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Farm-scale dam design and costs

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

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Australian Government
Department of Infrastructure, Regional Development and Cities

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CSIRO Northern Australia Water Resource Assessment acknowledgements

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

The Assessment was guided by three committees:

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

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

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

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

This report was reviewed by Cuan Petheram (CSIRO).

Photo: Gully dam in the Mitchell catchment. Source: CSIRO

Director's foreword

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

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

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

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

Chris Chilcott

Project Director

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Shortened forms

SHORT FORM	FULL FORM
AEP	Annual exceedance probability
DTM	Digital terrain model
FIA	Failure impact assessment
FSL	Full supply level
MFV	Mixed-flow volute

Units

UNITS	DESCRIPTION
GL	gigalitre (1,000,000,000 L)
ha	hectare
km	kilometre
KWh	kilowatt hour
L	litre
m	metre
ML	megalitre (1,000,000 L)
O&M	Operating and maintenance
mm	millimetre

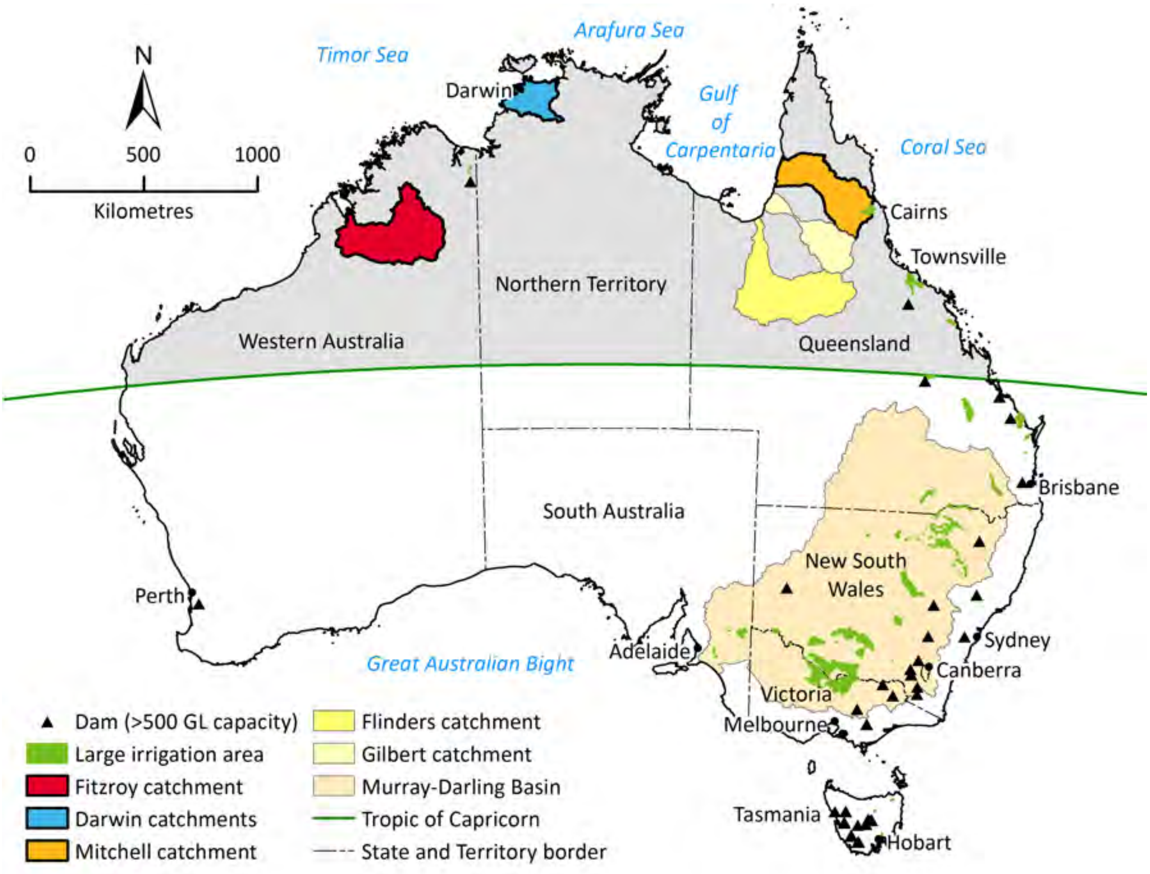
Preface

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

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

For each of the three regions, the Assessment:

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



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

While agricultural and aquacultural developments are the primary focus of the Assessment, it also considers opportunities for and intersections between other types of water-dependent development. For example, the Assessment explores the nature, scale, location and impacts of developments relating to industrial and urban development and aquaculture, in relevant locations.

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

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

Assessment reporting structure

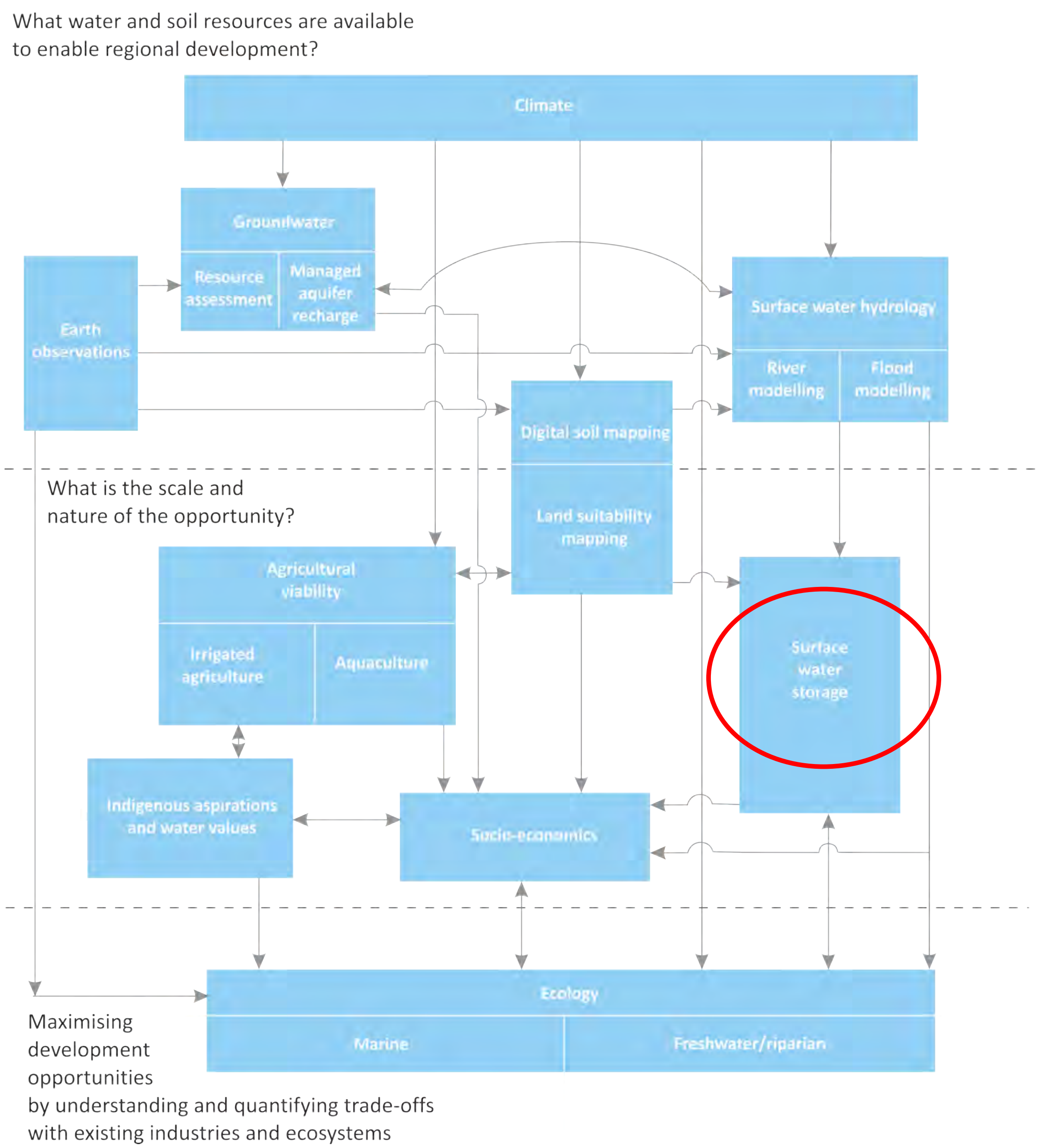
Development opportunities and their impacts are frequently highly interdependent and, consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports most reliably informs discussion and decision concerning regional development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

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

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

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

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



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

Executive summary

Large farm-scale dams constructed for the purpose of storing irrigation water supplies are usually of two principal types: gully dams, located instream and filled by capturing natural runoff, or ringtanks (also called offstream storages), filled by pumping from adjacent drainage features.

Farm irrigation dams need to be economical, have reasonable longevity, and be able to successfully and reliably deliver the anticipated water yield. Farm-scale dams are a compromise between best-practice engineering and affordability. This means that designers must follow accepted engineering principles relating to the important aspects of materials classification, compaction of the clay core and selection of an appropriate embankment cross-section. However, engineering principles are often stretched in the design of gully dams by employing earth bywashes and grass protection for erosion control; these items are much cheaper to implement than hard spillways and rock protection, as may be seen on major, industrial or municipal water supply storages.

This report gives an overview of general considerations in the construction of large farm-scale dams in northern Australia and provides conceptual design and indicative cost estimates for four hypothetical large farm-scale dams, each of capacity 4 GL. Indicative capital cost and operational and maintenance costs for the four hypothetical dams are summarised in Table 1-1.

Table 1-1 Summary of indicative costs for four hypothetical large farm-scale dams

DAM TYPE	CAPTIAL COST ($)	CAPITAL COST ($/ML)	OPERATION AND MAINTENCE ($/YEAR)	COMMENT
4-GL ringtank **Flat land†**	2,200,000	550	89,500	Capital cost includes pumping infrastructure and housing. O&M cost includes cost of pumping
4-GL gully dam #1 **Good site‡/30 km² catchment**	1,280,000	320	55,000	
4-GL gully dam #2 **Poor site‡/15 km² catchment**	1,474,000	369	35,000	
4-GL gully dam #3 **Poor site‡/20 km² catchment**	1,554,000	389	40,000	

†Zoned embankment construction and minimal flood inundation assumed.
‡No outlet works have been allowed for in the gully dam costs.

Importantly, this report 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 (e.g. QWRC, 1984; Lewis, 2002; IAA, 2007). Siting, design and construction of farm-scale dams should always be undertaken in conjunction with a suitably qualified professional and tailored to the nuances that occur at every site.

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Figures

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1 Large gully dam criteria

Design and construction of a successful large farm-scale gully dam for irrigation water supply in northern Australia can be a difficult proposition due to extreme climate variability and usually brief, but intense, wet season. Designers and landowners choose to create large, deep storages to attempt to provide 2 or more years of water storage. Catchment areas serving these large dams must be quite large in order to achieve reliable yield. Designers must then deal with potentially large runoff events that may result from monsoon storms or deluges associated with tropical cyclones. Spillway facilities (Figure 1-1) may frequently be required to cater for peak discharges of 200 to 300 m^3/second and prolonged low flows, well above the capability of a 'standard' grassed earth bywash on a large farm dam elsewhere in Australia.

Dam site selection is therefore often reliant on the presence of a suitable rocky ridge or saddle at the preferred elevation that may be developed as a durable, economical and low-maintenance spillway facility. Dual spillways and broad, stepped spillways (requiring less rock excavation) are often utilised to cater for large storm discharge events.

(a) (b)

Figure 1-1 Example spillways
(a) Spring Creek Dam spillway sill and apron in 2011 (Queensland) (b) Sharp-rock Dam spillway control sill (Queensland).
Photo: North Australia Water Strategies.

Large earthfill, or combination earthfill–rockfill dam embankments constructed for storage of irrigation water are usually a trapezoidal cross-section, possessing a crest wide enough to accommodate construction traffic; have appreciable freeboard between full supply level (FSL) and crest level; and are of modified, homogeneous earth construction (also referred to as zoned earthfill), often incorporating rockfill outer zones. An impermeable zone of compacted, good quality clay is generally located in the centre of the embankment directly over a clay-filled cut-off or core-trench. The clay core zone is supported on either side by sloping batter zones of lesser quality, more permeable material. Selection of the batter slopes is an important consideration to prevent slumping under saturated conditions, which may jeopardise the embankment's crest width. Flat batter slopes of 3.0 or 3.5 : 1.0 (height : volume) are used with materials of high clay content, whereas batter slopes of 2.0 : 1.0 (height : volume) may be used with coarse, well-drained materials such as clayey or sandy gravel and rock fill.

Engineering practice regarding earth dam design and construction is well documented; however, decisions concerning bywash size and location, storage volume versus reliable yield and embankment location to give the best storage to excavation ratio (S : E) are matters of experience and judgment, and are not able to be obtained from textbooks.

There are rules for earth dam design but not every dam site will conform to them. Topography at the dam site and of the ponded area will greatly affect design decisions, as will the reliable yield from the catchment.

Rule #1: There is no such thing as a 'rubber-stamp' dam design. Just because a particular embankment or bywash design worked successfully at one site does not mean it will be successful elsewhere. There are many variables to consider that will influence the success of the dam.

Rule #2: Dig as many test pits as possible. It is absolutely vital to know as much as possible about the foundation conditions and the range of borrow materials available. It is equally important to conduct sufficient testing to determine the effectiveness of the available borrow materials as an impermeable barrier when compacted in the embankment.

Each dam site is unique, with its own set of advantages and disadvantages. A site may provide economies in terms of storage gained per unit cost but may have limited annual yield due to a smaller than desirable catchment or poor catchment quality. Conversely, a dam site with a smaller S : E ratio may be served by a good quality, smaller catchment and therefore provide better annual yield. An example of a gully dam with a smaller S : E ratio and in a smaller catchment is shown in Figure 1-2.

Generally, earthfill, or combination earthfill–rockfill dam embankments with compacted clay cores are constructed to a maximum of about 20 m height, with some form of downstream batter drainage incorporated in embankments over 10 or 12 m high. It is possible to construct higher embankments but more intensive investigation of materials and foundation stability are required. More complex batter drainage and tighter construction specification, supervision and testing would also be required.

An earth dam to a height of 8 m will be about 3.3 times more expensive to construct than a 4 m high dam. It will, of course store more water, but for every dam site there is a height at which the variables of storage volume, reliable yield and construction cost provide the best economic outcome in terms of dollars per ML. A dam to a height of 16 m will require 3.6 times more material than the 8 m high version, but cost may be a factor of 5 greater, due to design and construction complexity.

General characteristics of a favourable site for a large (3 to 4 GL) dam include:

- a catchment area in the vicinity of 25 to 30 km^2
- a natural constriction in the topography that minimises embankment length to around 1 to 1.2 km
- broad, approximately U-shaped valley to maximise storage potential

- flat bed slope to provide economical S : E ratio, but not too flat so as to create a large impoundment area. Bed slope of 0.5 to 1.0% preferred
- durable rock in upper bank(s), ridge or saddle about 8 to 10 m above bed level to provide economic bywash options
- impermeable foundation material (firm clay or rock) within 1 or 2 m below natural surface
- absence of any groundwater discharge areas within the vicinity of the dam embankment
- a nearby source of good quality clay, preferably within the dam's ponded area. Up to 30,000 m^3 may be required
- a nearby source of durable, but easily won, rock for embankment protective works (riprap).

This report complements the companion technical report on surface water storage in the Fitzroy, Darwin and Mitchell catchments, Petheram et al. (2017).

Figure 1-2 Large farm–scale gully dam (~3.75 GL capacity) in Darwin catchments
Photo: CSIRO.

2 Investigation and design process for a gully dam

Farm-scale irrigation dams are expensive to build. They are even more expensive to build twice, in the event of a partial or calamitous failure. The costs involved in building a large earth dam with a capacity in the order of 4 GL may easily exceed $1.5 million, even at a favourable site. It is therefore obvious that an investor would take all available precautions to ensure the dam is a sound investment. Section 2.1 to 2.4 outline the investigation and design processes that should occur as part of the landholder's or investor's duty of care to ensure, as much as possible, the success of the irrigation storage project.

2.1 Initial investigation

The initial investigation should incorporate the following actions:

- identify the project water requirements and the annual yield expected from the proposed storage to match the water needs of the irrigation enterprise
- examine available mapping to identify possible dam sites on catchment areas that may potentially meet annual yield requirements
- assess potential peak flood discharge for the likely annual exceedance probability (AEP) rainfall event and calculate indicative bywash width requirement. (The term 'bywash' has been used in relation to farm-scale dams, as it implies a lower level of civil engineering than 'spillway', which would usually involve concrete works and/or some form of adjustable gates.)
- examine any available soils information
- inspect the possible dam sites. This would usually involve:
    - confirm the general topographic suitability of the embankment location (axis line) and the potential impoundment area
    - assess potential bywash facilities for available width, erosion resistance and appropriate return slope
    - conduct preliminary materials investigation of foundations and potential clay borrow area(s)
    - carry out a brief survey of the axis line, (to beyond the likely bywash limits) and the gully bed to beyond the likely extent of the ponded area
    - calculate estimated storage and embankment volumes from rule-of-thumb formulae
    - calculate a preliminary cost estimate using local unit rates for clearing, earthworks, access roads and rock excavation (if required).

2.2 Detailed investigation

Following consultation, further site visits are usually required in order to:

- conduct a more thorough assessment of the physical parameters of the catchment area
- conduct a detailed materials investigation of foundations and potential clay borrow area(s) to assess volume of suitable clay available
- carry out a topographic survey of the site, covering the works area (embankment, bywash return slopes and fishway area) and the proposed ponded area to above the likely FSL.

2.3 Preliminary design

The preliminary design should incorporate the following actions:

- convert the topographic survey data into a digital terrain model (DTM)
- use the DTM to compile a storage versus depth curve
- refine the design FSL and storage volume commensurate with the reliable annual catchment yield; usually the yield that is exceeded in at least 75% of years
- select the embankment cross-section with respect to the quality of the available construction materials and determine the embankment dimensions and earthworks volume
- refine the peak catchment discharge estimate and select size of bywash facilities having regard for maximum surcharge depth at the design annual exceedance probability (AEP) and freeboard requirements
- establish a suitable fishway design, if mandatory
- revise the cost estimate and consult with the client.

2.4 Final design

The final design should incorporate the following actions:

- prepare plans showing the general arrangement of the dam, setting out dimensions, typical embankment sections, bywash and fishway details
- seek fishway design certification by qualified consultant, if mandatory (Queensland)
- compile a schedule of materials
- compile an appropriate construction specification
- seek dam design certification by qualified engineer.

3 Hypothetical dam cost estimates

3.1 Large offstream storage (ringtank)

3.1.1 DESIGN CRITERIA

The term 'offstream storage' refers to any man-made impoundment that possesses no external catchment (Figure 3-1) and must therefore be filled with water by a gravity or pumped diversion or a combination of methods. They are usually fully enclosed, often surrounding a lagoon or anabranch located on the floodplain of a major watercourse from which floodwaters may be diverted or pumped at quite high flow rates. Offstream storages are often of circular, 'ringtank' design since this shape requires less earthworks per unit of ponded area than any other polygon. It is common to surround quite large areas with a low embankment to achieve very high S : E ratios.

Example 1: A ringtank embankment 4 m high and 500 m in diameter, on flat land, will store 720 ML and require 99,000 m^3 to construct. The S : E ratio will be 7.3 : 1 and the ponded area at FSL will be approximately 19 ha.

Example 2: A ringtank embankment 2.5 m high and 1000 m in diameter, on flat land, will store 1919 ML and require 119,000 m^3 to construct. The S : E ratio will be 16.2 : 1 and the ponded area at FSL will be approximately 78 ha.

Exceptions to the efficient circular design may be where a horseshoe lagoon or a river's cut-off meander is excised from the floodplain by small embankments at either end connected by low surrounding embankments. Such offstream storage sites have the benefits of a low embankment volume, a relatively large surface area and greater water depth due to the favourable topography. Sites such as these may have S : E ratios in excess of 20 : 1 and much higher reliable yield than ringtanks on flat land.

If the ringtanks in the above examples were located at Kowanyama, the annual evaporation loss from them would be about 395 ML and 1622 ML respectively, resulting in yields of 45% to only 15.5%. So while it seems attractive to surround a large area with a low embankment in order to gain economical storage, the actual yield from the ringtank may be quite low, unless stored water is able to be utilised in the first few months after filling. This is typically the strategy used by farmers in southern states, where water harvested in summer is applied to finish cotton or grain crops or pre-irrigate to establish early wheat crops.

It is obvious therefore, that as for a gully dam, there is a combination of embankment height and ponded area at which the variables of storage volume, reliable yield and construction cost provide the best economic outcome in terms of dollars per ML. Unlike gully dam designs, which are typically deeper than ringtanks and attempt to extend the storage duration over 1 or more years, ringtank design and operation employs an opportunistic strategy that utilises the stored water as soon as possible. This strategy also allows the operator to top-up the storage from subsequent flood events, should they occur, thereby improving the annual yield of the ringtank.

Large earthfill ringtank embankments are often designed as zoned structures and constructed utilising the same principles and machinery inventory as for gully dams, as discussed earlier. However, they are quite often of homogeneous earth design, pushed up by bulldozers with resultant minimal compaction and without an impermeable core zone. Landowners often have access to one or more large bulldozers, so this method is attractive because the cost of employing skilled contractors may be avoided. The success of this bulldozer method relies solely on the cohesive nature and moisture content of the construction material, which are usually heavy, dark, self-mulching clays. This method may be quite economical, as short haul distances are involved; generally pushing material into the embankment from an adjacent perimeter excavation. Batter slopes are usually flat, 3.5 or 4.0 : 1.0 (height : volume) on the inside and relatively steep, 2.0 : 1.0 (height : volume) on the outside.

Seepage from bulldozer-built ringtanks may often occur; however, as materials are usually quite cohesive, with naturally low permeability, loss of water through the embankment may be minimal. Since water is not stored permanently within the ringtank there is a risk of cracks developing that may potentially lead to failure upon subsequent rapid filling events.

3.1.2 TYPICAL DESIGN CRITERIA AND COST ESTIMATES

4-GL Ringtank on flat land – constructed as a zoned embankment with central, compacted clay core located over a compacted clay cut-off trench

The following dimensions for a circular ringtank were assumed (Table 3-1).

Table 3-1 Assumed dimensions for circular ringtank

EMBANKMENT DESCRIPTION	DIMENSION	COMMENTS
Height (m)	4.25	
Diameter (m)	1180	At embankment centre line
Crest width (m)	3.1	
Embankment length (m)	3707	At centre line
Batter slopes	3.0 : 1	Both sides
Water depth (m)	3.5	Above natural surface
Foundation depth (m)	1.0	

Estimates of embankment volume and total storage volume are presented in Table 3-2.

Table 3-2 Estimates of embankment volume and total storage volume

EMBANKMENT DESCRIPTION	DIMENSION	COMMENTS
Volume (m^3)	261,560	Includes 5% settlement
Earthfill in batters (m^3)	222,635	
Core volume (m^3)	38,925	
Cut-off trench volume (m^3)	11,120	
Topsoil stripping volume (m^3)	15,900	
Total earthworks volume (m^3)	288,580	
Total storage volume (ML)	3,973	
S : E ratio	13.8 : 1.0	

Earthworks cost estimate

The following earthworks rates have been used to arrive at the estimated cost of construction of the ringtank (Table 3-3):

- excavation and placement of selected, compacted clay: $6.50 per m^3
- excavation and placement of general earth fill in batters, stripping, stock-piling and replacement of topsoil on completed embankment: $5.00 per m^3.

Government permits and fees

In Queensland a development application is required for work involving clearing native vegetation and for operational works (earthworks of more than 1000 m^3). There are fees associated with both of these applications.

Investigation and design fees

Investigation and design fees include the cost of a consultant, which is based on 5% of the cost of earthworks.

Total costs

Total costs, based on the above assumptions, totalled $1,714,000. The above estimate does not include the cost of pumping equipment or pipework required to fill the ringtank. The pumping hardware requirements are very difficult to model due to the variation in stream hydrology, pumping opportunity and available energy. As an example, a flow rate of 160 ML/day (2000 L/second) would be required to fill this 4-GL (approximately) ringtank in approximately 25 days. A diesel-driven pump station comprising at least three 600 mm diameter axial-flow pump units (Figure 3-2) with 90 kW diesel engines would be sufficient to handle this flow rate. The cost of such a pump station and minimal pipework, (assume less than 100 m) may be in the order of $500,000, taking the total project cost to approximately $2.2 million.

Flood-harvesting pumps are often installed in multi-unit pump stations in order to access varying river flow levels. They are usually of either mixed-flow volute (MFV – similar to a centrifugal pump), or axial-flow (sometimes called line-shaft) design. MFV pumps are useful where there is limited variation in the water level of the stream, or where water is lifted from a sump or channel into a ringtank, because MFV pumps have limited suction capabilities (generally <6 m). Examples of water harvesting pumps are shown in Figure 3-3.

Table 3-3 Cost estimates for large farm-scale ringtank (4 GL capacity)

ITEM	COST PER UNIT	TOTAL COST ($)	COMMENTS
Earthworks cost estimate			
Compacted clay	50,045 m^3 @ $6.50/$m^3$	325,500	
Earthfill and topsoil	238,535 m^3 @ $5.00/$m^3$	1,193,000	
Mobilisation and de-mobilisation of machinery		7,500	
Vegetation clearing, stick-raking etc.	56 ha @ $400/ha	22,500	Assumes only 50% of the area requires clearing
Contractor accommodation costs	3 staff, 120 days @ $150/day	54,000	
Sub-total 1. Construction		**1,602,500**	
Government permits and fees			
Application fee for clearing native vegetation		12,500	
Application fee for operational work		23,000	1.5% of the value of the earthworks, i.e. for the ringtank
Sub-total 2. Government fees		**35,500**	
Investigation and design fees			
Consultant fee		75,900	Based on 5% of the cost of earthworks
Sub-total 3. Design fees		**76,000**	
Ringtank total cost		**1,714,000**	

Large ringtank at flood-prone site

Large offstream storages are typically constructed close to major watercourses in order to have access to the longest water harvesting window of opportunity and to minimise the cost of pumping. Ringtanks and other forms of offstream storages are therefore subject to reasonably frequent inundation, usually by slow-moving floodwater. Each site should be assessed for expected depth of inundation and flow velocity to determine if protection of the outer batters of the embankment and pump station is required. Protection works may vary from reducing the slope of the outer batter (or at least the lower section), allied with establishing and maintaining good grass cover through to riprap protection to above peak flood elevation.

If riprap protection of the 4-GL example was warranted to a height of 1.5 m above the embankment toe, the volume of rock required would be approximately 8000 m^3, at a cost of approximately $30/$m^3$ to quarry, cart and place riprap. Thus, an additional cost of up to $240,000 may apply to flood-prone ringtank sites.

Figure 3-1 Rectangular ringtank in the Flinders catchment, Queensland
Photo: CSIRO.

Figure 3-2 Diesel powered axial-flow flood-harvesting pump in Flinders catchment, Queensland
Photo: CSIRO.

3.1.3 TYPICAL ANNUAL OPERATING AND MAINTENANCE COSTS – 4-GL RINGTANK

The major operating cost for a ringtank on flat land will primarily be the energy required to fill the storage. For the 4-GL example above, the three 90 KW diesels operating for 25 days/year would generate approximately 143,000 kWh/year. Actual operating time is calculated based on 22 hours/day to allow for maintenance and breakdowns. A conversion factor of 0.4 L/kWh provides for fuel, oil and maintenance items. On this basis, this amount of power will require about 57,200 L of diesel and cost approximately $74,500/year.

The only other maintenance issue requiring attention may be regular mowing or slashing of the embankment crest and batters to maintain a good grass cover in order to minimise erosion. Slashing and/or herbicide treatment may be required annually to prevent shrubs and trees from becoming established. It is estimated that up to 60 hours/year should be budgeted for at a cost of $250/hour for machine and operator. Annual cost may be in the order of $15,000/year.

The estimated total operating and maintenance (O&M) cost may therefore be in the order of $89,500/year.

(a) (b)

Figure 3-3 Water harvesting pumps
(a) Irrigation pumps on rail-trolley with pontoon suction arrangement (b) Sharp-rock Dam Irrigation and priming pump units.
Photo: North Australia Water Strategies.

3.2 Large gully dam #1 (favourable site)

3.2.1 DESIGN CRITERIA

Typical design criteria and cost estimates are presented below for a 4-GL gully dam at a favourable site (i.e. topographically suitable with a simple, economical spillway facility such as a natural saddle). As previously discussed, it is preferable to limit embankment height to around 10 m, so in order to provide for freeboard (may vary, but usually 1.5 to 2.0 m is adequate), the bywash or spillway elevation will be approximately 8.5 to 10 m above the gully bed.

General characteristics of a favourable site for a large (~4 GL) dam include:

- a broad, U-shaped gully cross-section throughout the ponded area
- a natural constriction in the topography at the embankment site
- a flat to gentle bed slope
- a catchment area that is approximately 30 km^2
- durable rock in upper bank(s), ridge or saddle 9 to 10 m above bed level
- impermeable foundation material within 1.5 m below natural surface
- good quality clay within the dam's ponded area
- a nearby source of durable rock for embankment riprap
- in Queensland, a Failure Impact Assessment (FIA) is required to investigate the possible existence of any population at risk downstream of the site. (Other states probably have similar legislation)
- a catchment of this size will most likely have a significant resident native fish population; therefore, an approved fishway or fish-passage device will be required. (Queensland Planning Act – other states may vary.)

3.2.2 TYPICAL DESIGN CRITERIA AND COST ESTIMATES

Large gully dam built at a favourable site

The dimensions for a hypothetical, large gully dam at a favourable site assumed for this analysis are documented in Table 3-4. Two stages of construction of a large farm-scale gully dam are shown in Figure 3-4 and the finished dam is shown in Figure 3-5.

Table 3-4 Assumed dimensions for a hypothetical, large gully dam at a favourable site

DESCRIPTION	DIMENSION	COMMENTS
Embankment height (m)	9.5	
Embankment length (m)	1100	
Crest width (m)	4.0	
Batter slopes	3.0 : 1 upstream 2.5 : 1 downstream	
Impoundment width (m)	1000	At axis line
Bywash/spillway (m)	3.5	Above natural surface
Spillway width (m)	250	Approximately
Gully bed slope (%)	~0.5	
Foundation depth (m)	~1.0	

The following characteristics were also assumed for the construction of the large gully dam:

- a broad, U-shaped gully cross-section throughout the ponded area
- durable rock available in the bywash area at desired FSL requires minimal excavation
- suitable, good quality clay available within ponded area for core and cut-off zones
- suitable quarry rock available within ponded area riprap embankment protection.

Estimates of embankment zone volumes, total earthworks and storage volume are presented below in Table 3-5.

Table 3-5 Estimates of embankment volume and total storage volume

EMBANKMENT DESCRIPTION	DIMENSION	COMMENTS
Volume (m^3)	131,340	Includes 5% settlement
Earthfill in batters (m^3)	112,530	
Core volume (m^3)	18,450	
Cut-off trench volume (m^3)	3,675	
Topsoil stripping volume (m^3)	3,310	
Total earthworks volume (m^3)	138,325	
Total storage volume (ML)	4,055	
S : E ratio	29.3 : 1.0	
Ponded area (ha)	80	Approximately

Similar earthworks rates to those used for the ringtank example have been used to arrive at the estimated cost of construction of the gully dam discussed above. It was assumed that rock excavation was to a relatively shallow depth to achieve a level spillway bench. This may be achieved with an excavator and bulldozer and is estimated at $12.50/$m^3$. It is assumed that this excavation process will produce material suitable for use in the outer batter zones and as riprap protection on the upstream face of the embankment within the active storage zone. Placement of riprap could be expected to cost approximately $10/$m^3$ (additional to the cost of excavation).

Earthworks cost estimate

The following earthworks rates have been used to arrive at the estimated cost of construction of the large gully dam at a favourable site (Table 3-6).

Table 3-6 Cost estimates

ITEM	COST PER UNIT	TOTAL COST ($)	COMMENTS
Earthworks cost estimate			
Compacted clay	22,125 m^3 @ $6.50/$m^3$	144,000	
Earthfill and topsoil	106,840 m^3 @ $5.00/$m^3$	534,500	
Construction of fishway or fish passage		300,000	Estimate
Rock excavation for spillway	~6,000 m^3 @ $12.50 m^3	75,000	
Riprap protection	~3,000 m^3 @ $10.00/$m^3$	30,000	
Mobilisation and de-mobilisation of machinery		10,000	
Vegetation clearing, stick-raking etc.	40 ha @ $400/ha	16,000	Assumes only 50% of the area requires clearing
Contractor accommodation costs	4 staff, 80 days @ $150/day	48,000	
Sub-total 1. Construction		**1,157,500**	
Government permits and fees			
Application fee for clearing native vegetation		12,500	
Application fee relating to waterway barrier		12,500	
Application fee for operational work		11,000	1.5% of the value of the earthworks, i.e. for the gully dam
Sub-total 2. Government fees		**36,000**	
Investigation and design fees			
Consultant fee		36,500	Based on 5% of the cost of earthworks
Preparation and certification of FIA		20,000	
Investigation, design and certification of fish-passage device		30,000	
Sub-total 3. Design fees		**86,500**	
Gully dam total cost		**1,280,000**	

Government permits and fees

In Queensland a development application is required for work involving clearing native vegetation and for operational works (earthworks of more than 1000 m^3). There are fees associated with both of these applications.

Investigation and design fees

Investigation and design fees include the cost of a consultant, which is based on 5% of the cost of earthworks.

Total costs

Total costs, based on the above assumptions, totalled $1,280,000.

(a) (b)

Figure 3-4 Construction of Sharp-rock Dam
(a) construction of lower clay cut-off (b) embankment construction approaching design height
Photo: North Australia Water Strategies

Figure 3-5 Sharp-rock Dam embankment crest and batters
Photo: North Australia Water Strategies

3.2.3 TYPICAL ANNUAL OPERATING AND MAINTENANCE COSTS – 4-GL GULLY DAM #1

The only regular maintenance issue requiring attention may be regular mowing or slashing of the embankment crest and batters to maintain a good grass cover in order to minimise erosion. Slashing and/or herbicide treatment may be required annually to prevent shrubs and trees from becoming established. It is estimated that up to 20 hours/year should be budgeted for at a cost of $250/hour for machine and operator. Annual cost may be in the order of $5000/year.

Periodic maintenance of the spillway and return slope would usually be necessary following large runoff events. This may involve adding rockfill to eroded areas (either placement of large rock or construction of rock mattresses in selected areas). Minor dental concrete may also be required to maintain the spillway bench at the desired FSL. An annual maintenance budget of perhaps $50,000 would generally cover such work.

The estimated total operating and maintenance cost for a large gully dam on a favourable site may therefore be in the order of $55,000/year.

3.3 Large gully dam #2 (unfavourable site with small catchment)

3.3.1 DESIGN CRITERIA

Typical design criteria and cost estimates are presented below for a 4-GL gully dam on a minor watercourse or drainage feature, at a 'less-than-ideal' site (i.e. topographically challenging with limited spillway options due to topography such as steep gully banks, with no convenient ridge or natural saddle). The catchment at this hypothetical site is assumed to be not more than 15 km^2. The contributing catchment would therefore need to be of particularly good runoff potential to reliably fill the storage. Long-term yield from the dam would be somewhat less than the above example. On the other hand, peak spillway flows would be lower and could be expected to be of shorter duration than the larger catchment.

In this case it may be necessary to increase the embankment height to 12 or 15 m in order to achieve the desired storage volume. Additional freeboard will also be necessary due to the deeper spillway surcharge depth resulting from the restricted spillway width. Freeboard requirement of 2.5 to 3.0 m may be necessary. The spillway elevation is likely to be approximately 10 to 12 m above the gully bed.

General characteristics at an unfavourable site for a large (~4 GL) dam include:

- a moderate, V-shaped gully cross-section throughout the ponded area
- a minor constriction in the topography at the embankment site
- a flat to gentle bed slope
- a catchment area approximately 12.5 km^2
- a lack of rocky ridge or saddle 10 to 12 m above bed level necessitates deep rock excavation for spillway bench(es)
- impermeable foundation material within 1.5 m below natural surface
- good quality clay within the dam's ponded area
- nearby source of durable rock for embankment riprap
- in Queensland, an FIA is required to investigate the possible existence of any population at risk downstream of the site. (Other states probably have similar legislation)
- a catchment of this size will most likely have a significant resident native fish population; therefore, an approved fishway or fish-passage device will be required. (Queensland Planning Act – other states may vary.)

3.3.2 TYPICAL DESIGN CRITERIA AND COST ESTIMATES

Large gully dam built at an unfavourable site with a small catchment

The following dimensions for a hypothetical, large gully dam at an unfavourable site were assumed (Table 3-7):

Table 3-7 Assumed dimensions for a hypothetical, large gully dam at an unfavourable site with a small catchment

DESCRIPTION	DIMENSION	COMMENTS
Embankment height (m)	14	
Embankment length (m)	750	
Crest width (m)	5.0	
Batter slopes	3.0 : 1 upstream 2.5 : 1 downstream	
Impoundment width (m)	660	At axis line
Bywash/spillway (m)	11.5	Above gully bed
Spillway width (m)	180	Approximately
Gully bed slope (%)	~0.6	
Foundation depth (m)	~1.5	

The following characteristics were also assumed for the construction of the large gully dam:

- a moderate, V-shaped gully cross-section throughout the ponded area
- semi-durable rock available in bywash area at desired FSL requires excavation to maximum 3 m
- suitable, good quality clay available within ponded area for core and cut-off zones
- suitable rock available from selected spillway excavation for use as riprap embankment protection.

Estimates of embankment zone volumes, total earthworks and storage volume are presented below in Table 3-8.

Table 3-8 Estimates of embankment volume and total storage volume

EMBANKMENT DESCRIPTION	DIMENSION	COMMENTS
Volume (m^3)	175,550	Includes 5% settlement
Earthfill in batters (m^3)	151,500	
Core volume (m^3)	24,050	
Cut-off trench volume (m^3)	3,465	
Topsoil stripping volume (m^3)	9,520	
Total earthworks volume (m^3)	188,535	
Total storage volume (ML)	4,023	
S : E ratio	21.3 : 1.0	
Ponded area (ha)	63	Approximately

Similar earthworks rates to those used for the gully dam at favourable site example have been used to arrive at the estimated cost of construction of the gully dam at an unfavourable site discussed above. Moderately deep rock excavation was assumed, using rippers, rock-pick or a bulldozer to achieve a level spillway bench cut into the gully bank. This excavation work is estimated at $17.50/m^3$. It is assumed that this excavation process will produce material suitable for use in the outer batter zones and as riprap protection on the upstream face of the embankment within the active storage zone. As for the gully dam at favourable site example, riprap could be expected to cost approximately $10/m^3$ (additional to the cost of excavation).

Earthworks cost estimate

The following earthworks rates have been used to arrive at the estimated cost of construction of the large gully dam at an unfavourable site (Table 3-9).

Government permits and fees

In Queensland a development application is required for work involving clearing native vegetation and for operational works (earthworks of more than 1000 m^3). There are fees associated with both of these applications.

Investigation and design fees

Investigation and design fees include the cost of a consultant, which is based on 5% of the cost of earthworks.

Total costs

Total costs, based on the above assumptions, totalled $1,474,000.

Table 3-9 Cost estimates

ITEM	COST PER UNIT	TOTAL COST ($)	COMMENTS
Earthworks cost estimate			
Compacted clay	27,515 m^3 @ $6.50/$m^3$	179,000	
Earthfill and topsoil	151,500 m^3 @ $5.00/$m^3$	757,500	
Construction of fishway or fish passage		200,000	Estimate
Rock excavation for spillway	~8,500 m^3 @ $12.50 m^3	106,500	
Riprap protection	~2,000 m^3 @ $10.00/$m^3$	20,000	
Mobilisation and de-mobilisation of machinery		10,000	
Vegetation clearing, stick-raking etc.	32 ha @ $400/ha	13,000	Assumes only 50% of the area requires clearing
Contractor accommodation costs	4 staff, 90 days @ $150/day	54,000	
Sub-total 1. Construction		**1,340,000**	
Government permits and fees			
Application fee for clearing native vegetation		12,500	
Application fee relating to waterway barrier		12,500	
Application fee for operational work		15,000	1.5% of the value of the earthworks, i.e. for the gully dam
Sub-total 2. Government fees		**40,000**	
Investigation and design fees			
Consultant fee		49,000	Based on 5% of the cost of earthworks
Preparation and certification of FIA		20,000	
Investigation, design and certification of fish-passage device		25,000	
Sub-total 3. Design fees		**94,000**	
Gully dam total cost		**1,474,000**	

3.3.3 TYPICAL ANNUAL OPERATING AND MAINTENANCE COSTS – 4-GL GULLY DAM #2

The regular maintenance activities for this dam would be very similar to dam #1, with perhaps a little less time required on erosion repairs because of the shorter embankment and narrower spillway.

The estimated total operating and maintenance cost for a large gully dam on an unfavourable site with a small catchment may be in the order of $35,000/year.

3.4 Large gully dam #3 (unfavourable site with large catchment)

3.4.1 DESIGN CRITERIA

Typical design criteria and cost estimates are presented below for a 4-GL gully dam on a relatively large drainage feature, at a 'less-than-ideal' site, with similar issues as for gully dam #2 (i.e. topographically challenging with limited spillway options). The catchment at this hypothetical site is assumed to be more than 15 km^2, but not as large as gully dam #1. The contributing catchment may be expected to reliably fill the storage and may have quite a long flow duration or inflow hydrograph. Peak spillway flows would be substantial and the design would need to include a flow-flow facility to cater for lengthy flow duration. If the spillway is excavated into firm rock, then this is not an issue and no additional facility would be required.

General characteristics at this unfavourable site for a large (~4 GL) dam are as for gully dam #2, except for the larger catchment (assumed to be 20 km^2) and proportionately wider spillway (approximately 210 m) requiring deeper, more expensive rock excavation.

As for the above cases, an FIA is required to investigate the possible existence of any population at risk downstream of the site.

As this catchment is larger than gully dam #2, an approved fishway or fish-passage device will be required to facilitate native fish passage. There may be economies to be had by incorporating the fish-passage device into the flow-flow spillway facility.

3.4.2 TYPICAL DESIGN CRITERIA AND COST ESTIMATES

Large gully dam built at an unfavourable site with a large catchment

Estimates of embankment zone volumes, total earthworks and storage volume are as for gully dam #2.

Earthworks cost estimate

Earthworks and other costs will be similar to gully dam #2; however, the volume of rock excavation in the spillway may increase to 15,000 m^3, at a net cost of about $80,000, because all of this material is assumed to be utilised in the outer batter zones.

Total costs

The total cost of gully dam #3 construction would increase to about $1,554,000.

3.4.3 TYPICAL ANNUAL OPERATING AND MAINTENANCE COSTS – 4-GL GULLY DAM #3

The regular maintenance activities for this dam would be very similar to gully dam #1, with a little less time required on erosion repairs because of the shorter embankment, narrower spillway and smaller peak discharge from the catchment.

The estimated total operating and maintenance cost for a large gully dam at an unfavourable site with a large catchment may be in the order of $40,000/year.

3.5 Outlet works in gully dams

If the proposed dam is to be constructed on a watercourse, as defined by the legislation in various states, then it is likely that conditions applicable to the water licence would include bed-level outlet works capable of passing a prescribed flow. Such a prescribed flow may vary from that required to meet downstream riparian rights (stock and domestic water supplies), up to significant baseflow to meet any existing entitlements of downstream irrigators. Past experience would indicate that it is generally unlikely that a government would approve any of the cases discussed above if there was an existing large dam, with an associated water entitlement, on the same 15 to 30 km^2 catchment. If it was the case that a small to medium dam or water entitlement existed downstream, then a through-pipe and outlet regulator works would most likely be mandatory.

Small throughflows of less than about 0.5 ML/day could best be achieved by means of an overbank syphon at a relatively minimal cost. Releases of more than about 25 ML/day would, however, require a significant investment, incorporating 300 to 500 mm pipe encased in concrete, with anti-seep baffles, an inlet screen and a high-quality, heavy-duty regulator valve set in concrete head-walls. The cost would vary greatly but could easily be in the $50,000 to $100,000 range.

4 Actual gully dam costs

Actual costs for four large farm-scale gully dams constructed in northern Queensland are presented in Table 4-1.

Table 4-1 Actual costs for four gully dams in north Queensland
Costs are indexed to 2017.

DAM NAME	LOCATION	CAPACITY (ML)	YIELD (ML/y)	COST ($)	UNIT COST ($/ML)	COMMENT
Sharp Rock Dam	Lakelands	3300	1070	322,800	302	Chimney filter and drainage under-blanket. Two stage concrete sill spillway. No fishway. Pump station not included
Dump Gully Dam	Lakelands	1450	420	786,000	1871	Deep and wet cut-off. Chimney filter and downstream under drainage. No fishway. Pump station was $91,000
Spring Dam #2	Lakelands	2540	1377	895,600	650	Chimney filter and drainage under-blanket. Two stage rock excavation. Spillway with fishway. Fishway was $36,500. Pump station not included
Ronny's Dam	Georgetown	9975	1700	447,900	263	Very favourable site. Low embankment and 450-ha ponded area. Natural spillway. No pump station, gravity supply via through pipe

5 References

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