experience delivering water in these supply schemes. These data can be used to estimate conveyance efficiency of rivers.

Table 5.9 Water distribution and operational efficiency as nominated in water resource plans for four irrigation water supply schemes in Queensland

<table>
<thead>
<tr>
<th>WATER SUPPLY SCHEME IN QUEENSLAND</th>
<th>TOTAL ALLOCATION VOLUME (ML)</th>
<th>RIVER AND CHANNEL CONVEYENCE EFFICIENCY* (%)</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burdekin Haughton</td>
<td>928,579</td>
<td>78%</td>
<td>The primary storage is the Burdekin Falls Dam (1860 GL), approximately 100 km upstream of Clare Weir, the major extraction point. The Bowen River, a major unregulated tributary of the Burdekin River, joins the Burdekin River downstream of Burdekin Falls Dam. This may assist in reducing transmission losses between the dam and Clare Weir.</td>
</tr>
<tr>
<td>Lower Mary</td>
<td>34,462</td>
<td>93.8%**</td>
<td>The Lower Mary irrigation area is supplied from two storages, a barrage on the Mary River and a barrage on Tinana Creek. Water is drawn directly from the barrage storages to irrigate land riparian to the streams. Water distribution is predominantly via pipelines.</td>
</tr>
<tr>
<td>Proserpine River</td>
<td>87,040</td>
<td>72%</td>
<td>The scheme has a single source of supply, Peter Faust Dam (491 GL). At various distances downstream of the dam, water is extracted from the river bed sands and is distributed to urban communities, several irrigation water supply boards and individual irrigators.</td>
</tr>
<tr>
<td>Upper Burnett</td>
<td>26,870</td>
<td>68%</td>
<td>The Upper Burnett is a long run of river scheme with one major storage (Wuruma Dam (165 GL)) and four weir storages. The total river length supplied by the scheme is 165 km.</td>
</tr>
</tbody>
</table>

* Ignores differences in efficiency between high and medium priority users and variations across the scheme zone areas.
** Channel conveyance efficiency only.

An analysis of streamflow data from across northern Australia as part of the Assessment did not identify any relationships that could be used to predict river conveyance efficiency. An analysis of a number of river reaches confirmed that the percentage loss of streamflow is higher for low streamflow values. Inflow from ungauged tributaries is one of the major confounding factors in trying to compute river conveyance efficiency between upstream and downstream gauging stations.

5.3.2 CHANNEL DISTRIBUTION EFFICIENCY

Across Australia, the average water conveyance efficiency from the river to the farm gate has been estimated to be 71% (Marsden Jacobs Associates, 2003). On the heavier textured soils found in the Flinders catchment (Section 3.3), and for well-designed irrigation distribution systems, conveyance efficiencies are likely to be higher.

In the absence of larger scheme-scale irrigation systems in the Flinders catchment, it is useful to look at the conveyance efficiency of existing irrigation developments in order to estimate the conveyance efficiency of irrigation developments in the catchment. Australian conveyance efficiencies are generally higher than those found in similarly sized overseas irrigation schemes (Bos and Nugteren, 1990). Therefore, Australian data should be used in preference.

The most extensive review of conveyance efficiency in Australia was undertaken by the Australian National Commission on Irrigation and Drainage, which tabulated system efficiencies across irrigation developments in Australia (ANCID, 2001). Conveyance losses were reported as the difference between the volume of water supplied to irrigation customers and the water delivered to the irrigation system. For example, if
10,000 ML of water is diverted to an irrigation district and 8,000 ML is delivered to irrigators, then the conveyance efficiency is 80% and the conveyance losses are 20%.

Figure 5.28 shows reported conveyance losses across irrigation areas of Australia between 1999 and 2000, along with the supply method used for conveying irrigation water and associated irrigation deliveries. There is a wide spread of conveyance losses both between years and across the various irrigation schemes. Factors identified by Marsden Jacob Associates (2003) which affect the variation include delivery infrastructure, soil types, distance that water is conveyed, type of agriculture, operating practices, infrastructure age, maintenance standards, operating systems, in-line storage, type of metering used and third-party impacts such as recreational, amenity and environmental demands. Differences across irrigation seasons are due to variations in water availability, operational methods, climate and customer demands.

Based on these industry data, Marsden Jacob Associates (2003) concluded that on average 29% of water diverted into irrigation schemes is lost in conveyance to the farm gate. However, some of this ‘perceived’ conveyance loss may be due to meter underestimation (about 5% of water delivered to provider (Marsden Jacob Associates, 2003)). Other losses were from leakage, seepage, evaporation, outfalls, unrecorded usage and system filling.

![Figure 5.28 Reported conveyance losses from irrigation systems across Australia (ANCID, 2001)](image)

The shape of the marker indicates the supply method for the irrigation scheme: square (•) indicates natural carrier, circle (●) indicates pipe, and diamond (♦) indicates channel. The colour of the marker indicates the location of the irrigation system (by state), as shown in the legend.

### 5.3.3 On-Farm Distribution Efficiency

On-farm losses are losses that occur between the farm gate and delivery to the field. These losses usually take the form of evaporation and seepage from on-farm storages and delivery systems. Even in irrigation developments where water is delivered to the farm gate via a channel, many farms have small on-farm storages (i.e. less than 250 ML for a 500 ha farm). These on-farm storages enable the farmer to have a reliable supply of irrigation water with a higher flow rate, and also enable recycling of tailwater. Several studies have been undertaken in Australia on on-farm distribution losses. Meyer (2005) estimated an on-farm distribution efficiency of 78% in the Murray and Murrumbidgee regions, while Pratt Water (2004) estimated on-farm efficiency to be 94% and 88% in the Coleambally Irrigation and Murrumbidgee Irrigation areas respectively. On nine farms in these two irrigation regions, however, Akbar (2000) measured channel seepage to be less than 5%.
5.3.4 FIELD APPLICATION EFFICIENCY

Once water is delivered to the field, it needs to be applied to the crop using an irrigation system. The application efficiency of irrigation systems typically varies between 60% and 90%, with more expensive systems usually resulting in higher efficiency.

There are three types of irrigation systems that can potentially be applied in the Flinders catchment: surface irrigation, spray irrigation and micro irrigation (Figure 5.29). Irrigation systems applied in the Flinders catchment need to be tailored to the soil, climate and crops that may be grown in the catchment and matched to the availability of water for irrigation. This is taken into consideration in the land suitability assessment figures presented in Section 5.5. System design will also need to consider investment risk in irrigation systems as well as likely returns, degree of automation, labour availability, and maintenance and operation costs (e.g. the cost of energy).

Irrigation systems have a trade-off between efficiency and cost. Table 5.10 summarises the different types of irrigation systems, including their application efficiency, indicative cost and their limitations. Across Australia the ratio of areas irrigated using surface, spray and micro is 83:10:7, respectively. Irrigation systems that allow water to be applied with greater control, such as micro, cost more (Table 5.10) and as a result are typically used for irrigating higher value crops such as horticulture and vegetables. For example, although only 7% of Australia’s irrigated area uses micro irrigation, it generates about 40% of the total value of produce produced by irrigation (Meyer, 2005). Further detail on the three types of irrigation systems follows Table 5.10.

(a) (b) (c)

Figure 5.29 Efficiency of different types of irrigation systems
(a) In bankless channel surface irrigation systems, application efficiencies range from 60 to 85%. (b) In spray irrigation systems, application efficiencies range from 75 to 90%. (c) For pressurised drip irrigation systems on polymer-covered beds, application efficiencies range from 80 to 90%. Photos: CSIRO.
Table 5.10 Application efficiencies for surface, spray and micro irrigation systems

Application efficiency is the efficiency with which water can be delivered from the edge of the field to the crop.

<table>
<thead>
<tr>
<th>IRRIGATION SYSTEM</th>
<th>TYPE</th>
<th>APPLICATION EFFICIENCY (%)</th>
<th>CAPITAL COST ($/ha)*</th>
<th>LIMITATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>Basin</td>
<td>60 to 85%</td>
<td>$3400</td>
<td>Suitable for most crops; topography and surface levelling costs may be limiting factor</td>
</tr>
<tr>
<td>Border</td>
<td>60 to 85%</td>
<td>$3400</td>
<td></td>
<td>Suitable for most crops; topography and surface levelling costs may be limiting factor</td>
</tr>
<tr>
<td>Furrow</td>
<td>60 to 85%</td>
<td>$3400</td>
<td></td>
<td>Suitable for most crops; topography and surface levelling costs may be limiting factor</td>
</tr>
<tr>
<td>Spray</td>
<td>Centre pivot</td>
<td>75 to 90%</td>
<td>$2500 to $5500</td>
<td>Not suitable for tree crops; high energy requirements for operation</td>
</tr>
<tr>
<td>Lateral move</td>
<td>75 to 90%</td>
<td>$2500 to $5000</td>
<td></td>
<td>Not suitable for tree crops; high energy requirements for operation</td>
</tr>
<tr>
<td>Micro</td>
<td>Drip</td>
<td>80 to 90%</td>
<td>$6000 to $9000</td>
<td>High energy requirement for operation; high level of skills needed for successful operation</td>
</tr>
</tbody>
</table>

Adapted from Hoffman et al. (2007), Raine and Bakker (1996) and Wood et al. (2007).

* Source: DEEDI (2011a, b, c).

Surface irrigation systems

Surface irrigation encompasses basin, border strip and furrow irrigation, as well as variations on these themes such as bankless channel systems. In surface irrigation, water is applied directly to the soil surface with check structures (banks or furrows) used to direct water across a field. Control of applied water is dictated by the soil properties, soil uniformity and the design characteristics of the surface system. Generally, fields are prepared by laser levelling to increase the uniformity of applied water and allow ease of management of water and adequate surface drainage from the field. The uniformity and efficiency of surface systems are highly dependent on the system design and soil properties, timing of the irrigation water, and the skill of the individual irrigator in operating the system. Mismanagement can severely degrade system performance and lead to systems which operate at poor efficiencies.

Surface irrigation has the benefit that it can generally be adapted to almost any crop and usually has a lower capital cost compared with alternative systems. Surface irrigation systems perform better when soils are of uniform texture as infiltration characteristics of the soil play an important part in the efficiency of these systems. Therefore, surface irrigation systems should be designed into uniform soil management units and layouts (run lengths, basin sizes) tailored to match soil characteristics and water supply volumes.

High application efficiencies are possible with surface irrigation systems, provided soil characteristic limitations, system layout, water flow volumes and high levels of management are applied. On ideal soil types and with systems capable of high flow rates, efficiencies can be higher than 85%. On poorly designed and managed systems on soil types with high variability, efficiencies can be below 60% (Table 5.10).

The major cost in setting up a surface irrigation system is generally land grading and levelling, with costs directly associated with the volume of soil that must be moved. Typical earth moving volumes are in the order of 800 m$^3$/ha but can exceeded 2500 m$^3$/ha. Volumes greater than 1500 m$^3$/ha are generally considered excessive due to costs (Hoffman et al., 2007).

Surface irrigation systems are the dominant form of irrigation systems used throughout the world. Their potential suitability in the Flinders catchment would be due to their generally lower setup costs and adaptability to a wide range of irrigated cropping activities. They are particularly suited to the heavier textured soils (e.g. black vertosols) which are found extensively in the Flinders (Bartley et al., 2013) and areas in the Flinders which have small natural topographical changes in elevation that reduce setup or establishment costs of these systems. With surface irrigation, little or no energy is required to distribute
water throughout the field and this ‘gravity-fed’ approach reduces energy requirements of these systems (Table 5.11).

Surface irrigation systems generally have lower water use efficiency than spray or micro systems when compared across an industry and offer less control of applied water; however, well-designed and -managed systems can approach efficiencies found with alternative irrigation systems in ideal conditions.

**Spray irrigation systems**

In the context of the Flinders catchment, spray irrigation refers specifically to lateral move and centre pivot irrigation systems. Centre pivot systems consist of a single sprinkler, laterally supported by a series of towers. The towers are self-propelled and rotate around a central pivot point, forming an irrigation circle. Time taken for the pivot to complete a full circle can range from as little as half a day to multiple days depending on crop water demands and application rate of the system. Generally, lateral spans are less than 500 m.

Lateral or linear move systems are similar to centre pivot systems in construction but rather than move around a pivot point the entire line moves down the field in a direction perpendicular to the lateral. Water is supplied by a lateral channel running the length of the field. Lateral lengths are generally in the range of 800 to 1000 m. They offer the advantage over surface systems in that they can be utilised on rolling topography and generally require less land forming.

Both centre pivot and lateral move irrigation systems have been extensively used for irrigating a range of annual broadacre crops and are capable of irrigating most field crops. They are generally not suitable for tree crops or vine crops or for saline irrigation water applications in arid environments which can create foliage damage. Centre pivot and lateral move systems usually have higher capital costs but are capable of very high efficiencies of water application. Generally, application efficiencies for these systems range from 75 to 90% (Table 5.10). They are used extensively for broadacre irrigated cropping situations in high evaporative environments in northern New South Wales and south-west Queensland. These irrigation developments have high irrigation crop water demand requirements, which are similar to those found in the Flinders catchment. A key factor in the suitable use of spray systems is sourcing the energy needed to operate these systems, which are usually powered by electricity or diesel depending on costs and infrastructure available. Where available, electricity is considerably cheaper than diesel at powering spray systems (Table 5.11).

In moving to pressurised systems such as spray or micro systems, the water can be more easily controlled, and potential benefits of the system through fertigation (application of crop nutrients through the irrigation system, i.e. liquid fertiliser) are also available to the irrigator.

**Micro irrigation systems**

For high-value crops in the Flinders, such as horticultural crops, where yield and quality parameters dictate profitability, drip irrigation systems should be considered suitable across the range of soil types and climate conditions found in the Flinders.

Micro (drip) irrigation systems use thin-walled polyethylene pipe to apply water to the root zone of plants via small emitters spaced along the drip tube. These systems are capable of precisely applying water to the plant root zone, thereby maintaining a high level of irrigation control and water use efficiency. Historically, drip irrigation systems have been extensively used in tree, vine and row crops, with limited applications in complete cover crops such as grains and pastures due to the expense of these systems. Drip irrigation is suitable for most soil types and can be practised on steep slopes. Drip irrigation systems are generally of two varieties: above ground and below ground (where the drip tape is buried beneath the soil surface). Below-ground drip systems offer advantages in reducing evaporative losses and improving trafficability. However, below-ground systems are more expensive and require higher levels of expertise to manage.

Properly designed and operated drip irrigation systems are capable of very high application efficiencies, with field efficiencies of 80 to 90% (Table 5.10). In some situations, drip systems offer water and labour savings and improved crop quality (i.e. more marketable fruit through better water control). Management
of drip irrigation systems, however, is critical. To achieve these benefits requires a much greater level of expertise than other traditional systems such as surface irrigation systems which generally have higher margins of error associated with irrigation decisions. Drip systems also have high energy requirements, with most systems operating at pressure ranges from 135 to 400 kPa with diesel or electric pumps most often used (Table 5.11).

5.3.5 IRRIGATION SYSTEM COSTS

The capital costs for surface irrigation reported in Table 5.10 include earthworks for a supply channel, head ditch, field land forming, and drainage (including tailwater return), as well as pumps and structures. Mason and Larard (2011) reported capital costs for surface (furrow) irrigation in the Flinders catchment to be $1482/ha. This is considerably less than the $3400/ha reported for surface irrigation in Table 5.10; however, the calculation of Mason and Larard (2011) omitted expensive items such as laser levelling (which costs between $300 and $650/ha (DEEDI, 2011a)) and tailwater return ($580/ha (DEEDI, 2011a)). These items significantly increase the capital cost of surface irrigation.

The capital costs associated with the purchase of a centre pivot or lateral move in Table 5.10 include the purchase of the machine and installation costs, such as earthworks. In addition to the cost of the machine, Table 5.10 includes the capital cost of other items such as pipe work, pumping equipment and the power plant (either diesel or electric). The unit cost ($/ha) of both centre pivots and lateral moves is generally less for machines servicing a larger area. The most significant influence on machine price is the pipe diameter of spans (DEEDI, 2011b). As for surface irrigation, other site-specific capital costs could include power lines (and connection), supply channels, laser levelling, land clearing and road construction. Laser levelling and land forming are often limited to cut to drain as opposed to cut to grade. These additional items can add up to 50% of the system cost (DEEDI, 2011b). Mason and Larard (2011), in a report conducted in the Flinders catchment, estimated capital costs of pivot irrigation at approximately $4470/ha (which is in the range provided in Table 5.10), with $3800/ha for the centre pivot systems, and earthworks averaging around $670/ha.

Ongoing operational costs for all systems include pumping costs and general maintenance. Operation and maintenance of irrigation equipment is often costed at about 2% of the capital cost (Neil MacLeod, pers. comm.). These irrigation systems have various trade-offs between capital, operating and labour requirements. An important consideration in selecting an irrigation system is energy requirements, and this may become a more important consideration in the future if energy prices rise. Table 5.11 shows the variation in pumping costs for diesel and electricity for different irrigation systems. In addition, there are trade-offs between these costs and efficiency factors. Surface irrigation systems, for example, tend to have lower capital and annual operating costs, but are less efficient with higher water losses (Table 5.10).

Table 5.11 Pumping costs by irrigation type

<table>
<thead>
<tr>
<th>UNIT</th>
<th>FLOOD HARVESTING</th>
<th>SURFACE IRRIGATION</th>
<th>TAILWATER RETURN</th>
<th>CENTRE PIVOTS</th>
<th>LATERAL MOVES</th>
<th>SUBSURFACE Drip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate</td>
<td>ML/day</td>
<td>120</td>
<td>120</td>
<td>50</td>
<td>8.6</td>
<td>24.2</td>
</tr>
<tr>
<td>Total dynamic head</td>
<td>m</td>
<td>7</td>
<td>6</td>
<td>5.5</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>Pumping plant efficiency</td>
<td>%</td>
<td>50%</td>
<td>50%</td>
<td>50%</td>
<td>66%</td>
<td>66%</td>
</tr>
<tr>
<td>Power required</td>
<td>kWh/ML</td>
<td>38.9</td>
<td>33.3</td>
<td>30.6</td>
<td>210.4</td>
<td>147.3</td>
</tr>
<tr>
<td>Specific fuel consumption</td>
<td>L/kWh</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Equivalent diesel requirement</td>
<td>L/ML</td>
<td>9.7</td>
<td>8.3</td>
<td>7.6</td>
<td>52.6</td>
<td>36.8</td>
</tr>
<tr>
<td>Pumping cost, electricity</td>
<td>$/ML</td>
<td>7.0</td>
<td>6.0</td>
<td>5.5</td>
<td>37.9</td>
<td>26.5</td>
</tr>
<tr>
<td>Pumping cost, diesel</td>
<td>$/ML</td>
<td>10.9</td>
<td>9.3</td>
<td>8.5</td>
<td>58.9</td>
<td>41.2</td>
</tr>
</tbody>
</table>

Adapted from Culpitt (2011), with costs based on assumption of $1.12/L for diesel ($1.50/L less $0.38/L rebate) and $0.18/kWh for electricity.
5.3.6 IRRIGATION SUPPLY WATER QUALITY CONSIDERATIONS

Water quality for irrigation will need to be carefully considered in any potential development and has an effect on irrigation system suitability and also potentially on water demands. Increased leaching fractions are needed if water quality is extremely poor, i.e. high levels of soluble salts are applied through irrigation water. Water quality data is sparse for the Flinders catchment so it is difficult to draw conclusions on likely water quality from proposed developments. From the limited data available <http://watermonitoring.dnrm.qld.gov.au/host.htm> it would appear that existing water salinity measurements at gauging stations are generally below 0.75 dS/m and would be classified as a ‘non to low’ problem severity, see Table 5.12.

Table 5.12 lists other potential issues related to water quality and specifically to micro irrigation systems that will need to be considered when selecting appropriate irrigation systems for the Flinders catchment. Without further detailed measurements of water quality parameters it is difficult to draw conclusions on the potential for clogging and specific ion toxicity problems within the catchment. However, potential irrigation developments will need to be aware of potential irrigation supply water quality issues that could limit irrigation system suitability in specific cases.

### Table 5.12 Water quality limitations for micro irrigation systems (from Ayers and Westcott, 1985)

<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>RELATED CONSTITUENTS</th>
<th>UNIT</th>
<th>NON TO LOW</th>
<th>PROBLEM SEVERITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SLIGHT TO</td>
</tr>
<tr>
<td>Clogging</td>
<td>pH</td>
<td></td>
<td>&lt;7.0</td>
<td>7.0–8.0</td>
</tr>
<tr>
<td></td>
<td>Manganese</td>
<td>ppm</td>
<td>&lt;0.1</td>
<td>0.1–1.5</td>
</tr>
<tr>
<td></td>
<td>Iron</td>
<td>ppm</td>
<td>&lt;0.2</td>
<td>0.2–1.5</td>
</tr>
<tr>
<td></td>
<td>Hydrogen sulphide</td>
<td>ppm</td>
<td>&lt;0.2</td>
<td>0.2–2.0</td>
</tr>
<tr>
<td></td>
<td>Suspended solids</td>
<td>ppm</td>
<td>50</td>
<td>50–100</td>
</tr>
<tr>
<td></td>
<td>Bacterial population</td>
<td>Count per mL</td>
<td>&lt;10,000</td>
<td>10,000–50,000</td>
</tr>
<tr>
<td>Crop sensitivity</td>
<td>Electrical conductivity*</td>
<td>dS/m or mmho/cm</td>
<td>&lt;0.75</td>
<td>0.75–3.0</td>
</tr>
<tr>
<td></td>
<td>Nitrate-Nitrogen</td>
<td>ppm</td>
<td>&lt;5</td>
<td>5–30</td>
</tr>
<tr>
<td>Specific ion toxicity</td>
<td>Boron</td>
<td>ppm</td>
<td>&lt;0.7</td>
<td>0.7–3.0</td>
</tr>
<tr>
<td></td>
<td>Chloride</td>
<td>meq/L</td>
<td>&lt;4</td>
<td>4–10</td>
</tr>
<tr>
<td></td>
<td>Chloride</td>
<td>ppm</td>
<td>&lt;142</td>
<td>142–355</td>
</tr>
<tr>
<td></td>
<td>Sodium</td>
<td>Adjusted sodium adsorption ratio**</td>
<td>&lt;3.0</td>
<td>3.0–9.0</td>
</tr>
<tr>
<td>Infiltration***</td>
<td>Adjusted sodium adsorption ratio**</td>
<td>Electrical conductivity of irrigation water</td>
<td>≥0.7</td>
<td>0.7–0.2</td>
</tr>
<tr>
<td>0–3</td>
<td></td>
<td></td>
<td>≥1.2</td>
<td>1.2–0.3</td>
</tr>
<tr>
<td>3–6</td>
<td></td>
<td></td>
<td>≥1.9</td>
<td>1.9–0.5</td>
</tr>
<tr>
<td>6–12</td>
<td></td>
<td></td>
<td>≥2.9</td>
<td>2.9–1.3</td>
</tr>
<tr>
<td>12–20</td>
<td></td>
<td></td>
<td>≥5.0</td>
<td>5.0–2.9</td>
</tr>
<tr>
<td>20–40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Total dissolved solids in ppm (approximately) = 640 x EC (dS/m or mmho/cm).
** Adjusted sodium adsorption ratio: calculated based on concentrations of sodium, calcium, magnesium and bicarbonate to account for dissolution of calcium carbonate from the soil or precipitation of calcium carbonate from the water.
*** Affects infiltration rate of water into the soil. Evaluate using ECiw and Adj SAR together.
5.3.7 BEST MANAGEMENT PRACTICES FOR IRRIGATION SYSTEMS

Best management practices for the use of irrigation water can assist in increasing the efficiency and productivity of irrigation systems and help reduce or minimise off-site environmental impacts associated with irrigation systems. Generally, individual farms are unique in their biophysical characteristics and irrigation systems must be developed that are suitable for specific irrigation operations matching the soil, climate, water availability and crop needs. Irrigation best management practices include consideration of irrigation systems, irrigation scheduling, equipment operation, land levelling, tailwater and runoff recovery, tillage and residue management, and pesticide use, management and safety. Within the Flinders catchment, water availability will be the limiting factor in irrigation development; hence efforts to adopt best practice irrigation management and focus on achieving high water use productivity will have the greatest benefit to the catchment. The supply and use of water for irrigation farming purposes is a complex activity that requires high levels of knowledge and expertise to achieve successful outcomes in terms of both farm profitability and minimising non-beneficial effects on surrounding environments. As such, with any irrigation development on greenfield sites, research, development and extension support networks should be developed. The community can use these networks to address potential issues as they arise and also ensure best management practices are being applied to maximise profitability for irrigators and minimise any off-site environmental impacts.

5.4 Land development for irrigation

Construction costs for an irrigation scheme comprise those associated with channels, drains, roads, siphons, regulating points, road and culvert crossings, road and rail boring, metered outlets, drainage inlets, and overflow and drainage structures. On-farm developments are excluded from scheme costs. Costs will be driven by the length of channels, drains and roads, and depend on the location and catchment size, and design capacity of the channel.

Costs for a notional scheme layout for the O’Connell Creek were reported by SunWater (2009). The development, which assumed broad-scale gravity irrigation for about 7000 ha of development, estimated the construction at $14,168/ha (adjusted to 2012 values) with approximately half of the cost represented by direct costs (earthworks, structures and roads for the supply channel and area works), and the remaining half made up of contractor and project overhead costs, which are calculated as a percentage of direct costs. Taking out the costs of the supply channel (20% of total costs), the development is approximately $8000/ha (adjusted to 2012 values) which was reported as being consistent with similar developments.