5 Opportunities for irrigation in the Gilbert 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.

Figure 5.1 Schematic diagram of key engineering and agricultural components to be considered in the establishment of a greenfield irrigation development
5.1 Summary

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

There is currently limited cropping in the Gilbert catchment – there is no dryland production for human food or fibre and less than 400 ha of irrigated production. The catchment has the theoretical potential to produce around 7 million tonnes of grain per year with a gross value of over $1.8 billion.

5.1.1 SOIL SUITABILITY

More than 2 million ha of the Gilbert 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 Gilbert catchment has a highly variable climate and potential evaporation rates that typically exceed rainfall by a factor of 2.4. In the absence of suitable groundwater, water storages are essential to enable irrigation during the dry season. Large, instream dams are the most promising water storage options in the Gilbert catchment. Several potential dam sites in the Gilbert catchment combine suitable topography and geology with sufficient water yield and proximity to suitable soils for irrigation. These are sites on the Einasleigh River at Dagworth station and the Gilbert River immediately downstream of Green Hills station; another option is to upgrade the existing dam upstream of Kidston Dam (officially known as the Copperfield River Gorge Dam, but referred to in the Assessment as Kidston Dam). The Green Hills site is promising for its proximity (around 15 km) to suitable areas for irrigation. The soils adjacent to the Gilbert and Einasleigh rivers are highly permeable, making offstream storage challenging.

5.1.3 DRYLAND CROPPING

A wide range of crops is potentially suited to dryland production in the Gilbert catchment. Break-even yields could be expected more than nine years in ten for short-season dryland crops such as mungbean and lablab, approximately three years in ten for dryland crops such as sorghum (grain) and sugarcane, and fewer than two years in ten for dryland cotton and maize.

High rainfall variability, combined with low soil water storage, 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 2 million ha of suitable arable soil in the Gilbert catchment were, for example, devoted to dryland sorghum (grain), median potential regional production of around 7.6 million tonnes and a gross value of production of $1748 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 Gilbert catchment than there is water to irrigate it. If the most promising six instream storages were to exist, it would be possible to irrigate a maximum of approximately 4% of the catchment’s suitable soils.
If this irrigation water (estimated to be approximately 250 GL from two potential dams alone, after evaporation, seepage, conveyance and field application losses) were, for example, devoted to irrigated sorghum (grain) production, there would be potential to produce 500,000 tonnes of grain over 70,000 ha, and with a gross value of around $130 million. Actual yields and areas sown would probably be lower and would vary significantly from year to year.

The volume of water available for irrigation will also 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 Gilbert 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 Gilbert catchment using an automated process. This process, supported by field investigation, identified numerous new potentially suitable dam sites and confirmed the relative potential of some previously proposed dam locations, such as Green Hills. The most notable of these was Dagworth, a previously undocumented potential site on the lower Einasleigh River that had a larger yield and was closer to suitable soil than previously identified dam sites on the Einasleigh River. Three dam sites were short-listed for further analysis. These entailed the existing Kidston Dam, and the construction of dams at Dagworth station and immediately downstream of Green Hills station. The construction of dams at these locations is estimated to cost between $1500 and $2000 per ML of water supplied in 85% of years. These dams have an equivalent annual unit cost per ML of water supplied in 85% of years of between $100 and $140, which is considerably less than the equivalent annual unit cost per ML of effective offstream storage (i.e. after accounting for evaporation and seepage losses from the offstream storage) of at least $140 and $240, storing water for 4 and 12 months of the year respectively. The Gilbert River does not have many locations suitable for offstream storages due to its highly permeable soils and substrata. In select locations the soils adjacent to the Einasleigh River may be suitable for offstream storages.

Overview

Section 5.1 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 is typically used to supply water to broad-scale irrigation schemes such as those common in southern Australia, while the latter is 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. 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 Gilbert catchment. It starts with an introduction to large dams, examines the potential for large dams across the Gilbert catchment discusses ecological, sedimentation and cultural considerations and provides summary information for seven potential dam sites in the Gilbert catchment. An assessment of the cost and cumulative water yield from multiple dams in the Gilbert 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 Gilbert catchment. This section contains information on the reliability at which different quantities of water can be extracted from selected rivers of the Gilbert catchment, presents information on the likely suitability of the soils of the Gilbert catchment for offstream storages, and discusses evaporative and seepage losses and possible capital, operation and maintenance costs of offstream storages in the Gilbert 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. Large dams also better enable year round use of irrigation developments (e.g. two crops can be planted in a year instead of one) resulting in higher returns per hectare, making it more likely the investor will break even on land development costs.

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

#### Embankment dams

Embankment dams (EB) are usually the most economical (provided that suitable construction materials can be found locally) and are best suited to smaller catchment areas where the spillway capacity requirement is small, such as at the Belmore Creek 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 Gilbert 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.

Potential dam sites in the Gilbert catchment occur in erosion resistant units of the Etheridge Province (a province is an area in which geological history has been the same), the Kennedy Province, and where resistant granite intrusions occur (Figure 3.2).

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

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

Six potential locations were identified from published and unpublished literature accessed from the Queensland Government and SunWater archives. The extent of prior investigations ranged from a single reference of potential locations (e.g. Mount Alder and Mount Noble) to moderately detailed hydrological and geotechnical investigations (e.g. Green Hills). A difficulty in comparing the outcomes of these studies was that they were undertaken by a range of organisations, at different points in time, using different
methods and to varying degrees of rigour. 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 undertake a preliminary assessment of over 100,000 potential dam sites in the Gilbert catchment. This model uses a series of algorithms that automatically locate and assess favourable topographic and hydrological locations in the landscape as sites for intermediate to large water storages. The DamSite model identified numerous locations for siting dams in the Gilbert catchment. The better sites are shown in Figure 5.3.

The only new potential dam sites that were investigated further were those identified by the DamSite model that had higher water yields, were situated in geologically favourable formations, and were more favourably located than known potential dam sites. The most notable of these was Dagworth, a previously undocumented potential site on the lower Einasleigh River. In many cases, the DamSite model confirmed the relative potential of known potential dam locations, such as Green Hills and Mount Noble. In other cases it demonstrated that known dam site locations were topographically and hydrologically inferior to other nearby locations (e.g. North Head). The most favourable sites at seven potential dam locations in the Gilbert are summarised in Table 5.1 and a short comment provided in Table 5.2. Three potential dam sites in the Gilbert catchment were selected for further analysis because they were deemed to be the most likely site to proceed in three distinct geographical areas. The assessment of the three most promising sites was based on expert knowledge and primarily took into consideration topography of the dam axis, geological conditions, proximity to suitable soils, and water yield. The short-listed sites entailed raising the existing Kidston Dam, and potential dams at Dagworth and Green Hills. The Dagworth site had not been previously identified. As part of the Assessment, the majority of sites were visited by an experienced infrastructure planner and engineering geologist.
Ecological considerations

For instream ecology, dam walls acts as a barrier to movements of plants, animals and energy, potentially disrupting connectivity of populations and ecological processes. Some of the potential dam sites in the Gilbert catchment (e.g. Green Hills, Dagworth and Mount Noble) are likely to obstruct the movement of barramundi and freshwater sawfish.

The water impounded by a dam inundates an area of land, drowning not only instream habitat but surrounding flora and fauna communities. Despite the majority of the Gilbert catchment containing regional ecosystems that are ‘not of concern’ (~74%) (Figure 4.6), the majority of potential dam sites in the catchment inundate 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.

The inundation areas for the majority of potential dam sites in the Gilbert catchment contain some regional ecosystems considered to be either ‘endangered’ or ‘of concern’.

There are thousands of studies linking water flow with nearly all the various elements of instream ecology in freshwater systems (e.g. Robins et al., 2005). Dams also create a large, deep lake, a habitat 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 issues. 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 42 fish species are known from the Gilbert catchment (see companion technical report about waterhole ecology (Waltham et al., 2013)). The gradient of declining numbers of fish species with increasing distance from the ocean, so widely recognised in other catchments, is not clear here due to a lack of survey effort and data availability in the lower reaches, where the greatest diversity is to be expected. Available records for barramundi, freshwater sawfish and the freshwater whipray are scant, although both barramundi and sawfish are likely to occur further upstream than the currently available records suggest, and thus intersect with some potential dam sites. In the Gilbert catchment, freshwater sawfish are likely to be able to penetrate upstream of the Green Hills site on the Gilbert River and possibly as far as, or at least near to, the Mount Noble site on the Einasleigh River.

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 seven potential dams examined in the Gilbert catchment, 71% are estimated to have between 1.2% and 6.3% sediment infilling after 30 years and between 4% and 21% 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 2.5% to 17% after 30 years and 8% to 56% after 100 years for 71% of dams. For the remaining dams, Mt Noble is estimated to have greater than 50% sediment infilling after 100 years (most likely), and Mt Adler is estimated to have completely filled (100%) within 100 years. Under the worst case scenario, both dams are estimated to have completely infilled within 100 years.

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 (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, potentially 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 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 Gilbert 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.

Certainly the Gilbert 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 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 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 Gilbert 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**

Cost estimates for Green Hills dam undertaken as part of the Assessment are comparable to cost estimates undertaken by past studies (i.e. within 5%). However, previous cost estimates for Green Hills dam did not account for the additional saddle dam requirement identified by the Assessment. Cost estimates for other potential dam sites in the Gilbert catchment were not undertaken prior to the Assessment.

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

**Summary of potential dams assessed in the Gilbert catchment**

Table 5.1 and Table 5.2 provide summaries of potential dams assessed in the Gilbert 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 over 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. Studies at that level of detail are beyond the scope of this regional scale resource assessment.
Table 5.1 Potential dams assessed in the Gilbert catchment
At some locations, up to three alternative sites were assessed. For these locations, the most suitable alternative site is reported.

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

* Conventional concrete (CC), embankment dam (EB), roller compacted concrete dam (RCC). The existing Kidston Dam is a RCC dam but it would be raised using CC.
** The height of the dam abutments will be higher than the spillway height.
*** Water yield is based on 85% annual time-based reliability using a perennial demand pattern for the baseline river model under Scenario A. This is yield at the dam wall (i.e. does not take into account distribution losses or downstream transmission losses). These yield values do not take into account downstream existing entitlement holders or environmental considerations.
# Indicates preliminary cost estimate based on schedule of quantities estimated by McIntyre and Associates (1998). This includes raising of the dam and diversion infrastructure. □ Indicates preliminary cost estimate is likely to be –10% to +30%. △ Indicates preliminary cost estimate is likely to be –10% to +50%. Should site geotechnical investigations reveal unknown unfavourable geological conditions, costs could be substantially higher. Operation and maintenance costs are typically about 0.4% of the capital cost.
## This is the unit cost of annual water supply and is calculated as the capital cost divided by the water yield at 85% annual time reliability.
### Assuming a 7% real discount rate and a dam life of 100 years. Capital cost only. Does not include operation and maintenance costs.
^ Existing Kidston Dam capacity is 20 GL and annual water yield at 85% time reliability is 15 GL.
Table 5.2 Summary comments for potential dams in the Gilbert catchment

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

<table>
<thead>
<tr>
<th>DAM NAME</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bundock Creek</td>
<td>Very remote and low water yield. To increase the water yield water could be diverted from the upper Einasleigh River. This would be a very expensive option.</td>
</tr>
<tr>
<td>Dagworth</td>
<td>Large catchment and highest water yield of potential dam sites assessed in Gilbert catchment. The right bank saddle dam embankment adopted crest level was set to contain the 1:1000 Annual Exceedance Probability (AEP) flood event. Best potential dam site on Einasleigh River, but is still a moderate distance upstream of moderately suitable soils.</td>
</tr>
<tr>
<td>Green Hills</td>
<td>Large catchment and highest water yield of potential dam site on Gilbert River. Close to moderately suitable soils. Crest level of saddle dam No. 2 on the left bank would be set to contain the 1:1000 AEP flood event and crest level of saddle dam No. 3 set 0.5 m higher. In the event of larger flood events, the saddle dams would erode out increasing the total discharge capacity.</td>
</tr>
<tr>
<td>Raising Kidston Dam</td>
<td>Raising existing dam by 2 m. One of the more potentially viable options in the Gilbert catchment. Small water yield and moderate distance upstream of moderately suitable land.</td>
</tr>
<tr>
<td>Mt Alder</td>
<td>Low storage capacity. Relatively high risk of sediment infill. Long distance upstream of moderately suitable land.</td>
</tr>
<tr>
<td>Mt Noble</td>
<td>Effected by basalt flows which limits dam height and may act as leakage path under the dam. Long distance upstream of moderately suitable soils (Figure 5.4).</td>
</tr>
<tr>
<td>North Head</td>
<td>Remote. Long distance upstream of large areas of moderately suitable soils.</td>
</tr>
</tbody>
</table>

Figure 5.4 Mount Noble range looking upstream along Einasleigh River
Photo: CSIRO.
**The total divertible yield in the Gilbert catchment**

The total divertible yield, before losses, from six of the most promising dam sites in the Gilbert catchment is about 630 GL in 85% of years. Divertible yield is the amount of water than can be released annually from one or more storages in a controlled manner.

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

In Figure 5.5a the water yield from each dam was calculated at 85% annual time reliability at the dam wall. In Figure 5.5b the water yield from each dam was calculated at 85% annual time reliability and a 30% loss was applied to the water yield to approximate the loss of water that occurs during conveyance between the dam wall and the farm gate (Section 5.3). Given the distance between many of the dams in the Gilbert catchment and suitable soil, a 30% loss is likely to be conservative. It is important to note that these estimates of divertible yield take into consideration evaporation losses, and seasonality and inter-annual variability in streamflow. They do not, however, take into account environmental, social, cultural or economic factors or existing water users.

![Figure 5.5 Cost of water in $/ML versus cumulative divertible yield at 85% annual time reliability](image)

(a) At dam wall. (b) At farm gate. Cost based on capital cost of dam only, does not include cost of diversion or irrigation scheme infrastructure. A 30% loss between dam wall and farm gate is assumed. Dots indicate combined water yield at 85% annual time reliability of one or more dams, with the colour of the dot indicating the most recently included dam in the cumulative yield calculation. For example, Dagworth has a yield at the dam wall of 326 GL; Dagworth and Green Hills have a cumulative yield of 498 GL. Dam locations are shown in Figure 5.3. Squares indicate existing dams, triangles indicate potential dams.

Figure 5.5 illustrates that with the addition of more dam sites, the construction cost per ML of yield increases considerably with the third and subsequent dams. This is in part because i) each subsequent potential dam site is less favourable than its predecessor; and ii) in those instances where a dam is constructed upstream of an existing dam, their combined yield is less than the sum of their individual yields because the upstream dam reduces inflows to the downstream dam. An example of this is provided with the addition of Mount Alder on the Einasleigh River in addition to dams at Kidston, Mount Noble and Dagworth. The effect of adding a dam at Mount Alder reduces the inflows to Mt Noble and Dagworth dams downstream such that their combined yield (at 85% reliability) is reduced by 25 GL, yet the Mount Alder dam only contributes an additional yield of 35 GL to the system.

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

**Three short-listed potential dam sites in the Gilbert catchment**

The three short-listed sites are provided in alphabetical order. These sites are deliberately situated in three distinct geographic areas. This decision was based on cost of construction, yield and proximity to moderately suitable soil. The short-listed dams are presented in alphabetical order.

**Raising Kidston Dam**

Kidston Dam is an existing dam located in the upper reaches of the Gilbert catchment (Figure 5.6). There is currently potential to release 15 GL of water from the dam in 85% of years. Raising the dam wall by 2 m could supply 17 GL at the dam wall in 85% of years. A limitation of the dam is that it is about 70 km upstream from the town of Einasleigh, the nearest large area of moderately suitable soils. This is likely to result in large transmission losses between the dam and Einasleigh. As this is an existing reservoir, raising the dam wall carries low risk because the geology is known and there would be minimal additional ecological or social impacts.

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

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

The capital cost for a 2 m raising of the dam and diversion infrastructure is estimated to be $34 million, based on a schedule of quantities estimated by McIntrye and Associates (1998). Annual operating and maintenance costs for the dam should be relatively low given the type of raising suggested. No allowance has been made in the dam estimate for the cost of a fish transfer facility on the basis that the existing barrier has been in place for nearly 30 years and as a result there has been no movement of native fish from downstream of the dam into the reservoir during that time. If a fish transfer facility were required, the capital cost would increase by at least $5 million.

Figure 5.7a shows a cross-section of the ground surface along the dam axis and Figure 5.7b illustrates the relationship between dam height, reservoir volume and reservoir surface area.

Figure 5.8 illustrates the extent of inundation of the reservoir created by raising Kidston Dam by 2 m. The potentially enlarged reservoir does not inundate adjacent properties.
Figure 5.6 Kidston Dam looking upstream
Photo: CSIRO.

Figure 5.7 Dam cross-section, height, volume and reservoir surface area for Kidston Dam
(a) Cross-section of ground surface along dam axis, looking downstream. (b) Relationship between dam height, reservoir volume and reservoir surface area.
Figure 5.8 Raised Kidston Dam extent of inundation and property boundaries (indicated by coloured shading)

Figure 5.9a 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 total volumetric demand) of the reservoir created by raising the Kidston Dam. Under Scenario A (historical climate) for the baseline model the yield of the reservoir is approximately 17 GL at 85% annual time reliability. The ensemble of models had a 95% range of 15.7 to 19.5 GL at 85% annual time reliability. The ensemble of models estimates the uncertainty in the water yield estimate as a result of uncertainty in the measurement of streamflow.

The relatively incised landscape within which the Kidston Dam reservoir is situated constrains the reservoir volume (Figure 5.7b). However, it also results in a relatively small evaporative loss, with the ratio of evaporation to water supplied approximately 0.1 (at 85% annual time reliability).
Figure 5.9 Annual time reliability and volumetric reliability for Kidston 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 5.10 illustrates the difference in coastal floodplain area simulated as being inundated with the Kidston Dam and with the raised Kidston Dam empty prior to the 2001 and 2009 flood events. Raising the Kidston Dam wall by 2 m will not result in a noticeable reduction in inundated area on the Gilbert coastal floodplain during small or large flood events.

Figure 5.11 indicates that increasing the area of inundation of this impoundment is not likely to flood any regional ecosystems of concern. However, Tait (1998) identified a number of vine-thickets in the proposed inundation area, which may be too small to appear on existing vegetation mapping.

A desktop assessment of Indigenous cultural heritage considerations in the area surrounding the Kidston Dam area was undertaken by Northern Archaeology Consultancies in 1998 (NAC, 1998). This study found that the most common recorded site types in the locality are artefact scatters, and that stone
arrangements, quarries, axe-grinding grooves, scarred trees and rock shelters with art are also present. Sites are frequently located close to water and/or prominent natural features.

NAC (1998) concluded that the area has high archaeological potential and is likely to contain a range of sites. The region is known to have a large number of sites, and the available information indicates that major watercourses, such as the Einasleigh and Copperfield rivers, were a focus of occupation. Further investigation, including archaeological survey, would be required to assess the potential Aboriginal archaeological impact of works in this area. Any such investigation should be undertaken in consultation with relevant 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.

![Regional ecosystems inundated by the raised Kidston Dam reservoir at full supply level](image)

**Figure 5.11 Regional ecosystems inundated by the raised Kidston Dam reservoir at full supply level**

**Dagworth**

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

Two potential dam sites situated in similar geological conditions were identified using the DamSite model on the Dagworth property along the Einasleigh River. Following a site inspection and a preliminary assessment of both sites, the upstream Dagworth dam site was short-listed because it had smaller saddle dam requirements. The potential dam site commands a large catchment area (about 15,000 km²) and the geology of the site is favourable, being located in extremely high-strength dacitic ignimbrite. A concrete gravity dam with central overflow spillway 30 m above the river bed would be possible, with the main dam wall of RCC construction. On the right bank, an earth and rock fill embankment saddle dam approximately
650 m long and 22 m maximum height would be required (Figure 5.12). The crest level of the saddle dam embankment would be set to contain the 1 in 1000 year AEP flood and, in the event of more extreme flood events, erode away to form an auxiliary spillway. If this proposal were to be considered further, the impact of erosion of the large volume of fill from the saddle dam in the event of floods of high magnitude would need to be assessed in detail, as would the potential impact of the increase in flood discharge from the dam in such an event. The capital cost of the dam is estimated to be $474 million, not including the cost of any downstream distribution works. Annual operating and maintenance costs are likely to be relatively low for the type of dam suggested, although remoteness from service centres may increase some costs.

Figure 5.13a illustrates a cross-section of the ground surface along the dam axis and Figure 5.13b illustrates the relationship between the dam height, reservoir volume and reservoir surface area.

Figure 5.12 Dagworth potential dam site, looking upstream
Photo: CSIRO.
A large proportion of the reservoir created by the potential Dagworth dam would be greater than 10 m in depth at FSL (Figure 5.14). In this figure a dam wall and saddle dams are required to contain the reservoir at FSL where the reservoir touches the catchment boundary. A spillway notch 280 m wide and 11.5 m deep was assumed having a capacity to discharge a flood in excess of the 1:1000 AEP event. For larger flood events, the right bank saddle dam would progressively erode away, creating additional spillway capacity.

Figure 5.14 Dagworth dam depth of inundation and property boundaries (indicated by coloured shading)
Figure 5.15a 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 the Dagworth upstream site. Under Scenario A for the baseline model, the yield of the reservoir is approximately 326 GL at 85% annual time reliability. The ensemble of models had a 95% range of 310 to 340 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.

The favourable physiographic constriction of the river channel at the Dagworth site, the high dam wall and broad valley upstream of the potential dam site enable a reservoir with a large volume (Figure 5.13b), and a relatively small evaporative loss, i.e. ratio of evaporation to water supplied is approximately 0.15 (at 85% annual time reliability). Evaporation is approximately 13% of the regulated flow.

Figure 5.16 illustrates the difference in the total lower floodplain area simulated as being inundated without Dagworth dam and with Dagworth dam empty prior to the 2001 and 2009 flood events. The construction of Dagworth dam would result in a reduction in inundated area on the Gilbert floodplain for small flood events (Figure 5.16a). However, there would be no noticeable difference for large flood events (Figure 5.16b).

Figure 5.15 Annual time reliability and volumetric reliability for Dagworth 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 5.16 Comparisons of inundated area with and without the construction of Dagworth dam under Scenario A
(a) For an event in 2001 (equivalent to 1-in-4-year event at gauging station 917009A). (b) For an event in 2009 (equivalent to 1-in-32-year event at gauging station 917009A). Gauging station locations are shown in Figure 3.29.
The reservoir created by a 30 m high dam at the Dagworth site is predicted to experience persistent thermal stratification with a consistent top-to-bottom temperature difference of 6 to 10 °C (Petheram et al., 2013). The risk of blue-green algal blooms is high and the water column is predicted to mix on only a few occasions. The very long duration of stratification and weak mixing behaviour suggests this potential reservoir would be susceptible to experiencing profound anoxic conditions and associated water quality issues.

Downstream of this potential dam site there are numerous large permanent waterholes (Figure 3.41). Anecdotal evidence suggests this location is within the distribution of barramundi and freshwater sawfish. A dam at this location would provide a barrier to the upstream and downstream migration of numerous fish species and would therefore require a fish transfer facility.

Figure 5.17 indicates that the potential reservoir would inundate a mixture of dominant ‘of concern’, ‘not of concern’ and ‘non-remnant’ regional ecosystems.

No previous archaeological studies at this site have been located. However, results of investigations in the Gilbert catchment more generally indicate that the inundated area is likely to have high archaeological potential.

![Map of Regional Ecosystems](image)

**Figure 5.17 Regional ecosystems inundated by the potential Dagworth dam reservoir at full supply level**

**Green Hills**

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

Two sites approximately 5 km apart had previously been identified on the Gilbert River near the Green Hills station, though the downstream site had received most attention. Following a site inspection and an assessment of both sites, the upstream site was selected for further investigation because of the large, previously unidentified saddle dam requirements at the downstream site.
The potential Green Hills upstream dam site commands a large catchment (about 8300 km$^2$) and it is close to moderately suitable alluvial soils adjacent to the Gilbert River. Limited surface mapping and seismic traverses of the upstream (and downstream) site had previously been undertaken. The site geology is favourable, with slightly weathered high-strength ignimbrite outcropping on both abutments. The dam would consist of a concrete gravity dam of roller compacted concrete construction with a central overflow spillway 20 m above the river bed. Four saddle dams would be required to contain the storage, particularly during flood events (flood design of the Green Hills dam sites was not undertaken in previous studies). The crest level of saddle dam number two would be set at a level to contain the 1 in 1000 year AEP peak flood level and would be expected to fail in the event of more extreme floods to create an auxiliary spillway. Crest level of saddle dam number three would be 0.5 m higher and would also be expected to fail in the event of a more extreme flood event, again to increase the auxiliary spillway discharge capacity. The viability of this arrangement will need to be confirmed by further analyses should this proposal be advanced further.

A dam wall higher than 20 m would result in excessively large saddle dams.

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

Figure 5.19a presents a cross-section of the ground surface along the dam axis and Figure 5.19b illustrates the relationship between the dam height, reservoir volume and reservoir surface area.

Figure 5.20 shows that a large proportion of the reservoir created by the potential Green Hills dam would be greater than 5 m in depth at FSL. In this figure a dam wall and saddle dams would be required to contain the reservoir at FSL where the reservoir touches the catchment boundary.
Figure 5.19 Dam cross-section, height, volume and reservoir surface area for Green Hills potential dam site
(a) Cross-section of ground surface along dam axis; looking downstream. (b) Relationship between dam height, reservoir volume and reservoir surface area.

Figure 5.20 Green Hills upstream potential dam depth of inundation and property boundaries (indicated by coloured shading)
Figure 5.21 Annual time reliability and volumetric reliability for Green Hills 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 5.21a 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 the Green Hill site. Under Scenario A for the baseline model, the yield of the reservoir was approximately 172 GL at 85% annual time reliability. The ensemble of models had a 95% range of 160 GL to 180 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.

The favourable physiographic constriction of the river channel at the Green Hills site, the high dam wall and broad valley upstream of the potential dam site enable a reservoir with a large volume and a relatively small evaporative loss – that is, ratio of evaporation to water supplied is approximately 0.2 (at 85% annual time reliability) or evaporation is approximately 18% of the regulated flow (regulated flow is the sum of the evaporation losses and water supplied).

Figure 5.22 illustrates the difference in the coastal floodplain area simulated as being inundated without Green Hills dam and with Green Hills dam empty prior to the 2001 and 2009 flood events. The construction of Green Hills dam could result in a small reduction in inundated area on the Gilbert floodplain during small flood events (Figure 5.22a). There would be no noticeable difference during large flood events (Figure 5.22b).

The reservoir created by a 20-m-high dam at the Green Hills site is likely to experience persistent thermal stratification with a top-to-bottom temperature difference of about 5 °C during most of the year from mid-September to mid-May (Petheram et al., 2013). However, summer inflow events during the months of February appear to cause short-term deep mixing of the water column. The risk of blue-green algal blooms is moderate to high. The water column is predicted to be poorly mixed during periods of stratification each year when dissolved oxygen concentrations fall. Inflow-induced deep mixing during summer inflows is expected to resupply oxygen to the deeper waters and low dissolved oxygen with associated nutrient and metal releases from the sediments is less likely to be experienced in most years in Green Hills reservoir than in reservoirs not experiencing summer mixing events.

The Green Hills potential dam site hosts much less instream habitat than similarly-located dam options on the Einasleigh River (Figure 3.41). Anecdotal evidence suggests this location is within the distribution of barramundi and possibly freshwater sawfish. A dam in this location may therefore require a fish transfer facility. Figure 5.23 indicates that the potential reservoir would inundate a mixture of dominant ‘of concern’ and ‘not of concern’ regional ecosystems.

No previous archaeological studies at this site have been located. However, results of investigations in the catchment more generally indicate that the area is likely to have high archaeological potential.
Figure 5.22 Comparisons of inundated area with and without construction of Green Hills dam under Scenario A (a) For an event in 2001 (equivalent to 1-in-4 year event at gauging station 917009A). (b) For an event in 2009 (equivalent to 1-in-32 year event at gauging station 917009A). Gauging station locations are shown in Figure 3.29.

Figure 5.23 Regional ecosystem inundated by the potential Green Hills dam reservoir 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 Gilbert 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 type 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.

The Gilbert River below Green Hills dam is typically between 250 m and 500 m in width. The Einasleigh River below the confluence of the Einasleigh and Etheridge rivers is typically between 500 m and 1500 m in width. The bridges that span the Copperfield and Einasleigh rivers adjacent to the town of Einasleigh are approximately 120 m long. Hence a weir constructed in the lower reaches of the Gilbert and Einasleigh rivers would be the longest in Queensland. For this reason 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 type weirs have been founded on the rock at numerous locations across Queensland. This type of construction is less vulnerable to flood erosion damage, both during construction and 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 5.24). 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.

Table 5.3 provides a preliminary cost estimate for sheet piling weirs, which, is the most likely weir option in the narrower parts of the mid to lower Gilbert and Einasleigh rivers.

![Figure 5.24 Schematic diagram of sheet piling weir](image)

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.

A full list of assumptions upon which these costs are based is provided in the companion technical report on water storage options (Petheram et al., 2013).

Annual operating costs are likely to be low depending on location. However, depending on the frequency and magnitude of flood events, significant costs could be involved from time to time in the repair of scour damage (e.g. replacement of mattresses). Weirs would also be at risk of infilling with sediment. Annual operating costs could average between 1 and 2% of capital costs.

**Sand dams**

Sand dams are low embankments built of 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 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.
Table 5.4 Types of on-farm water storages
Adapted from Lewis (2002).

<table>
<thead>
<tr>
<th>TYPE OF ON-FARM DAM</th>
<th>DESCRIPTION</th>
<th>STORAGE TO EXCAVATION RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavated tanks</td>
<td>Restricted to flat sites and comprise excavations below the natural surface. Excavated material is wasted. Generally limited to stock and domestic use and irrigation of high-value crops</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. 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 an offstream storage or the creation of a pumping pool</td>
<td>10:1 (favourable conditions)</td>
</tr>
<tr>
<td>Hillside dam</td>
<td>An earth dam located on a hillside or slope and not in a defined depression or drainage line</td>
<td>5:1 (on flatter terrain) 1:1 (on steeper slopes)</td>
</tr>
<tr>
<td>Ring tank</td>
<td>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</td>
<td>Usually smaller than ring tanks and lower storage to excavation ratio</td>
</tr>
</tbody>
</table>

Offstream storages, such as ring tanks (Figure 5.25), 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 Gilbert 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:

- suitability for siting storages in the Gilbert catchment
- reliability of supply of water for water harvesting
- 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 Gilbert catchment the Assessment explored a range of potential options based on four locations in the Gilbert catchment (917107A, 917102A, 917001D and 917111A) four commence to pump thresholds (i.e. the streamflow value above which pumping 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 5.26 and Figure 5.27 present results from downstream gauging stations on the Gilbert and Einasleigh rivers (Figure 3.29) and the results from streamflow gauging stations located in two headwater catchments are presented in Figure 5.28 and Figure 5.29.
Figure 5.26 Annual volume of streamflow extracted versus annual time reliability for streamflow gauge 917111A
(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 5.27 Annual volume of streamflow extracted versus annual time reliability for streamflow gauge 917001D
(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 about 400 GL of water in 50% 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 5.29a in about 30% of years there is no water to extract.
- The years when water cannot be extracted are strongly dependent on the commence to pump threshold. Comparing Figure 5.26a and Figure 5.26b shows that increasing the commence to pump threshold 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 5.26 to Figure 5.29, 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 significant 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 dams in the Gilbert catchment

Above the confluence of the Gilbert and Einasleigh rivers a minority of the soils along the Einasleigh River may be suitable for siting offstream storages. The soils adjacent to the Gilbert River are highly permeable and are not likely to be suitable for offstream storages.

Figure 5.30 shows a desktop assessment of the suitability of offstream storages in the Gilbert 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 storages require consideration at a scale finer than is possible to assess in a regional scale resource assessment. Hence the results presented here are only indicative of where suitable locations may occur. The design and construction of offstream water storages should be undertaken following a site investigation by a suitability qualified professional.
Evaporative and seepage losses

Losses from an on-farm dam occur through evaporation and seepage. Mean daily evaporation losses from open water in the Gilbert 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 Gilbert 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 sown in March. Sorghum planted for hay is an example of a crop grown for about four months, sorghum planted for grazing an example of a crop grown for about six months and Rhodes grass, an example of a perennial crop. See Section 5.5 for sowing and growing dates for different crops in the Gilbert catchment.

Data in Table 5.5 are based on costs of $4/m³ for earthworks. Recent estimates of costs for earthworks from companies in the Assessment area 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 Georgetown

<table>
<thead>
<tr>
<th>BANK HEIGHT (m)</th>
<th>AREA (ha)</th>
<th>CONSTRUCTION COST ($1,000,000)</th>
<th>UNIT COST ($/ML)</th>
<th>SEEPAGE LOSS (mm/day)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>EFFECTIVE UNIT COST ($/ML)</th>
<th>COST ($/ML)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>EFFECTIVE UNIT COST ($/ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>25</td>
<td>$1,000,000</td>
<td>$1000</td>
<td>1</td>
<td>866</td>
<td>$1155</td>
<td>$1264</td>
<td>607</td>
<td>$1648</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>$1,000,000</td>
<td>$1000</td>
<td>2</td>
<td>836</td>
<td>$1197</td>
<td>$1342</td>
<td>516</td>
<td>$1940</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>$1,000,000</td>
<td>$1000</td>
<td>5</td>
<td>744</td>
<td>$1344</td>
<td>$1647</td>
<td>242</td>
<td>$4136</td>
</tr>
</tbody>
</table>

In Table 5.6 the cost of an offstream storage includes the cost and operation of pumping infrastructure, but ignores the cost of supply channels and levee banks, which will vary from one station to the next.

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 fuel 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 Equivalent annual 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 Georgetown

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* ($)</th>
<th>SEEPAGE LOSS (mm/day)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>ANNUAL UNIT COST ($/ML)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>ANNUAL UNIT COST ($/ML)</th>
<th>EFFECTIVE VOLUME (ML)</th>
<th>ANNUAL UNIT COST ($/ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 months</td>
<td>6 months</td>
<td>12 months</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(March to June)</td>
<td>(March to August)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>$123,000</td>
<td>1</td>
<td>866</td>
<td>$142</td>
<td>791</td>
<td>$155</td>
<td>607</td>
<td>$203</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>$123,000</td>
<td>2</td>
<td>836</td>
<td>$147</td>
<td>745</td>
<td>$165</td>
<td>516</td>
<td>$238</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>$123,000</td>
<td>5</td>
<td>744</td>
<td>$165</td>
<td>607</td>
<td>$203</td>
<td>242</td>
<td>$508</td>
</tr>
</tbody>
</table>

The total equivalent annual costs for the construction and operation of a 1000-ML ring tank and 200 ML/day pumping infrastructure is about $123,000 or $123 per ML of storage. In Table 5.7 the equivalent annual cost of the water yield from the offstream storage takes 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 Gilbert catchment.

For the large instream dams presented in Table 5.1, the lowest equivalent annual capital costs are for Dagworth and Green Hills dams, $102 per ML and $137 per ML, respectively, both at 85% annual time reliability. Including operation and maintenance costs – and assuming a 60% and 80% conveyance efficiency from Dagworth and Green Hills dam to the farm gate – results in an equivalent annual cost of about $160 per ML for each dam. This is considerably cheaper than the equivalent annual cost per ML of storing water in an offstream storage for 12 months, particularly considering the soils adjacent to the Gilbert River and many of the soils adjacent to the Einasleigh River are highly permeable and likely to have seepage losses greater than 5 mm/day (Figure 5.30).

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 that is 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.

No irrigation system research has previously been undertaken in the Gilbert catchment and 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 efficiency 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. There are few gaining rivers in the Gilbert catchment.
** 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 permeable soils and substrata of the Gilbert catchment (Section 3.3) achieving high conveyance efficiencies may be challenging without lined channels.

In the absence of larger scheme-scale irrigation systems in the Gilbert 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 Gilbert 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 5.31 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 5.31 Reported conveyance losses from irrigation systems across Australia (ANCID, 2001)
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 Gilbert catchment: surface irrigation, spray irrigation and micro irrigation (Figure 5.32). Irrigation systems applied in the Gilbert
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). Generally speaking the permeable soils of the Gilbert catchment are better suited to spray and micro irrigation systems than surface systems.

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.

![Figure 5.32 Efficiency of different types of irrigation systems](photos)

(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 system 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></td>
<td>Border</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></td>
<td>Furrow</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>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></td>
<td>Lateral move</td>
<td>75 to 90%</td>
<td>$2500 to $5000</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 skill needed for successful operation</td>
</tr>
</tbody>
</table>


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

**Surface irrigation systems**

Surface irrigation systems are not ideally suited to the permeable soils found in the Gilbert catchment. They are discussed here largely for completeness. 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 m³/ha but can exceeded 2500 m³/ha. Volumes greater than 1500 m³/ha are generally considered excessive due to costs (Hoffman et al., 2007).

Surface irrigation systems are the dominant form used throughout the world. 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.

Surface irrigation systems are less suited to the permeable soils found in the Gilbert catchment.

**Spray irrigation systems**

Spray irrigation is well suited to the permeable soils of the Gilbert catchment. In the context of the Gilbert 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 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 similar to those found in the Gilbert 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 Gilbert, 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 Gilbert.

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.

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 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 Gilbert 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>UNITS</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 Gilbert 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 in the Gilbert catchment 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 Gilbert 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>
<th>SLIGHT TO MODERATE</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clogging</td>
<td>pH</td>
<td>&lt;7.0</td>
<td>7.0–8.0</td>
<td>&gt;8.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Manganese ppm</td>
<td>&lt;0.1</td>
<td>0.1–1.5</td>
<td>&gt;1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iron ppm</td>
<td>&lt;0.2</td>
<td>0.2–1.5</td>
<td>&gt;1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrogen sulphide ppm</td>
<td>&lt;0.2</td>
<td>0.2–2.0</td>
<td>&gt;2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Suspended solids ppm</td>
<td>50</td>
<td>50–100</td>
<td>&gt;100</td>
<td></td>
<td></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>
<td>&gt;50,000</td>
<td></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>
<td>&gt;3.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nitrate-Nitrogen ppm</td>
<td>&lt;5</td>
<td>5–30</td>
<td>&gt;30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific ion toxicity</td>
<td>Boron ppm</td>
<td>&lt;0.7</td>
<td>0.7–3.0</td>
<td>&gt;3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chloride meq/L</td>
<td>&lt;4</td>
<td>4–10</td>
<td>&gt;10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chloride ppm</td>
<td>&lt;142</td>
<td>142–355</td>
<td>&gt;355</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sodium Adjusted sodium adsorption ratio**</td>
<td>&lt;3.0</td>
<td>3.0–9.0</td>
<td>&gt;9.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infiltration***</td>
<td>Adjusted sodium adsorption ratio**</td>
<td>Electrical conductivity of irrigation water</td>
<td>0–3</td>
<td>≥0.7</td>
<td>0.7–0.2</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3–6</td>
<td>≥1.2</td>
<td>1.2–0.3</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6–12</td>
<td>≥1.9</td>
<td>1.9–0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12–20</td>
<td>≥2.9</td>
<td>2.9–1.3</td>
<td>&lt;1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20–40</td>
<td>≥5.0</td>
<td>5.0–2.9</td>
<td>&lt;2.9</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 Gilbert 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.