Hydro Tasmania

Repurposing Tarraleah hydropower scheme for the future electricity market

Pre-feasibility study

Knowledge sharing report

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Contents

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1.0 Executive summary

Hydro Tasmania has initiated the Battery of the Nation (BotN) strategic initiative to investigate and map out future development opportunities for the State of Tasmania to make a bigger contribution to a future National Electricity Market (NEM). The Tarraleah scheme redevelopment pre-feasibility study was undertaken through this initiative, with funding support from ARENA under the Advancing Renewables Program. The outcomes of this study will support wider consideration of asset management strategies for existing hydropower generation infrastructure to support a more flexible and low emissions energy future.

Critical to the consideration of potential redevelopment options was the role the scheme might play in the future energy market, not just consideration of present or past market dynamics (which would drive a very different project outcome). Hydro Tasmania is currently modelling future possible market models and these future market dynamics underpinned the identification of potential options.

The pre-feasibility study started with an innovation phase, bringing together expertise from across the business. Six possible redevelopment options were identified. These options were then further refined and collaboratively assessed to shortlist three options to complete the pre-feasibility assessment. These three options are summarised as follows:

- Business as usual (i.e. maintaining the existing scheme and the current asset management strategy).
- Energy optimised redevelopment.
- Capacity optimised redevelopment.

The assessment of these options was based on the outcomes of detailed energy modelling and financial modelling, both undertaken by Hydro Tasmania. As part of this assessment, a sensitivity analysis on the long-term electricity market projections was undertaken.

The study concluded that capacity-optimised redevelopment is the most favourable option for the following reasons:

- There is a range of plausible future market scenarios where the optimisation of capacity provides financial benefits well in excess of maintaining the existing base load generation capability.
- The option contains a number of future flexible decision points which will allow investment decisions and timing to be staged based on emerging market drivers in future. In an uncertain future market environment, this optionality is considered valuable and does not exist in the current asset management pathway.
- The redeveloped capacity is of comparable value and cost to that provided by developing pumped hydro energy storage (pumped hydro); with the added benefit of avoiding pumping costs.
- Improved flexibility of operation to provide a broader range of market services is likely to be valuable in the future market, and likely to contribute to the financial benefits of a redeveloped scheme.

2.0 Introduction

The objective of the study was to identify and assess options for the redevelopment and future-proofing of the Tarraleah hydropower scheme in the highlands of Tasmania, in the context of likely future market changes.

The scheme, shown in Figure 1 and appendix B, commenced generation in 1938 and continued to be developed in a number of stages to 1966. It is comprised of a large headwater storage (Lake King William), three power stations (Tarraleah 90 MW, Butlers Gorge 12 MW and Nieterana 2 MW), a very complex system of water conveyance structures (~30 km length) and a number of small storages (Mossy Marsh Pond, No 2 Pond and No 1 Pond).

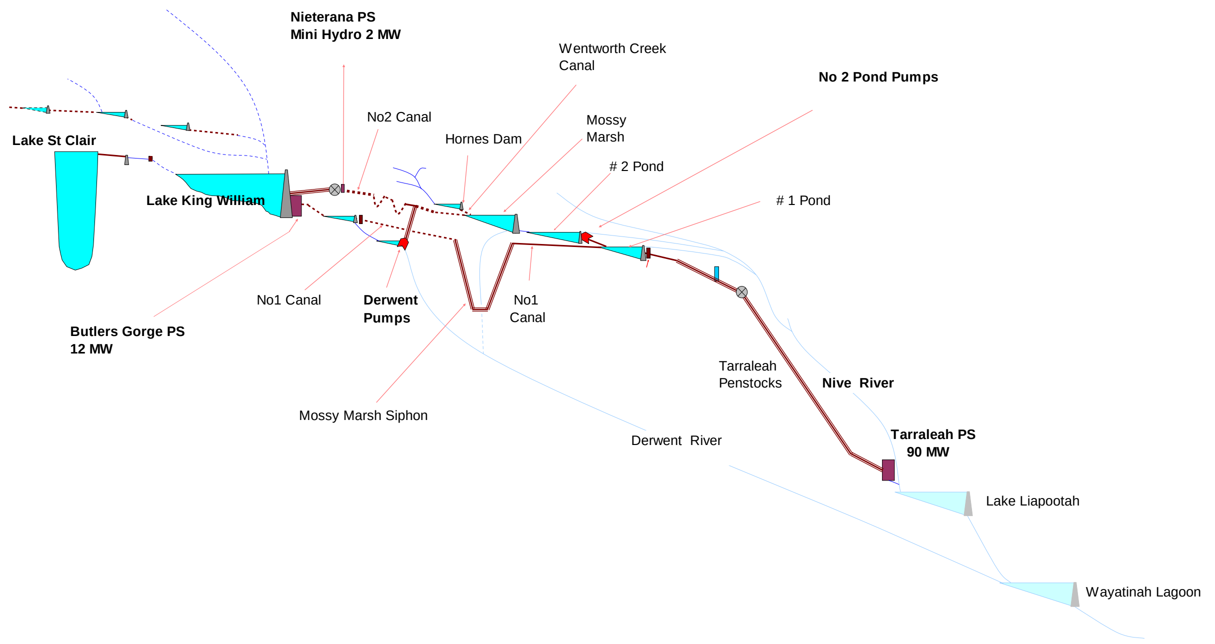


Figure 1: Tarraleah hydropower scheme – schematic

The scheme has very high utilisation and generates around 634 GWh/annum of largely base load energy, which is around 6.5% of Hydro Tasmania's total annual power generation. Aside from power generation, the Tarraleah scheme plays a key role in the regulation of flows to the Lower Derwent cascade system of dams and power stations.

The pre-feasibility study identified a range of options, summarised below:

- *Business as usual*: Ongoing operations and maintenance of the existing scheme, including an intensive outage schedule to undertake major maintenance work.
- *Energy optimised redevelopment*: Optimising the average flow and maximising the net head at the power station (i.e. base load). This is achieved through a long pressure conveyance (tunnel) directly linking Lake King William with the power station. The arrangement is shown in appendix C.
- *Capacity optimised redevelopment*: Maximising short-term generation output (i.e. peaking) and responsiveness to variable market needs. This is achieved at least cost by the provision of an intermediate (hilltop) storage dam at the top of the plateau close to the power station. This arrangement is shown in appendix C.

The scope of work included:

- Completion of a pre-feasibility study which included:
  - Options assessment of scheme redevelopment configurations.
  - Pre-feasibility level design, cost estimating and energy modelling of the options.
  - Sensitivity analysis on the impacts of different future markets on the revenue.
  - Financial analysis of redevelopment options.
  - Recommendations on the options to include in a full feasibility study.
- Development of a business case for a full feasibility study.
- Development of the feasibility study scope including a project schedule and cost estimate.
- The identification of key project risks and mitigation strategies to be applied to the feasibility study.

3.0 On river hydro – redevelopment

3.1 Description of asset class

Hydropower assets are a flexible and synchronous source of renewable energy generation with a long lifespan. These characteristics are conducive to addressing the issues of affordability, system security and emissions reduction in the energy sector.

Hydroelectric schemes can be classified as 'run of river' or 'conventional' depending on their configuration and operational characteristics. A 'run of river' scheme typically has limited storage and generates electricity continuously from the largely uncontrolled river flows, whereas a 'conventional' scheme can store water to generate when it is required.

Due to its location at the upper end of the Derwent system and its large headwater storage (Lake King William), the Tarraleah scheme plays a key role in the regulation of flows to the Lower Derwent cascade system of dams and power stations.

While the Tarraleah scheme is a conventional scheme in its layout, in practice it operates as a 'run-of-river' scheme due to constraints imposed by the complicated network of canals, tunnels and pipelines that convey water to the power station. This also means that there is little flexibility in the operation of the Lower Derwent power stations, which have a combined installed capacity of 273 MW.

Redeveloping the Tarraleah scheme will remove these constraints and enable it to act as a flexible conventional hydroelectric scheme with the ability to store energy and generate when required.

A typical hydropower station also provides power system support services (ancillary services). Due to the age and design of the current power station (6x 15 MW Pelton turbines), it provides little power system support. Ancillary services are expected to become more highly valued in the future market and the new power station will be designed to maximise opportunities for ancillary services revenue.

3.2 Applicable Market, Regulatory and System Development Issues

The NEM is facing a period of significant change. The aging coal infrastructure fleet is expected to progressively retire due to age-related deterioration (and possibly market pressures) and be replaced by new energy sources. The future NEM is expected to be vastly different to today, characterised by low-cost variable renewable energy sources being firmed by dispatchable (i.e. controllable) storage and generation.

Disruptions to electricity supply in the recent past have made Australia's electricity supply a hot topic. The debate has been driven by incidences of high prices, and a shortage of reliable generation causing (or at least threatening) black-outs and brown-outs (i.e. restrictions in available electric power).

These changes in the physical power system will also prompt a change in the markets. Energy services that help manage the reliability and security of the system will become more valued by the market. New services that can shift bulk energy from times of energy surplus to times of relative energy scarcity will become critical. The redevelopment of existing hydropower schemes will allow these valuable assets to be repurposed for a substantially different market paradigm to that for which they were originally designed, as Australia's electricity supply market transitions to a future characterised by a higher penetration of renewable energy sources. The redevelopment of Tarraleah with a capacity optimised focus offers a credible and cost-effective way of firming variable sources while accommodating the Energy Trilemma[1]: energy security, energy equity (accessibility and affordability) and environmental sustainability.

The existing market design is based on the short run marginal cost of energy (AEMO 2010), largely a derivative of fuel cost. In a future system with an energy mix primarily provided by variable renewable energy sources, conventional hydropower and storage, there would be no inherent fuel cost and the effective “floor” price would be removed. This would introduce substantial investment risk without substantial changes to the current dispatch market mechanism. There will need to be substantial redesign of the market to accommodate this kind of change.

In order to meet the physical requirements of the system new system services will be required that work alongside the low-cost variable energy sources. These services will help manage the variability of the future renewable generation sources and the magnitude and type of those services will depend on the characteristics of each region, particularly with reference to the need for short-term versus longer-term firming. Energy storage and flexible dispatchable capacity, both key improvement opportunities from redeveloping the Tarraleah scheme, are expected to play a major role in the provision of these new services. The pre-feasibility study has shown that, without considering and valuing these expected new services, the economic analysis of existing power station asset management strategies is very likely to lead to maintaining the status quo, which will create missed opportunities for improved support of the future system with existing renewable generation infrastructure.

The markets will also need to evolve to recognise and value these new services (such as inertia and fast rate of change) to provide the financial incentives to respond to the physical market needs. The current market price arbitrage mechanism for valuing storage and flexible, dispatchable capacity is not conducive to new investment and does not recognise the full value of services that it brings to the market.

In coming decades, reducing capital costs for electrochemical energy storage will likely give rise to significant investment in this area. Gas generation is also likely to be built. Pre-feasibility has shown that Tarraleah is a low-cost and reliable option that utilises proven sustainable technology. Tarraleah Redevelopment, and other such hydropower projects, will likely be competitive against alternative technologies and have an important role to play in the future market. Further interconnection throughout the NEM will enhance opportunities to co-optimise energy generation and firming between states, increasing value derived from geographically diverse natural resources, including the hydropower resources harnessed by the redeveloped Tarraleah scheme.

3.3 Social license considerations

The potential environmental and social impacts of redevelopment of the Tarraleah hydropower scheme were considered at a preliminary level during the pre-feasibility study and no high-risk impacts were identified. The existing scheme is located in a remote area in the Central Highlands of Tasmania with few local inhabitants, little through-traffic and occasional recreational activities. Redevelopment will not involve any new in-stream dams, only upgrading of the existing small to medium storages. New infrastructure will generally be in close proximity to existing infrastructure.

While sections of the Scheme are close to more recently established Tasmanian Wilderness World Heritage areas (TWWHA), the redevelopment options were constrained to exclude encroachment into these sensitive areas.

[1] World Energy Council 2017, *World Energy Trilemma Index*, https://trilemma.worldenergy.org/, accessed on 19/01/2018

The next stage feasibility study will have a dedicated ESIA (environmental and social impact assessment) team which will undertake extensive environmental and cultural heritage surveys along the alignments of the proposed new infrastructure. Any potential changes in Derwent River flows due to a new, higher-capacity station will be appropriately modelled and impacts assessed. Stakeholders will be managed with a project-specific stakeholder management plan.

3.4 Role of Basslink to new on-river hydro investments

Basslink has been in service since 2006. Given its limitation in import/export capacity, there are currently few drivers for new, on-river hydropower investments in Tasmania. Hydro Tasmania's system currently provides the majority of electricity to the Tasmanian market (base load and peaking). The objective of Basslink is to import base load power when prices are low in Victoria and to export peaking power when prices are high.

There is currently little appetite for new on-river hydro investments in Tasmania. The best hydropower resources have already been developed and much of the remaining resource is located in areas of high environmental value.

Future interconnection will reduce the constraint of import/export capacity and is expected to unlock Tasmania's potential to provide dispatchable renewable energy to the Australian mainland – the *Battery of the Nation*. While this is not expected to encourage on-river hydro investment, it is expected to encourage investment in a whole range of renewable energy technologies including repurposing existing hydropower schemes (such as Tarraleah), pumped hydro energy storage (pumped hydro) and private wind farms. Maximum value will be achieved by those schemes which can provide flexible capacity in a market with increasing penetration of non-dispatchable wind and solar generation sources.

4.0 Technical

4.1 Design characteristics and operational parameters

The pre-feasibility study recommended capacity optimised redevelopment of the Tarraleah hydropower scheme. The preferred option is shown on the plan in appendix C and comprises the following features:

- *Headwater storage*: Retain Clark Dam (which retains Lake King William) and construct a new intake to the north-east of Clark Dam.
- *Small hydro*: Decommission Butlers Gorge small hydro (12 MW) and Nieterana mini hydro (2 MW) and replace with a new small hydro (17 MW; 1x Francis turbine, 40m^3/s, 46 m net head) downstream of the new intake.
- *Water conveyance*: Decommission the existing No 1 and No 2 conveyance systems and construct a new No 3 conveyance system (~11.5 km) between the new intake and Mossy Marsh pond.
- *Intermediate storages*: Upgrade Mossy Marsh dam and construct a hydraulic control structure at its outlet; raise No 2 pond to increase its storage capacity around three-fold.
- *Pressure conveyance*: Construct a new power tunnel between No 2 pond and the new power station.
- *New power station*: Construct a new power station on the left bank of the Nive River opposite the existing power station (113 MW+; 2x Francis turbines, 20m^3/s, 305 m net head).
- *Existing power station*: The existing power station (90 MW; 6x 15 MW Pelton turbines) will be refurbished and retained in service depending on the planned staging.

The feasibility study will optimise the preferred option with a focus on the following:

- *Design capacity*: Select the ultimate design capacity (i.e. MW installed capacity and m^3/s design flow) based on downstream environmental and system constraints and forecast market demand.
- *Staging*: Determine the staging of redevelopment based on the timing of market demand and the planned timing and cost of rehabilitation of the existing assets.
- *Water conveyance*: Alignment and optimum configuration of canals, flumes and tunnels based on geotechnical, hydraulic and cost considerations.
- *Intermediate storages*: Optimisation of the storage volume and hydraulic characteristics of Mossy Marsh pond and No 2 pond to flexibly deliver water to the power station(s).
- *Pressure conveyance*: Alignment and optimum configuration of penstocks and tunnels. Consideration of future augmentation in design.
- *Power station*: Optimise the location and configuration of the new power station. Consideration of future augmentation in design.

The existing power station configuration has a number of significant limitations:

- The intermediate storage (No 2 pond) has limited capacity to provide flow to meet 'peaking' demand.
- The headworks (canal, forebay, hilltop pipeline and penstocks) are old, hydraulically inefficient and pose a significant asset risk.
- The Pelton turbines are old and in need of substantial refurbishment in the 2020s in order to prolong their operational life.
- The Pelton turbines are unsuitable to variable downstream water levels: they cannot be submerged which limits both net head and downstream operation.

- The Pelton turbines provide little power system support.

The construction of a new power station provides an opportunity to address these limitations by:

- enlarging No 2 pond to provide adequate storage capacity;
- constructing a new, hydraulically efficient pressure conveyance;
- installing large Francis turbines which maximise net head, can function under variable downstream water levels and provide power system support services such as black start, fast raise and inertia capability.

Redevelopment of the Tarraleah scheme will impact on the operation of the entire Derwent cascade system of dams and power stations (refer Figure 2). Currently both the Tarraleah (42 m^3/s) and Tungatinah (52 m^3/s) power stations discharge into Lake Liapootah, which diverts water into Liapootah power station (100 m^3/s). During periods of peak demand and adequate water availability, Tarraleah and Tungatinah provide close to the design flow of Liapootah. Increasing the design flow (and installed capacity) of Tarraleah therefore has the potential to increase spill downstream, unless it is substituting for flows from Tungatinah and the Nive River. This is possible during the drier months where water availability in the Tungatinah scheme becomes an issue. There is also some potential to capture short term peak discharges downstream through effective storage management.

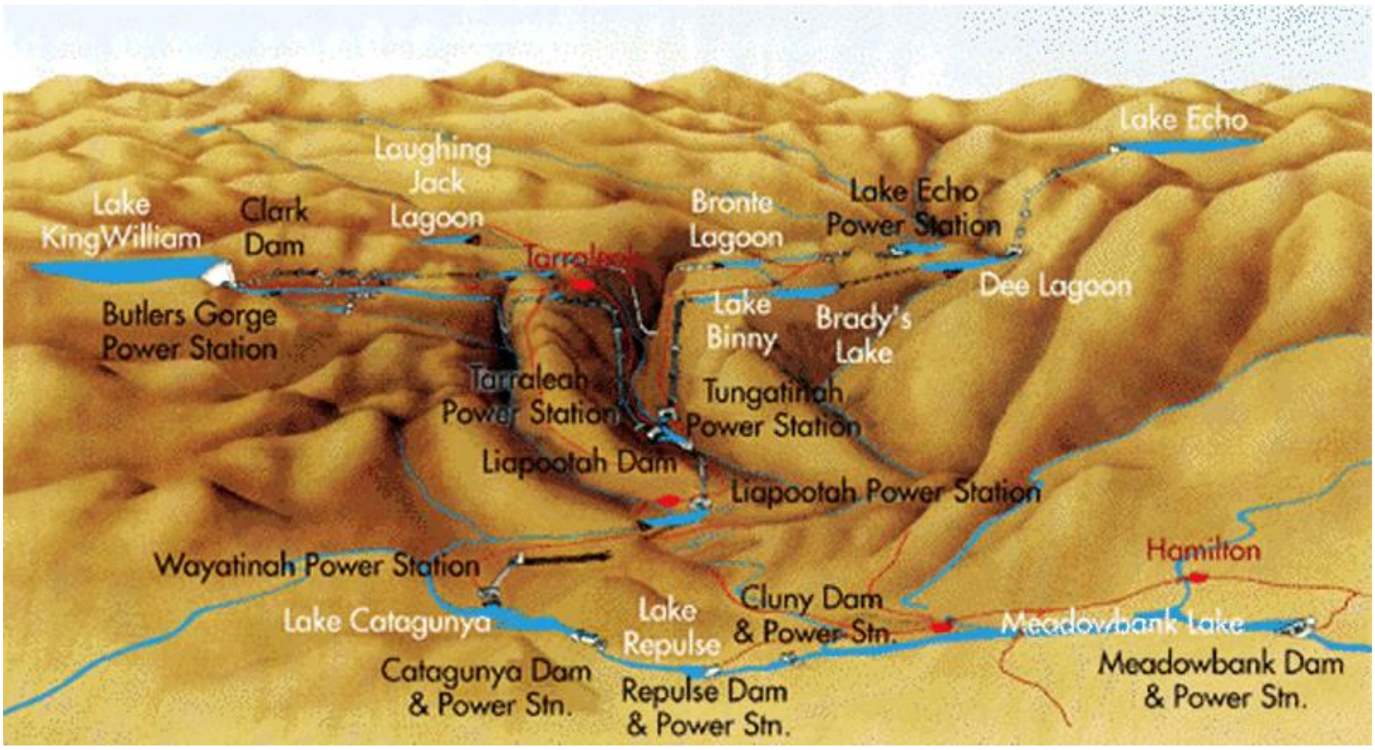


Figure 2: Derwent cascade system of dams and power stations

The feasibility study will include extensive in-house system modelling to select the optimum design capacity based on downstream environmental and system constraints and forecast market demand. The optimum design will be one which maximises net system benefits – including enhancing the revenue opportunities from the downstream stations through increased operational flexibility.

4.2 Key challenges in delivering solutions

The key challenges and learnings from the pre-feasibility study are grouped into the following categories: brownfields redevelopment, incentivising investment in long-life assets and future market uncertainty. These are summarised below.

Brownfields redevelopment:

- *Old and complicated hydropower scheme*: This increases the number of potential redevelopment options as many components of the existing scheme can potentially be retained as part of the redevelopment works. Combining old and new elements adds complexity and potential unknowns associated with existing asset condition and risk.
- *Asset risk is difficult to quantify*: The scheme is nearing the end of its operational life and a major asset failure is likely to have extreme consequences in terms of long forced outages, lost generation and reconstruction costs. However, asset risk (particularly for civil assets) is difficult to quantify accurately and to demonstrate in financial analyses.
- *Asset management plans are evolving*: As Hydro Tasmania's understanding of asset condition is evolving, so are its asset management plans. Major refurbishment works with long forced outages and associated lost generation is likely to favour redevelopment, as the refurbishment expenditure does not result in the benefit of increased operational flexibility. Delayed refurbishment will favour business as usual over redevelopment (requiring major capital investment) due to the discounted financial analysis approach.
- *Uncertainties relating to the ability to re-purpose existing scheme assets*: While there are a number of opportunities to re-purpose existing scheme assets, there are a number of uncertainties in doing so. These include: level of understanding of asset condition and asset risk, modern design standards, economies of scale and outage costs. In the case of water conveyance assets, the pre-feasibility study concluded that it is more effective to build completely new infrastructure than to attempt to re-purpose existing scheme assets such as augmenting an existing canal.
- *Major construction work needs to minimise impacts on operation of the existing scheme*: The Tarraleah scheme has a very high utilisation and regulates flow to the Lower Derwent cascade system of dams and power stations. Due to the existing water conveyance constraints, unplanned outages and major planned outages are likely to increase spill from the scheme, resulting in lost generation and high outage costs. Furthermore, generation will need to be sourced from other schemes or via Basslink, potentially at higher cost. Redevelopment approaches need to consider design and implementation methodologies that minimise outage requirements.
- *Effects of redevelopment on the Lower Derwent cascade system of dams and power stations*: Scheme redevelopment cannot be considered in isolation; it is important that the impact of any changes in operation on the adjacent Tungatinah scheme and the downstream Lower Derwent stations (and the broader Hydro Tasmania system) are understood and quantified.

Incentivising investment in long-life assets:

- How can we incentivise long-life assets using discounted financial analysis theory? Discounted financial analysis theory is effective for comparing a range of new investments but raises a number of questions when comparing the operation and maintenance of an existing asset with major capital investment of a long life asset. Depending on the discount rate used, the analysis outputs can be dominated by the first ten years of costs and benefits. A major hydropower investment has a lead time of around 5 years (i.e. costs incurred) before becoming operational (i.e. benefits received). A hydropower scheme has an operational life of at least 60 years (in some cases 80-100 years) but the benefits of scheme operation from year 20 to year 60+ are heavily discounted in such analysis.
- *Very little investment in long-life generating assets in recent years*: With the privatisation of the electricity generating sector, much of the (limited) investment has been made in gas, wind and solar. Such

investments have much shorter lead times, shorter design lives and smaller installed capacity than major hydropower or pumped hydro energy storage (PHES). Who is going to make the necessary investments in long-life generating assets with large installed capacity necessary to provide stability to the system?

- *Governments traditionally make these types of investments as they provide economic benefits*: Traditionally governments have made major investments in long-life generating assets with large installed capacity. They may be better placed to take the investment risk as the broader economic benefits potentially flow-on to industry, employment, migration, etc.

Future market uncertainty:

- *There is uncertainty in the timing and magnitude of future market signals*: Hydro Tasmania's future state NEM team is seeking to better understand the timing and magnitude of future market signals; however, there will always be uncertainty and the signals will change with time.
- *Hydropower development involves long lead times in terms of planning and construction*: Major hydropower development can take at least 5 years for the feasibility study, approvals, design, procurement and construction. The project proponent is required to make an investment decision many years in advance of project commissioning and project benefits (revenue) being received. The proponent necessarily requires a reasonable level of certainty on the market conditions and expected revenue to justify the investment.
- *It is prudent to start redevelopment soon before the market signals are felt*: Given the long lead times for major hydropower development, there are risks to waiting for certainty of market conditions. By the time the project has been approved, financed, constructed and commissioned, competition may erode the benefits.
- *Scheme redevelopment can be staged to align with future market signals*: The most prudent approach is to be 'armed' with a detailed scheme redevelopment plan so that all future expenditure is geared towards the future market and the timing of investments are linked to market triggers. In parallel with this, asset risk of the ageing scheme needs to be managed at all times.
- *Strong triggers are required to rapidly initiate staged redevelopment*: Given the magnitude of the investment, it is understandable that strong triggers are required to justify the investment. This requires a stable policy environment with a long-term vision.

4.3 Review of current turbine market

The scope of the pre-feasibility study did not include seeking input from turbine manufacturers on the range of options available for the proposed new hydropower station. Hydro Tasmania used its own knowledge of similar machines within the Hydro Tasmania system and elsewhere within Australia, as well as recent turbine replacements and upgrades within the hydro system, and Entura's experience with new hydro scheme developments.

The pre-feasibility design team established basic parameters of a new power station to comprise two Francis turbines with a design flow of 20 m^3/s (total 40 m^3/s), a net head of 305 m and an installed capacity of ~57 MW (total 113 MW). The turbine arrangement is very standard and expected to be readily available.

Turbine manufacturers will be engaged during the feasibility study to propose equipment which suits the functional requirements of the scheme. This includes the ability to provide power system support services (ancillary services) such as black start, fast raise and inertia capability which will maximise future revenue streams. Other key information to be provided includes hydraulic efficiency, cost and procurement lead time.

Depending on the asset management plan for the existing hydropower station (i.e. refurbishment or decommissioning), the new station could be designed to have additional units – either as part of its original construction or provision could be made for future augmentation.

5.0 Capital cost

5.1 Capital cost estimate and basis

Scheme redevelopment is highly sensitive to civil works costs, particularly the water conveyances. Previous studies into redevelopment of the Tarraleah scheme focused on a long pressure tunnel. The lack of detailed geotechnical information makes it impossible to estimate capital costs with any reasonable degree of accuracy. The pre-feasibility assessed a broader range of water conveyance options with different levels of geotechnical risk to give a better understanding of construction costs.

Capital costs were estimated using aggregated unit rates developed specifically for the pre-feasibility study by an experienced, independent construction cost estimator. The unit rates were developed using experience of both Hydro Tasmania and Entura from previous projects and input from the construction industry. The rates used are provided in appendix D.

The estimated capital costs for the new infrastructure required for the energy and capacity redevelopment options are presented in appendix E and are summarised below:

- Energy optimised redevelopment: $557M.
- Capacity optimised redevelopment: $484M.

Note that for the purposes of financial modelling, the capital costs for new infrastructure were combined with the refurbishment costs of existing assets to be retained. Assumptions were made with respect to the timing of investments in both new infrastructure and refurbishment works and a present value analysis was undertaken. The present value of costs, over the project life (65 years), for the Tarraleah options are summarised below:

- Business as usual: $267M (104 MW).
- Energy optimised redevelopment: $455M (130 MW).
- Capacity optimised redevelopment: $461M (220 MW+).

Hydro Tasmania is faced with the decision of either investing to maintain the existing system with 104 MW of inflexible capacity or to invest a greater amount to achieve 205 MW+ of flexible capacity. Capacity optimised redevelopment of the Tarraleah scheme was compared with possible pumped hydro energy storage (pumped hydro) options in Tasmania. **Figure 3** shows energy in storage and hours of storage. The graph demonstrates that the Tarraleah scheme is vastly superior to pumped hydro options due to Lake King William which essentially provides a very large storage without the need to pump. **Figure 4** shows installed capacity and installation cost. The graph demonstrates that redevelopment of the Tarraleah scheme provides modest additional installed capacity but at a very competitive installation cost.

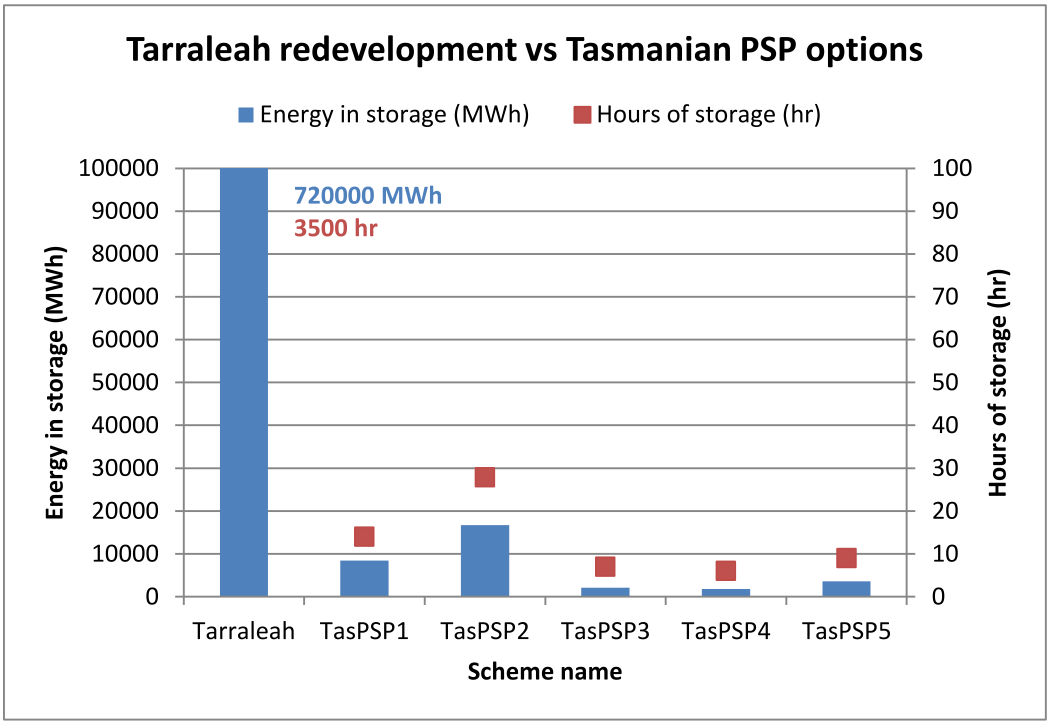


Figure 3: Tarraleah redevelopment vs Tasmanian PSP options – energy in storage and hours of storage

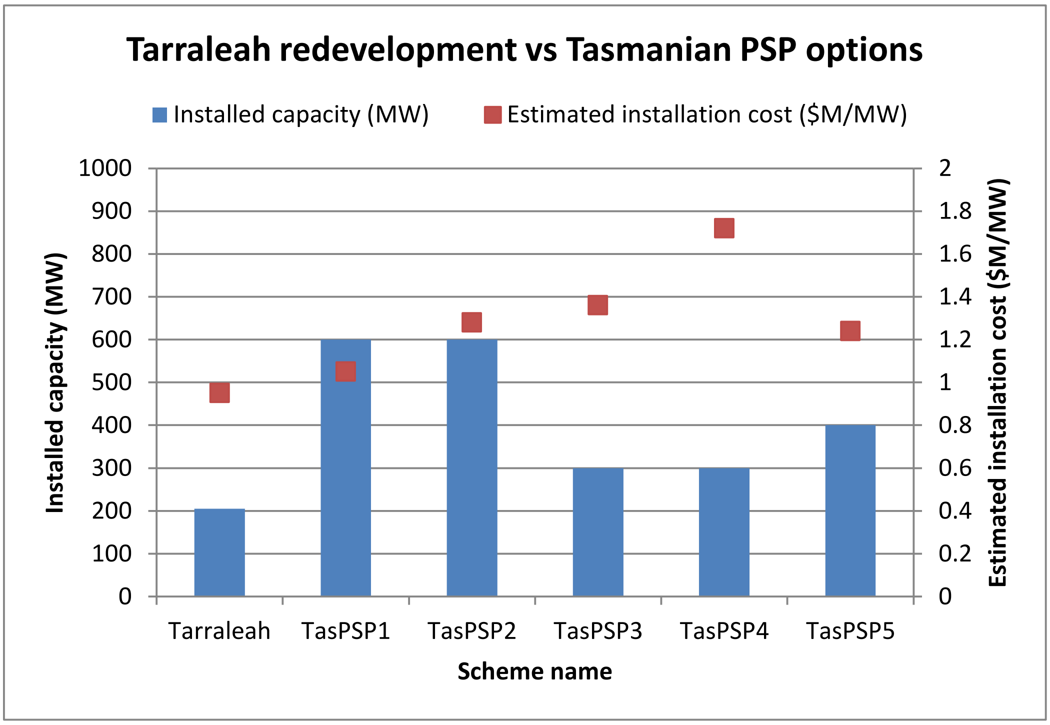


Figure 4: Tarraleah redevelopment vs Tasmanian PSP options – installed capacity and estimated installation cost

5.2 Approach to EPC/procurement

The pre-feasibility study did not include consideration of procurement methods; rather the objective was to identify a preferred redevelopment option for detailed consideration in a feasibility study.

The optimal redevelopment solution is highly dependent on Hydro Tasmania's asset management (i.e. refurbishment) plans for the existing assets. Ongoing investment in the existing assets weakens the case for redevelopment, while significant upfront CAPEX commitment to redevelopment requires strong future revenue streams and market certainty. The next stage feasibility study will look at opportunities to stage redevelopment and commitment decisions to align with the emergence of potential new market investment signals. One example is to construct the new conveyance infrastructure and refurbish the existing power station and delay construction of the new power station until strong market signals emerge which value capacity.

A particular focus of the feasibility study will be undertaking extensive geotechnical investigations and to optimise the alignment and configuration of the civil works. Much of the capital cost is involved in the water conveyance infrastructure which involves a combination of canals, flumes and tunnels. Input will be sought from civil works contractors as part of the feasibility study to determine the best solution in terms of construction risk, schedule and cost. Solutions will be adopted which maximise the potential to use local civil works contractors as this is expected to provide the best economic outcome for Tasmania.

Due to the size and complexity of the works, it is expected that 'design and construct' contracts will result in the best project outcome. Engineer-procure-construct (EPC) contracts may not give Hydro Tasmania sufficient control to achieve its desired operational outcomes or flexibility to respond to emerging market signals. 'Construct only' contracts require full detailed design which is very time-consuming and limits the ability for contractors to incorporate efficiencies. Given the linear nature and variety of the works (canals, flumes, tunnels, dams, power stations, etc.), one or several contracts could be used to implement the works.

A key aspect of the feasibility study is consideration of the commercial aspects of the construction contract, including identifying the best contractual model for this project based on the scope and staging of the works, provision of risk and market capability and capacity.

6.0 Revenue model

6.1 Commercial revenue strategy

Past studies on the potential redevelopment of the Tarraleah scheme were based on current market assumptions and projections, which effectively drove an energy optimised scheme with strong future price projections for (base load) energy. The conclusions of past studies, confirmed by this study, is that the current market revenue mechanisms are very unlikely to provide an economically justifiable case for major redevelopment of the existing infrastructure. Future state NEM modelling currently being undertaken by Hydro Tasmania suggests that increasing wind and solar generation sources pose a downside risk to inflexible base load energy in the future, and that more value is likely to attributed to firming (dispatchable) capacity and power system support services. The pre-feasibility revenue modelling therefore placed a strong focus on identifying options to maximise value in the future market.

Three sets of price projections were developed for the pre-feasibility study and were applied to each of the Tarraleah options to estimate project benefits (revenue):

- Hydro Tasmania's existing long-term price benchmark (LTPB) projections:
    - This projection is based on current 'energy' market conditions and includes weak, neutral and strong price projections.
- Future 'capacity' market with neutral to strong swap (energy + capacity) prices:
    - This projection includes future capacity prices centred on those available in today's market (~$17). Such a market would require coal to remain the price-setter for the foreseeable future and is also unlikely to support significant growth in wind and solar.
- Future 'capacity' market with very strong swap prices:
    - This projection includes a ceiling for the swap price based on the marginal cost of (open cycle) gas generation, with a higher range of capacity prices. This is the only set of future market projections likely to sustain future renewables development supported by firming capacity.

The future capacity market projections were modelled with three combinations of energy (swap-capped) and capacity (cap) prices to give an indication of what future capacity market signals are necessary to favour redevelopment.

Note that the price projections used were either approved by Hydro Tasmania's Board or were derived from the Board-approved projections and are therefore confidential. This knowledge-sharing report summarises the outcomes of the financial analyses to show the relative differences in the financial model outputs as a function of the revenue assumptions.

Table 1 summarises the outputs (MIRR and NPV) from the preliminary financial analyses for the LTPB weak, neutral and strong price growth projections.

	Progressive refurbishment	Energy optimised (131 MW)	Capacity optimised (not staged, 130 MW)	Capacity optimised (staged, 220 MW+)
LTPB weak growth projection				
MIRR (%)	13.3%	11.3%	11.4%	11.3%
NPV ($M)	$132.5	$90.1	$110.8	$61.4
ΔNPV ($M)	-	-$42.4	-$21.7	-$71.1
LTPB neutral growth projection				

	Progressive refurbishment	Energy optimised (131 MW)	Capacity optimised (not staged, 130 MW)	Capacity optimised (staged, 220 MW+)
MIRR (%)	16.9%	11.6%	11.8%	11.7%
NPV ($M)	$211.8	$192.1	$210.0	$152.1
∆NPV ($M)	-	-$19.7	-$1.8	-$59.7
LTPB strong growth projection				
MIRR (%)	85.1%	11.9%	12.0%	12.0%
NPV ($M)	$283.7	$285.3	$300.5	$237.1
∆NPV ($M)	-	$1.6	$16.8	-$46.5

Table 1: Preliminary financial analyses for LTPB weak, neutral and strong price growth projections – summary

The analyses show that the NPVs are comparable for progressive refurbishment and for the energy optimised and capacity optimised (not staged, 130 MW) redevelopment options. Progressive refurbishment has a higher MIRR. Higher price growth projections increase project benefits and NPV for all options. The capacity optimised (staged, 220 MW+) option has a lower NPV because it incurs the costs of extra capacity without receiving the revenue benefits. The LTPB projections place a very low future value on capacity ($7 in real terms compared with $17 in today's market) and as a consequence do not provide a strong financial driver for redevelopment.

Table 2 summarises the outputs (MIRR and NPV) from the preliminary financial analyses for the two sets of future capacity market projections. These assume that a future capacity market will develop coinciding with the commissioning of a second interconnector to Tasmania and increasing retirement of existing coal-fired generation on the mainland. LTPB projections have been used to FYE2028 and future projections from FYE2029 onwards.

	Progressive refurbishment	Energy optimised (131 MW)	Capacity optimised (not staged, 130 MW)	Capacity optimised (staged, 220 MW+)
FUTURE CAPACITY MARKET WITH NEUTRAL TO STRONG SWAP PRICES				
LTPB neutral (energy) + $11 real (capacity)				
MIRR (%)	16.9%	11.7%	11.8%	11.8%
NPV ($M)	$211.8	$207.0	$218.4	$193.3
∆NPV ($M)	-	-$4.8	$6.5	-$18.5
LTPB neutral - $10 (energy) + $17 real (capacity)				
MIRR (%)	16.8%	11.6%	11.7%	11.9%
NPV ($M)	$194.9	$202.8	$207.0	$221.9
∆NPV ($M)	-	$8.0	$12.1	$27.1
LTPB neutral -$20 (energy) + $23 real (capacity)				
MIRR (%)	16.6%	11.6%	11.7%	12.0%
NPV ($M)	$175.5	$198.1	$193.9	$254.6
∆NPV ($M)	-	$22.6	$18.4	$79.2
FUTURE CAPACITY MARKET WITH VERY STRONG SWAP PRICES				
LTPB neutral (energy) + $34 real (capacity)				
MIRR (%)	16.9%	11.8%	11.9%	12.4%
NPV ($M)	$211.8	$285.2	$262.2	$408.8
∆NPV ($M)	-	$73.4	$50.4	$197.0
LTPB neutral - $10 (energy) + $42 real (capacity)				
MIRR (%)	16.7%	11.8%	11.9%	12.5%
NPV ($M)	$193.1	$286.5	$252.9	$456.7

	Progressive refurbishment	Energy optimised (131 MW)	Capacity optimised (not staged, 130 MW)	Capacity optimised (staged, 220 MW+)
ΔNPV ($M)	-	$93.4	$59.8	$263.6
LTPB neutral -$20 (energy) + $50 real (capacity)				
MIRR (%)	16.6%	11.8%	11.8%	12.5%
NPV ($M)	$174.3	$287.8	$243.6	$504.6
ΔNPV ($M)	-	$113.4	$69.3	$330.3

Table 2: Preliminary financial analyses for future capacity market projections – summary

The capacity optimised (staged, 220 MW+) option has the highest dispatchable capacity (220 MW+) and is therefore best able to take advantage of a future capacity market. The preliminary financial analyses show that this option requires capacity prices of only ~$14 real (less than today's $17) to have an equivalent NPV to progressive refurbishment. It has a ΔNPV of $197-$330M under the future capacity market which is believed to be most likely to sustain future renewables development supported by firming capacity.

6.2 Role of new assets within existing portfolio of assets

The project should be seen not as a new asset but as re-purposing an existing asset to better suit future market drivers. A more flexible, fully dispatchable Tarraleah scheme is expected to have flow-on benefits to the entire Derwent cascade system of power stations and the broader Tasmanian system. These include:

- Reduced spill from the Tarraleah system, increasing annual energy generation potential.
- Improved regulation of the Tarraleah scheme will improve operational flexibility of the adjacent Tungatinah scheme, reducing spill at the downstream Liapootah dam.
- Increased capacity from the Tarraleah scheme presents opportunities to further increase capacity along the downstream cascade of power stations as part of future upgrades, lifting a current constraint to the improvement potential of the entire downstream cascade.

The Tasmanian system comprises a combination of 110kV and 220 kV transmission networks. The older stations in the system, typically clustered in the south of the state where Tarraleah is located, are connected via the 110kV system. The redevelopment of Tarraleah presents an opportunity for a new station connection into the 220kV system in the south of the state, which is likely to strengthen the system and has potential system support benefits such as stronger SRAS capabilities in the southern part of the system.

The impact of redevelopment of the Tarraleah scheme on the existing portfolio of assets will be extensively modelled in-house as part of the feasibility study. As mentioned above, the optimum design will be one which maximises net system benefits – including enhancing the revenue opportunities from the downstream stations through increased operational flexibility.

6.3 Analysis of potential increase in generation and impact on other revenue streams

Redevelopment of the Tarraleah scheme is expected to increase annual generation from 634 GWh to 808 GWh. This increase of 174 GWh (27%) is due to the following:

- Increased conveyance capacity and operational flexibility reduces annual spill from Lake King William.
- Improved headworks design including higher intermediate storage level (No 2 pond) reduces hydraulic losses and increases net head.
- Modern turbine and generator increases power output.
- Lower setting of Francis turbines (compared with Pelton turbines) increases net head.

This increase in annual generation increases potential energy revenue. In addition, the ability to operate the scheme much more flexibly increase the potential to target operation during times of peak demand (and prices), maximising potential revenue.

The Lower Derwent power stations have a combined installed capacity of 273 MW. More flexible operation of the Tarraleah scheme also means that there are potential opportunities to partially time shift the utilisation of these base load run–of-river stations from low demand periods towards peak demand times.

6.4 Ancillary services revenue

Ancillary services can be grouped under one of the following three major categories:

- Frequency Control Ancillary Services (FCAS).
- Network Support & Control Ancillary Services (NSCAS).
- System Restart Ancillary Services (SRAS).

For the redevelopment options, the new Tarraleah station is expected to be able to provide a range of ancillary services which the current station does not provide. These arise from the use of modern turbine design and control system arrangements and include: black start capability, inertia (running as a synchronous condenser), particularly fast raise (R6) capability. Revenue estimates for these services were modelled based on current market prices. The next stage feasibility study will quantify the projected future value of ancillary services.

7.0 Operational cost

At the pre-feasibility level, operational costs do not have a significant impact on the selection of a preferred option or on the outputs of the financial analysis. Nevertheless, Hydro Tasmania has 80 years of operational experience of the scheme and these learnings were used as the basis of the operational cost estimates.

The operational cost estimates were derived by identifying individual asset classes and types for each of the operations. For each individual asset type, a comprehensive program of operation and maintenance (O&M) activities was developed and costed as part of normal strategic asset management planning, which prides a 10 year asset management plan and a 30 year asset management forecast. The basis for the program and costing is the current O&M activities of the Tarraleah scheme and other Hydro Tasmania schemes.

The annual O&M cost varied from year to year depending on the asset type. As an annual average the cost was approximately $2M for business as usual (i.e. maintaining the existing scheme) and $1M for the redevelopment options. The redevelopment options have reduced operational costs in comparison to the existing due to the simplification and modernisation of the scheme, however with the long asset life and financial modelling duration used, mid life major refurbishment of the redeveloped assets was included in operational cost assumptions.

Assuming a total asset value of ~$500M, the annual O&M costs are approximately 0.4% (business as usual) and 0.2% (redevelopment options) of the total asset value. These estimates were benchmarked internally by Hydro Tasmania against actual O&M costs and were found to be reasonable.

It is noted that these estimates are asset and site specific to the Tarraleah scheme; however, the costs estimated for some operational activities are considered to be applicable to pre-feasibility studies for conventional and pumped hydroelectric schemes elsewhere.

8.0 Financing

Financing of the redevelopment works was not part of the pre-feasibility study scope and the standard business WACC assumptions were used in economic analysis.

Project financing options will be assessed as part of the next stage feasibility study as part of the 'commercial' work package which includes revenue modelling, financial modelling and consideration of contractual models.

9.0 Land acquisitions, connection and environment

10.1 Approach and issues with land acquisition

As part of the pre-feasibility study, a review of development and environmental approvals was undertaken.

In relation to land tenure, the infrastructure associated with the proposed options and new power station is likely to cross a number of other public and private land tenures, including but not limited to:

- Crown land managed by Sustainable Timbers Tasmania (new canals/tunnel).
- Tarraleah Conservation Area managed by Parks and Wildlife Service (tunnel/dam).
- Private land comprising the Tarraleah village (tunnel).

New above-ground infrastructure is likely to be limited to Crown land managed by Sustainable Timbers Tasmania and potential minor parts of the Tarraleah Conservation Area managed by Parks and Wildlife Service.

Consultation with Sustainable Timbers Tasmania will be required to secure the necessary access and land tenure. Any impacts on the Tarraleah Conservation Area will require the authority of the Parks and Wildlife Service through their Reserve Activity Assessment process. The likely timeframe for approval under this process may be 6-8 weeks depending on the nature of the impacts.

Upon determination of preferred site layouts and routes, consultation should be undertaken with the relevant land managers to progress landowner consent in support of the planning permit application.

10.2 Approach to network connection

Redevelopment of the Tarraleah scheme may require the transmission connection to be upgraded from 110 kV to 220 kV. Transmission network upgrades are the responsibility of TasNetworks and the costs are passed onto network users. Hence the costs of a transmission network upgrade are considered to be outside the scope of the Tarraleah scheme redevelopment project.

Upgrading the transmission line has substantial benefits in terms of increasing the marginal loss factor (MLF). These benefits apply to both the existing and redeveloped Tarraleah power station and the adjacent Tungatinah power station. The MLF is reviewed annually by the Australian Energy Market Operator (AEMO) and is currently 0.9338 (FYE2018). Early modelling indicates that upgrading the transmission line could increase the MLF as a high as 0.99; however, to account for additional generation coming online in the Central Highlands over the life of the project, a slightly conservative approach was taken and an MLF of 0.975 was adopted from FYE2024 onwards.

A number of preliminary options for the electrical connection were identified. These include a connection to the Liapootah and/or Waddamana switchyards. The new connection to Liapootah switchyard was adopted for the pre-feasibility study with a nominal commissioning date of FYE2024 adopted to coincide with commissioning of the new station(s) included in the redevelopment works.

The options are detailed in appendix F and will be further developed as part of the feasibility study in conjunction with TasNetworks, who will be the ultimate custodian of the transmission line upgrade project.

10.3 Development approvals required

A preliminary social and environmental impact assessment was undertaken for the redevelopment options as part of the pre-feasibility study. For complete details please see the risk assessments in appendix G.

Social and environmental impacts from redevelopment of the Tarraleah scheme were assessed to be Minor to Insignificant, with a single Moderate risk in regards to the legacy risk from decommissioned assets.

The majority of risks are associated with the construction of the new assets and the potential changes to the operating regime of Lake King William and the Nive River downstream of Tarraleah power station during the operational phase.

The following development and environmental approvals may be required to facilitate project development:

- A Planning permit from the local Council and *Land Use Planning and Approvals Act 1993* (LUPA Act) will be required for general works and changes of use such as new or enlarged canals, site offices, workers camp, access roads, new power station, decommissioning and rehabilitation. In addition, where tunnelling is proposed, it is likely that the process will also incorporate assessment as a Level 2 activity (excavation of > 5000 m^3/yr of material) under the *Environmental Management and Pollution Control Act 1994* (EMPC Act).
- Referral or assessment under the *Environment Protection and Biodiversity Conservation Act* (EPBC Act) for direct or downstream impacts on matters of national environmental significance (MNES).
- Mining Lease under the *Mineral Resources Development Act 1995* is likely to be required for the tunnelling works and securing of tenure.
- A dam works permit under the *Water Management Act 1999* for modification or enlargement of the existing No 2 Pond, and authority under the *National Parks and Reserves Management 2002*.
- Permit to take threatened species and permit(s) to disturb Aboriginal relics if impacted by works.
- Further consideration of the potential impact of changes in power station operations at a system wide level will be required.

The most significant timeframe for approvals are in respect of the planning permit for works (EPBC and LUPA Act). Current estimates for the approval the major component of the project (tunnels, powerhouse and new conveyances) is likely to between 10-12 months. Importantly, this process may also integrate assessment of the matters under the EPBC Act.

Provision should be made for approximately 18 months to secure all necessary development and environmental approvals (including contingency), subject to detailed ecological and cultural heritage studies being completed. An additional 3-9 months should be provided for detailed ecological and heritage surveys and assessments (depending on seasonal constraints).

It is considered that the current planning scheme and broader regulatory regime in place is suitable to facilitate the redevelopment of the Tarraleah scheme, subject to detailed ecological and cultural heritage studies being completed, and do not pose a serious risk to the project proceeding.

10.0 Conclusion/next step/other matters

11.1 Conclusion

The pre-feasibility study found that capacity-optimised redevelopment of the Tarraleah scheme is the most favourable option for the following reasons:

- There is a range of plausible future market scenarios where the optimisation of capacity provides financial benefits well in excess of maintaining the existing base load generation capability.
- The option contains a number of future flexible decision points which will allow investment decisions and timing to be staged based on emerging market drivers in future. In an uncertain future market environment, this optionality is considered valuable and does not exist in the current asset management pathway.
- The redeveloped capacity is of comparable value and cost to that provided by developing pumped hydro energy storage; with the added benefit of avoiding pumping costs.
- Improved flexibility of operation to provide a broader range of market services is likely to be valuable in the future market, and likely to contribute to the financial benefits of a redeveloped scheme.

The outcomes of this study also highlight the importance of ensuring that long term asset strategy decisions are future proofed against a changing energy market that may require firming energy supplies to compensate for a higher penetration of renewable energy sources.

Operators of large hydroelectric schemes should review their current ‘business as usual’ asset management plans will protect future revenue streams and to ensure that current investments do not compromise the ability of these assets to provide a significant role in future long term affordable firming services to the NEM.

11.2 Full feasibility study

A full feasibility study is recommended to fully understand and quantify the risks and benefits of scheme redevelopment in comparison with progressive refurbishment. The study will be undertaken on the capacity optimised option identified as most suited to the likely future market environment, with the provision of operational flexibility and additional capacity and consideration of staging opportunities.

The study will provide clear direction on the best way forward and a decision-making framework for the future based on changes in asset performance and risk and market signals.

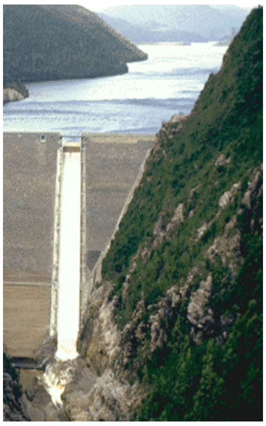
Key early stages of the study will be environmental and cultural heritage surveys and geotechnical investigations. Following this will be feasibility design and costing of the proposed new infrastructure and detailed planning and costing of refurbishment work on existing infrastructure to be retained. Revenue and financial modelling will quantify expected revenue streams based on future market projections provided by Hydro Tasmania’s separate future state NEM modelling project.

The feasibility will take around 18 months to complete and will cost approximately $5M. It will be implemented by a study team comprised of Hydro Tasmania and Entura employees and will be supported by input from construction contractors and equipment manufacturers.

Appendices

Appendix A – Managing a high penetration of renewables – a Tasmanian case study

Managing a High Penetration of Renewables– A Tasmanian Case Study



1. Background

The Tasmanian power system has been rapidly evolving over the past 15 years with increasing levels of renewables penetration in conjunction with the commissioning of the Basslink High Voltage Direct Current (HVDC) interconnector that connects Tasmania to the National Electricity Market (NEM). During these advances, Hydro Tasmania, TasNetworks (formerly Transend) and the Australia Energy Market Operator (AEMO) have worked collaboratively to identify key emerging issues and develop innovative and cost effective solutions to allow a largely unconstrained but secure network.

While Tasmania is not the region with the greatest deployment of wind and solar energy, the technical and market challenges tend to demonstrate themselves earlier due to its size and electrical isolation. Tasmanian hydro generation is on one hand the most flexible of all energy sources, but conversely, is subject to seasonal fluctuations, 'must-run' requirements and limitations on its ability to run at low output on a continuous basis. The Basslink HVDC interconnector adds significant additional flexibility to the system but some operational complexities exist which have driven a number of the technical solutions outlined in this paper. A key aspect of this is catering for the instantaneous loss of this interconnector being up to 50% of the total demand in Tasmania at a given time being a credible contingency.

The challenges experienced in Tasmania are now emerging in South Australia (SA) and are attracting NEM wide attention. The key reasons for Tasmania to have proactively managed emerging issues associated with renewables include, but are not limited to:

- The Basslink HVDC interconnector does not transfer the electrical properties of the Alternating Current (AC) system from Victoria, including inertia and fault level, although it does deliver synthetic inertia[1] and Frequency Control Ancillary Services (FCAS) when not operating at its limits;
- The Tasmanian transmission network is not as heavily meshed as many parts of the mainland;
- Tasmania has disproportionally large credible contingencies relative to the size of the power system:
  - Loss of Basslink, which can export 630 MW (from Tasmania) and import 478 MW.
  - Loss of the largest generator, being the Combined Cycle Gas Turbine (CCGT) at George Town rated at 208 MW.
  - Loss of the largest single load block, currently up to 230 MW.
- Hydro generators supply relatively limited quantities of fast FCAS (raise and lower); and
- Half of Tasmanian wind is currently non-scheduled (140 MW). A portion of the hydro generation fleet is also operated as non-scheduled in the market and not subject to dispatch constraints.

[1] The term 'synthetic inertia' in this case can be alternatively described as 'Fast Frequency Response (FFR)' given that Basslink is capable of responding to frequency deviations.

All of these issues need to be considered under 'system normal' operating conditions whereas much of the focus for SA is following a second contingency or non-credible contingency event.

In 2010, the Tasmanian government submitted a paper to the AEMC which canvassed several options for addressing the issues in the Tasmanian system. The paper was developed by an advisory panel called the Electricity Technical Advisory Committee. It stated:

> *Whilst not recommending a mechanism that enables the connection of asynchronous generation without unduly impacting on the operational flexibility of the Tasmanian power system, the following options are proposed for consideration and discussion:*
>
> - *development of minimum access standards; for example, frequency control capability, minimum inertia, and minimum fault level contribution which could then be enforced through the relevant rules, whether national or Tasmanian;*
> - *the application of National Electricity Rules (Rules) clause S5.2.5.12 in relation to intra-regional and inter-regional transfer limitations;*
> - *the introduction of new market ancillary services covering inertia and fault level;*
> - *a review of AEMO's Market Ancillary Service Specification (MASS) to provide for inertia contributions;*
> - *a review of the Tasmanian frequency operating standards for network events;*
> - *the development of new non-market ancillary services, network support and control ancillary service of inertia and fault level;*
> - *clarify the provision of network support and control services; and*
> - *the adequacy of constraint equations to manage the issues in this paper*.

It is interesting to note that these are the same issues that are now being considered in South Australia and that there has been essentially no change to the market to address these issues since 2010 despite the significant growth of renewables across the NEM.

One of the key lessons from this work was the need to consider the inter-related impact of inertia, fault level and voltage when assessing potential changes.

2. The Tasmanian Power System

To provide context, the following is a summary of the key aspects of the Tasmanian Power System:

- Generation (approximate):
  - 2300 MW hydro (14 hydro units capable of synchronous condenser operation)
  - 308 MW wind (2 local synchronous condensers installed at Musselroe Wind Farm)
  - 386 MW gas (3 Open Cycle Gas Turbines (OCGT) units capable of synchronous condenser operation)
  - ≈ 100 MW solar (as at end of 2016, embedded/behind the meter)
- Interconnector (Basslink, monopole HVDC), 478 MW import, 630 MW export;
- Demand: 900 MW (min, summer), ≈ 1800 MW (max, winter) ;
- Renewable energy production: 10,000 GWh (90% hydro) per annum; and
- Energy storage capacity: 14,000 GWh of hydro

3. Current Position

The current position for Tasmania is that the minimum demand can be as low as 900 MW, Basslink may be importing up to 478 MW and wind can contribute up to 308 MW. Under these conditions, there is little room left for synchronous generation noting that the minimum run of the river ('must run') generation is slightly over 200 MW. Additionally Basslink power transfer during import is limited by a minimum required fault level at George Town (maintained by a limit/constraint equation), a minimum inertia requirement to manage system rate of change of frequency (ROCOF, maintained by a limit/constraint equation) and interrelated availability of FCAS. Consequently, if these minimum system technical requirements cannot be met within the central dispatch process, constraints will limit Basslink flow and/or wind farm output so that more on-island synchronous generation is provided.

These constraints can also be alleviated by dispatching selected hydro generators in synchronous condenser mode. However under the existing rules, AEMO does not have a mechanism to dispatch this service and the service is provided by Hydro Tasmania on a voluntary basis. The cost of energy used to operate in this mode, along with the associated operation and maintenance costs, is ignored by the market. By taking this voluntary action, Hydro Tasmania masks significant dispatch issues which could result in significantly reduced amounts of renewable energy being supplied into the NEM. The capability of some of hydro generators to operate in synchronous condenser mode is a significant difference between the Tasmanian and South Australian systems.

Significant operating and capitals costs are borne by Hydro Tasmania for the provision of these services. Hydro Tasmania estimates the direct benefits of these services to the market exceed several million dollars per year. These benefits are calculated on the basis that the increased interconnector capability allows cheaper generation to be dispatched in both Victoria and Tasmania. Hydro Tasmania believes the existing Network Support and Control Ancillary Services (NSCAS) mechanism provides a framework for these services to be procured by either AEMO or TasNetworks, however the NSCAS Quantity procurement methodology is backward looking. Hydro Tasmania provides system support (NSCAS "type") services which mask these issues in Tasmania. Hydro Tasmania also believes that the mechanism does not consider future issues therefore will not promote investment to manage emerging technical issues. Hydro Tasmania is currently engaging with AEMO to progress this matter.

Frequency Control Ancillary Service (FCAS) requirements have been a function of system inertia for some time in Tasmania. The inclusion of inertia as a calculation variable was necessary to correctly calculate fast (6 second) FCAS requirements when frequency may reach its permissible limits in a shorter time frame (due to high ROCOF conditions). As a result, fast FCAS requirements are non-linear and increase dramatically under low inertia operating conditions as illustrated in Figure 1.

When Basslink is operating on its limits (high import or minimum export) or is transitioning through its 'no-go' zone during power reversals, there is no opportunity to transfer raise services from the mainland. Figure 1 demonstrates that adding inertia can reduce fast FCAS requirements and that reducing the contingency size also has a significant impact. The two surfaces represent a 144 MW contingency (higher requirement) and an 80 MW contingency (lower requirement).

In Tasmania, there are various schemes that have been deployed to reduce the effective contingency size including load inter-tripping following the loss of a large generator. The Tasmanian Frequency Operating Standard (TFOS) has a requirement that generator contingency events must not exceed 144 MW and that load tripping may be used to compensate for contingencies of higher value.

Figure **2** demonstrates a more detailed view of key variables in managing ROCOF and FCAS, as well as their inter-relationship with inertia.

It can be noted that the contributions from generators operating in synchronous condenser mode to inertia and fault level are the same as when generating. It is also noted that increasing system inertia to reduce fast raise and lower requirements is effective only up to a certain level of system inertia, and above this level, fast FCAS requirements are relatively linear.

Figure 1 - Impact of inertia on fast raise requirements

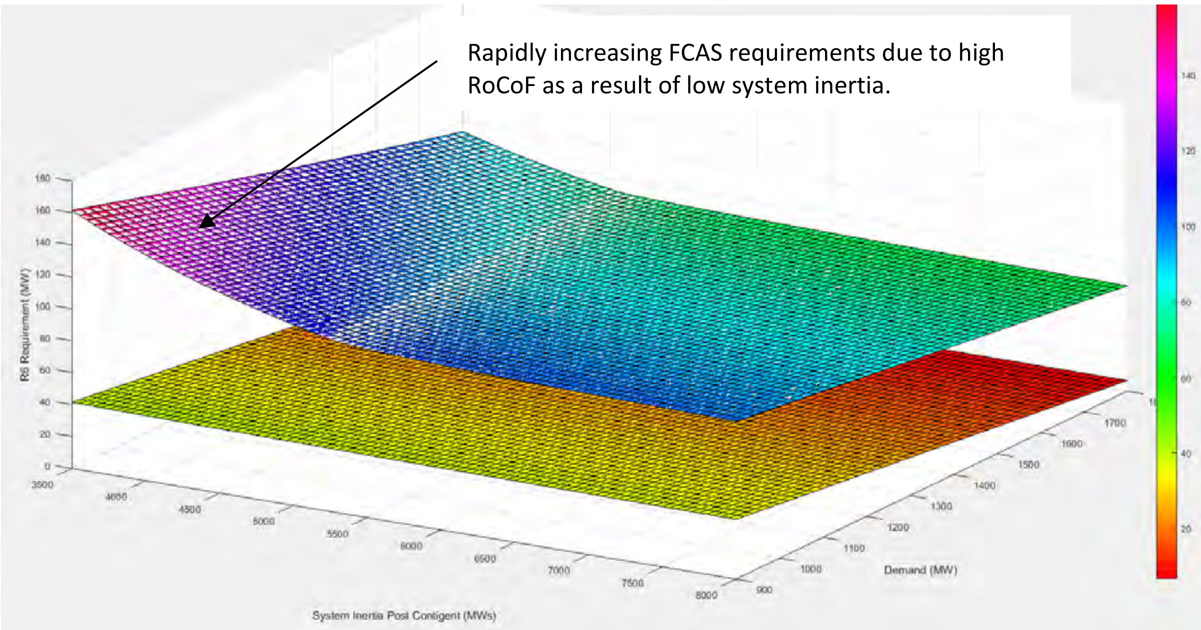
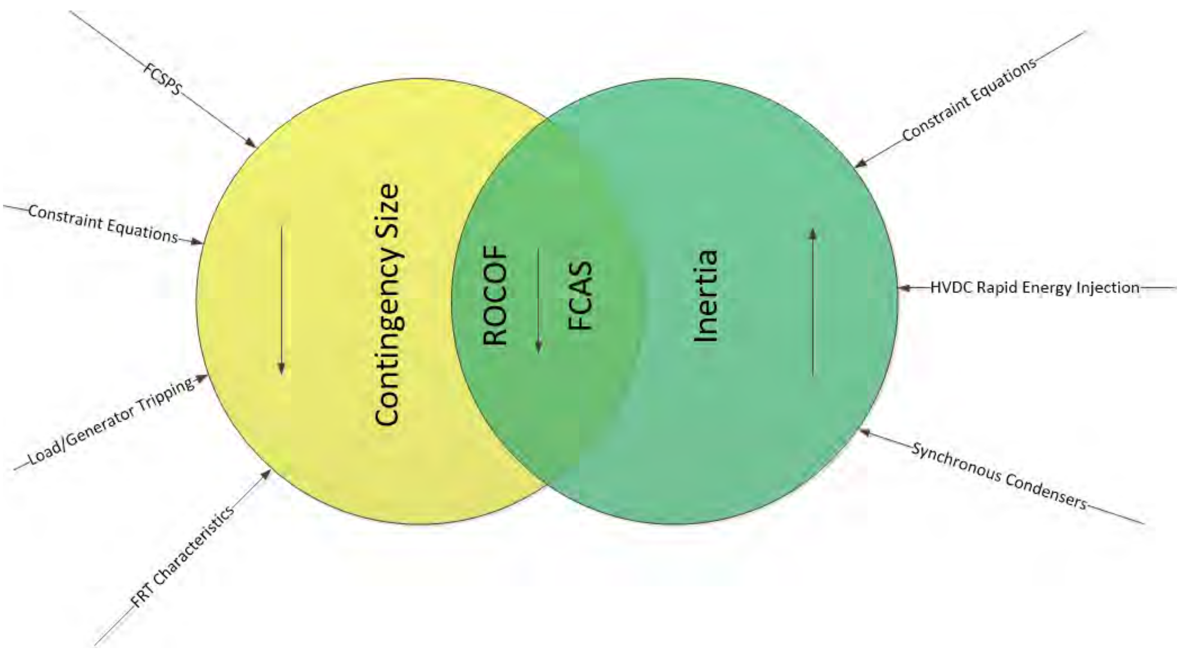


Figure 2 - Relationship between RoCoF, FCAS and Inertia



A key consideration in the future of the NEM is the increased variability of generation sources, particularly wind and solar. The value of fully dispatchable renewable generation from hydropower can play a significant role in supporting a diverse generation mix. As mentioned earlier over 14,000 GWh of energy storage capacity exists within Tasmania and over 2000 MW of capacity can be started within minutes. This also has the potential to provide significant ancillary services support to the mainland in addition to energy/capacity. The key limitation to this is currently the interconnector capability to the mainland of the NEM and should be a key consideration when understanding the future value of a second Bass Strait interconnector.

4. Remedial Actions

Over the last 10 years, Hydro Tasmania, TasNetworks (formerly Transend) and AEMO have undertaken numerous initiatives to assist with managing and maintaining system security and stability. This has included significant capital expenditure to increase the capability of selected hydro and gas generation plant.

An outcome from this work is that a number of technical issues have been successfully addressed In Tasmania and the impacts of these issues on energy market outcomes are, in the most part, manageable. Consequently, there has been little impetus for addressing these issues in a more systematic, 'NEM focused' way until they surfaced as significant considerations for South Australia.

Each of the following initiatives is discussed in more detail below:

- Hydro plant operating in synchronous condenser mode to support inertia and fault level requirements;
- Conversion of open cycle gas turbines (OCGT) to allow both generation and synchronous condenser operation;
- Generator governor modifications;
- Implementation of Frequency Control System Protection Scheme (FCSPS);
- Implementation of Network Control System Protection Scheme (NCSPS);
- Defining 'region appropriate' generator performance standards to maintain critical network capabilities;
- Network constraint formulation and optimisation; and
- Integrating new technologies to help manage high renewable penetration.

4.1. Hydro plant operating synchronous condenser mode to support inertia and fault level

Selected hydro plant can be operated as synchronous condensers. For Francis turbines, this is achieved by 'dewatering' using high pressure air to force the water level below the turbine so that it can spin freely and with minimal hydraulic resistance. This is also referred to as tail water depression mode. For Pelton turbines, synchronous condenser operation is generally easier to achieve, as the turbine is not submerged during normal operation.

It should be noted that not all Tasmanian hydro generators have been designed to operate in this mode, with fourteen units having the capability at present.

Hydro Tasmania has undertaken several upgrade projects in recent times to reinstate the capability of plant to run in synchronous condenser mode[2]. The upgrades required a significant financial and resource commitment to be made and provide a total of 1470 MW.s of synchronous condenser inertia in a system which typically requires at least 3500 to 4000 MW.s post-contingency.

It should be noted that in order to further increase system inertia, Hydro Tasmania has the option to dispatch certain hydro generating units at low output. Such measures are also used to increase Fast Raise FCAS (R6) capability when needed. Such an approach, although effective, may cause additional wear and tear to these units, as hydro machines are typically not designed to operate at low output for long periods. Hydraulic cavitation is a common issue which can cause elevated machine vibration levels as well as mechanical damage to the turbines themselves.

Fault level has been actively managed in Tasmania since Basslink was commissioned in 2006. The requirement to maintain a minimum fault level at George Town is managed by a limit/constraint equation embedded within AEMO's National Electricity Market Dispatch Engine (NEMDE). The constraint considers variables of interconnector flow and online synchronous generation until the minimum technical requirements are satisfied. The impact of the constraint can be assisted by the running of synchronous condensers, or dispatching generating units at low MW output, to boost network fault levels.

At present, neither AEMO nor TasNetworks has a contract for the dispatch of synchronous condensers for such purposes, so their running is determined only by Hydro Tasmania. This solution may not deliver the most efficient overall market outcome as it would be at the discretion of Hydro Tasmania. If synchronous condensers could be committed by Hydro Tasmania as part of a service offering to AEMO and co-optimised with other resources, the objective function of the dispatch is likely to be improved.

4.2. OCGT conversion synchronous condenser mode

Hydro Tasmania has four OCGT peaking plants located at Bell Bay in the state's north. Three units were successfully modified to operate in synchronous condenser mode. They provide a very cost effective source of fault level support for the George Town area when compared to building new synchronous condensers. The units also provide some inertia, although being aero-derivative machines, the inertia contribution is significantly less than would be provided by a hydro unit of similar MVA rating.

4.3. Generator governor modifications [Ref. 1 and 5]

Hydro Tasmania has implemented a number of governor enhancements as part of its core asset management program including:

- Development and implementation of governor boost functions to deliver rapid response FCAS. This allows the governor output to be temporarily saturated to force the fast opening of guide vanes (control gates). When a frequency disturbance occurs, the functions allows for an accelerated opening of the guide vanes to achieve a temporary boost in machine responsiveness; and
- Tail Water Depression (TWD) or synchronous condenser fast raise (SCFR) mode provides fast transition from synchronous condenser to generator mode, delivering fast raise FCAS (R6) in the process. This requires considerable governor and control system modifications,

[2] Where plant had not been used in this mode for a considerable time, efforts were required to ensure that cooling systems and other mechanical aspects of the machine were refurbished to ensure correct operation.

with not all hydro plant being suitable for such conversions due to original design limitations that are impractical to alter.

It can be noted that both of these control actions are activated by high ROCOF conditions and are not triggered for every contingency event. As a result, both modifications have created a new class of FCAS controller that is a combination of 'switching' and 'linear/proportional' controllers.

4.4. Frequency Control System Protection Scheme (FCSPS) [Ref. 2 and 3]

TasNetworks own and operate the FCSPS and were key in its development. This scheme was developed to allow the integration of the Basslink interconnector which has power transfer capability that significantly exceeds the size of the next largest system contingencies (load or generation). System Protection Schemes (SPS) had previously been used elsewhere in the world as a remedial action to manage non-credible contingencies. However in the case of Basslink, the concepts were applied to mitigate the effects of a credible contingency and in doing so, significantly optimised the import and export capability of the interconnector.

The scheme continuously monitors the interconnector flow and Tasmanian system load demand and calculates the required load or generation tripping that is necessary to mitigate the contingent loss of the interconnector. This occurs on a 4-second cycle. Contracted load blocks and generating units that participate in the scheme, are automatically 'armed and disarmed' as necessary to meet the calculated requirements. If Basslink flow is interrupted, the armed loads or generators are tripped in protection clearance time (within hundreds of milliseconds). The scheme allows system frequency to be maintained within the *operational frequency tolerance band* limits as defined by TFOS, even though Basslink could be operating at up to 630 MW export or 478 MW import.

The experience with the operation of this scheme has been very positive. The scheme has operated multiple times and on each occasion, has managed the Tasmanian power system successfully and in accordance with design expectations. The successful implementation of a wide area protection scheme such as the FCSPS has demonstrated what can be achieved with quality engineering design. Consideration should be given elsewhere to the benefits of implementing such countermeasures where system technical capabilities may not support desirable power flows, either within or across NEM regions.

4.5. Network Control System Protection Scheme (NCSPS)

TasNetworks own and operate the NCSPS and were key in its development. It allows dual circuit transmission corridors to increase their 'non-firm' operational capacity from 50% up to 95% of thermal rating. In the case of a transmission line contingency event that results in overloading of surrounding circuits, the NCSPS issues runback or trip commands to selected generators to relieve the overload conditions. The scheme works in unison with the frequency controller on Basslink to maintain system frequency within limits and has a speed of response that grades appropriately with other network protection functions.

While the NCSPS design as implemented in Tasmania is reliant on specific controls and equipment capability, the concept has direct applicability for broader network issues that include:

- The intermittency of renewables where it is perhaps not economic to build transmission capacity to enable traditional 'firm' operation of assets; and
- To mitigate the impacts of credible and/or non-credible contingencies when thermal overloading is the primary concern post contingency. An NCSPS could be used to prevent the cascading loss of transmission assets due to activation of overload protection.

As with the FCSPS, the experience with the operation of the Tasmanian NCSPS has been very positive. The scheme has only been required to operate a small number of times but in each case, reduced the affected transmission circuits to within continuous thermal ratings in accordance with design expectations.

4.6. Defining 'region appropriate' generator performance standards

Given the particular characteristics of the Tasmanian power system, TasNetworks is currently developing connection requirements that will be applicable for future renewable generation developments in the region. The connection requirements are based on Schedule 5.2 of the National Electricity Rules (Rules) and will define the minimum level of performance at which negotiation will be possible. The key objective of this undertaking is to preserve, as far as is reasonable to do so, the future capability of the network.

In doing so, the intent is to not inadvertently impede the connection of future projects by having to enforce performance standards that are overly onerous just to enable successful network integration. If every new connection provides certain capabilities to the network and is able to operate with a defined level of technical performance, then a situation where the 'next project to be considered' has to compensate for past or hidden issues can be avoided. In essence, all generating systems will be expected to contribute to the operability and security of the network rather than being allowed to be heavily reliant on the characteristics of the network to achieve adequate levels of performance.

4.7. Network constraint formulation and optimisation [Ref 4]

New and modified network limits/constraints have been developed as a result of the changing nature of the Tasmanian power system. The identification of new issues is likely to be ongoing as more asynchronous generation is connected over time.

Examples of constraints that have been modified and/or developed in recent times include:

- Management of fault levels at specific connection points;
- Control of maximum ROCOF to ensure that under frequency load shedding (UFLS) and over frequency generator shedding (OFGS) schemes in Tasmania can continue to operate correctly and provide protection against non-credible contingency events; and
- The inclusion of 'energy deficit' contributions into FCAS calculations to account for the fault ride through (FRT) characteristics exhibited by power electronic interfaced energy sources (e.g. wind and HVDC) and the impact that such characteristics have on power system frequency.

It needs to be recognised that the technologies currently being utilised within the renewable energy sector have very different technical characteristics to traditional synchronous generating units. This does not mean that they cannot be successfully integrated into the power system, just that their performance characteristics need to be understood and their impacts on the power system properly assessed. As demonstrated in Tasmania, new types of constraint formulations are likely to be required if the security of the power system is going to be adequately managed going forward.

It should be noted that the availability of quality design documentation and accurate mathematical models are important inputs for achieving this. TasNetworks and Hydro Tasmania have put significant effort into obtaining such information from various equipment suppliers, covering synchronous machines and their control systems, as well as wind turbines and various ancillary equipment associated with wind farms (including STATCOMs). As a result, Tasmania is in a fortunate position of having validated models for the vast majority of equipment connected to the transmission network. This is viewed as a key enabler for future developments within the state.

4.8. Integrating new technologies to help manage high renewable penetration.

In a quest to reduce the cost of supply on King Island over the past 10 years, Hydro Tasmania has developed significant intellectual property that is applicable to the development and operation of low inertia power systems. The key initiatives on King Island have been:

- Managing any excess of renewable energy by converting it to FCAS through the development of a resistor based frequency controller. Energy is dissipated in a resistor supplied through a power electronic interface that provides frequency regulation capability;
- Management of voltage, reactive power and rotating inertia through the use of heavy flywheel technology fitted to a diesel Uninterruptable Power Supply (UPS). The flywheel unit is capable of providing energy to the system following the largest contingencies until the diesel engine can be started and connected to the synchronous compensator via a dynamic clutch;
- Use of a dynamic clutch allowing mechanical synchronisation of the diesel UPS in an islanded system;
- Control of a power system without any synchronous generation in service, with all inertia and fault level support provided by the synchronous compensator;
- Parallel operation of light and high inertia generators; and
- Advanced control strategies for battery storage systems.

While not all of these developments can be directly scaled for use in larger power systems, the learnings obtained are directly applicable to other opportunities including control of embedded battery storage systems to provide frequency control and application of advanced power electronic technologies like Siemens SVC Plus with Frequency Stabilisation.

Hydro Tasmania and TasNetworks will continue to work together to identify opportunities to apply advanced technologies to enhance the operability and capability of the Tasmanian power system.

5. Implications for other NEM regions

Some of the solutions that have been developed in Tasmania will have direct applicability to other NEM regions as their level of renewable generation increases. With competing generators and a more complex environment, there will need to be market mechanisms which deliver the right incentives for participants. The underlying technical solutions, however, remain the same.

6. Conclusion

Tasmania's experience over the last 15 years has shown that there are many and varied technical solutions that can be applied to overcome the challenges created by the increasing penetration of renewables (asynchronous energy sources more generally). Some solutions implemented in Tasmania have been relatively low cost and without the need for significant capital investment. Tasmania has been leading the field in the development of innovative solutions which reduce the costs of the technical solutions significantly.

Hydro Tasmania, TasNetworks and AEMO have implemented many successful initiatives that help to manage and maintain the security of a power system that has a high penetration of asynchronous energy sources. Initiatives of note include, but are not limited to the following:

- Inclusion of Fault Ride Through characteristics in FCAS requirement calculations;
- Actively managing ROCOF and minimum system fault level requirements via limit/constraint equations;
- Improving the delivery of fast FCAS from hydro generators through modifications to hydro governor designs and introduction of new operating modes allowing automatic transfer from synchronous condenser to generation to provide fast raise FCAS;
- Optimisation of hydro machine synchronous condenser capability to manage network limits/constratins;
- Modification of existing OCGT generators to allow synchronous condenser operation;
- Implementing centralised control and protection schemes like the FCSPS and NCSPS to extend the capability of existing assets and maximise power system utilisation (without compromise to system security);
- Reducing the largest generator contingency size by introducing load inter-tripping schemes that manage FCAS requirements;
- Development of switching control based FCAS delivery mechanisms for fast raise and lower services; and
- Commencement of a process to define Tasmanian specific performance standards that will be applicable to future renewable energy developments which will ensure that the capability of the future network is proactively managed.

A key consideration in the future of the NEM is the increased variability of generation sources, particularly wind and solar. The value of fully dispatchable renewable generation from hydropower can play a significant role in supporting a diverse generation mix. As mentioned earlier over 14,000 GWh of energy storage capacity exists within Tasmania and over 2000 MW of capacity can be started within minutes. This also has the potential to provide significant ancillary services support to the mainland in addition to energy/capacity. The key limitation to this is currently the interconnector capability to the mainland of the NEM and should be a key consideration when understanding the future value of a second Bass Strait interconnector.

Hydro Tasmania believes the existing Network Support and Control Ancillary Services (NSCAS) mechanism provides a framework for these services to be procured by either AEMO or TasNetworks, however the NSCAS Quantity procurement methodology is backward looking. Hydro Tasmania provides system support (NSCAS "type") services which mask these issues in Tasmania. Hydro Tasmania also believes that the mechanism does not consider future issues therefore will not promote investment to manage emerging technical issues. Hydro Tasmania is currently engaging with AEMO to progress this matter.

It can be noted that many of these initiatives address issues that are now being considered in South Australia and that there has been essentially no change to the market to address such challenges despite the significant growth of renewables across the NEM.

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Appendix B – Maps of existing scheme

Key Scheme Data

Total Installed Capacity:	102 MW	Total Installed Pumping:	2 MW
Total Annual Generation:	661 GWh	Average Outage Loss:	(30) GWh
Total Pumping Load:	(6) GWh	System Spill Benefit:	0 GWh

Net System Generation: 634 GWh (Long term modelled average, expect significant outages for refurbishment works)

Station: Tarraleah (TAPS 1)

	Rated Output	Mean Output
Headwater Level (m)	643.7	643.7
Tailwater Level (m)	344.0	344.0
Headloss (m)	12.0	-
Net Head (m)	287.0	-
Flow (cumecs)	42	28.5
Output (MW)	90	75.5
Peaking Capacity (h)		N/A
Annual Energy (GWh)		575

TAPS 1 Station Conversion Chart

Station: Butlers Gorge

	Rated Output	Mean Output
Headwater Level (m)	719.9	715.1
Tailwater Level (m)	663.8	663.8
Headloss (m)	0.7	0.3
Net Head (m)	55.4	51.0
Flow (cumecs)	30	18.1
Output (MW)	12.7	8.4
Peaking Capacity (h)		N/A
Annual Energy (GWh)		74

BGPS Conversion Chart

Station: Nieterana Mini Hydro

	Rated Output	Mean Output
Headwater Level (m)	719.9	715.1
Tailwater Level (m)	687.7	687.7
Headloss (m)	1.5	1.4
Net Head (m)	30.7	26.0
Flow (cumecs)	8.5	7.5
Output (MW)	1.7	1.5
Peaking Capacity (h)		N/A
Annual Energy (GWh)		13

Nieterana Station Conversion Chart

Note: Energy figures quoted are measured at the station

●	Power Station	- - -	Tunnel	—	Canal		HT Freehold Title		LIST Cadastre
▲	Intakes	—	Pipe/Penstock	—	Major River		HT Vested Land		World Heritage Area
■	Dam/Weir	—	Flume	- - -	Water Course		Storages		

Scale 1:30,000 @A1
MGA94 Zone 55

Date: 14/11/2017
Prepared by: Grace Uziallo
Verified by: Edward Snowball
Approved by: Gregg Barker
Revision: 2

Reference Drawings
A-22817

Battery of the Nation - Tarraleah Redevelopment

Existing Scheme Infrastructure - Entire Scheme

Hydro Tasmania

Power Station | Tunnel | Canal | HT Freehold Title | LIST Cadastre
Intakes | Pipe/Penstock | Major River | HT Vested Land | World Heritage Area
Dam/Weir | Flume | Water Course | Storages

Scale 1:10,000 @A1
MGA94 Zone 55

Data Acknowledgments:
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Battery of the Nation - Tarraleah Redevelopment

Existing Scheme Infrastructure - Butlers Gorge & Upper Conveyances

Hydro Tasmania

Power Station
Intakes
Dam/Weir
Tunnel
Pipe/Penstock
Flume
Canal
Storages
Major River
Water Course
LIST Cadastre
World Heritage Area
HT Freehold Title
HT Vested Land

Scale 1:12,500 @A1
MGA94 Zone 55

Date: 30/10/2017
Prepared by: Grace Uziallo
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Approved by: Gregg Barker
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Battery of the Nation - Tarraleah Redevelopment

Existing Scheme Infrastructure - Lower Conveyances & Power Station

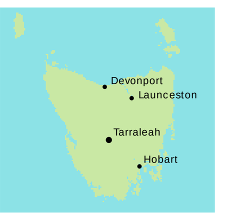
Hydro Tasmania

BotN-TAR-001-4-GEN-Existing Scheme Arrangement-A1-Rev2

Derwent Generation

Power Station	Turbine / pump capacity	Turbine / pump gross head	Turbine / pump net head	Turbine / pump capacity	Turbine / pump annual energy
	MW	m	m	m^3/s	GWh
Tungatinah	130.5	306	290	52	539
Liapootah	87.3	110	103	96	409
Wayatinah	45.9	62	56	102	219
Catagunya	50	45	44	132	229
Repulse	29.1	27	25	142	145
Cluny	18.6	27	15	162	91
Meadowbank	41.8	29	26	162	173
Tarraleah 1 (Existing)	90	299	287	42.1	554
Butlers Gorge	12.7	56.1	49	30	66
Nieterana	2.2	30	30	8.5	10.7

N.B. Data has been collated from a mixture of Blue Book, historic reports, Time Studio, original drawings and data on myHydro. Data will need to be verified before being used for detailed design.



Generation Asset
Tunnel
Transmission Line
World Heritage Area

Scale 1:100,000@A1
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Reference Drawings
A-22817

Battery of the Nation - Tarraleah Redevelopment

Existing Derwent Catchment Power Developments

Hydro Tasmania

Appendix C – Maps of scheme redevelopment options

Key Scheme Data

Total Installed Capacity:	131 MW	**Total Installed Pumping:**	5 MW
Total Annual Generation:	841 GWh	**Average Outage Loss:**	(5) GWh
Total Pumping Load:	(21) GWh	**System Spill Benefit:**	22 GWh

Net System Generation: 837 GWh

Station: TAPS 2

	Rated Output	Mean Output
Headwater Level (m)	719.9	713.3
Tailwater Level (m)	341.5	341.5
Headloss (m)	17.4	9.3
Net Head (m)	352	356
Flow (cumecs)	40	29.2
Output (MW)	131	95.9
Peaking Capacity (h)		Sustained
Annual Energy (GWh)		841

Note: Energy figures quoted are measured at the station

Portals | Access Drive | Access Road | Pipeline/Penstock | Tunnel (Steel lined) | Tunnel | Existing Canal | Existing Flume | Natural Channel | Existing Penstock | Existing Tunnel | Power Station | HT Freehold Title | HT Vested Land | Storages | Major River | World Heritage Area | Intake

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Battery of the Nation - Tarraleah Redevelopment

Long Pressure Conveyance Option

Hydro Tasmania

BotN-TAR-107-1-GEN-TarraRedev LPC-A1

Key Scheme Data

Total Installed Capacity:	130 MW	Total Installed Pumping:	2 MW
Total Annual Generation:	790 GWh	Average Outage Loss:	(5) GWh
Total Pumping Load:	6 GWh	System Spill Benefit:	29 GWh

Net System Generation: 808 GWh

Station: TAPS 2

	Rated Output	Mean Output
Headwater Level (m)	650.4	649.2
Tailwater Level (m)	341.5	341.5
Headloss (m)	3.7	2.0
Net Head (m)	305.2	305.7
Flow (cumecs)	40	29.5
Output (MW)	114	80.4
Peaking Capacity (h)		16
Annual Energy (GWh)		704

TAPS 2 Conversion Chart

Station: No. 3 Small Hydro

	Rated Output	Mean Output
Headwater Level (m)	719.9	713.1
Tailwater Level (m)	673.0	673.0
Headloss (m)	1.4	0.6
Net Head (m)	45.6	39.5
Flow (cumecs)	40	26.9
Output (MW)	16	9.8
Peaking Capacity (h)		N/A
Annual Energy (GWh)		86

No. 3 Small Hydro Conversion Chart

Note: Energy figures quoted are measured at the station

Portals | Pipeline/Penstock | Tunnel (Steel Lined) | Existing Canal | Existing Pipeline/Penstock | HT Freehold Title | Major River
Access Drive | Canal | Tunnel | Existing Flume | Existing Tunnel | HT Vested Land | Storages
Access Road | Flume | Flume Embankment | Natural Channel | Power Station | World Heritage Area | Intake

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Battery of the Nation - Tarraleah Redevelopment

No.3 Conveyance Option

Hydro Tasmania

BotN-TAR-108-1-GEN-TarraRedev No3-A1

Battery of the Nation - Tarraleah Redevelopment

No.3 Conveyance Option - Alternative Routes

Alternative Conveyance Data

Lake King William to No.2 Pond			
Option	**Total Conveyance Length (km)**	**Length Tunnel (km)**	**Comment**
Northern A	14.7	5.7	Or with Siphon - total length = 13.0 km. Small Hydro 11 MW
Northern B	15.5	3.9	Or with Siphon - total length = 13.8 km. Small Hydro 11 MW
Southern	12.5	5.1	Small Hydro 16 MW
No.2 Pond to New Station			
Station	**Total Tunnel Length (km)**	**Installed Capacity (MW)**	**Gross Head (m)**
TAPS2	3.3	114	309
Liapootah 2	11.2	160	419

Legend: Portals; Access Drive; Access Road; Pipeline/Penstock; Canal; Flume; Tunnel (Steel Lined); Tunnel; Intake; Existing Canal; Existing Flume; Natural Channel; Existing Pipeline/Penstock; Existing Tunnel; Power Station; Major River; World Heritage Area; Storages

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Approved by: Gregg Barker
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MGA94 Zone 55

Hydro Tasmania

Appendix D – Redevelopment options – unit rates

Internal memo

Private and confidential

To:	Gregg Barker		
From:	Edward Snowball & David Conley	**Ext no:**	N/A
cc:			
Date:	20/10/2017	Pages:	7 (includes cover sheet)
Subject:	Tarraleah Redevelopment Pre-feasibility study – Cost Estimate Rates		
Status:	**For review and approval**		

This memo provides a summary of the development of the Cost Model and Unit Rates used for the Tarraleah Redevelopment Pre-feasibility study cost estimate.

The objective of the Cost Model was twofold, the primary objective being to provide a high level cost estimate of each redevelopment option and secondary being to have a framework that allowed small changes to inputs such as conveyance alignments or capacities, station sizes to be calculated with minimal re-work during the development of options.

Cost items:

The Cost Model splits costs between indirect and direct:

- Direct costs: involves all cost involved in physical construction of an asset,
- Indirect costs: costs not involved in physical construction required for the overall works

Direct costs in the majority are related to the physical characteristics of the asset being constructed; whilst indirect costs are estimated as function of the projects total direct cost before contingency.

Initially a limited number of asset classes were considered for the direct costs. As rates were refined and 'optioneering' of the redevelopment was undertaken, it was deemed appropriate to further break down some asset classes into sub components to ensure that an accurate estimate was provided by the model.

The attached table of rates gives a breakdown of the asset classes and their subcomponents.

Conveyance and Station Capacity Sizing:

Conveyances were sized on the basis of the following fixed average design velocities:

- Canals & unlined tunnels: 1.5m/s and a nominal grade of 1:1000,
- Pump rising mains and concrete lined tunnels: 2.0 m/s
- Steel penstocks and lined tunnels: 3.0 m/s

These figures were cross referenced to other Hydro Tasmania assets and checked by Specialist Engineers at Entura to ensure that the design velocity was appropriate.

A number of standard canal and flume cross sections were derived for different flow capacities and these were costed to provide a price curve.

Station and pump station capacities were determined by the available/required head, including allowances for losses and flow rate

Rates and Contingency allowance:

Costs were based on a unit rates model; these rates are all in costs with the exception of;

- Mobilisation which is covered as a separate item,
- Site accommodation which is covered as a separate item,
- Hydro Tasmania Project Management, Site Supervision and Contract Management which is covered as a separate item

These rates were developed to be of reasonable accuracy at pre-feasibility design level.

The aim was to provide a consistent comparison across several options and for the rates to be flexible in their application. The flexibility was required such that minor changes to lengths, capacities or alignments would not require extensive rework, thus making 'optioneering' an efficient process.

The majority of rates used for civil infrastructure items are bottom up estimates provided by Engineering Estimating Services (EES) and Entura or developed internally by the pre-feasibility study team.

Key points:

- Electrical and Mechanical items top down estimates were provided by Specialist Engineers from Entura,

- Indirect costs were developed internally in conjunction with Julian Hickey from EES,

- Where appropriate, rates were sourced from recent existing cost estimates for the Tarraleah Re-development,

- Contingency was adopted to reflect the level of uncertainty in costing components, typically estimates provided by ESS allowed for 20% contingency,

- Contractors were not approached for market rates.

- Inputs to the rates are located in this directory: Cost Inputs

The attached table in appendix A gives a summary of the rates adopted for the Direct and Indirect costs for the Tarraleah Re-development Pre-feasibility Study.

Summary:
A Cost Model for the Tarraleah pre-feasibility study was developed to provide a high level cost estimate of the proposed redevelopment options. The Model is based on a unit rates system with quantity inputs from the study team and cost rates developed from the bottom up and top down by several sources and reviewed by the study team.

It is recommended that this cost model is retained and utilised during feasibility as a reference point for more detailed cost estimates.

Furthermore the author recommends that Hydro Tasmania develop a library of consistent rates for cost estimation to ensure consistency across BotN projects.

Hydro Tasmania

Appendix A: Summary of adopted rates

Direct Costs

Item	Sub Item	Adopted Rate	Adopted Contingency	Source	Comments, description and key assumptions
Miscellaneous					
Mobilisation		1.5% of Direct Costs Excl. Mobilisation	10%	EES & Internal est.	Nominal allowance for contractor mobilisation
Construction Camp	Installation	$50,000/person			Provision of accommodation and mess facilities
	Maintenance	$110/person/day			Maintenance incl. cleaning, food, water, power etc.
Access Road	Unsealed	$500/m	20%	Internal est.	Single lane
	Sealed	$850/m			Dual lane
	Bridge	$4000/m^2		Internal est.	Typical highway bridge, up to 30m span.
Conveyances - Intakes					
Intakes	Lake King William	$6,959,000/item	25%	EES est.	Based on an example drawing (Anthony Intake)
	TA No. 2 Pond	$5,609,000/item		Modified EES Price	Reduction in mass concrete volume due to reduced size in comparison to Lake King William intake.
	Electrical Connection	$290,000/item	40%	Entura est.	Communication and 22kV connection (approx. 1km in length) from Butlers Gorge line
Conveyances - Tunnels					
Portals		$1,150,000/item	20%	EES est.	Price based on Anthony Tunnel Headrace Service Portal
Headrace/power	Airshaft	$1,000,000/item			Raise bore 3m diameter.
	Excavation	$225/m^3			Drill and blast rate
	Support - Rock bolts	$600/item		EES est.	Grouted double corrosion protected bolt (DCP)
	Support - Mesh & Fibrecrete	$145/m^2			100mm fibre crete over mesh support
	Support – Concrete	$3,000/m^3			Formed concrete lining
	Invert Lining	$1,000/m^3			Concrete lining of tunnel invert
	Concrete Infill	$1200/m^3			Concrete infill behind steel liner
	Steel Lining	($70,818 x Ast + $1,479)/ m A_{st} = cross sectional area of steel (m^2)		Price curve derived from EES est.	Additional 10% to allow for access/handling issues due to installation in a tunnel
	Spoil disposal	$14/m^3		EES est.	Disposal within 5km of excavation site
Vertical Shaft	Excavation	$330/m^3		Internal est.	Based on a 6.2m diameter raise bore
	Support – Fibrecrete	$2,400/m^3		EES & Internal est.	Sprayed fibrecrete applied as part of raise bore
	Support – concrete lined	$3,500/m^3			Formed concrete lining, additional allowance for access difficulties
	Spoil disposal	$14/m^3		EES est.	Disposal within 5km of excavation site

Conveyances - Surface

Item	Sub Item	Adopted Rate	Adopted Contingency	Source	Comments, description and key assumptions
Surface Penstock & rising main		($64,380x$A_{st}$ + $1,345)/m A_{st} = cross sectional area of steel (m^2)	20%	Price curve derived from Penstock Prices provided EES	Includes surface supports and welding onsite, prices extrapolated for thicknesses greater than 16mm and diameters greater than 4m.
Penstock Bridge	Across Nive Rive	$2,390,000/item		EES est.	Based on drawing provided
Canal - lined	Moderate Topography	($160x Q + $3,800)/m Q = Design Flow (m^3/s)		Price curve derived from Canal Pricing	Allowance for concrete lined canal with 4m wide level access bench each side, gravel access road on oneside. Excavation allowed for a 1:8 side slope with 1:2 cut batters. Average velocity in canal assumed to be 1.5m/s.
Canal - unlined	Augmentation of existing Unlined	$30/$m^3$		Internal est.	Earthworks rate to enlarge existing channel, minor erosion protection assumed to be covered within rate
	10m deep cutting	$250 x Q + $3000 Q = Design Flow ($m^3/s$)		Internal est.	Option B1/2: 10m deep cut through mostly rock, unlined canal.
Flume	Embankment	$144x Q + $4325 Q = Design Flow ($m^3/s$)		Internal est.	Concrete flume with gravel access road alongside, built on top of a rock fill embankment(priced separately)
Rockfill embankment	Embankment	$20/$m^3$		Internal est.	Rock fill embankment using tunnel spoil
	Culvert	$3,100/m		Internal est.	1.2m diameter concrete culvert

Dam Upgrade

Dam Upgrade	Embankment	$60/m^3	20%	Internal est.	Based on rock fill buttress, with imported filters at 30% of volume.
	Spillway	$500,000/item		Internal est.	Nominal allowance for new concrete spillway
	Spillway channel erosion protection	$500,000/item		Internal est.	Nominal allowance for erosion protection works

Power Stations & Pump Stations

Large Power station > 100MW	Civil works	$16,000,000/item	20%	EES Price	Price based on example station drawing (Bogong)
	Elec. & Mech.	$550,000/MW		Entura est.	High level station estimate, two machines
Small Pump station < 15MW	Civil, Elec. & Mech.	$2,500,000/MW		Entura est.	High level station estimate excludes rising main.
Small Power station > 15MW	Civil, Elec. & Mech.	$2,000,000/MW		Entura est.	Electrical connection, switchyard etc included. Excludes intake and conveyance penstocks/tunnels.
Power station – augmentation existing	Civil, Elec. & Mech.	$550,000/MW		Entura est.	Only applicable to Option B1 so not refined, considered to be too low by internal review
Electrical Connection	TA SY Electrics	$7,600,000/item	10%	Entura est.	220kv switchyard works and transformers for two machine station
	TA SY Civils	$600,000/item	20%	John Holland Est.	As per estimate by John Holland (2016)
	Transmission line to LY	$8,960,000/item	50%	Entura est.	220kv transmission line to Liapootah Switchyard, not applicable to project
	LY SY Upgrade	$1,520,000/item	25%	Entura est.	Upgrade works to Liapootah switchyard, not applicable to project
	No. 2b MH	$290,000/item	40%	Internal est.	Assumed as per intakes

Indirect Costs

Item	Sub Item	Adopted Rate	Adopted Contingency	Source	Comments, description and key assumptions
Investigations		1.0% of Direct costs	10%	Internal est.	Allowance for investigatory works, such as; feasibility studies, geotechnical investigations, environment studies and surveying
Tender design		0.5% of Direct costs			Allowance for concept/tender design
Detailed design	Conveyances	2.0% of Direct costs			Allowance for detailed design for construction, Conveyance design as a percentage of expenditure expected to be less involved that E&M
	Civil and E&M	5.0% of Direct costs			
Contract management		2.5% of Direct costs			Management of contract, stakeholder management costs etc.
Contract supervision		2.5% of Direct costs			Supervision of contract, HT Project management and site supervision etc.

Decommissioning and rehabilitation Costs					
Item	Sub Item	Adopted Rate	Adopted Contingency	Source	Comments, description and key assumptions
Conveyances	Siphon removal	TBC	20%	Internal est.	Removal and disposal of siphons
	Stream/creek line reinstatement	TBC			Complete removal of structure and earthworks to reinstate creekline
	Canal/flume drainage works	TBC			Drainage works to ensure infilled canal/flume drains
	Concrete demolition and removal	TBC			Demolition, removal and tidy up of steel reinforced concrete structure
	Canal/flume infill	TBC			Infill utilising stockpiled spoil
	Surface cleanup and revegetation	TBC			Tidy up, placement of topsoil from stockpile and revegation works
Station		Various		Internal est.	Nominal allowance for station works to decommission and ensure duty of care obligations are met

Appendix E – Redevelopment options – capital cost estimates

Tarraleah Redevelopment - Long Pressure Conveyance
CAPEX COST ESTIMATE

Item	Quantity	Unit	Capacity	Unit	Ave. Rate (incl. cont) $M	Unit	Cost (incl cont) $M
DIRECT COSTS							**$ 512.7**
Mobilisation	1.0	item	n/a		7.0	$M/item	$ 7.0
Construction camp	3.0	years	200	people	0.1	$M/person/year	$ 37.5
Access Roads	3.8	km	n/a		0.7	$M/km	$ 2.6
Intake(s)	1.0	item	40	m^3/s	10.5	$M/item	$ 10.5
Tunnel - Access Drives & Air Shafts	4.3	km	n/a		14.2	$M/km	$ 60.9
Tunnel - Headrace & Power Tunnel - unlined	17.2	km	40	m^3/s	14.0	$M/km	$ 240.2
Tunnel - Power Tunnel - Steel lining	0.4	km	40	m^3/s	36.0	$M/km	$ 14.4
Tunnel - Headrace - Shaft	0.2	km	40	m^3/s	24.1	$M/km	$ 5.5
Penstock - Across Nive	0.1	km	40	m^3/s	34.0	$M/km	$ 3.1
Penstock bridge	1.0	item	40	m^3/s	2.9	$M/item	$ 2.9
Pump station - TA No. 2 Pond	3.0	MW	4	m^3/s	4.5	$M/MW	$ 13.5
Power station - TAPS2	1.0	item	131	MW	0.8	$M/MW	$ 105.7
Electrical Connection - TAPS2	1.0	item	n/a		9.1	$M/item	$ 9.1
INDIRECT COSTS							**$ 44.2**

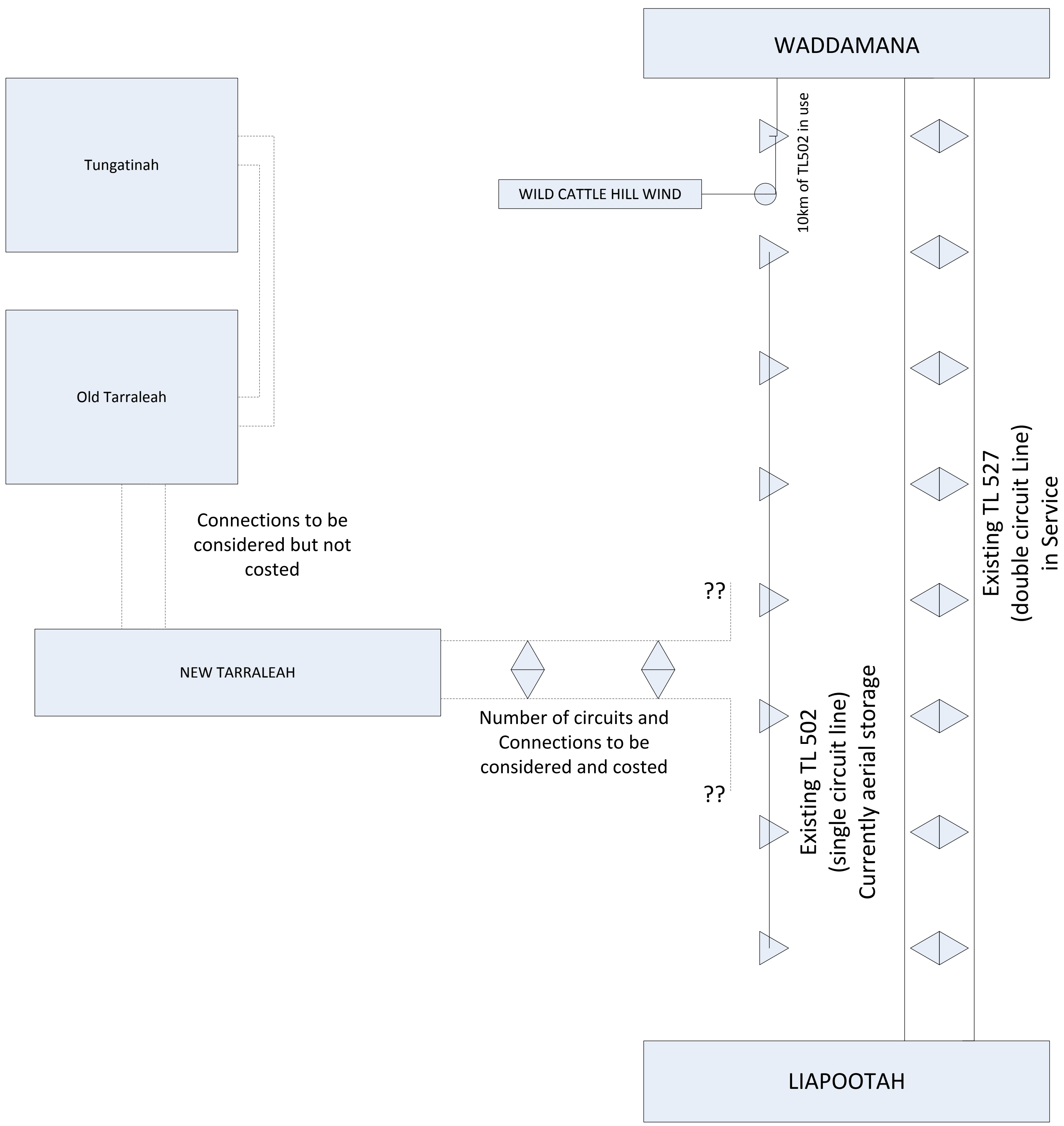
	Cost (excl cont)	Contingency sum	Cost (incl cont)
TOTAL COSTS ($M)	**$ 471.1**	**$ 85.8**	**$ 556.9**

Tarraleah Redevelopment - No. 3 Conveyance
CAPEX COST ESTIMATE

Item	Quantity	Unit	Capacity	Unit	Ave. Rate (incl. cont) $M	Unit	Cost (incl cont) $M
DIRECT COSTS							**$ 444.1**
Mobilisation	1.0	item	n/a		6.1	$M/item	$ 6.1
Construction camp	3.0	years	200	people	0.1	$M/person/year	$ 37.5
Access Roads	3.3	km	n/a		1.1	$M/km	$ 3.5
Intake(s)	1.0	item	40	m3/s	19.3	$M/item	$ 19.3
Tunnel - Access Drives & Portals	0.8	km	n/a		24.3	$M/km	$ 18.2
Tunnel - LKW to No. 3 Canal - unlined	1.3	km	40	m3/s	14.0	$M/km	$ 18.2
Tunnel - New MMT - unlined	3.8	km	40	m3/s	11.7	$M/km	$ 44.4
Tunnel - Headrace & Power Tunnel unlined	2.9	km	40	m3/s	14.0	$M/km	$ 40.5
Tunnel - Power Tunnel - Steel lining	0.4	km	40	m3/s	36.0	$M/km	$ 14.4
Tunnel - Shaft	0.8	km	40	m3/s	2.7	$M/km	$ 2.2
Penstock - Across Nive	0.1	km	40	m3/s	34.0	$M/km	$ 3.1
Penstock bridge	1.0	item	40	m3/s	2.9	$M/item	$ 2.9
Canals & Flumes	8.3	km	40	m3/s	9.8	$M/km	$ 80.6
Rockfill Embankments	150	10^3m^3	n/a		0.03	$\$M/10^3m^3$	$ 3.9
Dam Upgrade - TA No. 2 Pond Raising	60	10^3m^3	1.2	10^6m^3	0.10	$\$M/10^3m^3$	$ 5.9
Power station - TAPS2	113.0	MW	40	m3/s	0.8	$M/MW	$ 93.8
Power station - No. 3 Small Hydro	17.0	MW	40	m3/s	2.4	$M/MW	$ 40.8
Electrical Connection - TAPS2	1.0	item	n/a		9.1	$M/item	$ 9.1
INDIRECT COSTS							**$ 39.5**

	Cost (excl cont)	Contingency sum	Cost (incl cont)
TOTAL COSTS ($M)	**$ 409.3**	**$ 74.3**	**$ 483.6**

Appendix F – 220 kV transmission line upgrade options



WADDAMANA
10km of TL502 in use
WILD CATTLE HILL WIND
Tungatinah
Old Tarraleah
Connections to be considered but not costed
NEW TARRALEAH
??
??
Number of circuits and Connections to be considered and costed
Existing TL 502
(single circuit line)
Currently aerial storage
Existing TL 527
(double circuit Line)
in Service
LIAPOOTAH

Appendix G – Preliminary social and environmental impact assessment

Risk Level Table

IBRM BUSINESS UNIT OPERATIONAL IMPACT TABLE

Probability	
Almost Certain	91%-100% probability Event is expected.
Likely	61% to 90% probability Event is likely to occur.
Possible	21% to 60% probability Event may occur (but not likely).
Unlikely	6% to 20% probability Event not expected.
Rare	1% to 5% probability Event extremely unlikely
Extremely Rare	Less than 1% probability May only occur in extreme and exceptional circumstances.

Consequence	Health & Safety	Natural Environment	Social and Cultural Heritage	Reputation and Client Relationship (Retail / Commercial / MI)	Legal and Compliance	Annual Budget / Financial Loss	Strategic Initiatives	Project Delivery
Catastrophic	One or more fatalities. Injury, illness or disease resulting in deaths. Regulatory investigations show inability to safely continue operations with existing structure and/or processes. Business processes and operational activities are altered.	Serious environmental harm causing a significant impact on regional ecosystem with eventual recovery impossible. Business processes and operational activities are altered.	Irreversible damage to a place listed on a World Heritage, National Heritage, State Heritage listed place, or highly significant aboriginal relics/protected sites and landscapes. Devastating impacts felt at state level.	Irrecoverable breakdown in client / stakeholder relationship destroying both short-term and long-term customer value. Hydro Tasmania's brand / reputation with a broad range of key stakeholders is severely damaged. Issue requires CEO and LG intervention. Mandatory internal investigation with external assistance needed.	A breach resulting in penalties and jail terms for employees, LG or the Board. Regulator imposed constraints or enforcement proceedings that will directly impact business operations and ability to meet strategic objectives. Restrictions or loss of licence(s). .	25% over Business approved opex or capex budget Or Financial loss > $25M	Line of business unsustainable, impacting the viability of Hydro Tasmania. Achievement of more than one Balanced Scorecard objective is not possible, noting that some Balanced Scorecard objectives are more important than others.	>100% of project cost Or Operational over run >AUD$5M Delays >12 months, resulting in the unachievable project delivery. Formal arbitration or professional indemnity claim (>$1M) resulting in penalties and consequential damages. Liquidated damages uncapped.
Extreme	Severe injury, permanent disability to one or more persons. Investigations may require that significant changes are made to our Business processes.	Serious environmental harm to water or to sensitive land area. Eventual recovery of ecological systems, but not necessarily to the same pre-incident conditions. Loss of a threatened species or communities in a region. Mandatory monitoring of impacted areas.	Core change in the aesthetic or cultural heritage values over a broad area affecting World Heritage, National Heritage, State Heritage listed place, significant aboriginal relics and protected sites.	Significant loss of customers, key client(s) and stakeholder confidence reducing customer value. Loss of customers causing scrutiny of line of business. Issue requires CEO and LG oversight. Internal investigation with external assistance as required. Adverse publicity and associated brand damage.	Legal, regulatory or contractual compliance breach with certain prosecution and penalties likely. Regulator imposed constraints or enforcement proceedings which may impede business operations and ability to meet strategic objectives.	15% over Business approved opex or capex budget Or Financial loss >$15M - <$25M	Devastation of a key business objective and strategy. Achievement of a Balanced Scorecard objective is jeopardised. Sustainability of line of business threatened.	50% - 100% of project cost Or Operational over run AUD$1M - $5M Delays 6 - 12 months, impacting achievement of project objective. Intervention by LG member or CEO and change in Project Manager. Probable loss of client(s).
Major	Severe injury, temporary disability. Unexpected loss of key staff member(s) with specialist knowledge without which the Business Unit is extensively affected. Wide-spread low staff engagement.	Material environmental harm, such as a significant ecosystem impact with residual effects likely after follow up, or a large oil loss (> 1000 litres), especially if drinking water affected.	Damage to heritage values affecting World Heritage and National Heritage places, significant damage to State Heritage listed places, aboriginal relics or protected sites.	Breakdown in client / stakeholder relationship. Level of customer churn requires immediate retention strategy implemented. Reaction causes some disruption to business, resulting in short term damage to reputation / brand. Assistance from Senior Management, and / or an internal investigation may be required.	Legal, regulatory or contractual breach with probable prosecution or penalties. Regulator imposes constraints or enforcement proceedings that restrict business	5% over Business approved opex or capex budget Or Financial loss $1M - < $15M	Threat to the sustainability of key business objectives and strategies. Achievement of a Balanced Scorecard objective is at risk. Recovery possible.	20% - 49% of project cost Or Operational overrun AUD$100k - $1M Delays 3 - 6 months, impacting the achievement of project objective. Serious impact resulting in intervention by Senior Management. Potential loss of client(s).
Moderate	Serious injury with anticipated full recovery. Loss of one or more team members within a Business Unit resulting in short term low staff engagement.	Environmental harm resulting in environmental nuisance or possible material environment harm. -Loss of oil (200 - 1000 Litres loss to land or waterway) -Ecosystem impact such as fish kill Requires follow up monitoring and recovery with expert input and control.	Damage or disturbance to listed State Heritage listed places, aboriginal relics or protected sites without a permit.	Client / stakeholder reaction causing little disruption to business. Customer churn trending upwards requiring proactive retention strategy. Minimal short term damage to reputation as managed by business. May require commercial resolution management.	Legal, regulatory or contractual breach with possible prosecution or penalties. Regulator may monitor business activities. System changes needed.	2% over Business approved opex or capex budget Or Financial loss $250k - < $1M	Moderate effect on key business strategies. Achievement of a Balanced Scorecard objective possible, as recoverable within short timeframe.	5% - 19% of project cost Or Operational overrun AUD$50k - $100k Delays 1 - 2 months Project Manager may require assistance to manage client relationship. Client requires formal contractual management.
Minor	Medical treatment injury with no long term impact on health or wellbeing. Small impact on Business Unit staff engagement, quickly brought under control.	Possible environmental harm or an environmental nuisance to land or waterways - spills <200 litres where dispersal/clean-up is simple. Local impact on flora and fauna that may require regulatory response and follow up actions.	Minor damage or disturbance to State Heritage listed places without an exemption, incidental impacts to aboriginal relics.	Minor client / stakeholder reaction simply managed. Low levels of customer churn. Minimal short-term damage to corporate brand, and no impact on reputation as managed by Manager.	Minor breach of contractual obligations, legal, regulatory or internal policy failure. May require explanation but no penalty or censure, prosecution unlikely.	1% over Business approved opex or capex budget Or Financial loss $100k - < $250k	Minor impact on key business objectives and strategies. Minimal threat that is easily recoverable. No impact to achievement of a Balanced Scorecard objective.	1% - 4% of project cost Or Operational overrun AUD$10k to-50k Delays 1 week - 1 month Intervention by Project Manager to ensure relationship managed. Minor client reaction to variance.
Insignificant	First-aid treatment. Incident resolved by routine management activities.	Negligible, or no environmental harm. Possible incidental impact on flora and fauna. Minimal damage, such oil or fuel spill onto earth, where dispersal/clean-up is simple.	Incidental impacts on non-statutory heritage assets or exempted actions on state-listed places.	Minor irritation, easily managed by business. Negligible impact on client / stakeholder relationship. Easily managed by business.	Low-level compliance issue dealt with in-house. Negligible legal or contractual impact.	<1% over Business approved opex or capex budget Or Financial loss < 100k	Insignificant impact on business objectives and strategies. Immediate recovery.	<1% of project cost Or Operational overrun AUD<$10k Delays <1 week Minor project issues that are managed by the Project Team / Manager.

Risk Level	Action
Red	Immediately cease the activity
Yellow	Initiate steps to further control the risk
Blue	Review for improvement opportunities
Green	Reduce the risk further if practicable

Probability	Consequence: Insignificant	Minor	Moderate	Major	Extreme	Catastrophic
Almost Certain	7	17	21	28	35	42
Likely	6	12	18	24	30	36
Possible	5	10	15	20	25	30
Unlikely	4	8	12	16	20	24
Rare	3	6	9	12	15	18
Extremely Rare	2	4	6	8	10	12
1	2	3	4	5	6	7

Probability
Almost Certain
Likely
Possible
Unlikely
Rare
Extremely Rare

Consequence
Catastrophic
Extreme
Major
Moderate
Minor
Insignificant

Tarraleah Redevelopment Option A1									
Description	Tarraleah redevelopment option A1 (long pressure conveyance) includes the construction and operation of an 18 km pressurised conveyance system (tunnel with the possibility of some penstock sections) that will transfer water from Lake King William to a new Tarraleah power station and the construction of associated new infrastructure including: access roads, access portals, intakes, penstocks, penstock bridge river crossing and a pump station. The operation of the project will provide the ability to maintain lower water levels in Lake King William (LKW), will result in some changes to the flow regime in the Derwent River below Clark Dam and may have some impact on the flow regime in the Nive River downstream from Tarraleah PS. The project will also include decommissioning of Butlers Gorge and Nieterana power stations, the Tarraleah No 1 conveyance system and the No 2 conveyance system upstream of Derwent pumps. *Assessment assumes that LKW will be managed at a lower level (up to 2 m) and station releases will no longer occur in Reach 1 and spill events over Clark Dam are predicted to occur less often. Natural pickup will continue to be diverted via the Derwent pumps to the No 2 conveyance via the existing rising main; however, the design flow will not change from current. The existing Derwent weir and pumps will be retained; however, spill over Derwent weir will be reduced. The design capacity of the new power station will be similar to the existing power station (Q design = 38 m^3/sec existing, 40 m^3/sec new). The existing power station may be refurbished; however, given system constraints the Q design may be limited to ~ 10 m^3/sec. System modelling has not yet been conducted; therefore, it is unclear whether the downstream flow regime will vary significantly to current operation (e.g. spill from Liapootah Dam).* *Assumed that any change in the downstream flow regime in Derwent and Nive rivers will not extend beyond Wayatinah Lagoon, which will be subject to normal, current operations.*								
Stage: Construction									
Element	**Comments**	**Risk Assessment**			**Mitigation**	**Residual Risk**			
		Impact	**Likelihood**	**Risk Level**		**Impact**	**Likelihood**	**Risk**	**Cost Estimate**
Land tenure									
Land tenure	The construction works areas are mostly on Hydro Tasmania land: predominantly vested land with a small area of freehold. There may be some infrastructure (e.g. portal tunnels) located on Permanent Timber Production Zone Land managed by Sustainable Forests Tasmania. Use of land classified as Permanent Timber Production Zone Land may require a change of use which is done by Ministerial order. Ian to review.	Major	Unlikely	16	Consult with Sustainable Forests Tasmania. (in first instance) to assess risk of land access.	Major	Rare	12	HT
Environment									
Vegetation communities	The listed threatened community highland grassy sedgeland is mapped within the project area. Potential to be impacted by construction of infrastructure and access roads.	Minor	Possible	10	Undertake desktop assessment and field verification of vegetation communities.	Minor	Rare	6	$30,000
Flora	The threatened species Pomaderris elachophylla, Pimelea curviflora var. gracilis and Westringia angustifolia listed under Threatened Species Protection Act 1995 (Tas) (TSP Act) are known from the project area.	Minor	Possible	10	Undertake desktop assessment and follow-up field surveys to verify presence of threatened flora.	Minor	Rare	6	
Terrestrial fauna	The Tasmanian devil and wedge-tailed eagle, all of which are listed under the TSP Act and EPBC Act have been recorded in the vicinity of the project area. Den and nest sites present that could be affected by the proposed works. An increase in traffic during construction has potential to result in an increase in road kill of Tasmanian devil and quolls.	Moderate	Possible	15	Undertake desktop assessment and follow-up field surveys to verify presence of threatened fauna. Include road kill management in traffic management planning.	Minor	Unlikely	8	
Weeds and diseases	Spread of weeds (e.g. Orange Hawkweed) and PC on HT land and Sustainable Forests Tasmania land.	Moderate	Possible	15	Identify PC risk and survey for weeds. Manage through application of HT HSE system.	Minor	Rare	6	
Waste management	Waste will be generated during the construction of the project predominately from the tunnelling and minor vegetation clearing. There is a risk that the inappropriate storage, use/disposal of tunnel spoil and biowaste results in environmental and social harm.	Extreme	Likely	30	Develop a waste management plan that identifies appropriate storage and use/disposal of tunnel spoil and biowaste.	Moderate	Possible	15	HT
Surface water quality	Surface water drainage and/or quality affected by project construction (e.g. tunnel spoil deposits leading to erosion and sediment runoff during rain events).	Minor	Possible	10	Include measures to maintain surface water drainage (e.g. diversion) and prevent sedimentation of existing drainage (e.g. erosion and sedimentation control planning in accordance with IECA best practice).	Minor	Unlikely	8	HT
Cultural heritage									
Aboriginal heritage	Aboriginal heritage site is disturbed during construction works.	Moderate	Possible	15	Undertake desktop assessment and field verification of Aboriginal heritage where required. Ensure that a Aboriginal Heritage Unanticipated Discovery Plan (AHUDP) is incorporated in the EMP to account for previously unknown Aboriginal relics or sites that are uncovered during construction. The plan will include a direction that works in the area must cease immediately upon uncovering an Aboriginal relics or sites and the AHUDP must be implemented.	Moderate	Rare	9	$45,000
Historic heritage	Historic heritage site is disturbed during construction works.	Minor	Possible	10	Undertake desktop assessment and field verification of historic heritage where required.	Minor	Rare	6	
Social / Community									
Residential and business impacts	The construction of the project may impact owners and users of Tarraleah Village through noise, increased traffic and people associated with construction. There is also likely to be increased traffic and traffic disruptions on roads in the vicinity of Tarraleah and the Lyell Hwy. There is a risk that the amenity of residents and users of Tarraleah and surrounds will be impacted.	Major	Likely	24	Consult with owners of Tarraleah Village and other local businesses, plan for increased workforce in local area, include traffic management planning in CEMP.	Moderate	Possible	15	HT
Impacts to valued community assets	The construction of the intake on LKW will restrict access to camping and fishing locations (albeit only one isolated location). Access to fishing locations on the Nive River may also be restricted during construction.	Minor	Unlikely	8	Consult with IFS and stakeholder groups to notify stakeholders of change in access.	Insignificant	Unlikely	4	HT
Planning									
Land use, development and other approvals	Refer separate approvals memo prepared by HT-A&I (Ian Jones).	Major	Possible	20	Prepare approvals pathway and keep informed on land use planning changes.	Moderate	Unlikely	12	HT
Other approvals	Refer separate approvals memo prepared by HT-A&I (Ian Jones).	Moderate	Possible	15	Ensure permits and approvals are aquired as needed (e.g. use permits and approvals register).	Minor	Unlikely	8	HT
Stage: Operation									
Element	**Comments**	**Risk Assessment**			**Mitigation**	**Residual Risk**			
		Impact	**Likelihood**	**Risk Level**		**Impact**	**Likelihood**	**Risk**	**Cost Estimate**
Land tenure									
Land tenure	The Derwent River downstream of Derwent pumps is within the Franklin-Gordon Wild Rivers National Park. There may be downstream impacts on the Derwent River within the National Park.	Moderate	Possible	15	Determine change in downstream flows from current and consult with PWS (in first instance) to assess impacts on National Park values.	Moderate	Rare	9	HT
Environment									
Vegetation	Potential for riparian communities to be impacted by change in flows and lake level. There are listed threatened communities within LKW footprint - sphagnum peatland, highland Poa grassland, highland grassy sedgeland and wetland communities.	Minor	Possible	10	Undertake desktop assessment and field verification of vegetation communities where required. Assess potential impact of changed flow regime.	Minor	Rare	6	$25,000
Flora	The rocky river bed species *Barbarea australis is* listed under the Environmental Protection and Biodiversity Conservation Act 1999 (Cth) (EPBC Act) and TSP Act is known from the Derwent River above Wayatinah Lagoon and the Nive River downstream of Liapootah Dam. The riparian species *Westringia angustifolia* listed under TSP is known from the Derwent River above Wayatinah Lagoon and the Nive River at Liapootah Dam .	Major	Possible	20	Undertake desktop assessment and follow-up field surveys to verify presence of threatened flora.	Major	Rare	12	

Aquatic fauna	Potential for the change in the downstream flow regime in the Derwent and Nive rivers to impact on the availability of aquatic habitat and life histories of platypus. It is currently unclear if native fish species are present within the impacted reaches within the Derwent and Nive rivers.	Minor	Possible	10	Undertake desktop assessment (including characterising the change in the hydrological flow regime) and follow-up field surveys to verify presence of aquatic fauna species where required.	Minor	Unlikely	8	$60,000
General aquatic environment values	Change in current aquatic habitat condition of Nive and Derwent (particularly through the TWWHA) rivers and LKW. Outstanding Universal Values (OUV's) impacted by Project. There are OUV's which contributed to the criteria for which the Tasmanian World Wilderness Heritage Area was inscribed on the World Heritage List which may be affected by the proposed works including indigenous families of frogs with Gondwanan origins (e.g. Tasmanian froglet Crinia tasmaniensis) and aquatic insect groups with close affinities to groups found in South America, New Zealand and Southern Africa (e.g. dragonflies, chironomid midges, stoneflies, mayflies and caddisflies).	Major	Possible	20	Undertake desktop assessment and follow-up field surveys to assess current condition for assessment of impact of change in flows and to verify presence of OUV's.	Moderate	Rare	9	
Social / Community									
Residential and business impacts	Saltas possesses a water licence entitlement under the Tasmanian *Water Management Act 1999* (WM Act) for 31 572.5 ML/year (Surety 5 with a rate of 86.5 ML/day) from the Derwent River upstream from Wayatinah Lagoon, which is within the impacted reach downstream from Derwent pumps. Potential for the change in the downstream flow regime in the Derwent River to impact on the availability of water to meet the needs of an existing water right.	Major	Possible	20	Undertake a desktop hydrological assessment of change in water availability and follow up as necessary. Review existing MOU's and arrangements with fish farm and associated water rights. Communicate project to the fish farm and DPIPWE and seek their input into any perceived issues and requirements.	Moderate	Unlikely	12	HT
Stage: Decommissioning									
Element	**Comments**		**Risk Assessment**		**Mitigation**	**Residual Risk**			
		Impact	**Likelihood**	**Risk Level**		**Impact**	**Likelihood**	**Risk**	**Cost Estimate**
Environment									
Dangerous goods and environmentally hazardous materials	Storage, transport and disposal of hazardous materials during decommissioning of Butlers Gorge and Nieterana power stations (e.g. asbestos, PCB's)	Major	Possible	20	Develop a waste management plan in accordance with Hydro Tasmania's HSE system that describes appropriate identification, storage, transport and disposal of hazardous materials.	Moderate	Unlikely	12	HT
Threatened Flora	The threatened species *Pomaderris elachophylla* , *Pimelea curviflora* var. *gracilis* and *Westringia angustifolia* listed under Threatened Species Protection Act 1995 (Tas) (TSP Act) are known from Tarraleah canal alignment and may be destroyed during decommissioning.	Moderate	Possible	15	Undertake field survey to identify sites and avoid during decommissioning works or obtain permit if required.	Minor	Unlikely	8	$5,000
Safety of legacy structures	Water remains in decommissioned Tarraleah canal and is a drowning hazard to people and wildlife. Canal breaches causing a spill of sediment laden water into the Derwent River.	Extreme	Likely	30	Identify potential mitigations options to reduce safety and environmental risk (e.g. filling with tunnel spoil or partial or complete removal of certain sections).	Major	Possible	20	HT
Historic heritage	Historic heritage associated with Tarraleah scheme (e.g. Tarraleah power station, penstocks, surge towers) is demolished or damaged during decommissioning works.	Moderate	Possible	15	Comply with Hydro Tasmania HSE system (Historic Heritage Procedure).	Minor	Unlikely	8	$25,000
Planning									
Land use, development and other approvals	Failure to obtain appropriate demolition and waste disposal approvals and permits.	Major	Possible	20	Prepare demolition approvals pathway and permits register.	Moderate	Rare	9	HT
Social / Community									
Residential and business impacts	Increased traffic associated with removal of materials from decommissioned flumes removal and other infrastructure (e.g. Butlers Gorge and Nieterana power stations).	Moderate	Possible	15	Include traffic management planning in decommissioning plan	Minor	Unlikely	8	HT
Impacts to valued community assets	The ponds associated with the Tarraleah No 1 conveyance system are popular recreational fisheries. Decommissioning these ponds may result in the loss of this fishery (only No 1 Pond is proposed to be decommissioned; Mossy Marsh and No 2 ponds are proposed to be retained for all options).	Moderate	Possible	15	Consult with IFS and stakeholder groups to notify stakeholders of change in access.	Minor	Unlikely	8	HT
Total				**388**	**Total**			**224**	

Tarraleah Redevelopment Option C1

Description

Tarraleah redevelopment option C1 (No 3 conveyance system) includes the construction and operation of a new 400 m tunnel connecting LKW to a new small hydro. A new No 3 conveyance system will convey the flow from the small hydro parallel (and downslope of) the existing No 2 conveyance system. The flow will then be conveyed through a new tunnel running parallel (and downslope of) the existing Mossy Marsh tunnel, where it will enter Mossy Marsh Pond. A new 2.9 km pressurised tunnel will transfer water from No. 2 Pond to a new Tarraleah power station. Option C1 also involves the construction of associated new infrastructure including: access roads, access portals, intakes, penstocks, penstock bridge river crossing and a pump station. The operation of the project will provide the ability to maintain lower water levels in Lake King William (LKW), will result in some changes to the flow regime in the Derwent River below Clark Dam and may have some impact on the flow regime in the Nive River downstream from Tarraleah PS. The project will also include decommissioning of Butlers Gorge and Nieterana power stations, the Tarraleah No 1 conveyance system and the No 2 conveyance system upstream of Mossy Marsh Pond.

Assessment assumes that LKW will be managed at a lower level (up to 2 m) and station releases will no longer occur in Reach 1 and spill events over Clark Dam are predicted to occur less often. Natural pickup will be diverted via the Derwent pumps to the new No 3 conveyance via the existing rising main; however, the design flow will not change from current. The existing Derwent weir and pumps will be retained; however, spill over Derwent weir will be reduced. The design capacity of the new power station will be similar to the existing power station (Q design = 38 m3/sec existing, 40 m3/sec new). The existing power station may be refurbished; however, given system constraints the Q design may be limited to ~ 10 m3/sec. System modelling has not yet been conducted; therefore, it is unclear whether the downstream flow regime will vary significantly to current operation (e.g. spill from Liapootah Dam).
Assumed that any change in the downstream flow regime in Derwent and Nive rivers will not extend beyond Wayatinah Lagoon, which will be subject to normal, current operations.

Stage: Construction

Element	Comments	Risk Assessment: Impact	Likelihood	Risk Level	Mitigation	Residual Risk: Impact	Likelihood	Risk	Cost Estimate
Land tenure									
Land tenure	The construction works areas are on Hydro Tasmania land predominantly vested land with a small area of freehold and Permanent Timber Production Zone Land managed by Sustainable Forests Tasmania (small hydro and new No 3 conveyance system). Use of land classified as Permanent Timber Production Zone Land for power generation may require a change of use which is done by Ministerial order. Ian to review.	Major	Likely	24	Consult with Sustainable Forests Tasmania. (in first instance) to assess risk of land access.	Major	Unlikely	16	HT
Environment									
Vegetation communities	The listed threatened communities highland grassy sedgeland, freshwater aquatic sedgeland and rushland and lacustrine herbland are mapped within the project area. Potential to be impacted by construction of infrastructure and access roads.	Minor	Possible	10	Undertake desktop assessment and field verification of vegetation communities.	Minor	Unlikely	8	
Flora	The threatened species *Pomaderris elachophylla* , *Pimelea curviflora* var. *gracilis* and *Westringia angustifolia* listed under Threatened Species Protection Act 1995 (Tas) (TSP Act) are known from the project area.	Minor	Possible	10	Undertake desktop assessment and follow-up field surveys to verify presence of threatened flora.	Minor	Unlikely	8	$50,000
Terrestrial fauna	The Tasmanian devil and wedge-tailed eagle, all of which are listed under the TSP Act and EPBC Act have been recorded in the vicinity of the project area. Den and nest sites present that could be affected by the proposed works. An increase in traffic during construction has potential to result in an increase in road kill of Tasmanian devil and quolls.	Minor	Possible	10	Undertake desktop assessment and follow-up field surveys to verify presence of threatened fauna. Include road kill management in traffic management planning.	Minor	Unlikely	8	
Weeds and diseases	Spread of weeds (e.g. Orange Hawkweed) and PC on HT land and Sustainable Forests Tasmania land.	Moderate	Possible	15	Identify PC risk and survey for weeds. Manage through application of HT HSE system.	Minor	Rare	6	
Waste management	Waste will be generated during the construction of the project predominately from the tunnelling and minor vegetation clearing. There is a risk that the inappropriate storage, use/disposal of tunnel spoil and biowaste results in environmental and social harm.	Major	Likely	24	Develop a waste management plan that identifies appropriate storage and use/disposal of tunnel spoil and biowaste.	Moderate	Possible	15	HT
Surface water quality	Surface water drainage and/or quality affected by project construction (e.g. tunnel spoil deposits leading to erosion and sediment runoff during rain events).	Minor	Possible	10	Include measures to maintain surface water drainage (e.g. diversion) and prevent sedimentation of existing drainage (e.g. erosion and sedimentation control planning in accordance with IECA best practice).	Minor	Unlikely	8	HT
Cultural heritage									
Aboriginal heritage	Aboriginal heritage site is disturbed during construction works.	Moderate	Possible	15	Undertake desktop assessment and field verification of Aboriginal heritage where required. Ensure that a Aboriginal Heritage Unanticipated Discovery Plan (AHUDP) is incorporated in the EMP to account for previously unknown Aboriginal relics or sites that are uncovered during construction. The plan will include a direction that works in the area must cease immediately upon uncovering an Aboriginal relics or sites and the AHUDP must be implemented.	Moderate	Rare	9	$45,000
Historic heritage	Historic heritage site is disturbed during construction works.	Minor	Possible	10	Undertake desktop assessment and field verification of historic heritage where required.	Minor	Rare	6	
Social / Community									
Residential and business impacts	The construction of the project may impact owners and users of Tarraleah Village through noise, increased traffic and people associated with construction. There is also likely to be increased traffic and traffic disruptions on roads in the vicinity of Tarraleah and the Lyell Hwy. There is a risk that the amenity of residents and users of	Major	Likely	24	Consult with owners of Tarraleah Village and other local businesses, plan for increased workforce in local area, include traffic management planning in CEMP.	Moderate	Possible	15	HT
Impacts to valued community assets	The construction of the intake on LKW will restrict access to camping and fishing locations (albeit only one isolated location). Access to fishing locations on the Nive River may also be restricted during construction.	Minor	Unlikely	8	Consult with IFS and stakeholder groups to notify stakeholders of change in access.	Insignificant	Unlikely	4	HT
Planning									
Land use, development and other approvals	Refer separate approvals memo prepared by HT-A&I (Ian Jones).	Major	Possible	20	Prepare approvals pathway and keep informed on land use planning changes.	Moderate	Unlikely	12	HT
Other approvals	Refer separate approvals memo prepared by HT-A&I (Ian Jones).	Moderate	Possible	15	Ensure permits and approvals are aquired as needed (e.g. use permits and approvals register).	Minor	Unlikely	8	HT

Stage: Operation

Element	Comments	Risk Assessment: Impact	Likelihood	Risk Level	Mitigation	Residual Risk: Impact	Likelihood	Risk	Cost Estimate
Land tenure									
Land tenure	The Derwent River downstream of Derwent pumps is within the Franklin-Gordon Wild Rivers National Park. There may be downstream impacts on the Derwent River within the National Park.	Moderate	Possible	15	Determine change in downstream flows from current and consult with PWS (in first instance) to assess impacts on National Park values.	Moderate	Rare	9	HT
Environment									
Vegetation	Potential for riparian communities to be impacted by change in flows and lake level. There are listed threatened communities within LKW footprint - sphagnum peatland, highland Poa grassland, highland grassy sedgeland and wetland communities.	Minor	Possible	10	Undertake desktop assessment and field verification of vegetation communities where required. Assess potential impact of changed flow regime.	Minor	Rare	6	
Flora	The rocky river bed species *Barbarea australis is* listed under the Environmental Protection and Biodiversity Conservation Act 1999 (Cth) (EPBC Act) and TSP Act is known from the Derwent River above Wayatinah Lagoon and the Nive River downstream of Liapootah Dam. The riparian species *Westringia angustifolia* listed under TSP is known from the Derwent River above Wayatinah Lagoon and the Nive River at Liapootah Dam.	Major	Possible	20	Undertake desktop assessment and follow-up field surveys to verify presence of threatened flora.	Major	Rare	12	$25,000
Aquatic fauna	Potential for the change in the downstream flow regime in the Derwent and Nive rivers to impact on the availability of aquatic habitat and life histories of platypus. It is currently unclear if native fish species are present within the impacted reaches within the Derwent and Nive rivers.	Minor	Possible	10	Undertake desktop assessment (including characterising the change in the hydrological flow regime) and follow-up field surveys to verify presence of aquatic fauna species where required.	Minor	Unlikely	8	

General aquatic environment values	Change in current aquatic habitat condition of Nive and Derwent (particularly through the TWWHA) rivers and LKW. Outstanding Universal Values (OUV's) impacted by Project. There are OUV's which contributed to the criteria for which the Tasmanian World Wilderness Heritage Area was inscribed on the World Heritage List which may be affected by the proposed works including indigenous families of frogs with Gondwanan origins (e.g. Tasmanian froglet *Crinia tasmaniensis*) and aquatic insect groups with close affinities to groups found in South America, New Zealand and Southern Africa (e.g. dragonflies, chironomid midges, stoneflies, mayflies and caddisflies).	Major	Possible	20	Undertake desktop assessment and follow-up field surveys to assess current condition for assessment of impact of change in flows and to verify presence of OUV's.	Moderate	Rare	9	$60,000
Social / Community									
Residential and business impacts	Saltas possesses a water licence entitlement under the Tasmanian *Water Management Act 1999* (WM Act) for 31 572.5 ML/year (Surety 5 with a rate of 86.5 ML/day) from the Derwent River upstream from Wayatinah Lagoon, which is within the impacted reach downstream from Derwent pumps. Potential for the change in the downstream flow regime in the Derwent River to impact on the availability of water to meet the needs of an existing water right.	Major	Possible	20	Undertake a desktop hydrological assessment of change in water availability and follow up as necessary. Review existing MOU's and arrangements with fish farm and associated water rights. Communicate project to the fish farm and DPIPWE and seek their input into any perceived issues and requirements.	Moderate	Unlikely	12	HT
Stage: Decommissioning									
Element	**Comments**	**Risk Assessment**			**Mitigation**	**Residual Risk**			
		Impact	**Likelihood**	**Risk Level**		**Impact**	**Likelihood**	**Risk**	**Cost Estimate**
Environment									
Dangerous goods and environmentally hazardous materials	Storage, transport and disposal of hazardous materials during decommissioning of Butlers Gorge and Nieterana power stations (e.g. asbestos, PCB's).	Major	Possible	20	Develop a waste management plan in accordance with Hydro Tasmania's HSE system that describes appropriate identification, storage, transport and disposal of hazardous materials.	Moderate	Unlikely	12	HT
Threatened Flora	The threatened species *Pomaderris elachophylla* , *Pimelea curviflora* var. *gracilis* and *Westringia angustifolia* listed under Threatened Species Protection Act 1995 (Tas) (TSP Act) are known from Tarraleah Canal alignment and may be destroyed during decommissioning.	Moderate	Possible	15	Undertake field survey to identify sites and avoid during decommissioning works or obtain permit if required.	Minor	Unlikely	8	$5,000
Safety of legacy structures	Water remains in decommissioned Tarraleah canal and is a drowning hazard to people and wildlife. Canal breaches causing a spill of sediment laden water into the Derwent River.	Extreme	Likely	30	Identify potential mitigation options to reduce safety and environmental risk (e.g. filling with tunnel spoil or partial or complete removal of certain sections).	Major	Possible	20	HT
Historic heritage	Historic heritage associated with Tarraleah scheme (e.g. Tarraleah power station, penstocks, surge towers) is demolished or damaged during decommissioning works.	Moderate	Possible	15	Comply with Hydro Tasmania HSE system (Historic Heritage Procedure).	Minor	Unlikely	8	$25,000
Planning									
Land use, development and other approvals	Failure to obtain appropriate demolition and waste disposal approvals and permits (e.g. EPN).	Major	Possible	20	Prepare demolition approvals pathway and permits register.	Moderate	Rare	9	
Social / Community									
Residential and business impacts	Increased traffic associated with removal of materials from decommissioned flumes removal and other infrastructure (e.g. Butlers Gorge and Nieterana power stations).	Moderate	Possible	15	Include traffic management planning in decommissioning plan.	Minor	Unlikely	8	HT
Impacts to valued community assets	The Tarraleah ponds associated with Tarraleah No 1 conveyance system are popular recreational fisheries. Decommissioning these ponds may result in the loss of this fishery (only No 1 Pond is proposed to be decommissioned; Mossy Marsh and No 2 ponds are proposed to be retained for all options).	Moderate	Possible	15	Consult with IFS and stakeholder groups to notify stakeholders of change in access.	Minor	Unlikely	8	HT
Total				385	Total			232	