An opportunity analysis of hydro-electric power generation in the Southern Gulf catchments

A technical report from the CSIRO Southern Gulf Water Resource Assessment for the National Water Grid

Entura

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CSIRO Southern Gulf Water Resource Assessment acknowledgements

This report was funded through the National Water Grid's Science Program, which sits within the Australian Government's Department of Climate Change, Energy, the Environment and Water.

Aspects of the Assessment have been undertaken in conjunction with the Northern Territory and Queensland governments.

The Assessment was guided by two committees:

i. The Governance Committee: CRC for Northern Australia/James Cook University; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Agriculture and Fisheries; Queensland Department of Regional Development, Manufacturing and Water

ii. The Southern Gulf catchments Steering Committee: Amateur Fishermen's Association of the NT; Austral Fisheries; Burketown Shire; Carpentaria Land Council Aboriginal Corporation; Health and Wellbeing Queensland; National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Prawn Fisheries; Queensland Department of Agriculture and Fisheries; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Regional Development, Manufacturing and Water; Southern Gulf NRM

Responsibility for the Assessment's content lies with CSIRO. The Assessment's committees did not have an opportunity to review the Assessment results or outputs prior to their release.

This report was reviewed by Dr Cuan Petheram (CSIRO)

Acknowledgement of Country

CSIRO acknowledges the Traditional Owners of the lands, seas and waters of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture and pay our respects to their Elders past and present.

Photo

Gregory River, Northern Territory. Source: CSIRO

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Director’s foreword

Sustainable development and regional economic prosperity are priorities for the Australian, Queensland and Northern Territory (NT) governments. However, more comprehensive information on land and water resources across northern Australia is required to complement local information held by Indigenous Peoples and other landholders.

Knowledge of the scale, nature, location and distribution of likely environmental, social, cultural and economic opportunities and the risks of any proposed developments is critical to sustainable development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpin the resource security required to unlock investment, while at the same time protecting the environment and cultural values.

In 2021, the Australian Government commissioned CSIRO to complete the Southern Gulf Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to generate data and provide insight to support consideration of the use of land and water resources in the Southern Gulf catchments. The Assessment focuses mainly on the potential for agricultural development, and the opportunities and constraints that development could experience. It also considers climate change impacts and a range of future development pathways without being prescriptive of what they might be. The detailed information provided on land and water resources, their potential uses and the consequences of those uses are carefully designed to be relevant to a wide range of regional-scale planning considerations by Indigenous Peoples, landholders, citizens, investors, local government, and the Australian, Queensland and NT governments. By fostering shared understanding of the opportunities and the risks among this wide array of stakeholders and decision makers, better informed conversations about future options will be possible.

Importantly, the Assessment does not recommend one development over another, nor assume any particular development pathway, nor even assume that water resource development will occur. It provides a range of possibilities and the information required to interpret them (including risks that may attend any opportunities), consistent with regional values and aspirations.

All data and reports produced by the Assessment will be publicly available.

C. Chilcott

Chris Chilcott

Project Director

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Shortened forms

SHORT FORM	FULL FORM
ACSR	aluminium conductor steel-reinforced cable
AMTD	adopted middle thread distance (the distance measured along the middle of a watercourse that a specific point in the watercourse is from the watercourse's mouth or junction with the main watercourse)
DEM	digital elevation model
DN	nominal diameter
EGM96	Earth Gravitational Model 1996
EPC	engineering procurement construction
FSL	full supply level
LGC	large-scale generation certificate
MOL	minimum operating level
NEM	National Electricity Market
NWPS	North West Power System
PPA	power purchase agreement
RCC	roller compacted concrete
RL	reduced level
EL	elevation
SRTM	Shuttle Radar Topography Mission
TWL	tail water level

Units

UNIT	DESCRIPTION
GWh	gigawatt hour
km	kilometre
kW	kilowatt
kWh	kilowatt hour
m	metre
mEGM96	metres (Earth Gravitational Model 1996)
Mm^3	million cubic metres
MVA	megavolt ampere
MW	megawatt
MWh	megawatt hour

Preface

Sustainable development and regional economic prosperity are priorities for the Australian, NT and Queensland governments. In the Queensland Water Strategy, for example, the Queensland Government (2023) looks to enable regional economic prosperity through a vision that states 'Sustainable and secure water resources are central to Queensland's economic transformation and the legacy we pass on to future generations.' Acknowledging the need for continued research, the NT Government (2023) announced a Territory Water Plan priority action to accelerate the existing water science program 'to support best practice water resource management and sustainable development.'

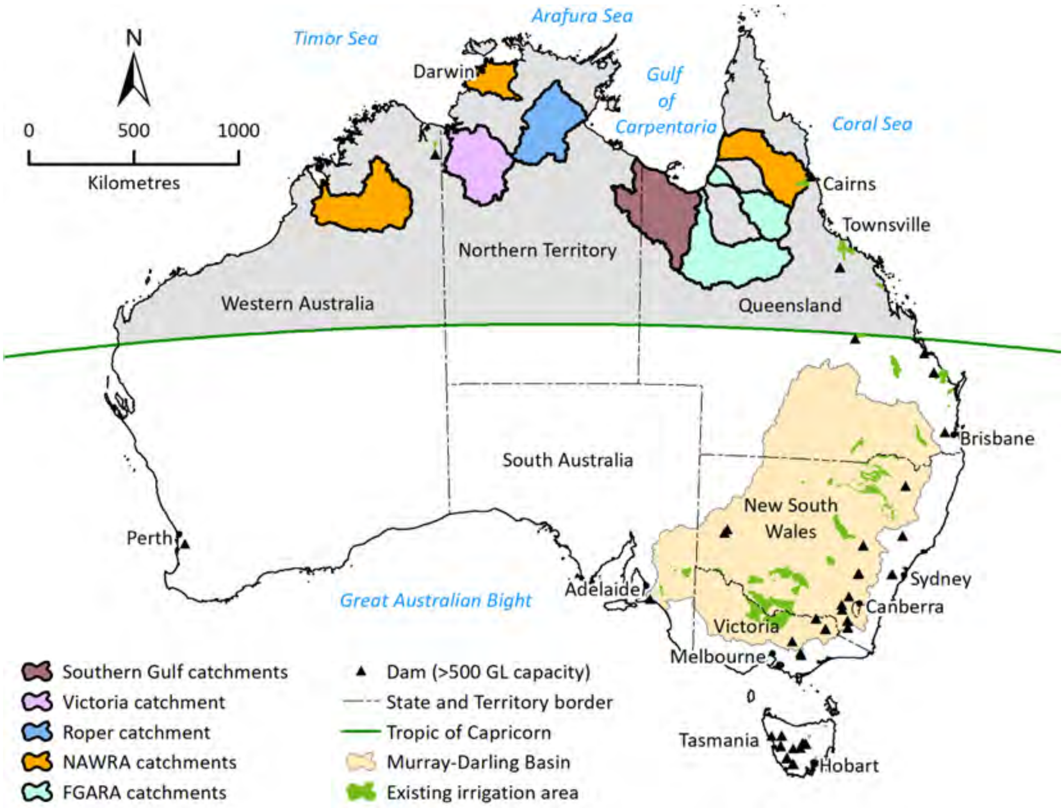
Governments are actively seeking to diversify regional economies, considering a range of factors, including Australia's energy transformation. The Queensland Government's economic diversification strategy for North West Queensland (Department of State Development, Manufacturing, Infrastructure and Planning, 2019) includes mining and mineral processing; beef cattle production, cropping and commercial fishing; tourism with an outback focus; and small business, supply chains and emerging industry sectors. In its 2024–25 Budget, the Australian Government announced large investment in renewable hydrogen, low-carbon liquid fuels, critical minerals processing and clean energy processing (Budget Strategy and Outlook, 2024). This includes investing in regions that have 'traditionally powered Australia' – as the North West Minerals Province, situated mostly within the Southern Gulf catchments, has done.

For very remote areas like the Southern Gulf catchments (Preface Figure 1-1), the land, water and other environmental resources or assets will be key in determining how sustainable regional development might occur. Primary questions in any consideration of sustainable regional development relate to the nature and the scale of opportunities, and their risks.

How people perceive those risks is critical, especially in the context of areas such as the Southern Gulf catchments, where approximately 27% of the population is Indigenous (compared to 3.2% for Australia as a whole) and where many Indigenous Peoples still live on the same lands they have inhabited for tens of thousands of years. About 12% of the Southern Gulf catchments are owned by Indigenous Peoples as inalienable freehold.

Access to reliable information about resources enables informed discussion and good decision making. Such information includes the amount and type of a resource or asset, where it is found (including in relation to complementary resources), what commercial uses it might have, how the resource changes within a year and across years, the underlying socio-economic context and the possible impacts of development.

Most of northern Australia's land and water resources have not been mapped in sufficient detail to provide the level of information required for reliable resource allocation, to mitigate investment or environmental risks, or to build policy settings that can support good judgments. The Southern Gulf Water Resource Assessment aims to partly address this gap by providing data to better inform decisions on private investment and government expenditure, to account for intersections between existing and potential resource users, and to ensure that net development benefits are maximised.



Preface Figure 1-1 Map of Australia showing Assessment area (Southern Gulf catchments) and other recent CSIRO Assessments

FGARA = Flinders and Gilbert Agricultural Resource Assessment; NAWRA = Northern Australia Water Resource Assessment.

The Assessment differs somewhat from many resource assessments in that it considers a wide range of resources or assets, rather than being a single mapping exercises of, say, soils. It provides a lot of contextual information about the socio-economic profile of the catchments, and the economic possibilities and environmental impacts of development. Further, it considers many of the different resource and asset types in an integrated way, rather than separately.

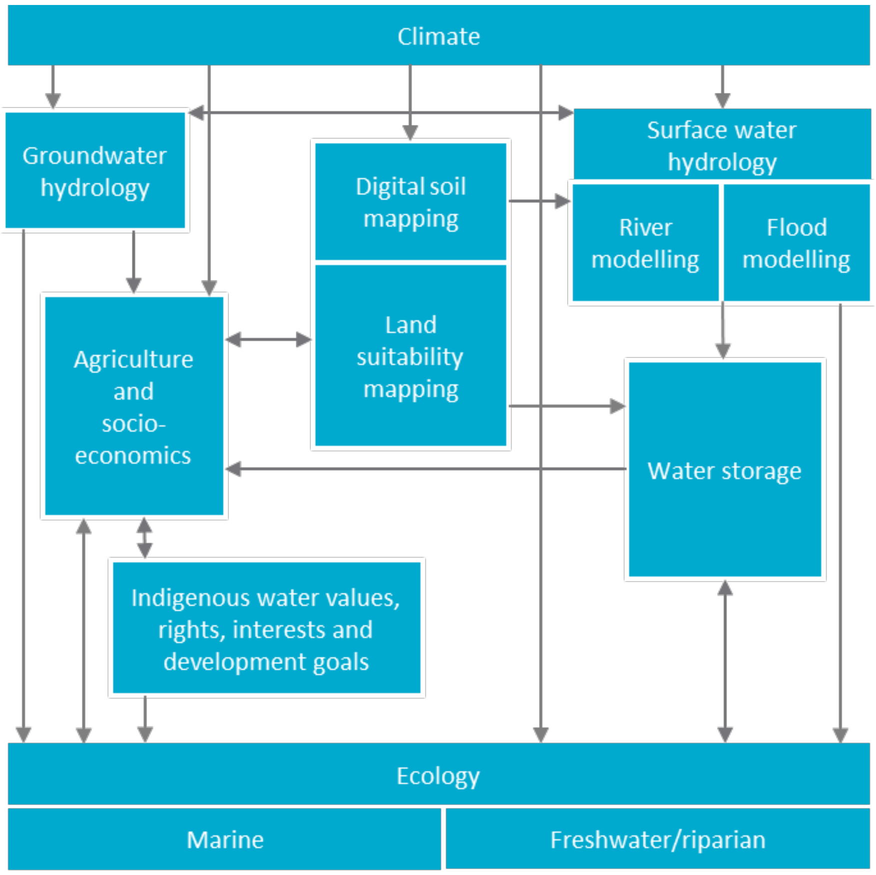
The Assessment has agricultural developments as its primary focus, but it also considers opportunities for and intersections between other types of water-dependent development. For example, the Assessment explores the nature, scale, location and impacts of developments relating to industrial, urban and aquaculture development, in relevant locations. The outcome of no change in land use or water resource development is also valid.

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 does not assume a given policy or regulatory environment. Policy and regulations can change, so this flexibility enables the results to be applied to the widest range of uses for the longest possible time frame.

It was not the intention of – 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 are discussed with reference to and in the context of the existing literature.

CSIRO has strong organisational commitments to Indigenous reconciliation and to conducting ethical research with the free, prior and informed consent of human participants. The Assessment allocated significant time to consulting with Indigenous representative organisations and Traditional Owner groups from the catchments to aid their understanding and potential engagement with its requirements. The Assessment did not conduct significant fieldwork without the consent of Traditional Owners. CSIRO met the requirement to create new scientific knowledge about the catchments (e.g. on land suitability) by synthesising new material from existing information, complemented by remotely sensed data and numerical modelling.

Functionally, the Assessment adopted an activities-based approach (reflected in the content and structure of the outputs and products), comprising activity groups, each contributing its part to create a cohesive picture of regional development opportunities, costs and benefits, but also risks. Preface Figure 1-2 illustrates the high-level links between the activities and the general flow of information in the Assessment.



Preface Figure 1-2 Schematic of the high-level linkages between the eight activity groups and the general flow of information in the Assessment

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 for each Assessment most reliably informs discussion and decisions concerning regional development when read as a whole.

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

- Technical reports present scientific work with sufficient detail for technical and scientific experts to reproduce the work. Each of the activities (Preface Figure 1-2) has one or more corresponding technical reports.
- A catchment report, which synthesises key material from the technical reports, providing well-informed (but not necessarily scientifically trained) users with the information required to inform decisions about the opportunities, costs and benefits, but also risks, associated with irrigated agriculture and other development options.
- A summary report provides a shorter summary and narrative for a general public audience in plain English.
- A summary fact sheet provides key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable users to better access information that is not readily available in print format. All of these reports, information tools and data products are available online at https://www.csiro.au/southerngulf. The webpages give users access to a communications suite including fact sheets, multimedia content, FAQs, reports and links to related sites, particularly about other research in northern Australia.

Executive summary

The catchment of the Leichhardt River forms part of the catchments of the Southern Gulf rivers, that is Settlement Creek, Gregory–Nicholson River and Leichhardt River, the Morning Inlet catchments and the Wellesley Island groups. A case study approach was undertaken to explore key considerations in establishing hypothetical hydro-electric power in the study area. For this study one of the more promising potential sites for hydro-electric power generation, Gunpowder Creek AMTD 66 km in the Leichhardt catchment, was used for the case study. This study found that:

- Development of a large in-river storage solely for hydro-electric power purposes is not commercially feasible in study area. For a potential large in-river storage on the Gunpowder Creek AMTD 66 km with a mean annual inflow of 177 Mm^3, an associated hypothetical hydro-electric power station would have an energy output of 11 GWh/year, a generating capacity of 5 MW and a utilisation of 25%.
- The addition of a small hydro-electric power station (functioning as an energy recovery system) to a dam developed for irrigation has potential. This could offset the electricity costs or fuel usage for pumping for irrigation (if developed by the irrigation owner) and could generate some electricity during the wet season for feeding into the grid when there is no irrigation. With the same large in-river storage on the Gunpowder Creek, the station would have an energy output of 10.5 GWh/year, a generating capacity of 7.5 MW and a utilisation of 16%.
- Assessment of a small hypothetical hydro-electric power station as an energy recovery system for an irrigation development indicated it is unlikely to be a financially attractive investment, based on the current assessment of cost. Given the low head and low discharge, combined with the significant distance from the existing grid, the capital costs would need to be significantly reduced to make this commercially viable.
- The inclusion of a small hypothetical hydro-electric power station in an isolated grid, in which the hypothetical hydro-electric power station only supplied the pumping requirements, was also considered. Due to the distance between the hypothetical dam site and the hypothetical re-regulating weir, the time between release or pumping at the weir for irrigation would be 1 to 2 days. Given this lag, it is considered very unlikely that a dispatch at the hydro-electric power station could easily align with the variable pumping requirements without a connection to the grid. To operate over the entire range of pumping requirements, a multi-machine power station would also be required, which would have an impact on the economic feasibility of a hydro-electric power station.

As part of this report, a concept arrangement for the electrical infrastructure required to connect an irrigation scheme to the power station was also considered. Given the significant distances associated with the connection (based on the very remote nature of the irrigation developments), opportunities to operate the irrigation schemes with remote energy sources (or at least to reduce the power demand required) should be investigated, so that the schemes could be connected to the existing distribution grid (at 19.2 kV), rather than requiring a separate connection.

Contents

Figures

Tables

1 Introduction

1.1 Background

In order to understand the risks and opportunities of water resource and irrigation development in the Southern Gulf catchments CSIRO undertook an opportunity analysis of locations potentially suitable for large water storages for the purpose of supplying water (e.g. for mining, agriculture, urban) and power generation (see companion technical report on surface water storage, Yang et al. 2024). The CSIRO also developed nominal conceptual arrangements and preliminary costs estimates for two hypothetical irrigation areas (see companion technical report on reticulation scheme infrastructure, Devlin 2024), the first adjacent to the Gregory River and the second near the junction of Gunpowder Creek and the Leichhardt River.

As part of the Assessment, the CSIRO requested Entura undertake a pre-feasibility assessment of the hydro-electric power potential for a potential dam on Gunpowder Creek, one of the most cost effective locations for hydro-electric power generation in the Southern Gulf catchments (Yang et al. 2024). The site, at adopted middle thread distance (AMTD) 66 km (Figure 1-1), is likely to be one of the better opportunities for hydro-electric power generation in the Southern Gulf catchments and provides a representative site to explore key considerations in establishing hydro-electric power in the study area. CSIRO also requested Entura provide a preliminary estimate of the cost of connecting the two hypothetical irrigation schemes to the grid network. It should be noted that these evaluations were not for the purposes of identifying viable projects but using these as case studies to highlight key considerations associated with hydro-electric power generation and energy transmission in the Southern Gulf catchments.

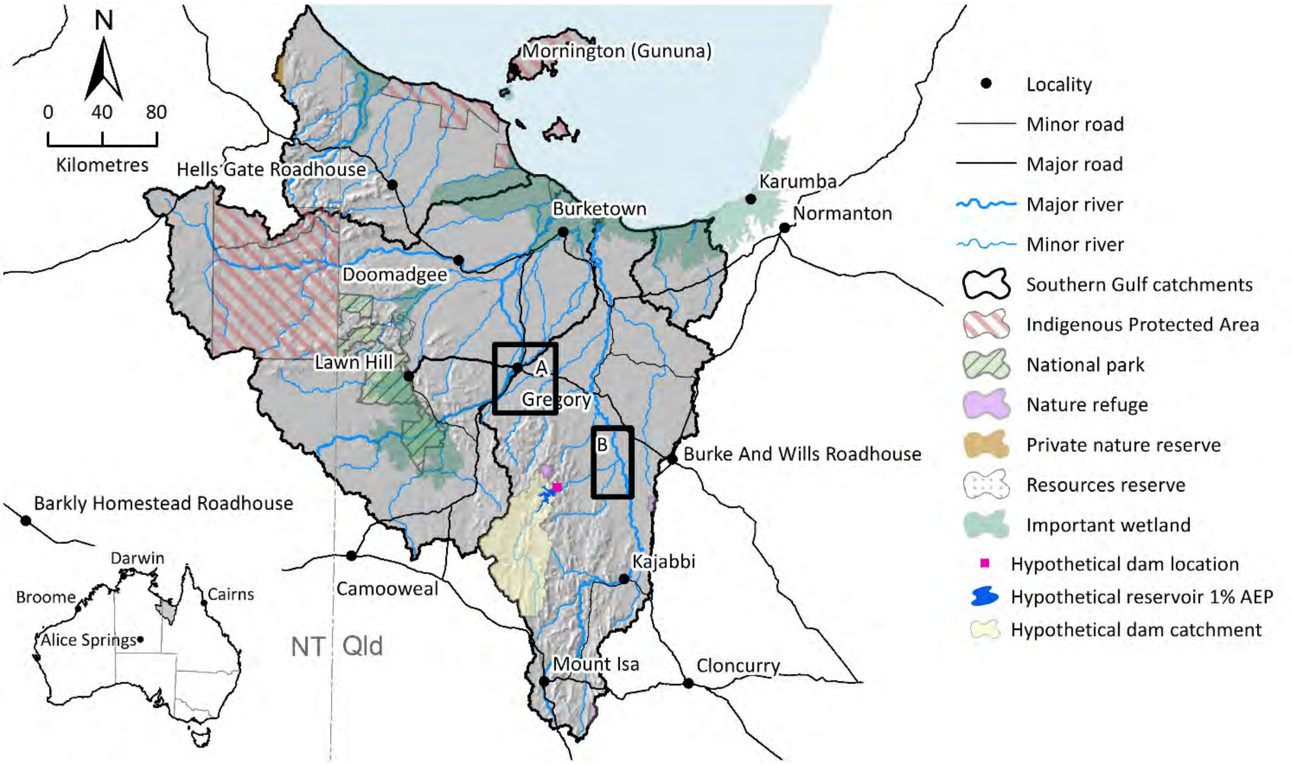


Figure 1-1 Study area and hypothetical hydro-electric dam on Gunpowder Creek and hypothetical irrigation areas

Note - Rectangular box A shows broad extent of hypothetical irrigation area adjacent to Gregory River. Rectangular box B shows broad extent of hypothetical irrigation area near the junction of Gunpowder Creek and Leichhardt River.

1.2 Objectives of this study

The overarching objective of this hypothetical study was to use a case study to provide information on the hydro-electric power potential in the Southern Gulf catchments and an overview of the electrical infrastructure in the region.

More specifically this pre-feasibility study sought to:

- undertake a pre-feasibility-level hydro-electric power assessment at the potential dam on Gunpowder creek AMTD 66 km for two potential options:
  - **Option A:** The reservoir is to be used solely for hydro-electric power generation for the National Electricity Market (NEM), assuming the completion of the CopperString 2032 connection between Townsville and Mount Isa.
  - **Option B:** Generation is to be limited to periods of spillway overflows and when releases are required for irrigation, and the potential is to be used for behind-the-meter generation for nearby pumping infrastructure at a downstream re-regulating weir.
- produce a high-level description (and cost estimate) of the additional energy infrastructure requirements for the two hypothetical irrigation developments adjacent to the Gregory River and Gunpowder Creek
- assess the power and energy generation capabilities of the hypothetical hydro-electric power scheme and the potential demand of the hypothetical irrigation schemes.

The structure of the report is as follows:

- Section 1 – Introduction

- Section 2 – Site review, and hydrological and energy assessment
- Section 3 – Technical assessment
- Section 4 – Review of costs and benefits
- Section 5 – Summary and discussion
- References.

1.3 Input data

The key reports and inputs which formed the basis of the hypothetical hydro-electric power pre-feasibility study, are listed in Table 1-1 and Table 1-2.

Table 1-1 Input information provided by CSIRO

REFERENCE	TITLE	DESCRIPTION
CSIRO, 25/07/2024	Gregory irrigation area shapefile	This shapefile contains the catchments within the Gregory irrigation development
CSIRO, 25/07/2024	Nominal location of Gunpowder Creek weir	This shapefile provides the location of the Gunpowder Creek weir
CSIRO, 16/08/2024	Reservoir shapefile	This shapefile provides the reservoir boundary at FSL, EL 186 mEGM96
CSIRO, 16/08/2024	Gunpowder dam climate data	The spreadsheet provides daily inflows to the potential reservoir on Gunpowder Creek; rainfall; evaporation; irrigation demand; and spill data from 1889 to 2023
CSIRO, 16/08/2024	24_HSaV	Lake storage volumes are provided from EL 136 m to EL 235 m
CSIRO, 19/08/2024	Spillway Discharge Rating	The spillway discharge rating is provided, from FSL to 14 m above FSL (EL 200 m)

EGM96 = Earth Gravitational Model 1996; FSL = full supply level; EL = elevation level.

Table 1-2 Additional input information used in this study

REFERENCE	TITLE	DESCRIPTION
Geoscience Australia, 2024	DEM	SRTM-derived 1-second DEM Version 1.0 was used to obtain the approximate river centreline level to calculate the head when the lake is at FSL
Australian Energy Market Operator (AEMO, August 2024)	Aggregate price and demand data	National Energy Spot Market historical data, sourced from https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/data-nem/aggregated-data on 29 August 2024
Queensland Government, 2021	Electricity supply options for the North West Minerals Province: Consultation Regulatory Impact Statement	Report on modelling for power prices associated with the CopperString 2032 project

DEM = Digital Elevation Model; FSL = full supply level; SRTM = Shuttle Radar Topography Mission.

1.4 Datums

Note: all heights are in the EGM96 height datum and are referred to herein as m or EL.

2 Site review, and hydrological and energy assessment

2.1 Gunpowder Creek dam and irrigation scheme – site review

The potential dam on Gunpowder creek AMTD 66 km nominated by CSIRO is located on in a locally narrow gorge, approximately 70 km north-east of Gunpowder (140 km north of Mount Isa). At the potential dam site, the gorge is approximately 80 m deep and 450 m wide. The geology at the dam site is sedimentary rock (arenite and rudite), and the creek bed is lined with alluvium deposited from yearly floods (see Yang et al. 2024 for more detail). The potential dam impounds an area of approximately 40 km^2 at full supply level (FSL).

Both options A and B (described in Section 1.2) include the operation of a hypothetical hydro-electric power station using the water impounded by the Gunpowder Creek dam. At a pre-feasibility level, the powerhouse is best located at the foot of the dam, minimising the length of the pressure conveyance, to save material costs and reduce head losses.

A potential re-regulating weir for an irrigation development on the lower reaches of Gunpowder Creek is located a nominal 55 km (flow distance) downstream of the potential dam (Figure 2-1). Given the distance between the two sites, water released from the potential dam on Gunpowder creek AMTD 66 km would take 1 to 2 days to reach the re-regulating weir. For Option B, a transmission line to a nominal location of the potential Gunpowder Creek weir would serve to power the transfer and irrigation pumps. This line would need to be nominally 45 km long.

A permanent access road (and construction road) would approach the site from Gunpowder, with the alignment being south of the area to be inundated and 50 km in length. The transmission line could follow a similar alignment, connecting to the transmission network at the Gunpowder substation and totalling 43 km of line. A conceptual diagram of the arrangement is shown in Figure 2-2.

At the pre-feasibility stage, CSIRO assumed a Roller Compacted Concrete (RCC) dam would be most suitable for this site, due to the potential for significant flooding during construction and the likely requirement for a large capacity spillway (see Yang et al., 2024). RCC dams are generally constructed quickly and can cost less than conventional concrete gravity dams, due to the construction method (in which the compaction utilises earthworks equipment in scale) and the lower cement content (which results in less heat of hydration). These features combined allow for higher construction rates, despite the total concrete volume being slightly larger.

For a potential dam on Gunpowder Creek AMTD 66 km CSIRO nominated the hypothetical hydro-electric power assessment be undertaken at a full supply level (FSL) of 186 m (an ~60 m-high dam).

Figure 2-1 Potential dam on Gunpowder creek AMTD 66 km and nominal potential re-regulating weir location

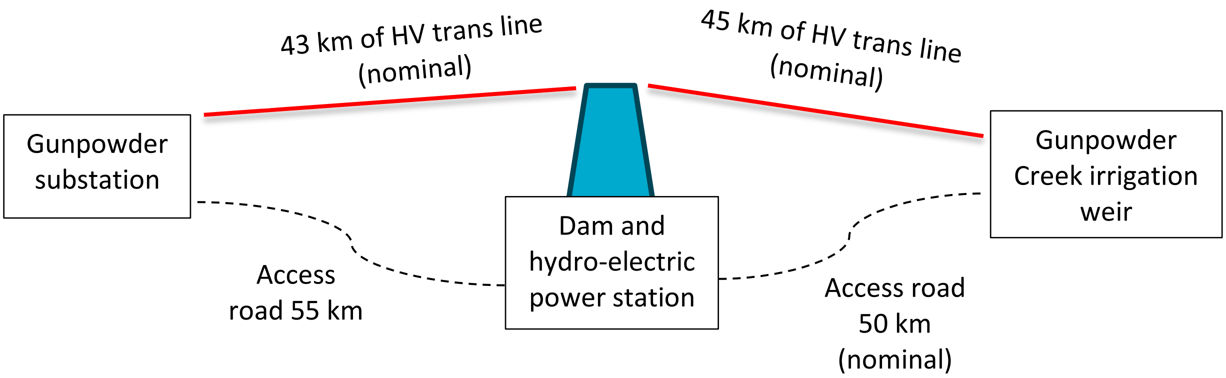


Figure 2-2 Dam site and irrigation scheme connection and access roads

2.2 Inflows

Potential dam on Gunpowder creek AMTD 66 km is an in-river water storage facility designed to harvest rainfall inflows from the upstream catchment area. The reservoir's operation is influenced by the variability of rainfall, seasonal evaporation, and inflows from the upstream catchment. The Southern Gulf catchments, where the site is located, experience a semi-arid climate with distinct wet and dry seasons, significantly affecting water availability and storage.

CSIRO has provided data on daily rainfall, potential evaporation, and inflows into the reservoir from 1890 to 2022. Figure 2-3 shows the daily inflows for the simulation period.

The reservoir elevation and the corresponding storage volume are provided in Figure 2-4, and Figure 2-5 provides the spillway rating curve prepared by CSIRO.

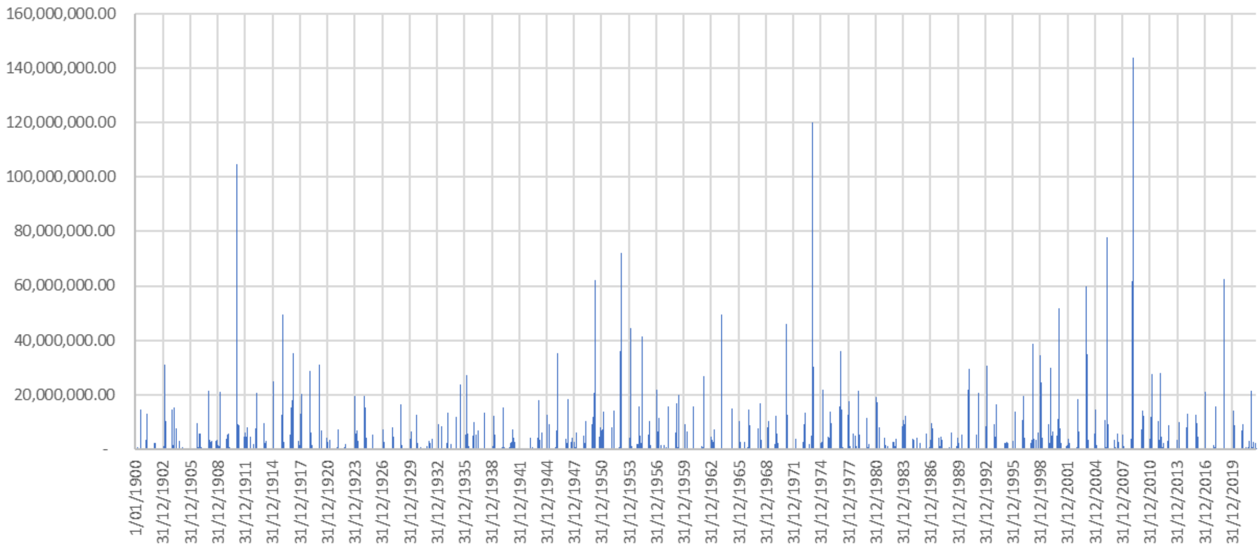


Figure 2-3 Daily inflows for the simulation period

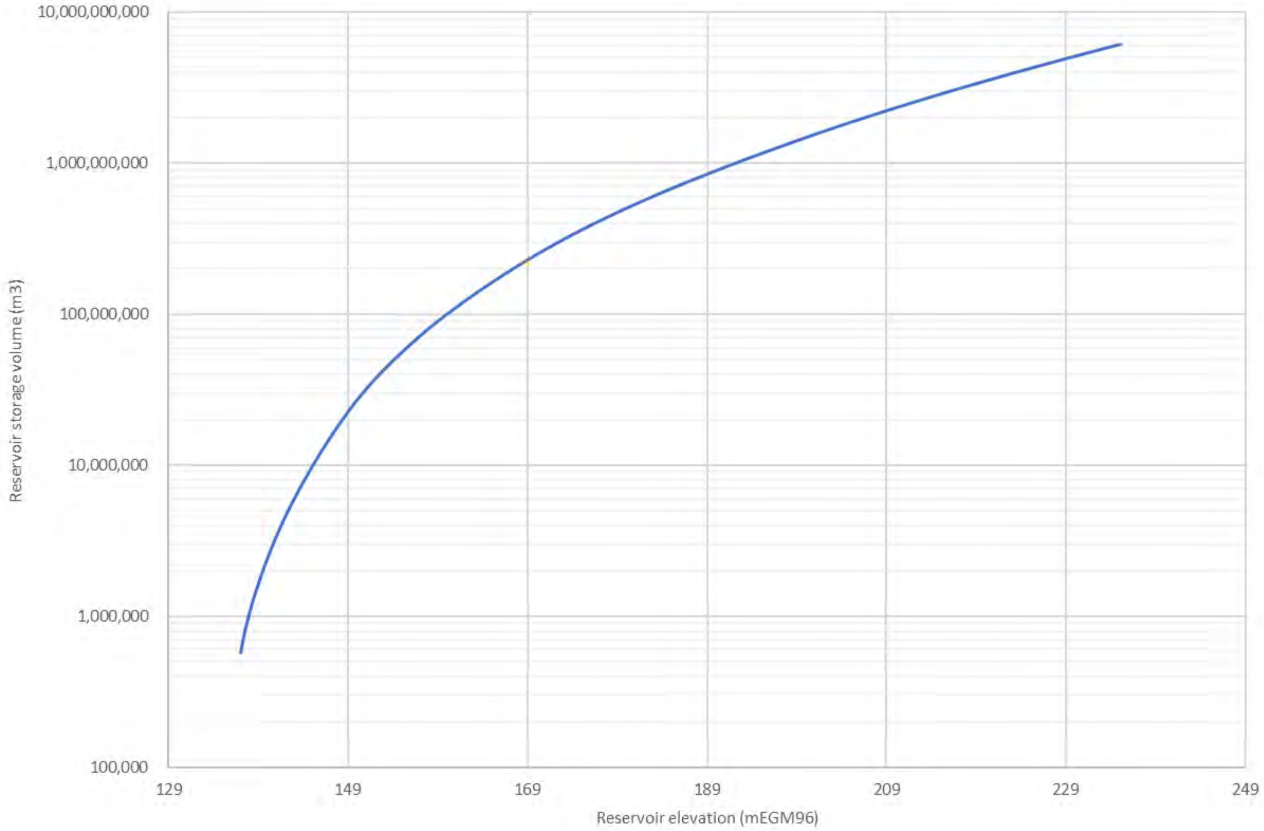


Figure 2-4 Reservoir storage volume curve

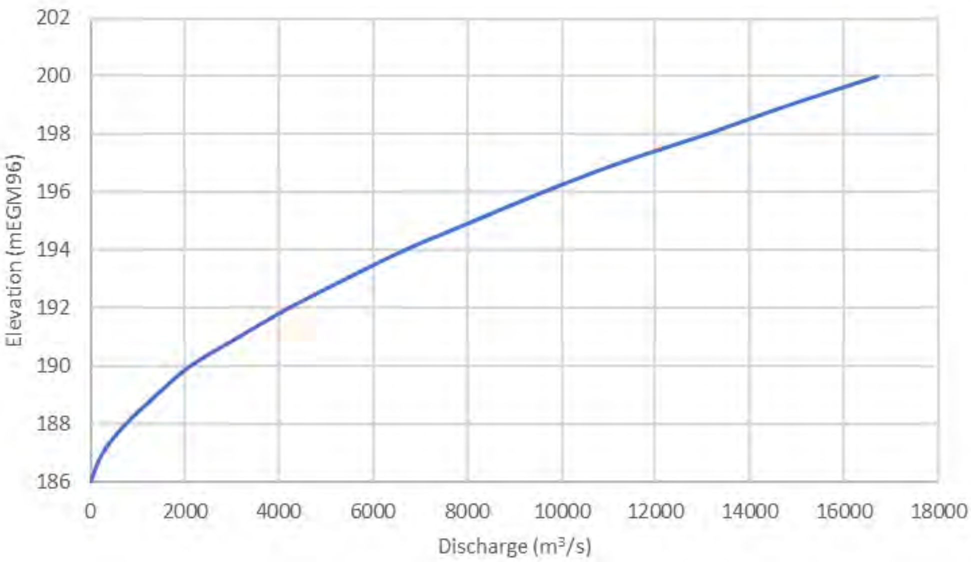


Figure 2-5 Spillway rating curve

2.3 Rainfall and evaporation

The Southern Gulf catchments have a semi-arid climate characterised by a distinct dry season from April to November and a wet season from December to March. Over 80% of the annual rainfall occurs during the wet season. The catchments experience high variability in rainfall. High potential evaporation rates during the summer months exacerbate water shortages, though the dry season experiences lower potential evaporative demand due to the cooler temperatures.

Figure 2-6 shows the rainfall over the hypothetical Gunpowder Creek dam reservoir catchment and the reservoir level for the simulated inflows and irrigation demand sourced from companion technical report on river model simulation (Gibbs et al. 2024). Environmental flow requirements are not provided and hence this analysis represents the bio-physical limit of what is possible.

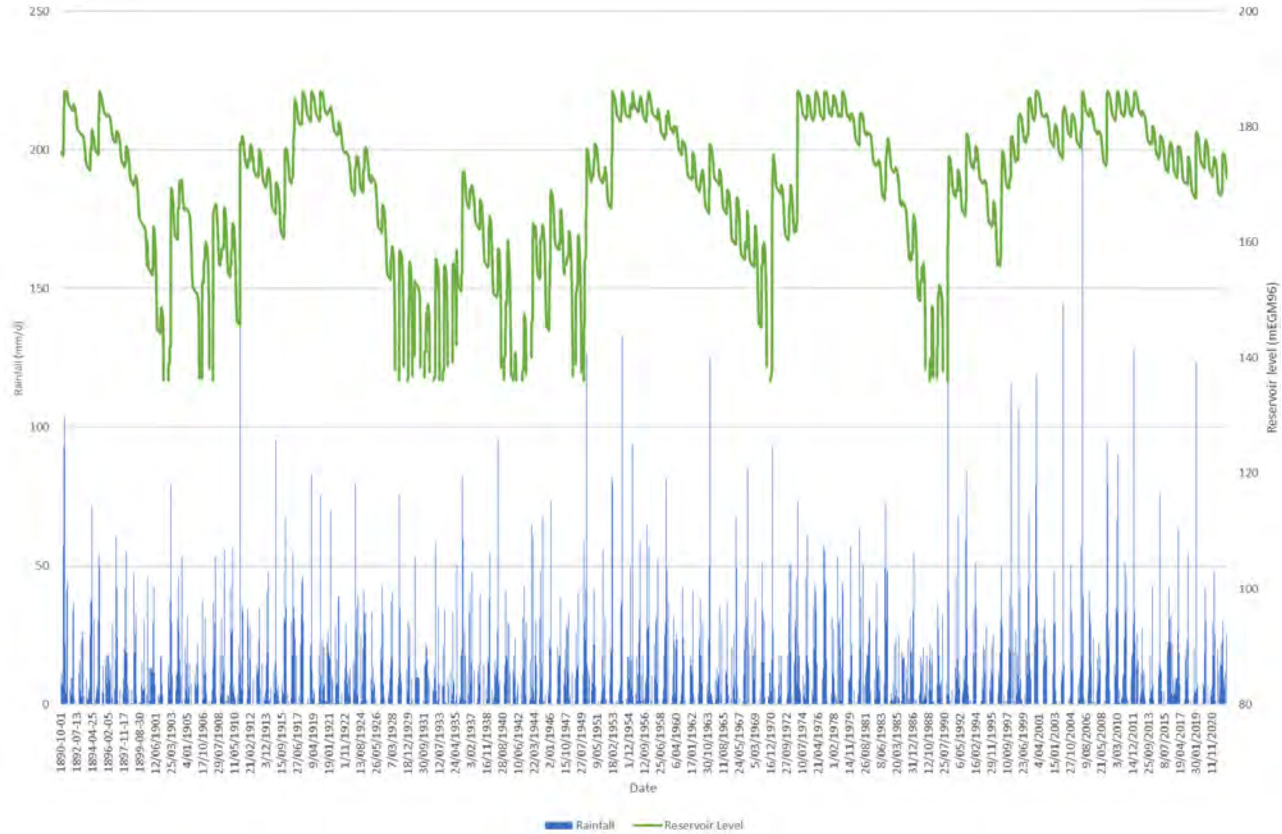


Figure 2-6 Potential dam on Gunpowder Creek AMTD 66 km reservoir storage level and rainfall for the simulation period

Note - FSL = full supply level.

This seasonal variability in rainfall and inflows directly affects the reservoir's storage levels, which typically rise during the wet season and decrease during the dry season due to evaporation, limited inflows and increased irrigation demand.

Additionally, long-term trends indicate cycles of wet and dry years, with certain periods of significant rainfall and corresponding higher storage levels, contrasted with low rainfall years, in which storage levels are reduced.

The considerable fluctuation between the maximum and minimum head is a key constraint for hydro-electric power generation. It would influence turbine selection and low reservoir levels would limit the ability to utilise the water for power generation.

2.4 Energy assessment and hydro-electric power sizing

Two options were assessed for this concept design:

- **Option A:** The reservoir is to be used solely for hydro-electric power generation for the National Electricity Market (NEM), assuming the CopperString 2032 connection between Townsville and Mount Isa.
- **Option B:** Generation is to be limited to periods of spillway overflows and when releases are required for irrigation, and the potential is to be used for behind-the-meter generation for nearby pumping infrastructure at a downstream re-regulating weir.

2.4.1 INITIAL SIZING ASSUMPTIONS

For the initial sizing of the hypothetical hydro-electric power station, the assumptions made and input parameters for the energy assessment are listed in Table 2-1.

Table 2-1 Input parameters

DESCRIPTION	INPUT PARAMETER	COMMENT/REFERENCE
Full supply level (FSL)	EL 186 m	From CSIRO concept
Maximum operating level	EL 190 m	From CSIRO modelling data
Tailwater level	EL 130 m	Nominally 1 m above the river centreline at the dam location (from the Queensland Digital Elevation Model)
Headloss	3%–5%	Assumed, based on typical waterway arrangement; 5% adopted for initial modelling, with the potential to optimise to 3% if required
Turbine efficiency	92%	Assumed will vary according to head and flow
Generator efficiency	98%	Assumed includes allowances for transformer losses
Turbine maximum flow	100% rated flow	Assumed
Turbine minimum flow	50% rated flow	Typical for Francis and Kaplan turbines, the most likely turbine to be adopted
Turbine maximum head	125% rated head	
Turbine minimum head	65% rated head	
Turbine minimum head (restricted operation)	50% rated head	Potential flexibility to operate between 65% and 50% depending on cavitation limits, hours of operation, and discharge

2.4.2 OPTION A

For Option A, the follow key assumptions were made for the initial sizing concept:

- The input climate and inflow data from 1890 to 2022 were used to simulate the yield from the potential dam.
- Historical NEM pricing data was used from 1 October 2021 until 31 July 2024 to represent the value of wholesale energy on the spot market in the Queensland region. (This represents the period in the NEM during which 5-minute trading intervals were introduced.) These data are presented in Figure 2-7.
- For the purposes of initial sizing, capacity payments and Large-scale Generation Certificates were ignored in the value proposition for the hypothetical hydro-electric power generation.

- To avoid negative pricing in the spot market, generation was restricted to a maximum of 16 hours in a day (typically not between 7:00am and 3:00pm but varying depending on the day).
- No other operational restrictions were assumed in the initial sizing.

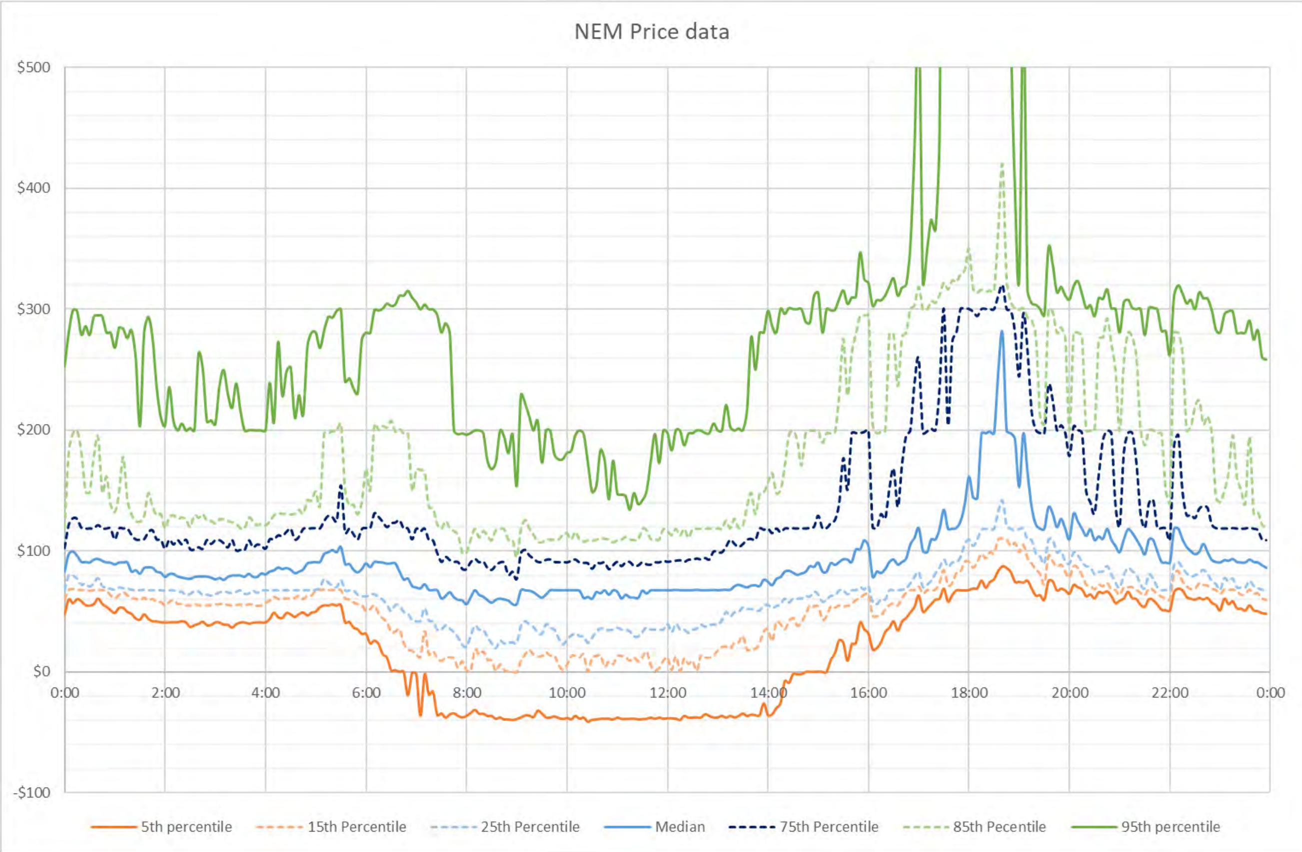


Figure 2-7 National Electricity Market (NEM) price data compared with time of day

The results of the initial sizing and optimisation are as follows:

- Utilising a simplified average price (mean of the median spot price) per hour of generation, an optimum generating duration of 12 hours was determined for the concept design. Based on the historical data, this represents generating from approximately 2:15pm to 2:15am, with a average price (mean of the median spot price) of $109/MWh. This could be optimised slightly more by generating from 2:30pm until 12:00am and then generating again from 4:00am to 6:30am, with an average price (mean of the median spot price) of $112/MWh. However, the day-to-day operation would generally be optimised based on the spot market demand and available water.
- Note that the average price (mean of the median spot price) is quite flat, and this tends to favour longer generation periods and smaller infrastructure. Looking solely at the mean price, a 16-hour generation period (with smaller capacity) might be favourable if the dam cost was not being taken into consideration. However, given the future market demand for flexibility, it was determined that there would be some value in providing a larger discharge. Hence, daily operation for shorter periods would be optimal for managing the variations in the daily market requirements.

- Based on a 12-hour operation cycle, an optimum rated discharge of 10.6 m^3/second was selected, which would require a 6 MVA generator that is capable of 5 MW of output for the hypothetical hydro-electric power unit.
- The operating range was optimised to maximise the energy of the scheme, resulting in a Minimum Operating Level (MOL) of EL 161 m being adopted (providing the best balance between generation availability and available head to maximise power output). Lower target MOL resulted in less energy as the overall head was lower, the efficiency of the turbine lower at these ranges and the average power output was lower for minimal extra duration. It is likely that further refinements to this would occur at a future stage once more information on the operational efficiency of the turbine is understood.

The result of this modelling is that the mean annual generation is 11 GWh, although it is noted that this would have significant variation from year to year. There is a median annual generation of 13.4 GWh, a lower quartile of 4.8 GWh and an upper quartile of 16.9 GWh. It is also noted that, in 8 of the 130 years of data (6% of the time), generation would be less than 1 GWh. Details of the modelling are provided in Figure 2-8 and Figure 2-9.

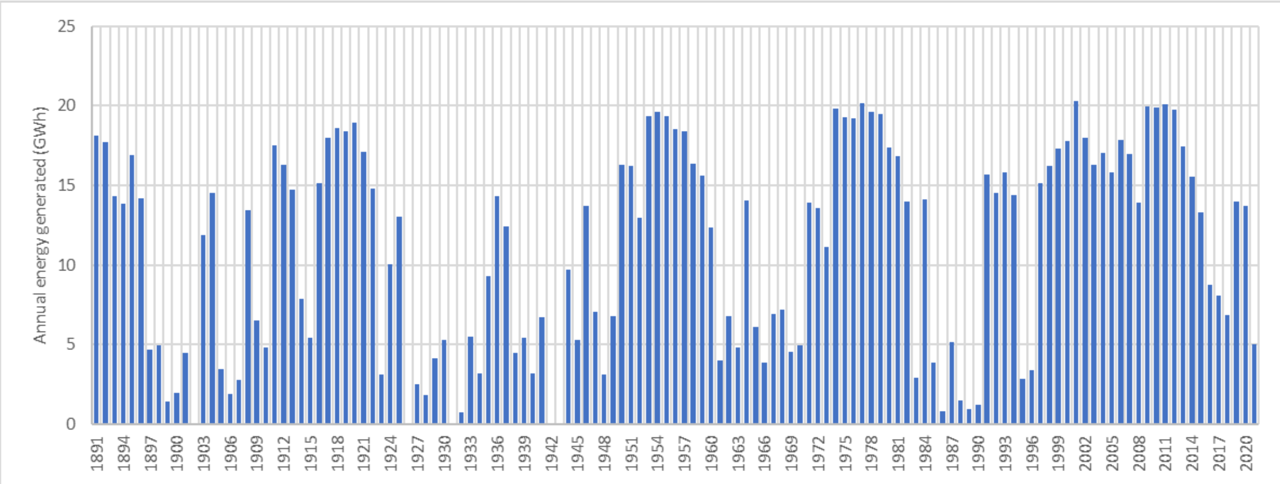


Figure 2-8 Option A simulation from 1890 to 2022

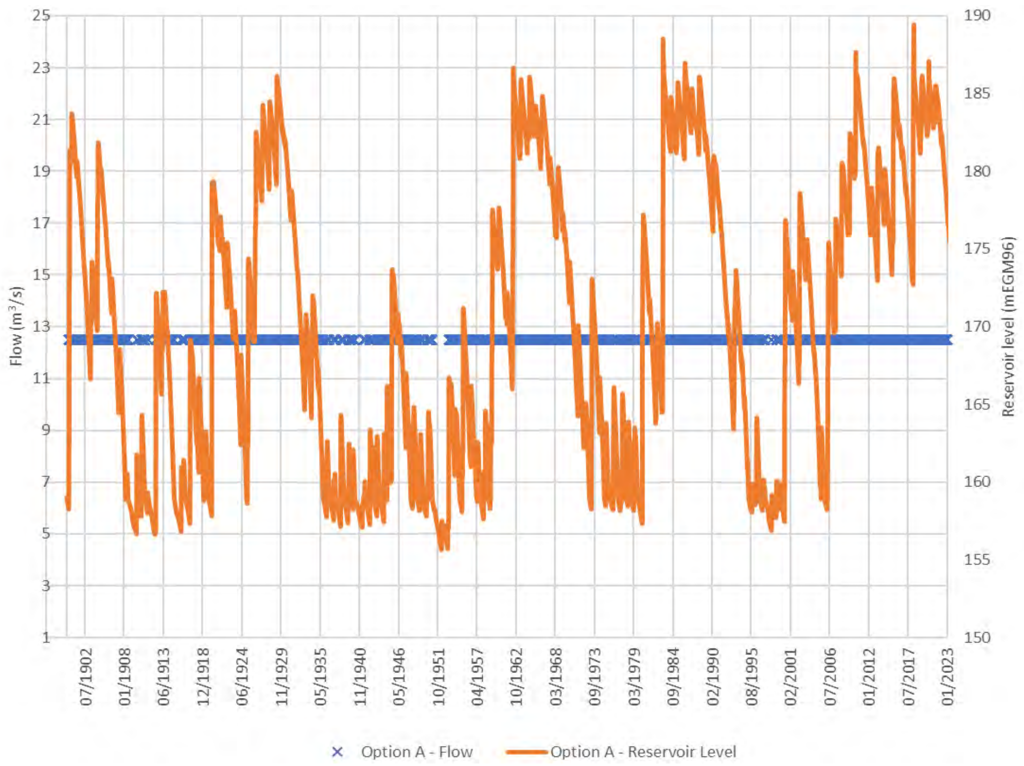


Figure 2-9 Option A simulated reservoir level and flow

2.4.3 OPTION B

The operating philosophy for Option B is to limit generation to periods of spillway overflows and periods when releases are required for irrigation.

For Option B, the following key assumptions were made for the initial sizing concept:

- During the irrigation season, information on simulated releases from the reservoir from March to August were provided by CSIRO (Gibbs et al. 2024) and are summarised in Table 2-2. This formed the basis for the calculation of energy generation needed during the irrigation season.
- Table 2-2 also provided the data needed for determining hours of irrigation release per day of operation. It is assumed at this stage that there are no restrictions on the intraday operations of the irrigation releases.
- For operation outside the irrigation season, it is assumed that generation is allowed in times of spill or when the reservoir is close to spill. Being able to operate targeting a level below FSL allows flexibility for flood harvesting for both irrigation and generation. The principal for this operation rule should be that the total simulated irrigation release available with the hypothetical hydro-electric power station should not change from the base case by more than 0.1%. The base case being the simulated irrigation releases without the hypothetical hydro-electric power station (as provided by CSIRO).
- For Option B, interconnection to the NEM is not considered a requirement. It is likely, however, that there would be interconnection to the local power grid. This would require a negotiated Power Purchase Agreement (PPA) for any power generated as well as any power drawn from the grid. It is also likely that the generator would have North West Power System (NWPS) rules, as a new generator on the grid.

- Consideration was given to operating the power station while only connected to the pumping station. However, this option was dismissed, based on the nominal 50 km distance from the weir to the pump station – once releases are made, it would likely take 1 to 2 days before the water arrived at the re-regulating weir. Timing the release of water at the dam for the pumping power requirements downstream would be very difficult. In addition to this, the pumping demand downstream would likely need additional power and a connection to the grid to supplement the power generated from the hypothetical hydro-electric power station. Hence, this option was not considered further.
- As in Option A, input data from 1890 to 2022 were used to simulate the yield from the scheme.

Table 2-2 Irrigation demand during the dry season and corresponding flow rate

MONTH	IRRIGATION DEMAND PER DAY (ML/D)	DURATION (H)	FLOW (M^3/S)	COMMENTS
March	96.8	3	9.0	To be discharged through the turbine at lower efficiency
April	96.8	3	9.0	To be discharged through the turbine at lower efficiency
May	775	14	15.4	Duration optimised for full discharge of station
June	1050	19	15.3	Duration optimised for full discharge of station
July	1320	24	15.2	Duration optimised for full discharge of station
August	542	10	15.1	Duration optimised for full discharge of station

The results of the initial sizing and optimisation are as follows:

- Assuming a fixed price for the power generated (either through a PPA or through offsetting the cost of pumping), the intraday duration of release and power generation is largely governed by the irrigation operations and the operational limits of the power station.
- Based on this, and assuming a 24-hour discharge duration during the peak month of operation (July), an optimum rated discharge of 15.5 m^3/second was selected, which would require a 9 MVA generator that is capable of 7.5 MW of output at the Transformer U.
- The MOL during the non-irrigation season was set at EL 184 m, or 2 m below FSL. This results in a reduction in irrigation potential of 0.04%.
- The MOL during the irrigation season was set at EL 153 m and was based on the likely limits of operation of the turbine. It is assumed that irrigation discharges below this level would be released through a separate outlet and would not generate power.

The result of this modelling is that the mean annual generation is 10.5 GWh. Details of the modelling are provided in Figure 2-10 and Figure 2-11.

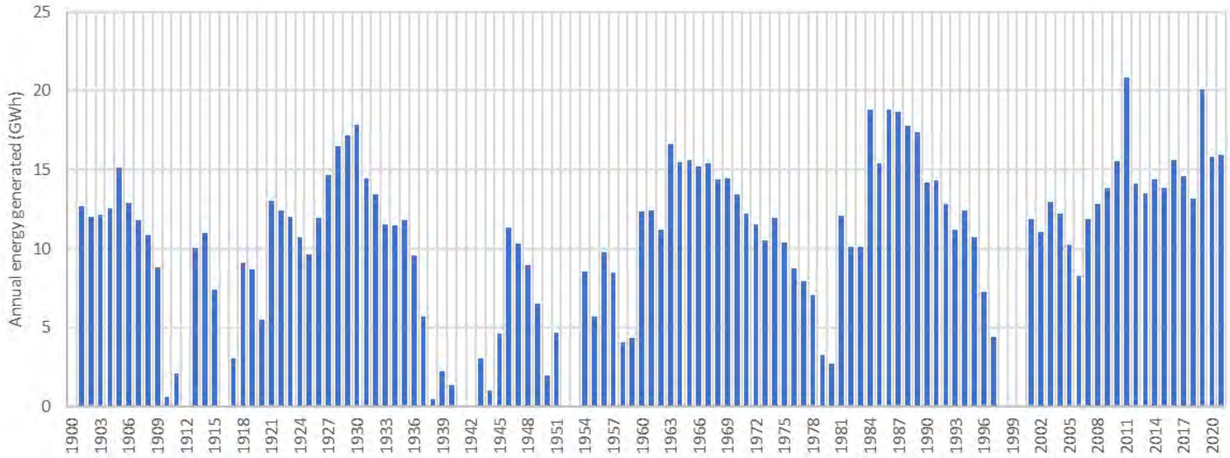


Figure 2-10 Option B simulation from 1980 to 2022

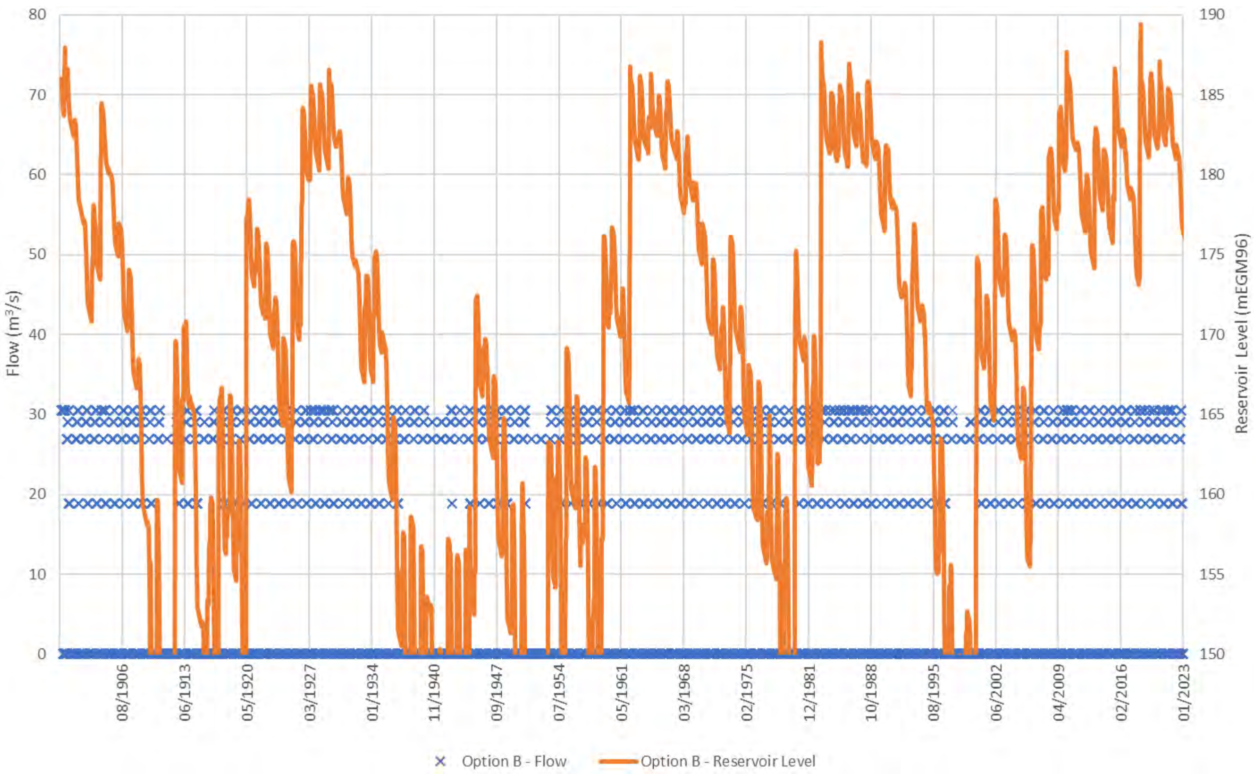


Figure 2-11 Option B simulated reservoir level and flow

3 Technical assessment

3.1 Hydro-electric power project characteristics

Based on the energy and hydro-electric power sizing assessment in Section 2, a feasible hydro-electric power arrangement can be considered at the potential dam site on Gunpowder Creek AMTD 66 km. Although the operating parameters and sizing differ between options A and B, the assumed technical arrangement would be largely the same. This section gives a high-level description of the conceptual layout developed for the project to be utilised for a corresponding cost estimate.

The basic scheme parameters for Option A are listed in Table 3-1, and the basic scheme parameters for Option B are listed in Table 3-2.

Table 3-1 Summary of the project characteristics – Option A (hydro-electric power only)

PARAMETER		VALUE
Upper reservoir	Maximum operating level (EL m)	**190**
	FSL (EL m)	**186**
	MOL (EL m)	**161**
	Active storage at FSL (Mm^3)	**604**
	Gross storage at FSL (Mm^3)	**716**
Gross head	Maximum net head (m)	**54**
	Median net head (m)	**34**
	Rated net head (m)	**45**
	Minimum net head (m)	**29**
Station	Station-rated capacity (MW at the generator)	**5.0**
	Machine type	**Francis**
	Machine centreline (EL m)	**131**
	Draft tube invert (EL m)	**5 m below turbine CL**
	Tail water level (EL m)	**130**
Waterways	Total waterway Length (m)	**50**
	Penstock diameter (mm)	**DN 1000**
	Rated flow (m^3/s)	**10.6**
Other parameters	Minimum flow (m^3/s)	**5.3**
	Median energy generated per year (GWh/year)	**11.0**
	Maximum output at connection point (MW)	**5.1**
	Transmission connection voltage (kV)	**33 – double circuit**
	Transmission length (km)	**43**

CL = Centreline; DN = Nominal Diameter; FSL = full supply level; MOL = Minimum Operating Level.

Table 3-2 Summary of the project characteristics – Option B (with irrigation)

PARAMETER		VALUE
Upper reservoir	Maximum operating level (EL m)	**190**
	FSL (EL m)	**186**
	MOL (EL m)	**153**
	Active storage at FSL (Mm^3)	**716**
	Gross storage at FSL (Mm^3)	**716**
Gross head	Maximum net head (m)	**54**
	Median net head (m)	**38**
	Rated net head (m)	**43**
	Minimum net head (m)	**22**
Station	Station-rated capacity (MW at the generator)	**7.5**
	Machine type	**Francis**
	Machine centreline (EL m)	**131**
	Draft tube invert (EL m)	**6 m below turbine CL**
	Tail water level (EL m)	**130**
Waterways	Total waterway length (m)	**50**
	Penstock diameter (mm)	**DN 1200**
	Rated flow (m^3/s)	**15.5**
	Minimum flow (m^3/s)	**6.2**
Other parameters	Median energy generated per year (GWh/year)	**10.6**
	Maximum output at connection point (MW)	**7.7**
	Transmission connection voltage (kV)	**66 – double circuit**
	Transmission length (km)	**88**

CL = Centreline; DN = Nominal Diameter; EGM96 = Earth Gravitational Model 1996; FSL = full supply level; MOL = Minimum Operating Level.

3.2 Concept layout of the hydro-electric power project

A high-level technical feasible layout was developed for the hypothetical hydro-electric power project. This arrangement and the style of this layout feeds into the cost estimate. The layout consists of the following:

- an intake structure designed for the hydropower on the right abutment of the roller compacted concrete (RCC) dam, with a waterway going through the dam. Note it may be possible to combine facilities with the irrigation intake structure for the dam, however this would need to be considered further if the potential project is further progressed.
- a steel-lined penstock that conveys the water from the intake to the turbine.
- a separate power station downstream of the dam discharging at right angles to the river (with the inlet at approximately 90 degrees to the outlet) through a tailrace structure.
- a switchyard adjacent to the power station for the transformers and switchgear, protected from flooding by a spillway training wall at the base of the dam.

The concept of the arrangement used for this report is provided in Figure 3-1.

A concept layout of the RCC dam has not been provided as part of this work. However, it is anticipated that it would consist of a central stepped spillway with an energy dissipater or flip bucket at the toe. The power station arrangement seeks to take advantage of this and has the tailrace and switchyard in between the dam and the plunge pool, allowing for greater stability in the tailwater.

The arrangement (i.e. an elongated, narrow power station and switchyard arrangement) has been initially designed to maximise the access to the right abutment, and to take account of the steep terrain downstream of the dam in this location. For hydro-electric power projects conceptual arrangements are optimised following site investigations when detailed survey data are available and when the dam arrangement has been further developed. Options for integrating the power station into the dam structure may be considered at this stage.

Details of the hypothetical arrangement for this concept are provided in the following sections.

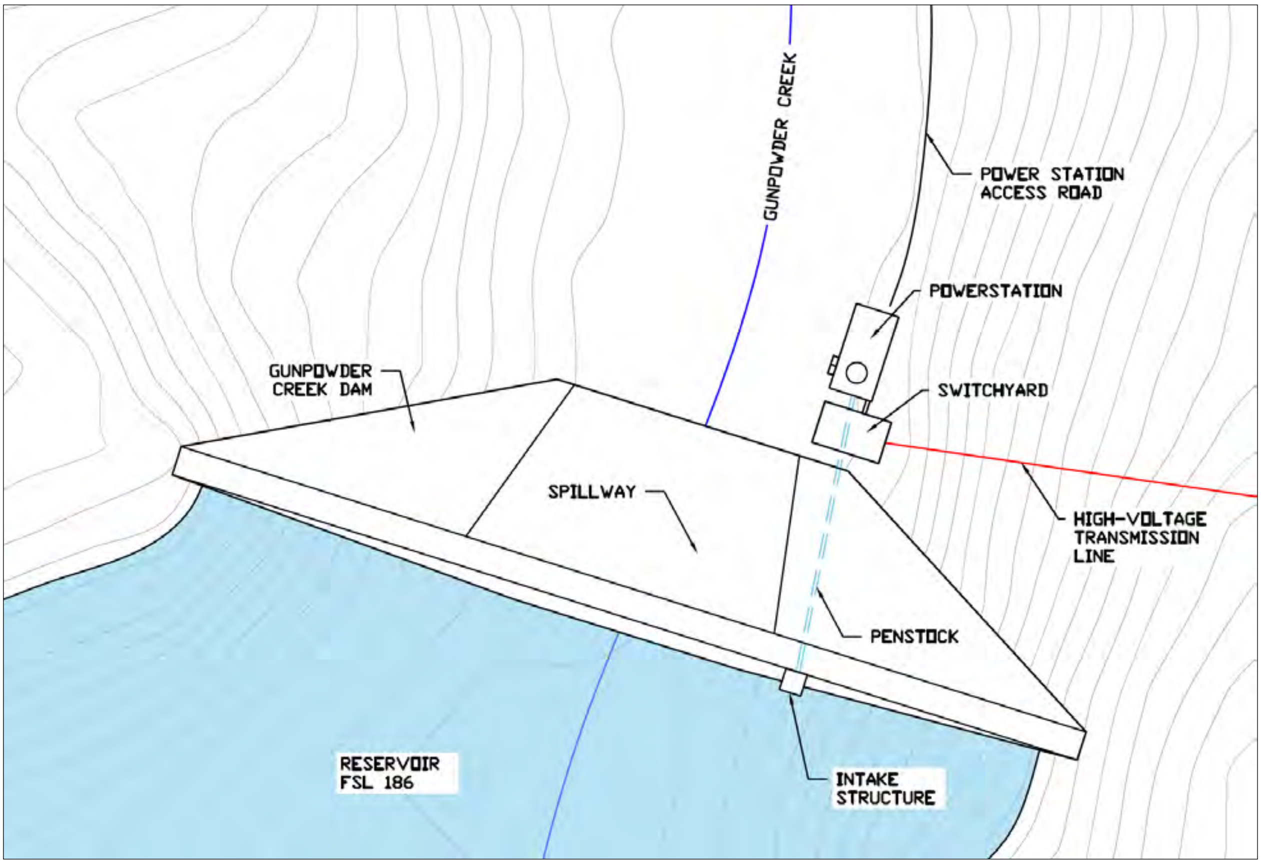


Figure 3-1 Concept arrangement of Gunpowder Creek Power Station at potential dam on Gunpowder creek AMTD 66 km– options A and B

FSL = full supply level.

3.2.1 WATERWAYS

The waterways for the hypothetical power station would consist of the following:

- The intake for the hypothetical hydro-electric power station would be located on the right abutment and assumed to be integrated into the upstream right abutment of the RCC dam. The intake would consist of a trash rack and be gated with a control gate and stoplog for isolation purposes.
- The equipment and sizing for the intake is based on the rated discharge, but is nominally a 4 m high × 2 m-wide gate opening for Option A and a 5 m high × 2.5 m-wide gate opening for Option B. The trash rack dimensions are nominally 5.5 m × 2.5 m for Option A and 6 m × 23 m for Option B.
- The invert for the intake for the hypothetical hydro-electric power station would be positioned 10 m below the Minimum Operating Level to achieve the required submergence for avoiding vortices and potential air entrainment. Access to the equipment for operating the gates would be from the dam crest, and waterproofed to the design flood level.
- A reinforced concrete transition structure within the dam would transition the rectangular intake to a 100 m-long circular embedded steel penstock that would carry water through the dam to the turbine situated in the power station. The penstock would be DN1000 for Option A and DN1200 for Option B.

- A transition piece would provide the transition from the penstock to the turbine inlet diameter and main inlet valve. If the supplied machine is close to the penstock diameter, the penstock could be optimised in diameter to suit, given the short length of the waterway.

The amount of headloss through the waterways is estimated to be 5% of the net head. Given the length of the waterways, it is likely this could be optimised and reduced in future stages. This headloss is based on a 4 m/second velocity in the waterways.

3.2.2 POWER STATION

The depth of the powerhouse is dependent on the required submergence and sizing of the turbine and generator. Typically, the submergence depth for the machine sizing is approximately 6 m below the centreline of the turbine for a Francis turbine. Based on this, the powerhouse would be located at 124 mEGM96.

The sizing of the proposed power station that is applicable for options A and B would have the following dimensions:

- width – 15 m
- length – 30 m – (12 m for the assembly bay, 12 m for the generating unit bay, and 6 m for ancillaries and amenities)
- height – 27 m (from the invert of the draft tube to the top of the station).

Within the power station, there would be one turbine and one generator. Adjacent to the machine there would be an assembly bay.

A tail bay would discharge the water from the turbines into Gunpowder Creek downstream of the potential dam. The tail bay would be the width of the generating unit bay. The downstream wall of the tail bay would be a weir designed to regulate the tailwater level, to provide adequate draft tube submergence. The nominal tailwater at full station discharge would be EL 130 m.

For this power station, the transformers and switchyard would likely be in an outdoor arrangement adjacent to the power station. The controls are likely to be contained within the power station, and the connections required to feed into the transmission line would exit from this point.

3.3 Hydro-Electric Turbine and Generator

The type of turbine and generator (TG) unit required is dependent on hydraulic parameters, such as head and flow, operation range of the turbine, efficiency of the TG units, proven design, and techno-economic considerations.

Based on the head, flow, and power potential available, a Francis turbine is considered suitable for this scheme. A single unit consisting of a Francis turbine connected to a synchronous generator was chosen for both options for the concept, based on the information received.

3.4 Electrical connection infrastructure requirements

3.4.1 SWITCHYARD AND TRANSFORMER YARD

For options A and B at the potential Gunpowder Creek power station, the transformers (located in the switchyard) and switchyard are best suited to be located in an outdoor arrangement adjacent to the power station, as shown in Figure 3-1. At a pre-feasibility level, the space required for a step-up transformer and its associated switchgear is 20 × 15 m.

The switchyard is expected to have a firewall between the power station and the E&M equipment, with an access road behind the power station to allow access for transformer and switchgear installation and maintenance. It is also expected to be behind the spillway training wall, to protect against spray and backflow from the spillway during flooding.

It is anticipated that all high-voltage transmission outside the switchyard at the hypothetical hydro-electric power station and pumping station would be built and owned by a transmission and distribution company (in this case Ergon Energy Network) but would likely need to be funded by investors in the development. This would need to be negotiated with the transmission company.

Further studies and comparison of costs would be required in subsequent stages to select the best arrangement. It may be possible to have an elevated switchyard behind the power station to make the arrangement more compact, but that would be dependent on the superstructure arrangement of the power station.

3.4.2 GRID CONNECTION INFRASTRUCTURE – OPTION A

The closest existing grid connection point to the potential Gunpowder Creek power station is the 220 kV substation at Gunpowder. For Option A, the following infrastructure would be required to connect the proposed generator to the grid:

- a step-up transformer to 33 kV at the power station site
- associated switchgear (current transformer, circuit breaker, etc.)
- 43 km of 33 kV double-circuit transmission line (Aluminium Conductor Steel-Reinforced cable (ACSR) Cherry) from a substation at the proposed hydro-electric power station to the existing Gunpowder substation
- a step-up transformer (33 kV to 220 kV) at the existing Gunpowder substation or at a new substation adjacent to the connection point (to be confirmed as part of a connection application process).

A concept of the route from the power station to the connection point is given in Figure 3-2. At this stage, the concept for the transmission network has been to limit the voltage drop between the connection point and the power station to <5.0% under full generation load (6 MVA).

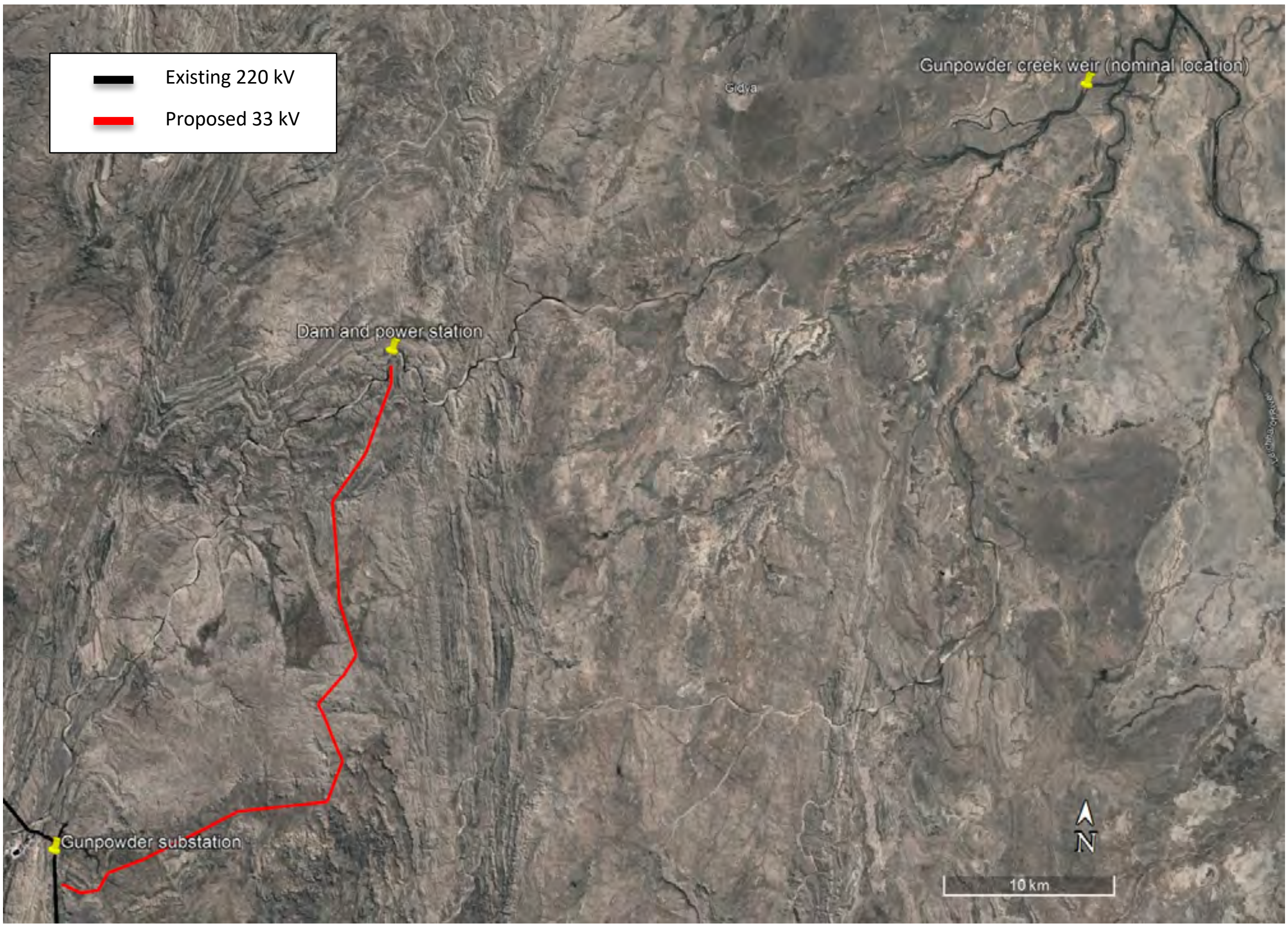


Figure 3-2 Concept of connection route from the dam and power station to the 220 kV transmission line for Option A

3.4.3 GRID CONNECTION INFRASTRUCTURE – OPTION B

The closest existing grid connection point to the potential Gunpowder Creek power station is the 220 kV substation at Gunpowder. For Option B, the following infrastructure would be required to connect the proposed generator to the grid:

- a step-up transformer to 66 kV at the power station site
- associated switchgear (current transformer, circuit breaker, etc.)
- 43 km of 66 kV double-circuit transmission line (ACSR Lemon) from a substation at the proposed hydro-electric power station to the existing Gunpowder substation
- 45 km of 66 kV double-circuit transmission line to the proposed irrigation weir for pumping
- a step-down transformer from 66 kV at the Gunpowder irrigation scheme pump station
- a step-up transformer (66 kV to 220 kV) at the existing Gunpowder substation or at a new substation adjacent to the connection point (arrangement to be confirmed as part of a connection application process).

A concept of the route from the pump station (via the power station) to the connection point is given in Figure 3-3. At this stage, the concept for the transmission network has been limiting of the voltage drop between the connection point and the pump station to <5.0% under full generation load (22 MVA).

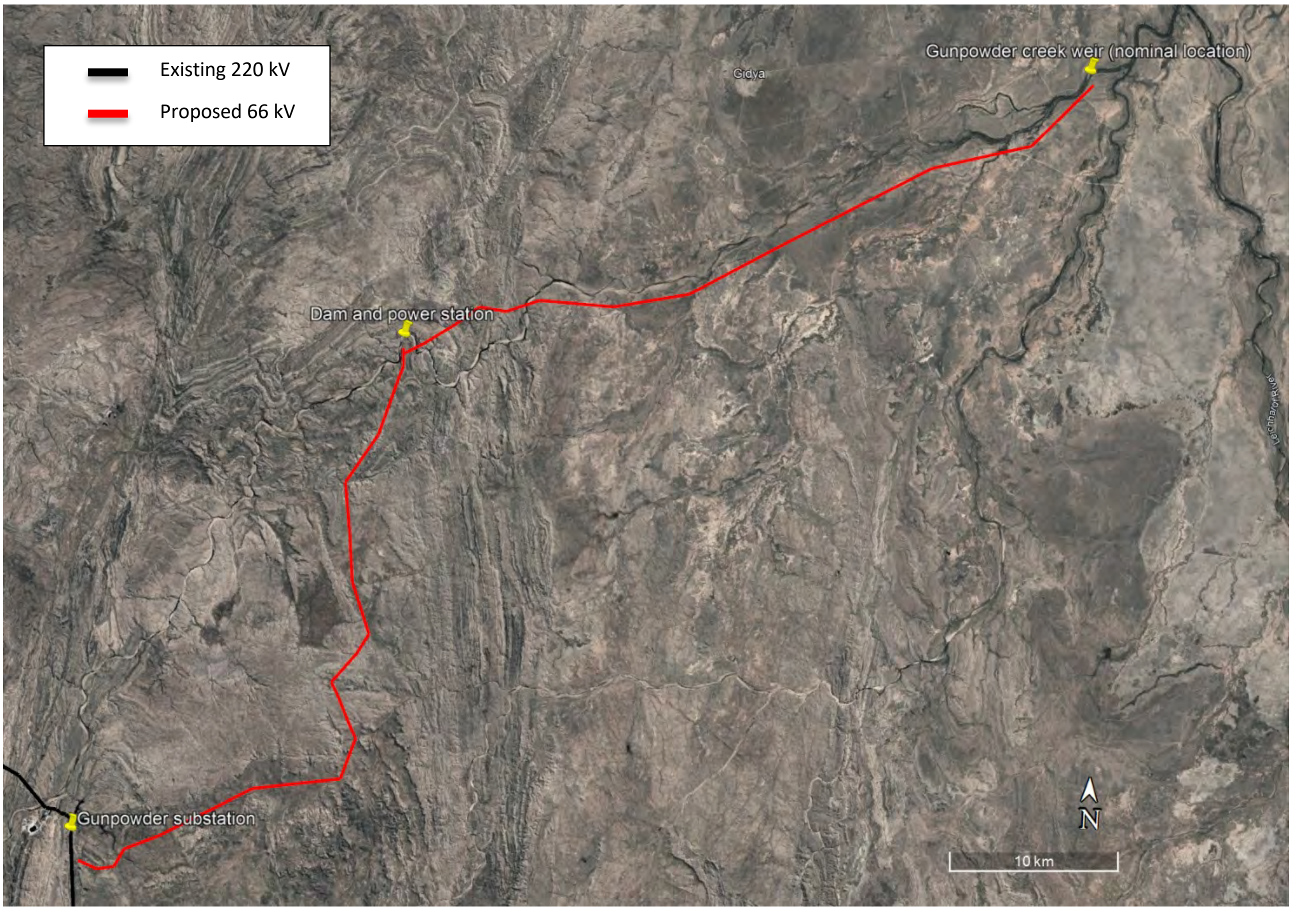


Figure 3-3 Concept of connection route from the Gunpowder Creek weir to the 220 kV transmission line for Option B

3.4.4 HYPOTHETICAL IRRIGATION AREA ADJACENT TO THE GREGORY RIVER

This section explores the costs and connection considerations of a standalone hypothetical irrigation area adjacent to the Gregory River.

The following details were provided by CSIRO (refer to Figure 3-4 – 131 GL development):

- The hypothetical irrigation scheme is based on a potential water supply dam upstream of the irrigation scheme. Details of the potential supply dam were not provided.
- Water is released from the supply dam to a re-regulating weir approximately 26 km downstream of the supply dam, where water is pumped into the irrigation network via a pump station.
- Two potential development options were explored by CSIRO (232 GL development and 131 GL development). Initially the sizing of infrastructure was undertaken for the larger of the two developments so that it could apply to either option. However as of 7th October 2024, CSIRO informed that the hypothetical 131 GL irrigation development was the preferred option for this analysis.
- Water is then channelled through the irrigation network via a series of open channels and gated structures, with a maximum flow rate of 10.9 m^3/second.
- The sizing for power demand of the pump station was advised as 1.6 MW installed motor power.
- It is assumed, given the above, that a minimum of six pumps would be installed at the pump station.

- An additional allowance is to be made for local draw of buildings and sheds as per the advice from CSIRO. Being a hypothetical surface irrigation scheme, additional demand for irrigation or tail water recycling on farm is minimal and will be supplied via a separate power system (e.g. diesel pumps).

Based on the above assumptions and allowing for a 2.2 MW draw at the site (assuming an additional draw on start-up of the sixth pump of 3-times the rated draw), the capacity required at the connection point is 2.6 MVA.

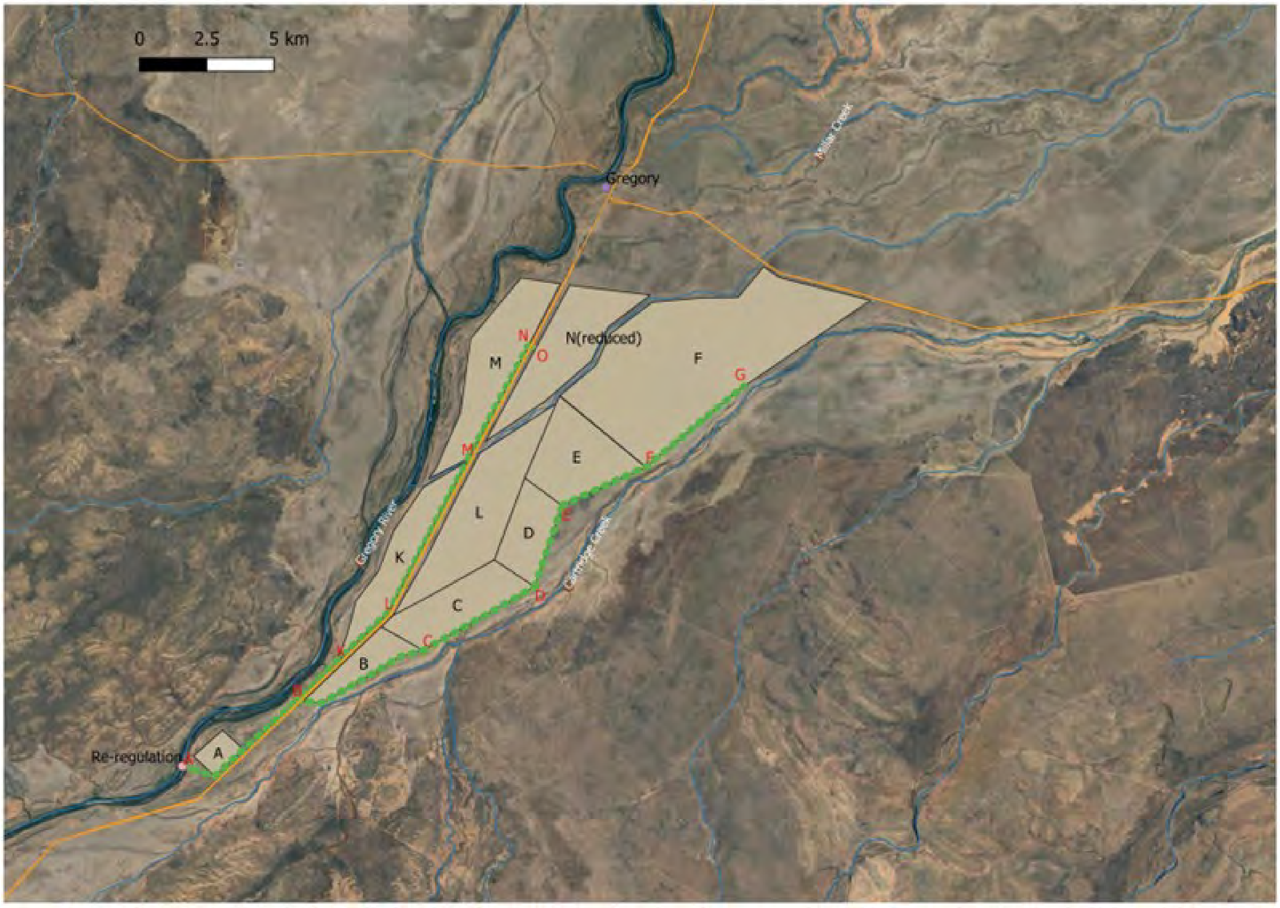


Figure 3-4 Dam site 1 and potential diversion and development areas (131 GL option)

Based on the above, two grid connection points were assessed as options:

- 80 km east and connecting into the nearest feeder line (Nardoo, 19.1 kV)
- 85 km west and connecting into the nearest substation (New Century Mine Substation, 220 kV).

The nearest feeder line has a current spare capacity of 1.1 MVA, and this is approximately the maximum capacity that could be transferred on the 19.1 kV distribution line from the pump station while keeping the voltage drop below 5.0%. On this basis, this connection point was ruled out for the irrigation scheme. The connection point selected is the New Century Mine Substation, and the following infrastructure would be required to connect to the proposed Gregory irrigation scheme to the grid:

- a step-down transformer (220 kV to 33 kV) at the existing New Century Mine Substation or at a new substation adjacent to the connection point (arrangement to be confirmed as part of a connection application process)

- 85 km of 33 kV double-circuit transmission line (ACSR Cherry) from the New Century Mine Substation to the Gregory irrigation scheme pump station
- a step-down transformer from 33 kV at the Gregory pump station.

A concept of the route from the pump station to the connection point is given in Figure 3-5. At this stage, the concept for the transmission network has been to limit the voltage drop between the connection point and the pump station to <5.0% under full generation load (2.6 MVA).

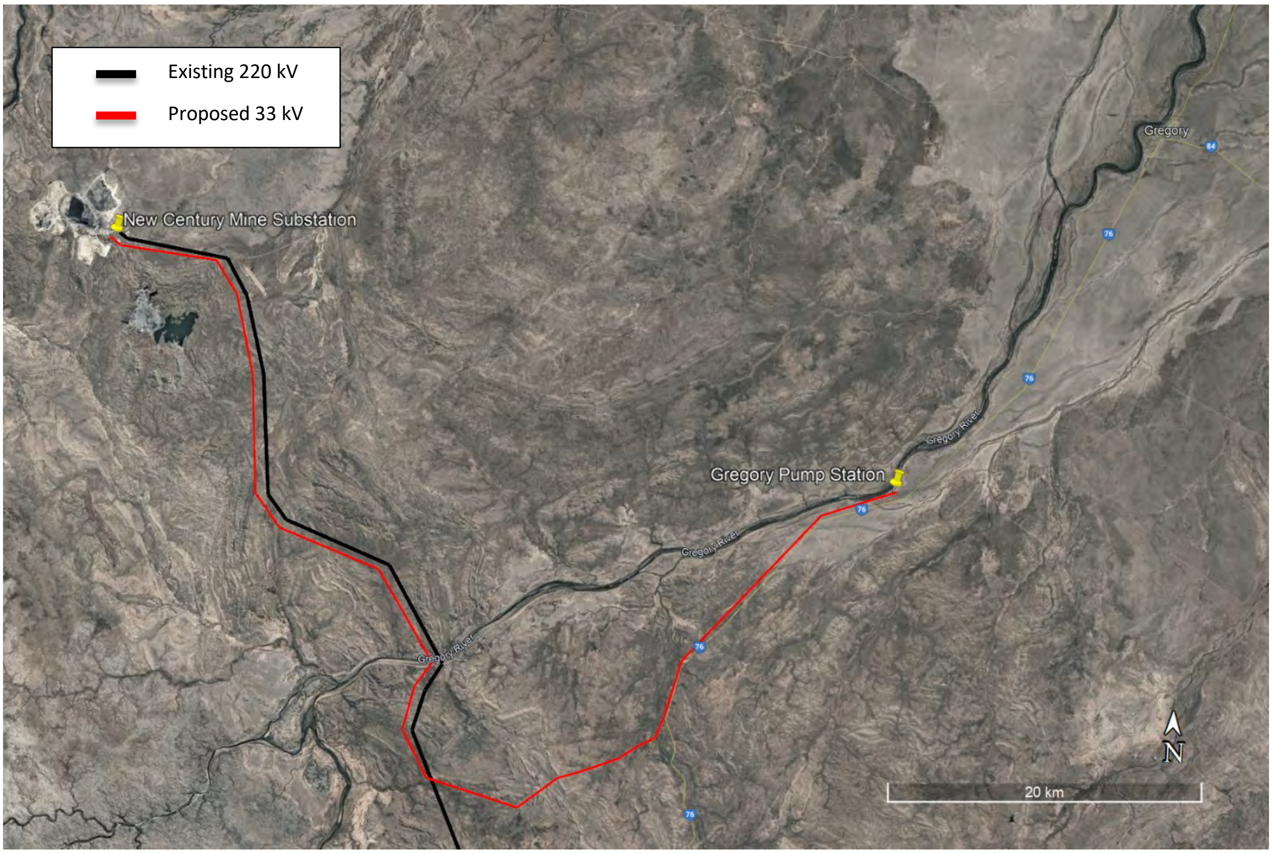


Figure 3-5 Concept of the connection route to the 220 kV transmission line for the Gregory irrigation scheme

4 Review of costs and benefits

4.1 Review of revenue (benefits)

4.1.1 GUNPOWDER CREEK – OPTION A

The key revenue benefits for Option A are based on the interconnection to the National Electricity Market (NEM) (CopperString 2032) going ahead and the hypothetical hydro-electric power station being able to generate into the NEM. For Option A, the following revenue opportunities would be available:

- spot price on the NEM, based on selling at 5-minute intervals
- a power purchase agreement (PPA) to provide power to a retailer
- large-scale generation certificates (LGCs)
- provision of capacity payment, operating on an as-required basis
- provision of ancillary services to the grid.

Given the small size of the hypothetical hydro-electric power scheme and the high variability in annual rainfall and inflows (which means low reliability of generation capability), provision of capacity payments or ancillary services is not considered a feasible revenue source. Similarly, a PPA with a retailer would generally be of lesser value than the spot price on the NEM, given the variability in the availability of generation. Hence, spot price on the NEM and the selling of LGCs are considered the most likely source of revenue for this scheme.

On this basis, a high-level summary of the revenue options is as follows:

- As described in Section 2.4.2 and Figure 2-7, the historical spot price data indicate a mean cost per MWh of between $109 and $112, assuming 12 hours of generation per day. It is noted that there is the possibility of optimising this further, with less duration, enabling the targeting of higher price points through the consequence of more water being available to take advantage of high prices. There is uncertainty in using historical data for estimating future market potential. However, this is considered a fair representation of the potential.
- LGCs are a scheme to underpin the renewable energy target. They apply to new generation for installed capacity of >100 kW. The historical and projected spot price of LGCs is shown in Figure 4-1. Note that future spot prices are a futures market and have an element of risk priced in. Hence, they decrease over time. However, the price generally rises if they are traded on the spot market, and it has been consistently sitting at $40–$50/MWh. Hence an LGC value of $40/MWh is a reasonable expectation until 2030. Note, however, that the LGC scheme is only legislated through until the end of 2030, and currently there is no mechanism to replace it. As CopperString 2032 does not come online until after that date, no incentive or offset mechanism can be guaranteed.

Based on the above, it is considered that the scheme would need to be able to make adequate return at $110/MWh (in today’s dollars) to warrant investment.

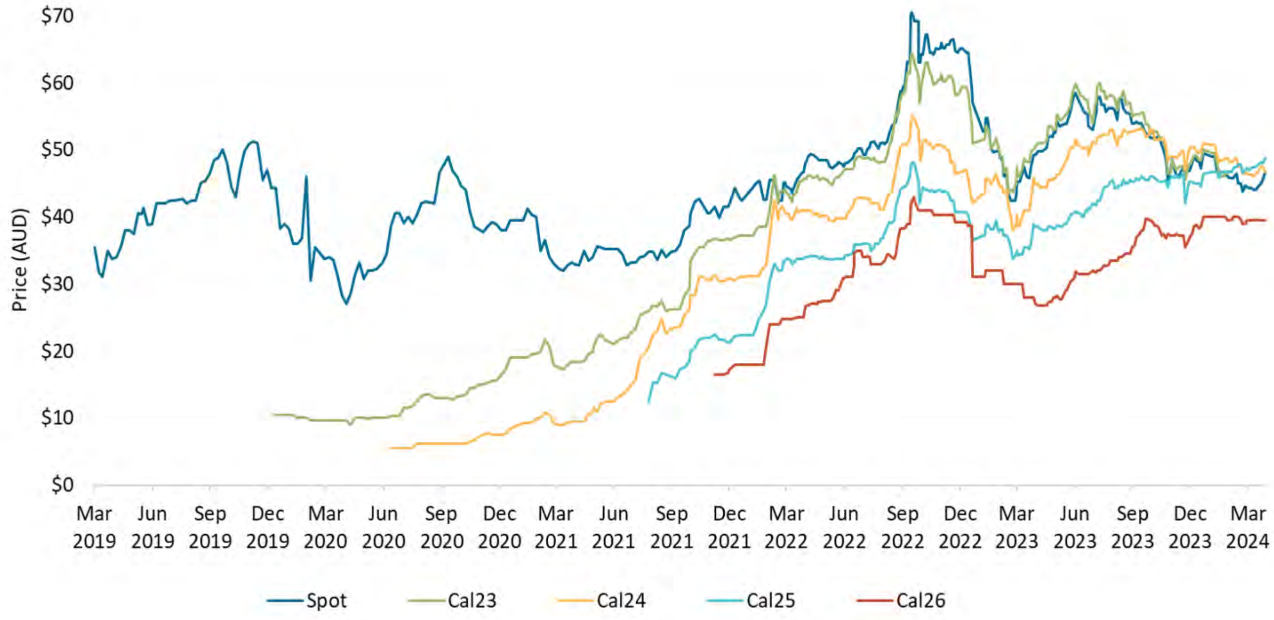


Figure 4-1 Large-scale Generation Certificate (LGC)–reported spot and forward prices
Reference: (Australian Government Clean Energy Regulator, 2024), A). Cal – Calendar year.

4.1.2 GUNPOWDER CREEK – OPTION B

For Option B, the assumption is that the hypothetical hydro-electric power station is not connected to the NEM but is connected to the local grid North West Power System (NWPS). This would allow access to additional pumping energy for the irrigation scheme when the power station is not available, and to export power when the hydro-electric power station is generating power or releasing water, but not all the power is required by pumping. It would also enable the local grid to provide frequency and voltage regulation. Provision of these functions would likely require additional generation or load if the hydro-electric power station and pump station formed an isolated power grid.

In this option, the revenue opportunities for the hypothetical hydro-electric power station are as follows:

- a PPA to provide power to the local retailer or large industrial users.
- offsetting of the cost of power for pumping from 'behind-the-meter' generation, which would be more valuable than selling the energy wholesale. This would, however, require the developer to own and maintain a transmission connection with a connection point at Gunpowder Creek, which would have additional cost.

Regarding a PPA with the local retailer or a large industrial user, most major customers in the NWPS have individual, confidential supply contracts with a generating business, and it is difficult to estimate a value for a PPA. However, the report (Queensland Government, 2021)(Queensland Government, 2021) states that, for the 'Business as usual' option (i.e. no connection of CopperString 2032):

- the current price for the analysis (as of 2021) is assumed to be $140/MWh (based on the cost of gas generation)

- the modelled cost of power is projected to be $119 to $134 per MWh (median $119/MWh) by the financial year 2024-25 (i.e. the current projected cost)
- the future projected cost of power in 2031 and 2041 is projected to be $108 to $136 per MWh (Median $113–$114/MWh).

Based on the above, a power price of $115 per MWh is assumed for the revenue.

To offset the energy costs for pumping, the cost of power in the NWPS is currently pegged to the NEM through subsidies provided by the government. Hence, Ergon Energy's general tariffs are applicable to use for the cost of power. Tariff 51A is a tariff for Connection Asset Customers supplied at 66kV, whilst tariff 51B is a tariff for Connection Asset Customers supplied at 33kV. Typically for these tariff's you pay charges for demand, capacity connection, and a daily supply charge. The key advantage for the hypothetical hydro-electric power station is offsetting of the usage cost, which is currently $165/MWh. It is also noted, however, that this arrangement may allow for the connection demand and capacity charge to be reduced if the hydro-electric power station can be relied upon to partially supply the peak demand during irrigation, with each MVA reduction in capacity being worth $8696/month.

It is also noted that a hydro-electric power station may have more non-tangible benefits to the development in the irrigation scheme, as it could offset some of the power usage, which may make the overall development of the irrigation scheme more viable and more likely to be approved, if power constraints in the local grid are of concern. This aspect has not been assessed at this stage and would need to be considered in the overall context of the irrigation development.

4.2 Review of the capital cost

Table 4-1 provides a high-level capital costing for developing a hydro-electric power station. In accordance with the Association for the Advancement of Cost Engineering (AACE, 2005) 18R-97 Cost Estimate Classification Scheme, the level of development would be a Class 5 cost estimate, which is suitable for concept screening purposes. The expected accuracy range, with an 80% confidence interval, is −20% to −50% ('low') to +30 to +100% ('high'). For a hydro-electric power scheme, the electrical and mechanical elements, which are typically better defined, tend towards the lower end of the range, while the civil components tend towards the higher end of the range.

These cost estimates are based on reference projects that Entura has been involved in with similar capacities, and they factor in the current costing environment and the location of the project. It should be noted that, for these costs:

- The cost of access roads is excluded. Options A and B will require the construction of new 50 km-long site-access roads. However, these costs may be integrated into the costing for the development of the dam and irrigation scheme. Furthermore, upgrades to the existing roads may also be considered in the overall cost estimate of the project.
- Costs for land acquisition or easements are excluded and assumed to be undertaken as part of the overall irrigation development costs (or dam costs).
- Costs for building the supply dam and the associated infrastructure are excluded and are reported in Yang et al., 2024 (Yang, 2024). Only the extra costs associated with the hydro-electric power scheme are included in this assessment.

- The capital costs are for a Turn-key Engineering Procurement Construction (EPC) contract and do not take into consideration any owners' costs.

Table 4-1 Capital cost estimate for Option A and Option B

COMPONENT	OPTION A COST ($)	OPTION B COST ($)
Intake structure	5,000,000	7,000,000
Powerhouse	9,000,000	9,000,000
Penstocks	900,000	1,000,000
Switchyard civil cost	1,000,000	1,000,000
Powerhouse turbine and station electromechanical and switchgear	8,000,000	11,000,000
Sub-total for construction, excluding access roads and transmission line connection	23,900,000	29,000,000
Project management and development cost (15%)	3,600,000	4,400,000
Design and approvals (10%)	2,400,000	2,900,000
Total cost estimate (hydro-electric power)	29,900,000	36,300,000
Transmission line connection	22,000,000	52,000,000
Total cost estimate, including connection	51,900,000	88,300,000

4.2.1 BENEFIT VS COST COMPARISON

Being part of the Hydro Tasmania Group, Entura is not able to provide any financial advice, and the figures presented in this report are purely calculations based on the historical pricing and other assumptions listed.

In undertaking this assessment comparison, the following is assumed:

- A hydro-electric power station will take 2 years to construct.
- For cashflow purposes, the construction costs increase at 5% per year, while power generation revenue increases at 3% per year.
- The internal rate of return is estimated based on 20 years of generation.
- Operation and maintenance costs of 2% of capital costs are assumed and grow at 5% per year.

OPTION A

Based on the cost for the hypothetical hydro-electric power scheme only, the internal rate of return over 20 years of generation has been estimated at −6.5%. If the operation and maintenance costs are ignored, then the internal rate of return would be 0.4%. To achieve an internal rate of return of 0%, including maintenance costs, the capital cost of investment would need to be less than $19 million.

Given this estimate does not cover the costs of building the water storage or the connection costs, it can be concluded that there is insufficient revenue and benefit to warrant a hydro-electric power station as a stand-alone investment.

OPTION B

Based on the cost for the hypothetical hydro-electric power scheme only, the internal rate of return over 20 years of generation is −13.1%. If the operation and maintenance costs are ignored, then the internal rate of return is −1.3%. To achieve an internal rate of return of 0%, including maintenance costs, the capital cost of investment would need to be less than $19 million.

If the scheme was used to offset the pumping costs at a higher value than the wholesale generation value (i.e. behind-the-meter generation at $165/MWh), and it is assumed that the entire cost of the power generation could be offset (an optimistic assumption), then the internal rate of return over 20 years of generation would be −4.6%. If the operation and maintenance costs are ignored, then the internal rate of return would be 2.0%. To achieve an internal rate of return of 0%, including maintenance costs, the capital cost of investment would need to be less than $27 million.

Given this costing does not include the connection costs (but assuming these costs must be paid for by the irrigation scheme), it can be concluded that there is insufficient revenue and benefit to warrant investment in a hydro-electric power station associated with the water storage. Even with offsetting of the pumping costs, it is concluded that it would likely be more effective to purchase the power required outright than to build the hypothetical hydro-electric power station.

5 Summary and discussion

5.1 Hydro-electric power potential

Based on the work undertaken in this technical study, it can be concluded that, while hydro-electric power offers an opportunity to add value to a water resource investment in a large in-river storage developed for irrigation at this location, it is very unlikely to be a financially sound investment for any developer, either as a stand-alone development or as part of an irrigation development. The key aspects that make this financially unviable include:

- The catchment is in a semi-arid environment with a low median rainfall (460 mm) and a highly variable rainfall from year to year. This ultimately results in the yield of the reservoir being relatively low and unreliable, even for the large seasonal storage (also referred to as carryover storage) proposed.
- The head for the hypothetical hydro-electric power is relatively low, as it is located at the base of an approximately 60 m-high dam that has a median head of 36 to 40 m. Thus, there would be a relatively low energy output for the discharges being considered.
- The location of the hypothetical hydro-electric power scheme is a significant distance both from the connection point to the 220 kV transmission lines and from the pump station where the load from the irrigation scheme would be situated. This would require a significant length of transmission line to connect the hypothetical hydro-electric power. A higher-voltage (33 kV or 66 kV) line would be needed to reduce the overall voltage drop. The combination of this requirement and the length involved would result in a significant cost for connection of the scheme.

A case for the hydro-electric power station as a stand-alone investment cannot be made, given the likely costs of both the storage dam and the connection costs. The addition of a small hypothetical hydro-electric power station as an energy recovery strategy on a dam developed for irrigation is also considered unviable in its current format. There could, however, be a case made if the capital costs of the hydro-electric power station work could be reduced by incorporating some of the civil works into the dam construction. These opportunities would include:

- having a single intake and penstock for both the hydro-electric power and the discharges. This would likely still incur some additional costs for the hydro-electric power, but they would be less than the current assumed cost. However, a bypass for water releases at lower levels would still need to be incorporated
- incorporating the power station structure into the dam and having a draft tube discharging at the dam toe. This would reduce some of the civil costs of the power station associated with the structure.

The above could be considered further by a future developer. However, the likely benefit would be relatively marginal. The only benefit that is likely to be of any significance would entail the hydro-electric power station reducing the peak demand from the pumping to reduce the overall connection and usage costs.

5.2 Electrical infrastructure requirements

As part of the Assessment, the electrical grid connection requirements have been assessed at a high level to provide an order-of-magnitude cost input into the overall water resource assessment. Energy infrastructure constraints in the North West Power System (NWPS) are a key consideration for pumped irrigation developments in the Leichhardt catchment, given the very remote nature of the developments.

As part of this assessment, the following points are highlighted for potential developments:

- For larger pumped irrigation developments, the availability of electrical infrastructure for pump stations is limited, both by geographical location and capacity. Currently, as an isolated grid, the availability of generation is largely matched to the existing demand of the major mining customers. Under dispatch protocols, there may be a limitation on the availability of power to large retail customers (such as operators of pumping irrigation).
- The key electrical transmission infrastructure that could supply major hypothetical irrigation schemes around the Gregory River area and the Gunpowder Creek area are the Ergon Energy 220 kV transmission line that runs from Mount Isa via Gunpowder to New Century Mine. Capacity for demand on this transmission line is limited, and schemes would need to negotiate with both Ergon Energy and major customers on the transmission line to obtain the required energy and capacity.
- Larger pumped irrigation developments will need the development of dedicated electrical distribution infrastructure. This would likely include new substations (or transformer equipment in an existing substation) and distribution lines from the existing substations to the pumping sites. This would entail:
    - For the Gregory River area (nominally a 2.5 MW connection), this is likely to consist of 85 km of 33 kV distribution lines from the New Century Mine Substation to a transformer at the pump station.
    - For the Gunpowder Creek area, up to a nominal 18 MW connection based on both the re-regulation pumping requirements and considerable on and off-farm and processing infrastructure supporting the irrigation development (information , provided by CSIRO). This is likely to consist of nominally 88 km of 66 kV distribution lines from the Gunpowder substation to a substation at the pump station.
- CopperString 2032 will connect the NWPS to the National Electricity Market, alleviating any constraints in generation. However, constraints in the transmission and distribution system would remain.
- It could be possible for the hypothetical irrigation scheme adjacent to the Gregory River to negotiate a connection based on the peak power requirement of 2.5 MW.
- The hypothetical irrigation scheme on the lower reaches of Gunpowder Creek would potentially face constraints if the on-farm irrigation was electrified in addition to the re-regulating pumping. Transmission structure upgrades or supplementary local generation would likely be required to meet a nominal peak power requirement of 18 MW.

Given the above constraints and the distances faced in connecting to the grid, the following should be considered as part of irrigation developments in the region:

- Given the high capital cost of connecting to the existing grid and depending upon the demand pattern investigate remote power supply for irrigation pumping requirements. See companion technical report on techno-economic analysis of electricity supply (Hayward 2024) for more information.
- Consider the above strategy for reducing the peak load for the hypothetical irrigation schemes (i) to reduce the required voltage of the connection and (ii) to allow it to connect to the existing distribution network at 19.2 kVA. This could be a valid strategy for the Gregory River irrigation scheme.
- For the hypothetical irrigation scheme adjunct to the Gregory River, investigate further whether a tee-off from the existing 220 kV line is achievable with a separate substation at the intersection with the existing access road. This would save approximately 50 km of transmission line length and potentially allow for the connection voltage to be dropped to 19.2 kVA, resulting in a saving of up to two-thirds of the capital cost. This connection strategy would need further development and consultation with Ergon Energy and other stakeholders.

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